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Reactors, radioisotopes, and the HIFAR controversy

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REACTORS, RADIOISOTOPES, & THE HIFAR CONTROVERSY

A thesis submitted in fulfilment of the requirements for the award of the degree

DOCTORATE OF PHILOSOPHY

from

UNIVERSITY OF WOLLONGONG
NEW SOUTH WALES, AUSTRALIA

by

JIM GREEN, B.Med.Sci. (Hons.)

SCIENCE AND TECHNOLOGY STUDIES

1997
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DECLARATION

This thesis has not been submitted for a degree to any other university or institution.

Signed:

Jim Green
This thesis concerns a controversy as to whether Australia's one operating nuclear research reactor, HIFAR, should be replaced with a new reactor. HIFAR will almost certainly be permanently shut down in the next 5-10 years, and there is considerable pressure on the federal government to make a firm decision, in the near future, for or against the replacement of HIFAR.

Much of the thesis is focused on a sub-debate within the broader HIFAR replacement controversy - whether a new reactor is justified for the production of radioisotopes used in nuclear medicine. Alternative radioisotope supply scenarios - involving greater reliance on imported radioisotopes and cyclotron-produced radioisotopes - are proposed and evaluated.

The medical radioisotope sub-debate, and the HIFAR replacement controversy more generally, are analysed in the context of civil and military nuclear development around the world and in Australia. This material serves two purposes - it provides context for the HIFAR replacement controversy and the medical radioisotope sub-debate, and it develops a set of arguments concerning the problems with research reactor programs, in particular their links to covert nuclear weapons programs.

In terms of situating the thesis in the context of Science and Technology Studies scholarship, the thesis draws on strands of the "new" sociology of technology literature but pays greater attention to structural analysis. The principles which guide most studies in the sociology of scientific knowledge tradition - such as reflexivity, impartiality, and symmetrical treatment of knowledge claims - are recast as practical problems within a social problem centred approach.
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LDE Low-dose exposure (to ionising radiation)
LEU Low-enriched uranium
LLW Low-level radioactive waste
L.s.a. Low specific activity
MEU Medium-enriched uranium
Mo-99/ The radioisotope molybdenum-99 and its daughter technetium-99m.
Tc-99m Magnetic resonance imaging
MW or
MW(t) Megawatts (millions of watts) of thermal power
MW(e) Megawatts (millions of watts) of electrical power
NDP Nuclear Disarmament Party
NERDDC National Energy Research Development and Demonstration Council
NH&MRC National Health and Medical Research Council
NHTAP National Health Technology Advisory Panel
NMC National Medical Cyclotron (Sydney)
NPT (Nuclear) Non-Proliferation Treaty
NSB Nuclear Safety Bureau
NSG Nuclear Suppliers Group
ORNL Oak Ridge National Laboratory
PET Positron emission tomography
PNE Peaceful nuclear explosion
PRA Probabilistic risk assessment
R&D Research and development
RERTR Reduced Enrichment for Research and Test Reactor Program
RPAH Royal Prince Alfred Hospital (Sydney)
RASCO Nuclear Research Centre, Peru
SCK-CEN Belgium Nuclear Research Centre
SCOT Social construction of technology
SAAEC South African Atomic Energy Commission
SPECT Single photon emission computed tomography
SSK Sociology of scientific knowledge
STS Science and Technology Studies
TRIUMF Tri University Meson Facility, Canada
UCCAP University of California Chemistry and Agriculture Program
UEGA Uranium Enrichment Group of Australia
UK United Kingdom
US United States of America
CHAPTER ONE: INTRODUCTION

1.1. INTRODUCTION
1.2. THE THESIS IN THE CONTEXT OF SCIENCE AND TECHNOLOGY STUDIES

1.1 INTRODUCTION

OVERVIEW
AIMS
CHOICE OF TOPIC
OUTLINE

OVERVIEW

This thesis concerns an ongoing controversy as to whether a new nuclear research reactor should be built in Australia. The one existing research reactor, the High Flux Australian Reactor (HIFAR), is located at Lucas Heights, just south of Sydney. HIFAR has been in routine operation since 1960, and is operated by the major Australian nuclear agency, the Australian Nuclear Science and Technology Organisation (ANSTO). Proposals to replace HIFAR with a new reactor have surfaced periodically since the mid 1970s. Such proposals have generated considerable opposition from a number of environmental and anti-nuclear groups, as well as localised opposition in the Lucas Heights region. Successive federal governments have deferred making a decision on the replacement of HIFAR.

Several years ago the federal government established the 1992-93 Research Reactor Review to investigate the issue and advise government as to whether a replacement reactor should be built. The Review recommended that a decision be deferred for "about five years", and that recommendation was accepted by the government. On the strength of those events, and developments since the Research Reactor Review, it seems very likely that the government will make a decision for or against the replacement of HIFAR in 1997 or 1998. An alternative option is a major refurbishment and upgrading of HIFAR, but that option has very little support from ANSTO or anti-reactor groups.

Proponents of a replacement reactor argue that it is necessary for a host of scientific, medical, commercial, and "national interest" reasons. Other aspects of the controversy include radioactive waste management, and environmental and
public-health issues associated with the operation of a research reactor. The controversy is also linked to broader debates about Australia's role in nuclear programs overseas. All of these issues are addressed in the thesis, but the only issue analysed in detail is whether a new reactor is justified for the production of medical radioisotopes.

The debate over medical radioisotope production and supply is set in the context of a more general analysis of the HIFAR controversy, which in turn is set in the context of an analysis of the history of nuclear power, weapons, and research reactor programs in Australia and around the world. This material is used not only to contextualise the current debate as to whether a new reactor is justified for medical radioisotope production, but also to develop a set of arguments concerning the problems with research reactor programs, in particular their use in support of covert nuclear weapons programs.

There is a theme running through the thesis. While nuclear weapons and nuclear power have been subjected to great scrutiny, and have been the focus of mass public opposition, research reactor programs have not been subjected to nearly the same level of scrutiny or opposition. Critical analyses of the radioisotope industry and nuclear medicine are particularly scarce. By opening up these topics to critical analysis, the thesis demonstrates that research reactors, the radioisotope industry, and nuclear medicine are very much bound up in the socially and environmentally problematic aspects of nuclear development.

Receiving particular emphasis are the interconnections between research reactors and covert nuclear weapons programs. I argue that it is unlikely that an Australian government would seriously entertain the idea of a nuclear weapons program in the foreseeable future, and that such considerations are marginal vis a vis the debate over the replacement of HIFAR (see chapter four). Nevertheless the interconnections between research reactors and nuclear weapons programs warrant analysis for the following reasons:

- the relevance of nuclear weapons issues to the HIFAR replacement controversy is of sufficient importance as to warrant a thorough examination, whatever the conclusion;
- I do not entirely discount the possibility that a desire to leave open the weapons option, as a longer-term contingency, is a possible, partial reason for the support for a new reactor by sections of the Australian state; and
- it is openly argued, by proponents of a new reactor, that a reactor is necessary to maintain and develop expertise in order to monitor and influence nuclear programs overseas, not least nuclear weapons programs.
In view of the above, the thesis tackles the following issues:

- the current status and underlying trends with respect to nuclear weapons programs around the world;
- the historical interest in a nuclear weapons capability in Australia (and the waning of this interest since the early 1970s); and
- the use of research reactors in weapons programs.

The thesis also discusses the overlap between reactor radioisotope production and covert weapons programs. Partly this reflects the concerns outlined above. In addition, this issue is addressed because the thesis presents a comprehensive analysis of the radioisotope industry which would be incomplete without consideration of the weapons connections.

AIMS

The primary aims of the thesis are as follows:

- to analyse the HIFAR replacement controversy, through analysis of the specific sub-debates (medical radioisotope supply, neutron science, etc.) and by locating the controversy in the context of i) the history of the nuclear industry in Australia and ii) the global development of nuclear power, weapons and research reactor programs; and
- to analyse, in depth, the cases for and against the construction of a new research reactor in Australia for the production of medical radioisotopes (taking into account alternative options for future radioisotope production and supply).

Some further aims can be identified as follows:

- to make a modest contribution to the literature on the history and current status of nuclear development in Australia; available literature is mostly patchy and generally focused on specific topics such as uranium mining;
- to make a modest contribution to the literature on research reactor programs, in particular their intersection with nuclear weapons programs; and
- to develop a more comprehensive analysis of the global radioisotope industry than is available in publicly-accessible literature.

CHOICE OF TOPIC

My decision research the HIFAR replacement controversy was based on two primary considerations: the importance and currency of the issue.
As for the importance of the issue, the operation of research reactors raises the same concerns as power reactors, though generally on a smaller scale. These concerns include the potential for serious accidents, the environmental and public health effects of routine radioactive emissions, the management of radioactive waste, the potential for sabotage or terrorism, large financial costs, and the use of research reactors for covert development of nuclear weapons.

The controversy over the replacement of HIFAR is not only important, but also topical. As mentioned, there is considerable pressure on the federal government to make a decision, in the near future, for or against a new reactor.

Once I had decided to study the HIFAR replacement controversy, a short-list of potential topics was arrived at through preliminary research and discussion with a number of groups involved in the campaign against a new reactor. (ANSTO's views were extensively covered in over 1500 pages of material submitted to the Research Reactor Review.) A short-list of potential topics emerged, such as radioactive waste problems, the social and economic impact which would follow from a serious reactor accident at Lucas Heights, the health effects to the surrounding population of routine radioactive emissions from HIFAR, and issues surrounding the production and supply of medical isotopes.

I chose to focus much of my research on the debate over medical radioisotope production and supply because this is one of the most prominent debates impinging on the reactor controversy, because there is considerable scope for useful research into this topic, and because the topic overlaps, to some extent, with my previous experience in medical sociology and public health. Other possible topics were not so amenable to study. For example, there is little data on the health effects of radioactive HIFAR emissions and thus it would have been difficult to study that issue though certainly not impossible (indeed the lack of data could itself be taken as a starting point for useful research). Other topics – for example the radioactive waste issue – were not pursued because they have already been the focus of much research.
Here I present a brief chapter-by-chapter outline of the thesis.

Chapter one proceeds with a discussion on Science and Technology Studies (STS) scholarship and the place of the thesis within STS.

Chapter two begins with a sweeping analysis of nuclear power programs around the world. Then nuclear weapons programs are discussed, with emphasis on the potential for further proliferation of nuclear weapons in the post Cold War period and also on the intersection between civil and military nuclear programs. Lastly, the place of research reactors within the broader scope of nuclear development is introduced, with emphasis on the use of research reactors in covert nuclear weapons programs.

Chapter three locates the HIFAR replacement controversy in the context of the history of nuclear development in Australia. This includes discussion on the British weapons tests in the 1950s and 1960s, the hosting of military bases operated by the United States (US) military, the uranium mining industry, an abandoned nuclear power program, an abandoned uranium enrichment research program, a brief flirtation with "peaceful" nuclear explosives, some high-level interest in the possibility of a domestic nuclear weapons capability at times, the operation of two research reactors, and public opposition to all the above to a greater or lesser degree. Tied in with all these projects is the history of ANSTO and its predecessor the Australian Atomic Energy Commission (AAEC). From its historical role as the guardian of Australia's entry into the nuclear age, the AAEC/ANSTO has gradually been downgraded to just another public-sector civil science agency. This downgrading has been resisted to a considerable extent, but the AAEC/ANSTO has also trimmed its sails to the political breeze, carving a niche for itself through involvement in a plethora of scientific, medical, and commercial activities, some of which are dependent on the operation of HIFAR.

Chapter four discusses the recent history of the HIFAR replacement controversy, in particular the 1992-93 Research Reactor Review. The politicking surrounding the Review is discussed. Then I consider the various sub-debates which were taken up during the Review. These sub-debates include the "national interest" debate, a set of nebulous arguments concerning the maintenance of nuclear fuel cycle expertise, policy advice, national defence/security, and so on. Debates over medical radioisotope production and supply - which were prominent during the
Review - are introduced. Other sub-debates within the HIFAR replacement controversy are summarised, as are developments since the Review.

In chapters 5-8, the focus narrows to the debate about whether a new reactor is needed in Australia for production of medical radioisotopes. Chapter five briefly traces the history of the medical radioisotope industry, which developed largely as an outgrowth of nuclear power and weapons programs in the decades after World War II. The integration of nuclear medicine into medical practice, primarily as one of a number of diagnostic imaging modalities, is considered.

One alternative to a new reactor is greater reliance on imported radioisotopes. Whether that is a feasible alternative depends on radioisotope production overseas, in particular research reactor radioisotope production. There is little current and accurate information on reactor radioisotope production in publicly-accessible literature, and thus chapter six is dedicated to an empirical survey of research reactors and radioisotope production around the world.

Chapter seven provides an analysis of the global radioisotope industry, taking up a range of issues: radioisotope demand; production levels; concentration of the industry; public and private sector involvement; vertical integration; dedicated production facilities; the links between radioisotope production levels and nuclear power, weapons, and research programs; technical innovations; and non-reactor methods of radioisotope production (in particular particle accelerators including cyclotrons).

On the basis of the information and analysis presented in chapters 5-7, the issue of future supply of medical radioisotopes in Australia is tackled in chapter eight. An alternative to domestic reactor radioisotope production is proposed and evaluated. This alternative supply scenario involves much greater reliance on imported radioisotopes, and further development of domestic cyclotron radioisotope production. Some organisational and logistical matters relating to this proposed scenario are addressed. It is also argued that in the longer term it would be desirable to break the nexus between research reactors and radioisotope production - one consequence of which would be reduced reliance on imported radioisotopes - and some lines of medical-scientific research are proposed towards this end, concerning cyclotron radioisotope production in particular.

Nuclear medicine and the radioisotope industry have been the subject of very little sustained analysis; this thesis is by no means exhaustive in its analysis of
these topics and thus I conclude chapter eight with some suggestions for future research.

Chapter nine looks forward to future struggles over the replacement of HIFAR, and the place of my research in that context. It then summarises, and further develops, arguments developed throughout the thesis concerning the problematic aspects of research reactor programs (including radioisotope production) and nuclear medicine. I conclude with some comments on the implications of the thesis for STS.

Chapter ten is a brief postscript outlining events between September and November 1997 (i.e. between the first and second/final submissions of this thesis). During this period, the federal government announced a decision to replace HIFAR, subject to an Environmental Impact Statement (EIS) assessment under the Environmental Protection (Impact of Proposals) Act 1974. The announcement met with considerable public and political opposition. As well as the EIS, the proposal to replace HIFAR will be the subject of investigation by a Senate Committee.

1.2 THE THESIS IN THE CONTEXT OF SCIENCE AND TECHNOLOGY STUDIES

TRENDS IN SCIENCE AND TECHNOLOGY STUDIES
RESEARCH METHODS
THE FOURTH GENERATION OF SOCIOLOGY OF SCIENTIFIC KNOWLEDGE
THE NEW SOCIOLOGY OF TECHNOLOGY
INTEGRATED ANALYSES OF SCIENCE AND TECHNOLOGY

TRENDS IN SCIENCE AND TECHNOLOGY STUDIES

In 1959 C. Wright Mills (1959, p.20) wrote that the sociological imagination stands opposed to social science as a set of bureaucratic techniques which inhibit social inquiry by "methodological" pretensions, which congest such work by obscuring conceptions, or which trivialize it by concern with minor problems unconnected with publicly relevant issues. These inhibitions, obscurities, and trivialities have created a crisis in the social studies today without suggesting, in the least, a way out of that crisis.
Not long after Mills' polemic, the academic discipline of Science and Technology Studies (STS) was consolidated as a discrete field of scholarship within the social sciences. With origins in the academic disciplines of sociology, history, and philosophy, problems familiar to the social sciences were evident from the start. However there was another current in the first generation of STS, with roots in progressive movements such as the critical science-and-society movement, the environmental movement, and the peace movement. Within this current, important and topical science-in-society issues were tackled. Political conservatism in the social sciences, which had reached a high-point with the elaborate functionalism of Talcott Parsons, gave way to a range of critiques of dominant groups and dominant ideologies. The arbitrary and unhelpful boundaries of academic disciplines were crossed on a number of fronts. Better still, there was considerable movement of people and ideas between academia, progressive social movements, and in some cases also scientific institutions, to the benefit of each domain.

There is still a current of critical scholarship within STS. A considerable volume of work has amassed on important issues such as environmental issues and the politics of medicine and health. Some STS academics still bridge academic disciplines freely and imaginatively. There are still some links with progressive social movements – Marxism has largely gone out of favour, but left-liberal academics maintain some connections with various social movements (which are themselves predominantly left-liberal in political orientation).

However the critical current within STS has lost ground in the past 10-20 years. The academic and political roots of STS varied from country to country, but in the 1980s there was a convergence with theoretical and methodological issues taking centre stage (Bijker, 1993). As Woodhouse (1991, p.390) argues:

*The field of science and technology studies (STS) started with an intention of helping humanity to understand and partially to overcome the myriad obstacles to using technical ingenuity for human betterment. In the 1980s, however, a good chunk of the field’s best energy went toward posing (and, in some eyes, solving) intellectual puzzles regarding the social construction of scientific knowledge. While fascinating and possibly of long-term use for debunking myths about modern science, much of the work moved away from engagement with real human problems.*

The trend has been towards obscure topics, esoteric theory, and methodological pretensions. STS scholars have become prone to focusing on issues which, while
sometimes fascinating, are of little importance – gravity waves, fluorescent lights, automated door closers, bicycles, the learning ability of worms, and so on.\(^1\) MacKenzie (1986) points to the striking example between the mountain of literature on science and religion, and the relative paucity of STS analyses of science, technology, and the military. A related problem is that issues tend to be treated as little more than vehicles for the resolution of theoretical, methodological, and epistemological puzzles, or for the development and elaboration of programmatic STS statements.

At a broad level the sociology of science has been dominated by the "old" Mertonian, positivist current and the "new" post-Kuhnian sociology of scientific knowledge (SSK). These two orthodoxies have been tailed by a small and dwindling thread of critics including Marxists, ecologists, feminists, anarchists and radical science advocates. (Restivo, 1994.) The new, post-Kuhnian relativism has proven to be similar to the old Mertonian current in some respects, with relativist/constructivist conservatism having dethroned positivist celebrations of science and scientific method. Functionalism and liberal pluralism permeate the new SSK as they did the Mertonian current. The focus remains largely on micro-level action between groups within the scientific community, with little analysis of broad, structural influences on science and technology such as class struggle. (Restivo, 1994; Hård, 1993.)

Sometimes the inward, theoretical turn of the 1980s is justified by dubious and pretentious arguments to the effect that academic squabbles over esoteric theory are inherently political. For example Jasanoff (1996, p.413) claims that "a deeply normative project ...... runs through even the most playful narratives that we in science and technology studies construct ......" Indeed, but generally it is only the norms of STS academics and the nuances of esoteric theory that come into the picture. Few people outside STS, and still fewer outside academia, have any knowledge of, interest in, or use for this literature.

An illustration of the problematic inward turn of STS/SSK is an exchange between (William) Lynch and Fuhrman, and (Michael) Lynch, in Social Studies of Science. Lynch and Fuhrman (1991) argue for a Marxist sociology of knowledge (though without a word on how Marxist sociology might be linked to Marxist praxis). What is revealing is Lynch's reply in which he situates himself as a "radical" relativist (Lynch, 1992, pp.229-232):

\(^1\) See Collins (1981) for a survey of the empirical scope of STS.
The emphasis in SSK and laboratory studies (is) on the less obviously politicised but arguably more pervasive, practical conventions, forms of life, literary rhetorics, modes of disputation, and sociosemiotic networks which do not correlate in any clear-cut way with "stable sociological variables" such as gender categories, hierarchical structures of authority, and social class arrangements.

The possibility remains alive that sociological research may demonstrate occasional, historically contingent, and reformable relations ..., but the general arguments in SSK about the "social" organization of science ..., do not necessitate such empirical findings and purposive reforms. And, while many of the general arguments and case studies in SSK are interesting and suggestive, to my knowledge they do not supply the sort of firm "meta-social" criteria that L&F's normative proposals demand. If anything, they suggest that the search for such criteria is pointless.

As many have argued in SSK, a radical analyst cannot hope to trace the branching pathways of these "social roots" back to a unitary "base," "totality," or "ground"; instead, the analyst faces a labyrinth ....... from one emergent "social" site through an endless series of others.

(The) demand for a normative SSK seems premature, or worse, regressive, because it ignores the failure of positive social science to achieve agreement on the most basic policies of theory and method. Rather than fantasizing yet another Queen (or perhaps Prime Minister) of the Sciences to stand in judgment of all the other disciplines, I would urge that the most radical (and socially beneficial) thing we can do with SSK studies is to puncture the "epistemological" confidence exuded by proponents of normative proposals for reconstructing occupational life-worlds.

There is much to argue with here. As with Jasanoff (1996), Lynch grossly overstates the importance of decontextualised, micropolitical SSK. The notion that the most radical and socially beneficial thing that STS/SSK scholars can do is to produce ever-more impenetrable intellectual labyrinths - and to puncture the normative proposals of anyone who suggests otherwise - is utterly at odds with the vision of the social sciences put forward by C. Wright Mills. Conversely Lynch fails to understand the links - and the importance of the links - between micropolitics and broader structural processes. Another problem is the belief that there could ever be agreement on theory and method. Lynch of all people - with his eclectic combination of SSK and postmodernism, spiced with hints of
Frankfurt school critical theory—ought to understand the potential for endless debating over theory and method. He might also have learnt from Lynch and Fuhrman (1991) that the irreconcilability of class interests under capitalism is a major obstacle (though not the only one) to reaching any sort of closure let alone consensual closure on debates over theory and method. Lynch and Fuhrman (1992, p.235) neatly lay to rest Lynch’s naive ideas about reaching such a consensus:

Waiting for a mythical, complete set of technical tools before dirtying our hands, while science is both called upon to solve complex social problems and itself increasingly becomes a social problem, has much the character of Nero’s fiddling while Rome burned.

Lynch represents an extreme example of a broader current in STS, which in turn reflects the broad current of postmodernist obfuscation throughout the social sciences.2

Woodhouse (1991) argues that it may be possible to use the "theoretical ammunition" gained through the 1980s to strengthen critical analysis of science-in-society. However the theoretical ammunition itself is not enough, nor even a good starting point. As Martin (1993) argues:

For students looking for a critique that can provide help for social action, recent theoretical developments can be incredibly frustrating. The frustration is inevitable, because creating social change by extending the analysis is impossible. The flaw in the theoretical search is the assumption that a grounding for analysis can be founded on ideas alone. Analysis ultimately depends on practice. The analysis by academics for the most part reflects a practice of professional advancement and scholarly theorising. An analysis relevant to social problems must be linked to a relevant practice.

STS needs to be resituated both intellectually and politically.

The movement in STS is not all in the direction of an inward-looking "radical" relativism. There are signs of a renewal of critical STS scholarship. A number of STS scholars have argued in recent years for a return to the politically-relevant issues that informed the field more than a decade ago.3 Certainly there are many

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3 See for example Winner, 1993; Bijker, 1993; Restivo, 1988, 1994; Chubin, 1992; Cozzens, 1993; Brante et al., 1993; Woodhouse, 1991.
important science-in-society issues which could benefit from critical analysis and engagement. Moreover theoretical debates can easily be pursued in the context of analysis of important issues. And there are many opportunities for fruitful collaboration between STS academics and progressive activists and movements. Rebuilding a milieu of critical academics and progressive activists can potentially improve understanding of science-in-society issues and also provide opportunities for social change.

**RESEARCH METHODS**

Critical STS scholarship must be grounded in important science-in-society issues and problems. Methodology and theory ought to be secondary considerations. As discussed the starting point for this thesis was the choice of an important, topical issue. Now I will discuss methodology, first commenting on some different approaches to research methodology adopted by STS academics, and then outlining my own approach.

Academics in the social sciences, carrying out their work in stereotypical academic fashion - presenting their findings in books, journal articles, conference presentations and so on - can certainly have an impact in the academic community but their impact outside that sphere is generally limited. Social scientists ought to explore a whole range of methods of intervening in social issues, both as academics and in other roles (citizens, activists), but they rarely do; this despite their training and skill in social criticism, their pretences to being self-reflective, and their relative freedom to involve themselves in social issues (Martin, 1984). Most academics accept ideologies of academic neutrality and non-involvement which are supposed to foster scholarly objectivity. This, combined with other factors such as a preoccupation with esoteric theory and trivial topics, ensures that their work has little or no impact outside academia.

In STS, ideologies of neutrality and non-involvement predominate in both the old (positivist, Mertonian) and new (mostly constructivist) sociologies of science and technology. Even within the critical current running through the history of STS, the emphasis has been on intellectual radicalism; attempts to join intellectual radicalism with political engagement have been less frequent.

On occasions, particularly when controversial public issues are studied, processes of capture or enrolment can occur - academic literature is taken up by participants in a public controversy. In effect the social analyst becomes a participant in the controversy even if he/she tries to maintain a neutral, disengaged stance. A
variation on this theme is when academics are alert to such processes and manipulate the situation to have a desired impact. There has been considerable debate in STS on the capture or enrolment of social analysts and/or their work, much of it focused on the politics of even-handed symmetrical analyses. Some academics involved in these debates are happy for their work to be taken up by participants in a controversy, and may actively involve themselves in the controversy to some extent. However the debate has generally gone little further than considering the fate of (ostensibly) symmetrical scholarship and manipulating the process to some extent; it amounts to little more than variations of the dry "trickle-down" theory according to which academic studies will eventually be taken up by people outside academia. Other participants in this debate (e.g. Collins, 1991; 1996) cling to conservative ideas about academic neutrality and non-involvement.

Some academics undertake participatory studies or fieldwork in which they involve themselves (as participants, "members", "natives") in the issues they are studying, but their primary concern is scholarly understanding (and advancement) rather than social change. STS studies which attempt to open the "black box" of science and technology to sociological analysis, such as lab studies, sometimes fit this category. A variation of participant comprehension is when academics involve themselves in the issue but with just as much or more interest in social change as in scholarly understanding. Beder's (1989; 1991) intellectual and political engagement with a political controversy over sewage outfalls is a good example. Another example is Martin's (1996) involvement in a dispute as to whether polio vaccination might be implicated in the origin of HIV/AIDS in humans - a notable example in that Martin helped to generate the dispute rather than intervening in an already-established dispute. Another model which can be adopted to fuse improvements in understanding with social change is to engage in participatory action research in which small groups engage in a problem-centred dialectic of theory and action (Action Research Issues Association, 1991).

One form of academic work which clearly involves engagement in social issues is when academics are contracted to conduct research, often by government or industry. Such work is commonplace and can be prestigious and financially rewarding, but it can be quite the reverse for academics supporting community or social-action groups or political parties. Moreover there is limited scope for serious critique of science or society in the context of government or industry contracts - co-option or mute compliance are the norm.

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Some camps in the new sociology of science argue for greater self-reflection (reflexivity) on the part of STS academics. It is commonplace for STS scholars to argue that science and technology are shaped by a range of social and personal interests and ideologies rather than being a straightforward application of a neutral scientific method. This has given rise to the argument that STS scholars should be aware of, and perhaps attempt to analyse and explain, the interests and ideologies shaping their own work. So far so good, but the debate has become sterile and inward looking, disconnected from questions about relevance and political engagement. It has collapsed into relativist obfuscation – an "endlessly enchanting hall of mirrors" as Winner (1993, p.376) puts it.5

As with reflexivity, the debate in the STS literature about the normative dimensions of STS/SSK has largely degenerated into a theoretical puzzle rather than a (re)turn to political engagement. Radder (1992) for example is concerned with "normative reflexions" in relation to constructivist STS but his concern is narrowly intellectual. It remains to be seen whether the broader "politics of SSK" debate, which has resurfaced in recent years, will go down the same path.6

Chubin and Restivo (1983), proponents of the "weak program" in STS, begin with a critique of the detached conservatism common to most constructivist and relativist schools in STS. Their solution is to assert that the roles of researcher and citizen are inseparable. However they are cryptic when it comes to articulating concrete strategies for their "meta-analysis". They say (p.62) their agenda emanates primarily from a political program and only secondarily from a research program. However the political program is not spelt out and to the extent that it can be teased out of their writings, it is narrowly confined within a liberal pluralist framework which goes no further than influencing "policy-makers". Associated with their liberal pluralism is a naive, idealist conviction in the power of ideas (Chubin and Restivo, 1983, p.74, emphasis in original):

Value-criticism is the message and the science policy-maker is presumed to be listening. The future of meta-analysis is staked on this presumption – and the confidence that listening makes a difference.


6 See for example the special edition of Social Studies of Science (May, 1996) devoted to the politics of SSK.
Proponents of the weak program can be considered part of the broader "academic left". Comprising (left) liberals, academic Marxists, and supporters of one or more of the social movements (feminism, gay and lesbian rights, environmentalism and so on), most members of the academic left are critical of contemporary science and society but short on strategies for change and unlikely to be involved in social action.

In defence of the nebulous prescriptions of Chubin and Restivo, it can be argued that it is difficult to be more prescriptive than they are about how the analyst/citizen should engage himself/herself politically because of the need to deal with the idiosyncrasies of any given issue. There are any number of contingencies, such as the relative need for research or activism. In general, a positive impact is more likely when the analyst/citizen is actively, politically engaged in the issue, rather than adopting ideologies of neutrality or relying on the trickle-down theory. The increasingly sterile academic outgrowths of the social movements - e.g. women's studies, peace studies, or the generic sociology-of-social-movements literature - are testament to the importance of maintaining links beyond academia.

In terms of adopting a participatory/reflexive approach to my research, some comments need to be made on the nature of the long-standing debate as to whether a new reactor is to be built in Australia. The controversy livens up whenever there is an imminent likelihood of the federal government making a decision one way or the other, such as during the 1992-93 Research Reactor Review. At other times the controversy goes into hibernation, with little media attention and only a few activists maintaining ongoing involvement by way or research or lobbying.

My research has been conducted during a low period of the controversy. This has been advantageous in that it has given me the time to research issues in depth without being constrained by deadlines associated with an impending review. It has however limited the scope for participatory research and active involvement in the campaign during the period of research. In short this means that my research methods have differed only minimally from the usual academic approach of information collection and synthesis. Nevertheless, the thesis has a practical, political agenda. Moreover the numerous contacts I have made throughout the research period - with anti-nuclear groups, nuclear agencies, radioisotope retailing companies and others - may prove to be of some value when the controversy next flares up.
As for the actual research methodologies deployed, these can be considered in two parts. Chapters 1-4 encompass an analysis of STS; analyses of nuclear power, weapons and research reactor programs around the world and in Australia; and analysis of the 1992-93 Research Reactor Review. This material is drawn from a range of primary and secondary sources: books, journals, organisational reports, written and verbal submissions to the Research Reactor Review, etc.

Chapters 5-8 encompass an empirical survey of radioisotope production around the world, an analysis of the global radioisotope production and processing industries, with the empirical and analytical material then being used to analyse the alleged need for a research reactor in Australia for future supply of medical radioisotopes. A wider range of research strategies were deployed in compiling this material, including written and verbal correspondence with a range of people involved in nuclear medicine and the radioisotope industry. These strategies are further discussed in chapter 6.1.

The originality of the thesis lies primarily in chapters 5-8. This material is original in the compilation and synthesis of empirical material from a wide range of sources. The analysis of the global radioisotope industry is also original. For some aspects of the analysis - e.g. the links between public and private enterprise, and the links between radioisotope production and nuclear programs - the analysis is entirely original. For other aspects of the analysis, some superficial analyses exist but nothing as comprehensive as that presented in this thesis (e.g. the vertical integration of the radioisotope industry, and the trend towards dedicated production facilities).

THE FOURTH GENERATION OF SOCIOLOGY OF SCIENTIFIC KNOWLEDGE

Some methodological, epistemological, and political issues can be addressed by locating this thesis in the fourth generation of SSK according to the schema outlined by Pinch (1993). According to Pinch, the first generation of SSK was the establishment of symmetrical analysis. The tenets of this line of research were most clearly laid down by the pioneers of the so-called strong program (Barnes, 1974, 1977; Bloor, 1976). These tenets are the epistemological position that scientific knowledge is considered to derive from social processes rather than residing in nature; impartiality at various levels; symmetrical treatment of all knowledge claims (as opposed to a positivist sociology of error in which the only task for sociology is to explain fallacious knowledge claims); and the notion that explanatory patterns apply reflexively to the social analyst as well as the scientist. The second generation of SSK was the elaboration of the first through
contemporary and historical studies. The third generation was the extension of the symmetrical thesis to other areas such as applied science, science policy, gender issues, and public understandings of science.

There are any number of variations and permutations in the first three generations of SSK. A useful categorisation is that of Mercer (1993), who considers four camps. These are the strong program (Edinburgh School) and the closely related empirical program of relativism (Bath School); textual and discourse analysis and experimentation with new literary forms; actor network analyses; and fourthly, lab studies and ethnographic approaches. All that needs to be said here about these various SSK camps is that, despite the enormous variety of approaches, the work of all four camps hinges around the four SSK shibboleths of reflexivity, impartiality, symmetry, and epistemological/causal positions which emphasise the social over the natural.

Pinch (1993) argues that exploration and development of non-neutrality ought to inform a fourth generation of SSK. Some tentative steps in this direction can be seen in attempts to analyse and manipulate the partisan impact of ostensibly symmetrical analyses. A second approach is to abandon symmetry altogether. Pinch suggests as much himself - after all, symmetrical analysis is generally underpinned by a naive belief in methodological neutrality and a conservative commitment to political non-commitment. Far better to acknowledge that the adoption and application of methodologies and theories inevitably carries with it ideological and political baggage. Abandoning symmetrical analysis can lead in many directions. In general it will mean resituating the analysis – a simple example would be to focus sociological analysis on one side of a debate. Pinch uses the example of Richards’ (1988, 1991) symmetrical analyses of the vitamin C and cancer controversy, which could usefully be reworked as straightforward critiques of clinical trials – still drawing on SSK though the narrative and audience would differ.

Symmetry is not the only SSK shibboleth that needs to be resituated in a fourth generation of SSK. As mentioned all the camps and generations of SSK hinge around the four issues of epistemology, reflexivity, impartiality, and symmetry. I will take these up in turn, recasting them as practical problems within a social problem centred methodology rather than as narrowly intellectual issues.

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2 This phrase is a play on Collins’ (1996) argument that “commitment to commitment” is an incoherent position. If so, then his commitment to non-commitment has nothing more to recommend itself.
Epistemological issues will need to be considered in the fourth generation of STS/SSK, though they ought not become *de facto* subjects of analysis at the expense of science-in-society issues. As Russell (1986) argues, relativism can be useful as a limited heuristic device: suspending judgement on the validity of technical arguments (in other words bracketing them) can help to clarify the social aspects of science-in-society issues. However as Russell goes on to argue it is easy for methodological relativism to slide into a substantive, political relativism. Jasanoff’s (1996) argument that STS/SSK does not abandon a commitment to be explanatory and normative by adopting a "relativizing pose" belies the empirical record which shows that such a commitment has indeed been largely abandoned, with the "radical" relativists leading the march into an inward-looking obscurantism.

Relativism if it is to be used at all must be treated cautiously. Likewise positivism has its intellectual and political pitfalls. Intellectually, STS/SSK has done much to undermine the epistemological claims of positivist science by demonstrating the pervasive social/political factors which shape science; claims relating to the objectivity of scientific method, or the inevitability of technological development, can usefully be seen as rhetorical devices deployed by scientists and their benefactors. Politically, positivism has a long history of being deployed in support of dominant ideologies and dominant interests. This is anything but clear-cut - much political mileage can be and has been made through positivist critiques of science - but it holds in general.

As Giere (1993) notes, there are a number of intermediary positions between positivism and relativism, and these intermediary positions can overcome the limitations of both positivism and relativism and the corollary problems with crude technological or social determinisms. Such an approach is adopted in this thesis - it is constructivist in that it is alert to the socially-constructed nature of science and technology, but it does not apply relativism as a methodological principle.

One advantage of adopting an intermediary approach, as an alternative to an all-embracing positivism or relativism, is that it is potentially more flexible. Thus on occasions, particularly when dealing with the radioisotope industry and future radioisotope supply scenarios for Australia, my approach is skewed towards a

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8 Pinch (1993) focuses on SSK but the arguments can be applied to STS more generally.
2 This is essentially the same as the distinction made by Knorr-Cetina and Mulkay (1983, p.5) between epistemic relativism (all knowledge is rooted in time and culture) and judgmental relativism (which further claims that all forms of knowledge are valid), or the distinction made by Pinch and Bijker (1986, pp.355-356) between cognitive and moral relativism.
10 See also Pinch and Bijker, 1986; Restivo, 1988.
positivist treatment, with the socially-constructed nature of the debates receiving less attention. On other occasions – such as when dealing with the safety/danger to patients of nuclear medicine procedures, or the public health consequences of routine radioactive emissions from research reactors – I largely bracket the technical issues and focus primarily on the social manoeuvring, thus adopting more of a relativist position. This is done for no other reason than that these issues are highly complex, and in some cases hotly contested, and it is beyond the scope of the thesis to explore them deeply and to attempt to resolve the technical debates.

Epistemological authority is only one plank of the authority of science as Mercer (1993) notes: science is as much underpinned by instrumental, strategic, economic, and other such social/political claims. Epistemological authority is still less central to debates over technological artifacts and systems. Thus for example the HIFAR replacement controversy revolves around a series of sub-debates in which political, social, and economic claims are paramount; the epistemological authority of science, and the concomitant authority of scientists, is no more than one component of some of the sub-debates.

As for reflexivity, the second of the four SSK shibboleths to be considered, my project is one in which the aim of reflexivity is taken seriously rather than being hived off as yet another esoteric debate. I support Chubin and Restivo's (1983) advocacy of a reflexive combination of the roles of analyst and citizen but aim to go beyond their idealist fetishisation of intellectual critique and the liberal pluralist framework which underpins it. As discussed previously, the HIFAR replacement controversy will re-emerge in the public sphere in the near future, and my intention is to contribute to the public debate. Tied in with the question of reflexivity – which I have essentially recast as political engagement – is the choice of topic. Fourth-generation STS/SSK will remain a sterile extension of the previous generations unless important science-in-society issues are tackled.

Now to consider the question of impartiality/partisanship, which ties in with the more general issues of reflexivity and political engagement. Intellectual understanding and political engagement in science-in-society issues can be symbiotic. However intellectual understanding certainly can be compromised by engagement, and this is all the more likely when that engagement is openly partisan. Partisanship can lead to analyses in which certain arguments and positions are distorted or ignored, complexities and ambiguities oversimplified,
and so on.\footnote{Of relevance here are Yearley's (1989, 1991) studies of the ambiguous relationship between science and the environmental movement.} Clarity on these issues is all the more important for fourth-generation STS/SSK given the currency of conservative, scientistic critics of STS.\footnote{See for example the much publicised critique of STS by Gross and Levitt (1994) and Martin's (1996B) critique of Gross and Levitt's book.}

How is the balancing act between partisanship and scholarly rigour managed in this thesis? The research was shaped from the outset by a critical attitude to many aspects of nuclear development, and a degree of scepticism towards the claim that a new reactor is needed in Australia. However this has not involved an uncritical acceptance of arguments put forward against a new reactor. Indeed even if that was the intention it would be difficult to carry out because the anti-reactor campaign embraces a range of people and groups, with different perspectives on the HIFAR replacement issue, with different political philosophies, and with many other differences besides.

Despite my partisanship I do attempt to concentrate on providing information and constructing arguments that can withstand scrutiny from both pro- and anti-nuclear partisans as well as disinterested observers. Thus for example in chapters 5-8, having set myself the task of analysing the cases for and against a new reactor for medical radioisotope production, I pursue the analysis as even-handedly and thoroughly as possible despite my preference (and that of most nuclear critics) for the non-replacement of HIFAR for various reasons. To do otherwise would compromise scholarly rigour. One consequence of this partial disengagement (impartiality) is that the thesis provides some information and arguments which might be used to support the case for a new reactor (though it has more to offer anti-reactor campaigners). The selective use and misuse of any study in support of various conflicting positions is commonplace and inevitable and can be controlled by the analyst only to a certain extent.

A more subtle aspect of partisanship is \textit{de facto} partisanship - the notion that choices of topics (and sub-topics), methodologies, and theories inevitably entail political and partisan implications (Bammer and Martin, 1992). Certainly academics frequently choose topics, methodologies, and theories which make it likely that their work will not become part of public political discourse, but that amounts to nothing more than an acceptance of the political status quo which is itself a type of partisanship. An acceptance of the political status quo can also be ascribed to the "radical" relativists for all their pretensions. Other academics are oblivious to the political implications of their choices of topic, methodology, and theory, but that amounts to nothing more than naivete.
The issue of *de facto* partisanship is complex and its relevance for this thesis will be discussed only briefly. As mentioned the thesis was pre-figured by an anti-nuclear partisanship. The choices of sub-topics are partisan at times but at other times these choices are guided by the aim of analysing issues as rigorously and thoroughly as possible. (The partisan choices of sub-topics could be reframed in a more neutral, sanitised manner by saying that I add balance and depth to public debates by addressing a number of issues which have not been subjected to rigorous analysis in relation to the HIFAR controversy (e.g. the use of research reactors in support of nuclear weapons programs) or the medical radioisotope sub-debate (e.g. iatrogenesis). The lack of consideration of these issues reflects the shaping of the controversy by powerful state and nuclear interests.) As for methodology and *de facto* partisanship, this is not much of an issue in relation to my research since the controversy has been in hibernation throughout the research period. As for theory and *de facto* partisanship, the impartiality or partisanship of the analytical model proposed in the following section depends on its deployment; it is not inherently partisan to any significant degree.

The fourth and last SSK shibboleth to be considered is symmetry. I use symmetrical analysis to some extent, but focus more attention on teasing out the social interests underlying nuclear development and the arguments deployed by pro-nuclear advocates. Less effort is made to critically analyse arguments deployed by nuclear critics, though this by no means amounts to an uncritical acceptance of those arguments. My approach is indeed symmetrical at another level: pro-nuclear advocates have had decades of advantage through funding and institutional power to push their preferences (e.g. their preference for research reactors over cyclotrons for radioisotope production), to set issue agendas, and to establish bodies of knowledge. Opponents of the replacement of the HIFAR reactor, and nuclear critics more generally, have had far less resources. There is no neutral position from which to analyse such an inherently unequal dispute. Rigorous research, prefigured by anti-nuclear partisanship, can potentially add balance (and depth) to a debate which has been dominated by pro-nuclear partisans.

A final point on (a)symmetry is that I am less concerned to deconstruct the views of others than to construct my own arguments in relation to the HIFAR replacement controversy and the medical radioisotope sub-debate. In particular the treatment of nuclear medicine and the radioisotope industry, in chapters 5-8, goes well beyond an exegesis of existing literature on these topics.
THE NEW SOCIOLOGY OF TECHNOLOGY

The most relevant body of STS theory for this thesis is the "new" sociology of technology literature. As Bijker (1993) notes, contemporary technology studies have diverse origins such as economic studies of technical change, and sociological-historical studies drawing from history of technology and SSK. Moreover technology studies has by no means been the sole preserve of STS – historians and economists in particular have had much to say. My overview is necessarily schematic and focuses on the STS/SSK literature.

There are several recurring themes in the new sociology of technology.13 Many of these themes borrow from constructivist schools in SSK. Technologies are seen as representing sets of different meanings associated with different social connections. For some, such as the Edinburgh "interests school", both social interests and meanings are at work. Technologies are constituted or constructed through the interplay of these different meanings and social interests. Technological development is seen to be a complex, contingent, and open-ended process with a spectrum of possible alternatives and branching points, rather than being seen as the unilinear application of scientific knowledge. The SSK concept of interpretive flexibility can be applied as can the related notions of technological flexibility and contingency. Technologies can undergo stabilisation (closure) when there is a sufficient coalition of consensual interests and meanings and/or when some interests and meanings are marginalised. Generally technological flexibility correlates with success (growth, spread), but not always, and closure or stabilisation can certainly be more difficult with a flexible technology (Sætman, 1991).

Some variations of the new sociology of technology can be considered – perhaps uncomfortably given their diversity – under the banner of actor network analysis (ANA) (e.g. Latour 1983, 1987; Callon and Latour, 1981; Callon et al., 1988). In one approach the scientist occupies centre stage. Social analysts follow actors to discover how technologies are constituted and to reveal negotiations between actors. Some writers consider actors other than scientists. For example in the work of Law (1988) and Law and Callon (1988), "heterogenous engineers" constitute a resolvable problem or project and enrol the support of technical and human actors, thus creating an actor network. Success or failure depends on the ability to enrol and combine all the necessary elements which can include artifacts, social groups, beliefs, finances and so on. This approach is in some respects similar to resource mobilisation theory, which has some currency across a number of social

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13 See for example Pinch and Bijker, 1984; 1986; Bijker et al., 1987; MacKenzie and Wajcman, 1985.
science disciplines. In other branches of ANA there is emphasis on science as the organisation of persuasion through literary inscription, science as the struggle for the transformation of conjectural statements into statements of "fact", the crystallisation of knowledge claims into instruments and systems of measurement, and other such notions (e.g. Latour and Woolgar, 1979). Translated to technology studies, the notion of struggles over the transformation of knowledge claims into "facts" has a parallel in the notion of stabilised technological artifacts becoming tools with which to pursue further interests.

The various branches of ANA have done much to reveal the social dimensions of science and technology. However they share some common limitations. The focus on actors comes at the expense of an adequate conception of social structure and structured relations. Some exponents of ANA claim to break down the division between technology and society, which they do to some extent, but they generally present a reified, abstracted view of actors and artifacts. More precisely, actors and artifacts are seen in a social context, specifically a network, but the network tends to be reified. Technological artifacts have the status of actors ("actants") in Latour's work, and the science/society dichotomy is further broken down with notions of scientists constructing both science and society, but these concepts do not substitute for an adequate conception of the social structuring of technological development and lead to a form of technological determinism (Rowse, 1986). A related set of problems stems from the empiricism of ANA: there is little scope for analysis of the place of non-actors or would-be actors in technological development, groups that have no voice or are deliberately excluded. Pre-existing networks are inadequately conceptualised, and the focus on consensus building neglects power relations. Lastly, there can be a tautological element to ANA notions of success or failure resulting from the subjective capacity of actors to mobilise alliances or to combine the elements of a network.

Pinch and Bijker (1986, 1987) offer an approach - the social construction of technology (SCOT) model - which borrows heavily from the strong program and the empirical program of relativism. They discuss "relevant social groups", with different groups having different interests and attaching different meanings to technologies. This is far more useful than the focus on a single scientist or engineer or entrepreneur; it can more adequately deal with overlapping networks, pre-existing networks, and competing interests. Their approach generally involves demonstrating interpretive and technological flexibility, then showing how an artifact is stabilised and finally relating the form of the artifact to the wider social

14 Some of these problems are discussed by Sætman, 1991; Martin and Scott, 1992; Russell, 1986.
context. In short, technological development is seen as a contingent process involving the clash of competing interests.

The SCOT model goes some way beyond ANA. However it falls into some of the same problems. It is agency-oriented and lacks discussion of power, stratification, and hierarchy. Pinch and Bijker (1987) argue that "aspects such as power or economic strength (may) enter the description, when relevant", but an ad hoc approach to structural analysis is inadequate.15 The different meanings and interests that social groups attach to technologies are discussed, but social groups need to be located not only in relation to technologies but also in relation to other sections of society and to broad economic, political, historical, and ideological forces. As Blume (1992, pp.53-54) argues, the relevant social groups in the work of Pinch and Bijker emerge "from thin air": the problematisations of the relevant social groups are related to their experiences and preferences, but there is little analysis of the structuring of those experiences and preferences. The SCOT model tends to result in a liberal pluralist conception which implies that the various social groups are equal in power (Winner, 1993, p.369; Russell, 1986; Hård, 1993). The SCOT model is also empiricist, not easily able to consider the relevance of non-actors or would-be actors. Among other problems there is also a tendency to over-aggregate groups, masking internal divisions (Russell, 1986).

Because of their failure to securely tie technological development to the backbone of social and economic history, Pinch and Bijker are prone to lapses such as dropping their conflict perspective when it comes to closure/stabilisation, which they see in consensus terms. Conflict among competing groups is addressed but broad, structural antagonisms and contradictions are not. Conflict is seen as extrinsic; thus for example the SCOT model is not easily able to address processes such as the incentive for technological development and innovation stemming from class conflict in the workplace or the broader dialectics between class conflict and technological development. (Hård, 1993; MacKenzie, 1984; Winner, 1980).

The various problems with ANA, SCOT, and sundry other branches of constructivist technology studies, are neatly summarised by Winner (1993, p.373):

(The) methodological posture of social constructivism is characteristically unwilling to engage in argument about the aspects of technology that now weigh heavily in key debates about the place of technology in human affairs. Such concerns are now deleted from historical accounts of how technologies arise, as well as from contemporary descriptions of technological and social

15 Pinch (1993) has acknowledged this problem more recently, if only partially.
change. There is, similarly, no willingness to examine the underlying patterns that characterise the quality of life in modern technological societies. There is also no desire to weigh arguments about right and wrong involved in particular social choices involved in energy, transportation, weaponry, manufacturing, agriculture, computing, and the like. Even less is there any effort to evaluate patterns of life in technological societies taken as a whole. All the emphasis is focused upon specific cases and how they illuminate a standard, often repeated hypothesis, namely, that technologies are socially constructed.

Despite their limitations, many of the concepts (e.g. flexibility, contingency) used in ANA and SCOT analyses are useful. There is no need to throw the baby out with the bath water as Yearley (1994) argues. Constructivist technology studies have added insight and conceptual rigour to the field. Detailed studies of specific technologies (and technological systems) have made it far easier to counter appeals to technological determinism by revealing social interests, contingency and so on – the main problem being the tendency to raise the constructivist toolkit to the level of methodological principle. Detailed empirical studies are a necessary antidote – and addition – to deductive, structuralist approaches starting from theoretical schemas, such as the economic studies which largely leave unopened the black box of technology. And of course constructivism is an improvement upon Whig hagiography and technological determinism.

One step beyond the work of Pinch and Bijker, and of considerable relevance to this thesis, is the analysis of the medical imaging industry by Stuart Blume in his 1992 book *Insight and Industry*. This book is by far the most sophisticated and useful overall analysis of the medical imaging industry, with case studies addressing ultrasound, thermography, computerised tomography, magnetic resonance imaging, and x-radiology. I will return to Blume's study in later chapters; for now I will just summarise the ways in which Blume advances the SCOT model.

Blume (1992, p.55) is keenly aware that the study of technology-in-society requires an interdisciplinary framework, his own analysis drawing from the "very disparate areas" of medical sociology and the economics of innovation. He argues (pp.54-55) that the lack of any conception of structure is a "fatal flaw" in much recent sociology of technology, and he turns primarily to literature on the economics of innovation to conceptualise the structural dimensions of the medical imaging industry.
Blume develops the notion of an interorganisational structure of medical imaging. An interorganisational structure characterises the common interests and specific structural relations - modes of integration and interdependence - between producers (companies), purchasers (mainly hospitals), and users (radiologists) of medical imaging equipment. The interactions between the actors are structured by market forces and, conversely, the medical imaging market is constituted through these interactions. Within this milieu of structured collusion and collision, the technological artifacts (various imaging modalities) are dependent for their existence and form on the structured relations between producers, purchasers, and users.

As Misa (1992) argues, constructivists (such as most sociologists of technology) tend to overstate the fluidity of sociotechnical relations whereas structuralists (such as most economists) tend to understate (or ignore) sociotechnical fluidity. In many respects Blume's conceptualisation of an interorganisational structure demonstrates a sophisticated understanding of the dialectical relationship between agency and structure. The emphasis in debates on agency and structure has shifted away from reified conceptions towards a focus on the process of structuring (Barley, 1986). This suggests the need for longitudinal studies of technological change. Here again Blume's analysis is useful because his study begins with the development of x-radiology in the late nineteenth century. Thus he analyses the initial development of the interorganisational structure of medical imaging and its evolution over the best part of a century including successful and failed attempts to incorporate new imaging modalities into the structure, the effects of changes in the external environment (such as government regulation, economic cycles), and so on.

The interorganisational structure of medical imaging has undergone continual modification - mostly incremental, sometimes more extensive as with the introduction of a number of modalities from the 1960s. Modifications create a new environment which shapes further technological development. Moreover the external environment in which the co-development of technologies and markets takes place is by no means set in stone. Blume (p.72) makes the pertinent point that

"The "contexts" into which successive innovations are introduced are not strictly speaking the same. At the same time the broader social, industrial, and demographic structure of society also changes, so that the historian is"

16 For useful discussions on the structure/agency issue in relation to technology, see also Bijker 1993; Barley, 1986.
properly enjoined to embed the history of technology in a more general social and economic context.

Blume (1992) has much to say about the interaction between the interorganisational structure of medical imaging and the external environment, taking up issues such as the redeployment of military technology and the impact of nuclear research and development in the post World War II period; the development and commercialisation of computers and microelectronics from the 1970s; and challenges in the past generation to both industrial oligopoly and professional monopoly by radiologists, stemming from a web of interconnected developments such as increasing development costs and attempts to impose stricter regimes in relation to technology evaluation.

In his analysis of the economic structuring of medical imaging technologies and markets, Blume has much to say on mergers, concentration ratios, entry barriers, the relationship between industry concentration and innovation, and so on. However recognising the importance of industrial interests, and recognising that the development of imaging modalities is constrained by the structured relations of a market, does not allow a one-sided analysis in which medical professionals are seen to be drip-fed whichever imaging technologies promise a handsome profit. Rather, there is a co-development of markets and technologies, and further innovation occurs only when there is a convergence of industrial and professional interests. (Blume, 1992, pp.66-67.)

Arguing that economists fail to consider social dynamics which do not fit neatly with economic concepts, Blume (p.55) draws not only from the economics of innovation literature but also from medical sociology. An adequate analysis of medical imaging modalities - including nuclear medicine - would be flawed without a grasp of medical sociology because medical markets are peculiar in many respects. The health-care system is both a purchaser of technology and a provider of services based on those technologies. Buyers (such as hospitals and doctors) and sellers (such as manufacturing companies) have common interests - in particular extending the size of the market - which are often not constrained by marketplace price mechanisms. The ultimate consumers - patients - have very little input into decisions which shape the development of the industry, generally deferring to ideologies of professional expertise. In contrast to many other industries, health-care systems have tended to become increasingly capital and labour intensive; once again the lack of marketplace cost constraints is relevant. In these and many other respects, health-care systems fail to fit ideal-type economic conceptualisation.
Blume’s schema is a considerable improvement on ANA and SCOT models. While he does not directly discuss nuclear medicine, his analysis of other imaging modalities, and the interorganisational structure of medical imaging in general, is suggestive of how an analysis of nuclear medicine might proceed. However his analysis of the broad social structuring of the medical imaging industry could be further developed. While Blume is well able to analyse the impact on the imaging industry of structures that are superficially identifiable - such as government, companies, and the military - he is unwilling to go any further. Thus his analysis remains constrained by empiricism and an implicit liberal pluralism, even if less so than much other writing in the sociology of technology.

Blume is well aware of the significance of the symbiotic integration of professional and industrial interests in medicine, and he cites Brown's (1979) *Rockefeller Medicine Men* in which that symbiosis is linked to common class interests and ideologies. However Blume (pp.259-260) simply asserts that his analysis is "distant cousin" to Brown's and he has nothing more to say on the class structuring of the medical imaging industry. There is an abundance of detailed, sociologically-sophisticated literature on the class structuring of all aspects of medicine. When medical specialists, the elite of the medical profession, meet capitalists in a lucrative market situation, as has generally been the case with medical imaging modalities, class interests and ideologies are all too obvious.

As Hård (1993, p.413) argues, tied in with the liberal pluralism and empiricism of STS conceptualisations of sociotechnical systems is a strong thread of functionalism17:

> The world of a sociotechnical system looks and feels like an iron cage. There is no place for critique and no way out. Established sociotechnical systems are conservative. By adhering to a functionalist methodology, we can never succeed in being critical in a substantial manner. By presenting a view of technology in terms of functionally arranged sociotechnical systems, we will support those who benefit from harmony and cooperation and discourage those who might benefit from conflict and opposition. We might be able to reveal both unexpected and unwanted aspects of a technology, but we will remain unable to suggest an alternative.

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17 Hård points specifically to the business organisations approach and to Hughes' (1987) conceptualisation of technological systems, but the same could be said in relation to actor networks, Bijker's (1993) "technological frames" and "sociotechnical ensembles", and also to Blume's interorganisational structures. See also Hull (1994) for a brief but useful critique of sociotechnical systems thinking in STS.
Blume sits with the functionalists: a sophisticated analysis of the interpenetration of science and society but a critique of neither.

That the various conceptions of sociotechnical systems being developed in STS are beset with problems does not mean they need to be done away with. They may necessitate awkward distinctions between internal and external forces, but attempts to go further into the realms of the "seamless web" tend to be so amorphous as to be no improvement at all. Moreover there has been an uneven progression in STS from the analysis of specifics – specific artifacts, debates, individuals, institutions – towards a more general analysis of sociotechnical systems. To give up on the latter would be a backwards step.

Conceptions of sociotechnical systems must be further developed. As to how this should be done, the limitations of the various conceptions currently in use would strongly suggest that there is little to be gained through further abstractions and generalisations derived from constructivist studies of technological development. As Winner argues (1993, p.376), the focus needs to shift from an academic interest in how technologies are constructed to an intellectual and political commitment to reconstructing our technology-centred world in ways inspired by democratic and ecological principles. Studying how this can be done is a great challenge for cross-disciplinary study as Winner goes on to say. One path – though not a panacea – is to build on and learn from the practical attempts of the (embryonic and vacillating) alternative technology movement which aims to construct alternative technologies or reconstruct existing technologies (MacKenzie, 1984).

Analysis of alternative technologies certainly forms a part of this thesis; for the moment however the concern is to introduce an analytical framework.

INTEGRATED ANALYSES OF SCIENCE AND TECHNOLOGY

The framework to be deployed in this thesis takes inspiration from a number of integrated, multi-level approaches which have been proposed and/or deployed by STS scholars in recent years. Giere (1993) argues that analysis of technological systems requires an understanding of technological artifacts in their scientific-technological context; an understanding of relevant psychological or cognitive features of various actors (e.g. inventors, entrepreneurs, managers, consumers); an understanding of relevant microsocial interactions; and an understanding of

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18 On seamless webs, which aim to break down analytical distinctions such as that between science and society, see Bijker, 1993; Giere, 1993; Hughes, 1986.
various macrosocial interactions, including cultural and economic factors. Another example is Mercer's (1993) study of the ongoing controversy about the health effects of non-ionising electromagnetic radiation. Mercer adopts an "eclectic" approach to controversy analysis, drawing elements from controversy-as-politics, technocratic politics, fact-value approaches, historico-narrative approaches, controversy closure studies, and SSK. A third example is the integrated approach to controversy analysis proposed by Martin and Richards (1995), bringing together structural, group politics, SSK/constructivist, and technical analysis.

From what has been said it is clear that the major limitation of much contemporary sociology of technology is the lack of consideration of the broad social structuring of science and technology. Integrated approaches can retain what is of value in constructivist and (functionalist) systems approaches while going beyond those approaches through closer attention to structural analysis. Another common limitation is the tendency to prefigure analyses through attachment to theoretical or methodological schemas. Once again integrated approaches are advantageous in that they offer some scope for flexibility – different levels of analysis can be used as appropriate, and different topics can be addressed at different levels. This flexibility is important for this thesis since the empirical scope is wide-ranging.

There is no need here to map out the various levels of analysis to be used in this thesis – to do so might risk schematically prefiguring the analysis, and in any case the scope of the thesis is too broad and the approaches used are too varied to be neatly mapped out. Suffice it to say that many of the approaches suggested by Giere (1993), Mercer (1993), and Martin and Richards (1995) will be used and to make some preliminary comments on how the analysis will proceed.

Generally, the analyses in the following chapters are cognisant of i) the specific features of the system/technology/debate under discussion, ii) the aims of the discussion and its place within the thesis as a whole, iii) the variety of approaches and levels of analysis that could be deployed, and iv) the approaches to generic STS/SSK issues (reflexivity, symmetry, partisanship/impartiality, and epistemology) most suitable for a fourth generation of (politically-relevant) STS/SSK.

The thesis is concerned with two overlapping sociotechnical systems – nuclear programs and health-care systems – with much of the thesis focused on the intersection of these two broad systems in the radioisotope industry and nuclear
medicine. These sociotechnical systems are located in the overarching structural milieu of capitalism since World War II. The dialectics between science, technology, and capitalism will not be systematically explored, but some attention to these connections is necessary to overcome the limitations of constructivist STS/SSK. In particular the analysis of nuclear programs in chapters 2-3 needs to be related to the broad contours of post World War II capitalism and international political and economic history more generally.

The analysis of the radioisotope industry and nuclear medicine in chapters 5-8 mostly operates at lower levels. The analysis in these chapters is driven by the practical question of future radioisotope production and supply for nuclear medicine in Australia, and this requires some detailed consideration of mundane issues such as the scale of radioisotope production and export operations overseas. The analysis is alert to the themes of constructivist technology studies but development of those themes is not given emphasis. As for the broad social structuring of nuclear medicine and the radioisotope industry, the main concern is to tease out the interconnections between nuclear medicine, the radioisotope industry, and nuclear development more generally.

Finally, some comments on how the different levels of analysis relate to one another. Essentially, I argue that the more detailed, lower-level analyses of the HIFAR replacement controversy and the radioisotope industry are much better understood in the context of the broad, historical analyses of nuclear power, weapons and research reactor programs around the world and in Australia.

As discussed in chapter 4.1, my integrated approach to the analysis of the HIFAR replacement controversy encompasses technical/positivist analysis, and it embraces a number of themes from constructivist STS/SSK. It is argued that further important insights can be gained through greater attention to the structural and historical location of the controversy. Of particular interest in this regard are the multifaceted and somewhat nebulous "national interest" arguments put forward for the construction of a new reactor. According to the Research Reactor Review (1993, p.2), the national interest issues connected to the operation of a research reactor in Australia concern "how necessary it is to maintain some degree of nuclear capability to assist non-proliferation initiatives, to find out what others are doing, or to protect its own national interest if occasion demanded."

In general terms, the national interest debates are much better understood in the context of the historical tension between the AAEC/ANSTO as an institution of
key strategic importance (*vis a vis* nuclear weapons and power) versus the AAEC/ANSTO as one public-sector civil science agency among many. That tension is fully explored in chapter three. In addition, the national interest debates relate to Australian involvement in nuclear industries overseas, and thus the overview of nuclear programs around the world, provided in chapter two, provides important contextual material.

The historical analysis of nuclear programs in chapters 2-3 also facilitates the detailed analysis of nuclear medicine and the radioisotope industry in chapters 5-8. In particular, the radioisotope industry is seen as an outgrowth of the nuclear weapons and power programs of the post World War II period. The ongoing links between the radioisotope industry, and nuclear programs more generally, are also analysed in detail. Thus for example the problems faced by the nuclear power industry over the past two decades are shown to have impacted, in various ways, on the research reactor infrastructure around the world and thus on reactor radioisotope production. Similarly the history and trajectory of nuclear weapons programs impacts on reactor radioisotope production in many ways.
CHAPTER TWO:
THE GLOBAL CONTEXT:
NUCLEAR POWER, WEAPONS, AND RESEARCH REACTORS.

2.1. INTRODUCTION
2.2. NUCLEAR POWER
2.3. NUCLEAR WEAPONS
2.4. RESEARCH REACTORS

2.1. INTRODUCTION

This chapter presents summaries of nuclear weapons, power, and research reactor programs around the world. This provides useful context for the closer analysis, in chapters 3-4, of Australia's nuclear history and the HIFAR replacement controversy.

The other main task of this chapter is to discuss the interconnections between civil and military nuclear development, in particular the links between research reactors and covert weapons programs. Again, this provides useful context for the analysis of the intersection of civil and military nuclear development in Australia.

This chapter also provides a backdrop for the analysis of the radioisotope industry in chapters 5-8. The radioisotope industry developed as an outgrowth of the nuclear power and weapons programs of the post World War II period, and there are still strong connections between nuclear programs and the radioisotope industry.

Even a sweeping analysis of nuclear programs deserves some consideration of anti-nuclear opposition. However to avoid duplication, anti-nuclear opposition is only briefly addressed in this chapter, and is considered in more detail in chapter three.
2.2. NUCLEAR POWER

THE DEVELOPMENT OF NUCLEAR POWER

THE DECLINE OF NUCLEAR POWER

THE FUTURE OF NUCLEAR POWER

THE DEVELOPMENT OF NUCLEAR POWER

There is no need in this thesis for anything more than a sweeping overview of nuclear power, and I will focus this discussion on the development of nuclear power in the capitalist countries.

During World War II and in the immediate post-war period, civil nuclear applications were generally accorded a much lower priority than nuclear weapons and were developed largely along lines dictated by military requirements. For example the first "commercial" nuclear power plant, the Calder Hall complex in the United Kingdom (UK), was designed primarily to produce plutonium for weapons.

The viability and success of any technology depends on the ease with which it can be subsumed within existing social structures or, failing that, the degree to which social structures and technologies can be reshaped to accommodate each other. Nuclear power was broadly commensurate with the structure and trajectory of post-war capitalism, and was seen to be an important element in the reconstruction of the international capitalist order. It was to be an important industry in itself, and a means to further expansion in other industries through the generation of cheap electricity. It promised some advantages over other energy/electricity industries, which were more labour intensive and sometimes prone to labour militancy. Nuclear power was also seen as a way of "cashing in" on technologies developed for nuclear weapons. (Falk, 1982; Roberts, 1976; Camilleri, 1984.)

Notwithstanding the broad compatibility of nuclear power with post-war capitalism, a great deal of social and technological engineering was required to establish nuclear power industries. Existing scientific institutions generally lacked the necessary organisational and financial resources to accommodate and develop nuclear power. The military had a large degree of control over nuclear development during the war in some countries, but military control over (civil) nuclear power was ideologically unacceptable and logistically impractical. Industrial interests had been established to some degree – for example
Westinghouse had gained experience in reactor manufacture during the war - but it soon became clear that nuclear power was a complex, multifaceted system, the commercial risks were high, and the developmental phase would last for some years. (Spence, 1984.)

The net effect of the various strategies employed by early advocates and sponsors of nuclear power was to create the institutional and ideological framework for the establishment and acceptance (however limited) of nuclear power. In countries pursuing nuclear programs a "nucleocracy" was established, institutionalised, and further developed, comprising a coalition of state, industrial, and professional interests involved in the civil and military development of nuclear technologies. There would be deep divisions between sections of the nucleocracy at times, but a fundamental, shared commitment to nuclear development. Atomic energy agencies (a.k.a. institutes, laboratories, commissions) were established in many countries, well supported by public funds and closely connected with private industry and numerous branches of the state apparatus; these agencies were central to nuclear development. In some countries (e.g. France, the Soviet Union), little effort was made to separate civil and military nuclear programs; in others (e.g. the US), efforts were made to disentangle them if only to a certain extent; and in other countries, nuclear power was developed but there was no serious pursuit of nuclear weapons (e.g. Canada) or a weapons program was pursued for a time but then abandoned and the emphasis was on civil applications (e.g. Sweden).

The nuclear fuel cycle is highly integrated and requires a great degree of co-ordination, regulation, and financing. The reactor industry cannot be considered in isolation because it depends on "front-end" technologies (uranium mining and processing, uranium enrichment for some types of reactors, fuel fabrication), and "back-end" technologies (reprocessing of spent fuel, and management and disposal of radioactive wastes). Each facet of the cycle must operate adequately or the viability of the entire nuclear power industry can be threatened. All the necessary components of the nuclear fuel cycle were in the early stages of development in the post-war period. In some cases technologies developed for weapons production, such as enrichment, had direct spin-offs for nuclear power; but other aspects of nuclear power, such as reactor technology, required a great deal more development.

The role of the capitalist state was crucial for the development of nuclear power and the nuclear fuel cycle more generally. Many of the political, judicial, financial, administrative, and coercive arms of the state have been involved. The state has always been central to capital accumulation, and accumulation has increasingly
been marked by industrial and financial concentration, technological innovation, and centralised production and distribution. Nuclear power was a prime example of these trends, but an unusually high degree of state support was necessary because of the cost and complexity of nuclear power. Another reason for the central role of the capitalist state was the reluctance of the private sector to become involved – particularly in the formative years of the industry – because of the high capital costs and high risks. The military potential of nuclear energy provided a further reason for substantial state regulation over all facets of the nuclear fuel cycle. (Spence, 1984; Camilleri, 1984, pp.274-278.)

In many countries, energy demand rose substantially and steadily in the post-war generation. State subsidisation of electricity production – in particular nuclear power generation – stimulated electricity demand. Electricity utilities, public or private, could be directed, or at least encouraged, to meet at least some demand with nuclear power as opposed to coal, oil, gas, or hydroelectricity. Forward estimations of electricity demand rested on variables that were difficult to predict; thus there was scope for creative accounting to bolster nuclear power. (Camilleri, 1984, ch.2.) More directly, state institutions funded and/or conducted a great deal of research and development (R&D). In addition, private companies were offered a range of financial incentives and concessions to encourage their involvement in the industry, such as indemnity legislation limiting private-sector liability in the event of accident, opportunities to commercialise state-funded R&D, and sundry other incentives such as generous support in relation to fuel use and fuel fabrication charges and waste management. (Falk, 1982.)

Another major area for the state has been regulation, including the implementation of security systems to prevent sabotage, theft, or terrorism; control of information; licensing and regulation of radiation hazards; and the development of international safeguards systems to prevent weapons proliferation. Regulatory processes were (and are) complex and contested. Traditional models of scientific research, including open-ended ("pure") research and the free flow of information across national borders, were restrained in the context of bureaucratised and militarised nuclear science. Vetting of employees, security provisions attached to employment, and limited disclosure of information, resulted in the state and the nucleocracy having a near monopoly of nuclear expertise, with independent critical inquiry subordinated to institutionalised interests. Regulatory agencies have generally not been sufficiently strong or independent to call into question major aspects of nuclear development. Politicians and bureaucrats have often been the prisoners of blinkered "expert" advice from the nucleocracy. (Camilleri, 1984; Moyal, 1975.)
Commercial nuclear power plants came into operation in the 1950s, but growth was slow. Then from the mid 1960s, there was an upsurge of orders - 105 power reactors were ordered around the world from 1966 to 1971. In the early to mid 1970s, uncertainty over oil maintained the momentum of nuclear power. (Camilleri, 1984, pp.167-178.) Most of the powerful capitalist countries developed substantial nuclear power programs - in particular the US, the UK, France, West Germany, Japan, Canada, and Sweden. A major nuclear power program was also pursued in the Soviet Union. Small or moderate nuclear power programs were established in various other capitalist and Eastern European countries and in a small number of developing (third-world) countries.

Some national industries - such as those in the US, the UK, France, and India - strove for independence across the nuclear fuel cycle. Independence was sought to avoid the financial burden of dependence on foreign suppliers, because independence in nuclear power fitted well with nationalist ideologies, and in some cases because expansion into areas such as reprocessing and enrichment facilitated the development of nuclear weapons. However for most countries, complete independence was impractical for a system as complex and costly as nuclear power. There was a demand-side pull for nuclear equipment and services, and also a supply-side push with many national industries seeking export markets to recover the huge investments made in the nuclear power industry. Thus there has been a great deal of international cooperation and competition, carried out in the context of an international division of labour characterised by stratification, competition and uneven development. As with the management of domestic nuclear industries, the state has been heavily involved in all aspects of international nuclear relations - attempting to protect and strengthen the national nuclear industry vis a vis foreign competitors, supporting the export initiatives of the national industry, and managing international issues such as control of weapons proliferation. (Camilleri, 1984; Falk, 1982.)

The US had enormous political and economic power in the first two decades after the war, and that strength was used to shape the international development of nuclear power. Light-water reactors\(^{19}\), developed in the US, had advantages over reactor types being developed elsewhere, and the American industry enjoyed other advantages such as a virtual world monopoly, outside the Eastern Bloc, of uranium enrichment facilities. The US government launched the Atoms for Peace policy in 1953. This involved supply of enriched fuel and agreements to take

\(^{19}\) Light-water reactors use ordinary ("light") water as the moderator of the uranium fission reaction, and are fuelled with low-enriched uranium. Heavy-water reactors use heavy water (deuterium oxide) as the moderator, and some can be fuelled with natural uranium.
back spent fuel; access to training facilities and research results; and loans for privately-owned utilities. These funds were made available only if they were used to buy equipment, materials, and technical services from the US nuclear industry. Behind the Atoms for Peace policy was a strategy to stimulate the global nuclear power market, to control and profit from it as much as possible, and to control weapons proliferation. (Clausen, 1985.)

American light-water reactors led the field when there was a surge of orders for power reactors from the mid 1960s. A number of countries with significant nuclear power industries also based their programs on US light-water reactor technology, including West Germany, France, Japan, Sweden, and Switzerland. In some cases (e.g. France), indigenous reactor designs were developed but dropped in favour of light-water reactor types. The UK and Canada developed and persisted with their own reactor types, some of which use natural uranium as fuel and thus avoid the problems associated with reliance on overseas enrichment services or the cost and complexity of construction of domestic enrichment facilities. (Thomas, 1985; Spence, 1984; Wohlstetter et al., 1979.)

The strong position of the US nuclear industry was under threat even before the end of the 1960s. The erosion of US dominance in nuclear power was part of a broader trend of declining US hegemony in the face of the growing strength of European and Japanese capital; America's military superiority was secure but its economic dominance was not. Even when based on US light-water technology, competitors began to threaten US dominance in the nuclear power export market. By the late 1960s, a controlled market, dominated by the US, gave way to more classical market mechanisms. (Rees, 1990; Spence, 1984.) There was a gradual spread of enrichment technology, fierce competition for reactor sales, a race for technological leadership in the development of fast breeders20, and diverging approaches to international safeguards which tended towards the lowest common denominator. (Camilleri, 1984, pp.286-288.)

In addition to the growing strength of individual nation states vis a vis the US, alliances were undermining American control over nuclear power. One of the informal alliances was between French technology and German industrial muscle in areas such as reprocessing and fast breeders. A number of European countries collaborated to develop enrichment facilities, thus gradually reducing their

20 "Breeder" reactors are fuelled with natural uranium and plutonium-239. They produce more plutonium-239 than they consume, through conversion of uranium-238 which constitutes 99.3% of natural uranium. The development of breeder technology has been extremely expensive, unsuccessful, and also contentious for various reasons including the weapons proliferation implications of the plutonium economy. See Collingridge, 1983, ch.9.
dependence on the US. Alliances involving major capitalist countries and semi-peripheral countries were also emerging – for example between West Germany and Brazil, West Germany and Argentina, and France and South Africa – and other nuclear alliances, for civil and/or military nuclear development, were forming independently of any of the powerful capitalist or Eastern Bloc countries. (Camilleri, 1984.)

**THE DECLINE OF NUCLEAR POWER**

Some countries have managed to maintain growth in nuclear power over the past 20 years, such as France, Taiwan, Japan, South Korea, and to a lesser extent Canada, India, and China (where nuclear power was not seriously pursued until the 1980s). In most cases these countries have been able to proceed with nuclear power expansion because of an exceptionally high degree of state involvement in and control over nuclear power, often a function of a more general political centralisation. (Thomas, 1985; Camilleri; 1984.) However growth was the exception rather than the rule from the mid 1970s. Nuclear power programs in many other countries went into decline.

A number of factors were responsible for the decline of nuclear power. Major accidents, most notably those at Three Mile Island and Chernobyl, had a substantial impact. More generally, concerns about the social and environmental impact of the nuclear fuel cycle generated significant public opposition and mass anti-nuclear movements. Accidents and heightened public opposition led to more stringent environmental and safety regulations. Increased regulation, in turn, resulted in delays and major cost blow-outs. Lead times blew out to 12-15 years or more, requiring planning which greatly exceeded the industry's forecasting capabilities, and lengthening lead times resulted in spiralling capital costs due to additional interest payments and increased inflationary effects. (Thomas, 1985; Camilleri, 1984; Falk, 1982.)

Delays and cost blow-outs occurred at a time when countries all around the world were hit by economic stagnation and recession, with a consequent decline in energy and electricity demand. Electricity utilities were faced with over-supply which ambitious construction programs could only exacerbate. Financing nuclear power projects became far more difficult against a background of economic stagnation, high inflation, and high interest rates. The economics of nuclear power vis a vis alternative electricity sources had always been dubious, and such comparisons were still less flattering as the nuclear power industry went into decline. Technical problems also plagued the industry and had further
consequences for costs, delays, increased regulation, and public opposition. (Collingridge, 1983; Thomas, 1985; Camilleri, 1984; Falk, 1982.)

When orders for power reactors slowed down or dried up altogether, reactor manufacturers could cut their losses, thus abandoning any share in a future revival. Alternatively they could maintain their manufacturing capability, but only by seriously jeopardising profitability in the short term. Some stop-gap measures were available: fixing problems resulting from deficiencies in various reactor designs; expanding into other facets of the nuclear fuel cycle; and transferring personnel into R&D projects. (Falk, 1982; Camilleri, 1984, pp.133-134.)

The decline in demand for nuclear power had obvious implications for the reactor industry. This in turn impacted on other aspects of the nuclear fuel cycle, significantly affecting the economics of uranium mining, enrichment, and reprocessing. The nexus between nuclear power and nuclear weapons further debilitated the nuclear power industry (even if a degree of symbiosis persisted), through public opposition and stricter export policies. Reprocessing and fast breeder programs, which promised at least some hope of improving the viability of the nuclear power industry, were scaled down in some countries because of their implications for weapons proliferation. (Camilleri, 1984, pp.284-285.)

Attempts were made to reorganise national industries with a view to achieving economies of scale, reducing capital costs, and ensuring long-term viability. This included efforts to merge or amalgamate companies in order to protect the domestic industry from the encroachment of foreign competitors. State intervention was aimed at improving the overall situation of the national industry though sections of it were disadvantaged or even sacrificed at times. Efforts to streamline regulatory and licensing processes were pursued, but were often frustrated by factors such as patchy technical performance and public pressure. Moreover in a number of countries the state apparatus was incapable of significantly reducing the regulatory burden. For example in the US, the complex division of powers between national, state, and regional political institutions could not be refashioned to any significant extent, nor could it be bypassed, and in West Germany the judiciary was heavily involved in nuclear regulation and was a major obstacle to streamlining. Growing public opposition and activism presented the state with an acute dilemma: decisive action by the state to salvage the nuclear power industry tended to sharpen political conflict and to undermine the state's legitimacy, whereas procrastination or concessions to anti-nuclear movements could only deepen the predicament of the industry. (Camilleri, 1984.)
In the context of declining domestic prospects for nuclear power, there was intensified rivalry for export markets. There was growing interest in stimulating and supplying markets for nuclear power in developing countries. Nuclear power promised to be still more problematic in developing countries than in the advanced industrial countries: the expertise and industrial infrastructure was generally lacking; electricity demand and grids were not suited for the large plants being favoured in the advanced capitalist countries; and financing was a big obstacle. Nevertheless, suppliers made use of political, military, and economic leverage to stimulate nuclear power markets in developing countries. Inducements were important - these could include bribery, or low-interest loans and generous trade packages designed to give exporters a toe-hold in a market. As with so many other aspects of nuclear power, state support was crucial in the attainment of export contracts; the loans offered by the US Export-Import Bank being an important example. Suppliers often found a receptive audience among political and military elites, and Western-trained scientists, in recipient countries. However these efforts had only modest success, although they did give some companies some important breathing space. (Ne'eman, 1981; Sharma, 1985; Hayes and Bello, 1979; Hayes and Shorrock, 1982.)

With declining US hegemony, international nuclear commerce has largely followed the classical model of imperialist rivalry in which large national capitals, each backed by its domestic state, vie for markets and raw materials. In the difficult environment of the past 20 years, national rivalries have become increasingly sharp, and insecurity and shrinking markets have also added momentum to the contradictory tendency for suppliers to pool resources in collaborative ventures. (Spence, 1984.)

**THE FUTURE OF NUCLEAR POWER**

Thirty-two countries operated a total of 437 power reactors as at late 1996, with power reactors under construction, planned, or on order in a further five countries. Thirty-two power reactors were under construction, nine were on order and 70 were planned. (ANSTO, 1996F.) On the strength of the past 20 years it can safely be said that a fair percentage of the 70 planned power reactors will not be built.

One of the major impediments to a resurgence in the nuclear power industry is ongoing global economic stagnation, and there are no signs of a significant, lasting abatement of that stagnation. Notwithstanding the profound changes in international relations over the past decade, the nuclear power industry is still
embedded in a system of international multipolarity with intense competition for export markets between rival corporations and nation-states. The collapse of the bureaucratic collectivist (Stalinist) regimes has opened up some commercial opportunities for Western nuclear export, but the broad outlook for nuclear power remains poor.

Lower-level determinants of the future of nuclear power include containment of public opposition, further efforts to streamline regulatory procedures, and resolution of radioactive waste problems. No significant progress has been made in these areas, although anti-nuclear movements are generally smaller and weaker than in the 1970s and 1980s. Technical innovation is another variable. Innovation proceeds across the nuclear fuel cycle in the hope of sparking a revival - or at least a neutralisation of some of the major deficits. There is much ongoing work in the field of reactor design, but much of this involves modifications of existing designs - a major technical breakthrough such as a viable breeder industry is unlikely (Kabanov et al., 1992).

Despite the significant decline in power reactor sales and construction in the past 20 years, this has not resulted in a steady decline in nuclear power output. For example there has been a slight, uneven increase in nuclear power output in the mid 1990s. This growth has had little to do with the commissioning of new reactors, instead reflecting temporary fixes such as refurbishments of existing reactors to increase production capacity, extensions of plant life, and improving load factors (efficiency). Growth could not be sustained through these technical fixes for any length of time. (Anon., 1996H.)

2.3. NUCLEAR WEAPONS

INTRODUCTION
SURVEY OF NUCLEAR WEAPONS PROGRAMS
NUCLEAR WEAPONS AND "THE NEW WORLD ORDER"

INTRODUCTION

This section begins with a survey of nuclear weapons programs, followed by some commentary on the potential for further proliferation of nuclear weapons in the post Cold War period. The cross-fertilisation of civil and military nuclear development is discussed in this section and again in the following section (2.4) on research reactor programs.
Some preliminary comments should be made in relation to the manufacture of nuclear weapons. Weapons-grade fissile material is the crucial ingredient in nuclear weapons. Production of plutonium-239 (Pu-239) by neutron bombardment of uranium-238 in a reactor, and enrichment of uranium to produce highly-enriched uranium (HEU), are the two most common methods of producing fissile material for bombs. (A third method is reactor irradiation of thorium to produce fissile uranium-233.) Production of plutonium requires a reactor – either a purpose-built reactor, a power reactor, or a research reactor – plus reprocessing facilities for extracting the plutonium from spent fuel. Uranium enrichment facilities are generally complex and expensive, but as methods of enrichment have been developed and improved the potential for production of HEU bombs has increased. In nearly all countries pursuing nuclear weapons programs, efforts have been made to domestically produce plutonium and/or to enrich uranium, but it is also possible to acquire weapons-grade fissile material by gift, theft, or purchase (including diversion of material acquired for civil purposes). In addition to fissile material, components such as high explosives, firing triggers, and handling devices are also required. Developing these components requires considerable technical skill, although producing or acquiring weapons-grade fissile material is the biggest obstacle. Another requirement is a sizeable team of highly-trained specialists. Some delivery systems, such as aircraft modified for delivery of nuclear weapons, pose no great obstacle, but advanced missile systems are far more complex and expensive.

SURVEY OF NUCLEAR WEAPONS PROGRAMS

In the decades following World War II, the US and the Soviet Union built over 40,000 increasingly powerful and sophisticated nuclear weapons between them, as well as associated technologies such as advanced missile-delivery systems. While neither of the superpowers used nuclear weapons in military conflict since 1945, threats and posturing were common enough (Booker, 1993). The Cold War confrontation and arms race had profound implications through the shaping of international political alignments, the enormous resources committed to nuclear militarism, the social and environmental impact of weapons tests, and the hundreds of accidents involving nuclear military facilities, bombs, planes, silos, submarines, and so on. (Vallentine, 1992.)

There is no need here to recount the history of Cold War nuclear politicking. A summary of recent developments is in order however, since the situation is fluid. The collapse of the Stalinist regimes throughout the Eastern Bloc, giving way to capitalist restoration, has had significant implications for nuclear weapons.
development and politicking. The most important of these implications is that the potential for nuclear war between the US and former Soviet countries is considerably less likely than was the case during the Cold War. Russia and the US have deactivated hundreds of strategic nuclear weapons and thousands of tactical nuclear weapons and have dismantled thousands of warheads. There has also been some progress in other areas - for example the blending down of some weapons-grade fissile material for use in power reactors, and recent initiatives to stop weapons testing. (Spector et al., 1995.)

Despite these encouraging developments, the post Cold War world promises a continuation of inter-state economic and military conflict, and the potential for nuclear attacks cannot be disregarded, whether between the US and former Soviet countries (in particular Russia), or between other countries. The nuclear weapons stockpiles in the US and former Soviet countries are still very large. As at 1995 the estimated US stockpile was 8 500 strategic nuclear weapons, and 7 000 tactical weapons, with the estimates for Russia being 7 200 strategic weapons and 6 000 - 13 000 tactical weapons. (Spector et al., 1995.)

Historically, the various nuclear disarmament treaties between the US and the USSR/Russia have had limited success in terms of disarmament, more success as publicity stunts (Rees, 1990). The most recent initiative involves preliminary negotiations concerning a third Strategic Arms Reduction Treaty, START III, which aims to gradually reduce arsenals of strategic warheads in the US and Russia to 2 000-2 500 - still an enormous inventory and it needs to be kept in mind that START II has yet to pass the Russian Duma (Schweid, 1997).

While some of the energies of the US nuclear-industrial complex have been redirected into reduction of nuclear stockpiles, there is still enormous expenditure on nuclear weapons programs. For example, from 1994-96 the US Department of Energy (DOE) approved a $US 2.3 billion National Ignition Facility (a superlaser to aid in the simulation of weapons tests); the DOE announced a $US 93 million deal with IBM to build the world's fastest supercomputer (again for use in simulated weapons tests); the B-2 Stealth Bomber program was extended; construction of a third Seawolf nuclear attack submarine was approved; and an anti-missile defence system, closely related to the Strategic Defence Initiative (Star Wars) program, was approved. (Anon., 1996G; Beers, 1995.)

The partial break-up of the Soviet Union has meant that Russia, Ukraine, Belarus, and Kazakhstan all have nuclear weapons on their territories. All four states have signed the Nuclear Non-Proliferation Treaty (NPT). Belarus, Kazakhstan, and
Ukraine have joined the NPT as non-weapons states, with International Atomic Energy Agency (IAEA) inspections of nuclear facilities but not of the nuclear weapons still on their territory. None is able to use its remaining nuclear weapons independently of central command in Russia.²¹ (Spector et al., 1995.)

There is no likelihood of complete nuclear disarmament in Russia. The intention to maintain a significant arsenal is underpinned in part by the strong thread of national chauvinism in post-Soviet Russia, shared by all the major power blocs including the ruling power bloc and the remnants of the Communist Party. (Kagarlitsky, 1995). This national chauvinism can spill over into military conflict easily enough, as in Chechnya. In addition, the economic situation in Russia (as throughout Eastern Europe) is dismal and worsening (Clarke, 1996). For a state with a powerful military and a declining economy, there must always be the temptation to use the former to prop up the latter. The economic problems associated with capitalist restoration also underscore a considerable level of political instability within Russia.

With respect to Russian involvement in horizontal nuclear weapons proliferation, two immediate concerns are state-sanctioned sales of nuclear materials to countries with nuclear weapons ambitions such as Iran (discussed later), and smuggling of nuclear materials. There has been evidence in recent years of smuggling and sales of nuclear materials, including weapons-grade HEU and plutonium, from the former Soviet countries. In some cases, the volumes of HEU have been sufficient for manufacture of crude nuclear weapons. Historically every country that has seriously pursued a nuclear weapons program has developed an indigenous capacity to produce HEU or plutonium (even if other strategies, such as diversion of imported HEU fuel, have also been pursued). The black market in weapons-grade fissile materials may change this situation. In addition, illicit trafficking increases opportunities for sabotage, terrorism, and black-mail without actual weapons manufacture. (Dolley and Leventhal, 1994; Blix, 1995; Spector et al., 1995; Montague, 1995.)

The UK, France, and China all have advanced nuclear weapons systems - including thermonuclear fusion weapons, which are usually fuelled by isotopes of hydrogen and also require a nuclear fission detonator - as well as relatively advanced delivery systems. The logic behind the nuclear weapons programs in both the UK and France was questionable given that they would always remain peripheral to the arms race between the US and the USSR. In both cases national prestige/chauvinism was an issue, as was the strategic place of Western Europe in

²¹ The NPT/IAEA non-proliferation safeguards regime is discussed later in this section (2.3).
the context of the Cold War. In the case of the UK another issue was resentment at the broken commitment by the US to collaborate for civil and military nuclear development. (Booker, 1993.) As at 1995 the UK had an estimated 100 strategic nuclear weapons and 100 tactical weapons; for France the figure was 482 strategic weapons but no tactical weapons. (Spector et al., 1995.) China began its nuclear weapons program in 1957. China's arsenal was estimated in 1995 to consist of 284 strategic nuclear weapons and 150 tactical weapons. (Spector et al., 1995; Booker, 1993; Gordon, 1992.)

Israel, which is not a party to the NPT, has covertly developed a reasonably sophisticated nuclear weapons arsenal. It probably has between 50-100 nuclear weapons, and it has nuclear-capable ballistic missiles. The Israeli nuclear weapons program was launched in 1956, in the wake of the Suez crisis. The IRR-2 (Dimona) research reactor, supplied by France, has been central to the program. It is fuelled with natural uranium, thus optimising plutonium production. France also supplied information on the design and manufacture of nuclear weapons, and assisted in the construction of other facilities at the Dimona site including a reprocessing plant. Israel has also made some progress in the development of laser enrichment technology - thus while plutonium extraction from spent research reactor fuel has been the major source of fissile material for Israel's bombs, uranium-235 bombs may be constructed with the help of the enrichment facilities. In 1977, 200 pounds of HEU went missing from the Nuclear Materials and Equipment Corporation (NUMEC) in Pennsylvania - it is suspected to have ended up in Israel although there is no unequivocal evidence.

Israel is one of a number of countries where an ostensibly civil research reactor program has facilitated a covert weapons program. There are no power reactors in Israel, although the pretence of a nuclear power program may have facilitated the transfer of materials and expertise from France and other countries.

Israel's nuclear weapons capability is entangled in the complex web of Middle Eastern politics. Iran is thought to be 5-10 years away from being able to build a nuclear weapon, but this could be accelerated if nuclear materials leak from former Soviet countries. There have been reports of the Iranian regime attempting to purchase fully-fabricated nuclear weapons. Iran has been supplied with nuclear materials from a number of countries over the years. Dual-use

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22 For literature on Israel's nuclear weapons program, see Reiss, 1988, ch.5; Holdren, 1983; Quester, 1985; Booker, 1993; Spector et al., 1995; de la Court et al., 1982; Carnesale, 1981; Bar-Or, 1972.

23 Natural uranium contains about 99.3% uranium-238 and 0.7% uranium-235. Fissile Pu-239 is produced by neutron bombardment of uranium-238 and thus Pu-239 production decreases as the level of uranium-235 enrichment increases.
technologies – ostensibly for civil purposes but with potential uses for weapons development – have been purchased. These include two power reactors which were damaged by Iraqi air strikes in 1987-88 and are no longer operating. A 5 MW\textsuperscript{24} research reactor has been in operation since 1967, and three very low power research reactors (two of them sub-critical facilities) began operation between 1992-94 (IAEA, 1994). The US has attempted to put in place an embargo on the sale or supply of nuclear materials to Iran. The embargo has been supported by Western governments, but not by Russia or China, both of which have signed agreements to sell nuclear power plants to Iran. Two nuclear-capable ballistic missiles were sold to Iran by North Korea, and efforts may be in train to increase the arsenal of ballistic missiles through negotiations with China and North Korea. (Spector et al., 1995; Arnett, 1995; Gordon, 1992.)

As in Israel, a civil research reactor program has facilitated a covert weapons development program in Iraq.\textsuperscript{25} The Iraqi regime has been trying to develop nuclear weapons at least since the 1960s. At various stages it has been supplied with nuclear materials by West Germany, Portugal, Niger, Brazil, Italy, France, Britain, and the Soviet Union. Some of these transfers were fairly benign, such as the 2 MW research reactor supplied by the Soviet Union. Other transfers were obviously risky in terms of facilitating weapons production, such as the French-supplied 40-70 MW Osirak research reactor, and hot cells (radiochemical processing laboratories) supplied by Italy. Iraqi oil has been an important bargaining chip for a number of nuclear transfers, although oil exports were severely disrupted by the Iran-Iraq war.

In 1979, in France, the cores of two research reactors destined for Iraq were damaged by an explosion – a French ecology group claimed responsibility, but it is also possible that Israeli agents were responsible. In 1980, a scientist involved in the Iraqi nuclear program was murdered while in France – again it is possible that Israel was involved. In September 1980, two Iranian warplanes bombed the Iraqi Al Tuwaitha nuclear reactor facility. A French-supplied 0.8 MW research reactor, one of the three reactors at the site, was operating at the time, but the bombing caused little damage. In 1981, an Israeli strike on the Al Tuwaitha site damaged the 40-70 MW French-supplied Osirak reactor (which was shortly to begin operation), but not the two low-power research reactors. After the Israeli strike, Saddam Hussein called on "peace-loving" countries to help the Arabs build a nuclear

\textsuperscript{24} MW, or MW(t), is megawatts (millions of watts) of thermal power; kW or kW(t) is thousands of watts of thermal power.

\textsuperscript{25} For literature on Iraq's covert nuclear weapons program, see Snyder, 1985; de la Court et al., 1982; Froggatt, 1991; Spector et al., 1995; Nuclear Control Institute, 1995C; Uranium Information Centre, 1995; Richter, 1981; Fainberg, 1981; Gruemm, 1981; Carnesale, 1981; Ne'eeman, 1981; ANSTO, 1995B.
bomb, and Libya's Colonel Qaddafi declared it time for the Arabs to destroy the Dimona nuclear complex in Israel.

A covert weapons development program continued through the 1980s in Iraq. Several methods of weapons development were in train – domestic enrichment, domestic reprocessing (plutonium extraction), and, on occasions, diversion of HEU fuel supplied for the research reactors. Iraq repeatedly violated its NPT obligations, by pursuing a number of techniques for uranium enrichment, efforts to design an implosion-type nuclear device and to test its non-nuclear components, planning to produce lithium-6 (which converts to tritium when irradiated with a neutron beam) for "boosted" atomic bombs and hydrogen bombs, and pursuit of a missile delivery system. In addition, a small amount of plutonium was separated using unsafeguarded hot cells supplied by Italy; the fuel was irradiated in IAEA-safeguarded research reactors. Estimates of the annual plutonium production (separation) capacity of the hot cells ranged from 0.3-10 kg; if the actual capacity was closer to the high estimate, the hot cells would certainly have been of value for weapons development.

The extent of the Iraqi program was revealed after the 1991 Gulf War. IAEA officials estimated that Iraq may have been able to manufacture its first nuclear bomb as early as 1993. Most of Iraq's nuclear facilities were destroyed by US bombing during the Gulf War, including the two remaining research reactors at the Al Tuwaitha site. After the war, other nuclear facilities were destroyed by order of the Iraqi regime, possibly in an effort to deceive IAEA inspectors as to the nature of the nuclear program. Later, some other nuclear facilities were destroyed by IAEA inspectors.

The close scrutiny and control over what remains of Iraq's nuclear program, by the IAEA under direction from the United Nations, precludes the possibility of nuclear weapons manufacture in Iraq in the short term. Moreover the nuclear program has been set back many years by the destruction of so many facilities. Nevertheless Iraq is still under the rule of a military dictatorship, deeply embroiled in a volatile regional situation, and it still has hundreds of nuclear scientists and engineers as well as a range of nuclear facilities, some of which are still intact if not operational.

Libya allegedly attempted to purchase a nuclear bomb from China in the 1980s although the deal fell through.26 Over the years there have also been reports of

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26 For literature on Libyan efforts towards a nuclear weapons capability, see Booker, 1993; Holdren, 1983; Ne'eman, 1981; Spector et al., 1995; Quester, 1985, pp.46-47; de la Court et al., 1982.
negotiations with France, India, and Pakistan in relation to nuclear transfers. Libya ratified the NPT long ago, but its obvious pursuit of nuclear weapons indicates how hollow such a commitment can be. A 10 MW research reactor, fuelled with HEU, is in operation. The reactor was supplied by the Soviet Union, which made NPT ratification a condition of supply. There is no evidence of diversion of HEU fuel but it remains a possibility. Extraction of plutonium from spent fuel for weapons production is also a possibility.27 Another possibility is that nuclear materials being smuggled out of the former Soviet Union could facilitate a covert weapons program in Libya.

In 1987, Algeria purchased a 1 MW research reactor from Argentina. In early 1991 US intelligence agencies discovered that a second research reactor, known as Es Salam, was under construction. This raised suspicions since it was being built in secret, it was unusually powerful (10-15 MW) in relation to Algeria's rudimentary nuclear research program, and it was not subject to IAEA safeguards. The reactor was supplied by China. An agreement was reached to place the Es Salam reactor under IAEA safeguards, and in 1995 Algeria formally acceded to the NPT. Algeria also has hot cells for processing of radioisotopes; they were not under IAEA safeguards as at 1995 but would come under IAEA inspection when processing spent fuel from either of Algeria's two research reactors. (Spector et al., 1995; Booker, 1993.)

Some other countries in the Middle East and North Africa warrant passing mention. Egypt may have undertaken some preliminary work in pursuit of nuclear weapons. Syria may have made some effort to acquire nuclear weapons, but there are no power or research reactors in Syria and it would be many years before nuclear weapons could be produced. (Booker, 1993.) There have been reports that Saudi Arabia collaborated with Iraq in a joint nuclear weapons development program during the 1980s, at which time Saudi Arabia also acquired nuclear-capable missiles from China. The collaboration between Saudi Arabia and Iraq, such as it was, ceased at the time of the 1991 Gulf War, by which time Saudi Arabia had joined the NPT. (Spector et al., 1995.)

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27 HEU-fuelled research reactors are generally not suitable for production of Pu-239, but it depends on many variables such as reactor power, level of fuel enrichment, irradiation time, and sophistication of plutonium extraction facilities. One option - which was almost certainly pursued in Iraq - is to surround the reactor core with a "blanket" of natural uranium. In this way an HEU-fuelled reactor can potentially produce large amounts of Pu-239.
India has a significant nuclear weapons capability, developed largely as a result of protracted tension and conflict with China and Pakistan.\(^{28}\) India has the technological infrastructure and materials to produce nuclear weapons independently of other countries, including a domestic uranium mining industry, reprocessing facilities sufficient to process several hundred tonnes of spent fuel each year, a large nuclear power program, and sufficient fissile material for tens or even hundreds of nuclear weapons. India probably has 60+ tactical nuclear weapons.

A "peaceful" nuclear test explosion was conducted in India in 1974. This used plutonium extracted from fuel irradiated in a research reactor known as Cirus, which was supplied by Canada. The US administration denied having provided materials which were used to produce the Indian bomb, but later admitted supplying heavy-water reactor moderator without restrictions on its use. Other research reactors – in particular the Purnima reactor – were used to conduct research crucial to the development of a weapons capability. The Dhruva research reactor, and a number of power reactors, are also believed to have been used for plutonium production over the years. The reprocessing facilities used to extract plutonium have been justified by a long-term plan to develop breeder reactors.

India has historically gone to great lengths to avoid participating in safeguards agreements or treaties, yet it found little trouble finding nuclear suppliers in the early period of its nuclear program. There is now little scope for nuclear suppliers to threaten or implement supply cut-offs to retard India's weapons program, because of India's independent nuclear fuel cycle capabilities. Indeed India has itself become a modest nuclear supplier, and in recent years there have been reports of potential weapons proliferants such as Iran and Syria negotiating with India for supply of nuclear equipment including research reactors.

Pakistan launched a covert nuclear weapons program in the aftermath of the Indo-Pakistani war in the early 1970s.\(^{29}\) In 1974 an agreement was struck between Libya and Pakistan, before the Indian test explosion, for Libya to help fund Pakistan's nuclear weapons program in return for nuclear materials and information. This was tied in with plans among a number of countries to build an "Islamic" bomb, which were stepped up once India exploded a "Hindu" test bomb. The weapons program in Pakistan has been assisted by China, and some

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\(^{28}\) For literature on India's nuclear weapons program, see Arnett, 1995; Cronin, 1985; Booker, 1993; Reiss, 1988, ch.7; Gordon, 1992; Spector et al., 1995; Bellany, 1972; de la Court et al., 1982; Findlay, 1990, ch.12.

\(^{29}\) For literature on Pakistan's nuclear weapons program, see Cronin, 1985; Booker, 1993; Spector et al., 1995; Arnett, 1995; Ne'eman, 1981; de la Court et al., 1982.
equipment and materials have been procured through clandestine deals with private Western companies.

Pakistan's weapons program was initially geared around plutonium separation from reactor fuel irradiated in a 137 MW(e) power reactor. However in 1978 France pulled out of an agreement to build a reprocessing plant because of the weapons implications. Efforts to complete the plant without further French assistance struck insurmountable obstacles. During the 1970s Pakistan also began secret construction of a small reprocessing plant at Rawalpindi. In addition, a hot cell facility was completed, with French and Belgian assistance, and this facility could be used to produce small amounts of plutonium. While there have been ongoing efforts to develop plutonium separation capabilities, the emphasis of the covert weapons program shifted to uranium enrichment. In 1978 France broke off an agreement to supply an enrichment plant, but later that year news began to leak out that an enrichment plant was being built, with some Libyan funding and some equipment bought by "dummy" companies from European and North American suppliers.

Currently Pakistan has a small nuclear power program, uranium enrichment plants, reprocessing facilities, uranium reserves and facilities for processing uranium and for fuel fabrication, a variety of aircraft which could be used to deliver nuclear bombs, and it probably has sufficient weapons-grade material for 15-25 nuclear warheads. Pakistan has refused to become a party to the NPT. As at 1995, a 50 MW research reactor was under construction at Khusab, with the potential to provide Pakistan with its first supply of unsafeguarded spent fuel. The reactor is being built with Chinese assistance. Two operating research reactors are under IAEA safeguards. One of these reactors, PARR-I, may have been used clandestinely to produce tritium for advanced nuclear weapons.

North Korea's nuclear weapons ambitions have been deeply entangled in the politicking between North and South Korea, China, the USSR, and the US. North Korea became a party to the NPT in 1985, but did not allow IAEA inspections until 1992. In 1992, IAEA inspectors discovered discrepancies indicating that a reprocessing plant, and possibly some laboratory-scale hot cells, had been used more often than had been declared and that weapons-grade plutonium could have been produced and separated. The covert plutonium separation, if it took place, probably involved irradiated fuel from a 5 MW(e) "Experimental Power Reactor" at the Yongbyon site. In early 1993 the IAEA asked

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20 MW(e) is megawatts of electrical power output.
21 For literature on the North Korean nuclear weapons program, see Gordon, 1992; Spector et al., 1995; Uranium Information Centre, 1995.
for permission to inspect two undeclared waste sites, which might have revealed more about the covert weapons program. The request was refused, and North Korea announced an intention to withdraw from the NPT. In mid 1993 North Korea announced it had "suspended" its withdrawal from the NPT.

In short, the North Korean weapons development program proceeded under cover of a rudimentary nuclear power program plus reprocessing facilities. The situation is still fluid, but it has eased somewhat since the 1994 signing of an "Agreed Framework" between North Korea and the US. This involves the building of two light-water nuclear power plants in North Korea; these reactors are said to be less suitable for plutonium production than the 5 MW(e) Experimental Power Reactor and a partially-completed 50 MW(e) power reactor. The Agreement also provides for a verified freeze of the activities at the North Korean facilities believed to have supported the weapons program – including the 5 MW(e) and 50 MW(e) reactors and the reprocessing facilities – and the eventual dismantling of those facilities.

North Korea also has an expanding ballistic missile program, which has been supplied and/or supported by Egypt and Iran, and there have evidently been efforts by the North Korean regime to sell long-range missiles to Iran and Libya. North Korea has a 4 MW research reactor (called IRT) as well as a critical assembly and a sub-critical assembly, all supplied by the Soviet Union and all under IAEA safeguards. These research reactors do not seem to have been directly involved in the weapons program.

Other countries in the Asian region warrant brief mention. South Korea has for many years hinted at the possibility of developing nuclear weapons, in part to encourage the US to maintain its military presence in the peninsula. (Reiss, 1988; Kennedy, 1980.) There has been occasional interest in the development of nuclear weapons in Taiwan, but this has been held in check by pressure from the US and the possibility of retaliation, such as a pre-emptive strike, from China. Both South Korea and Taiwan have substantial nuclear power programs which would greatly facilitate weapons development. (Booker, 1993; Arnett, 1995; de la Court et al., 1982.) The technical and economic barriers to nuclear weapons development in Japan are very low, although domestic and foreign political circumstances are far less conducive (Reiss, 1988).

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32 If the light-water reactors are built, they will presumably use LEU "caramel" fuel. Plutonium production may be high but separating it from the spent fuel may be beyond North Korea's technical capacity, and inspection provisions would further limit the potential to use the light-water reactors in pursuit of a weapons capability. As at early 1997 the light-water reactor project was proceeding, though slowly (ANSTO, 1997).
From the 1970s until the late 1980s, South Africa pursued a nuclear weapons program, initially under the guise of a peaceful nuclear explosives program and then under the cover of a nuclear power program. Power reactors were not used to produce plutonium for use in bombs, but the power program provided important, and perhaps crucial, justification for nuclear supplies from France and other countries. The major strategy for weapons production was the development of enrichment facilities. This culminated in the production of six HEU bombs. In 1990, under instructions from President de Klerk, the enrichment plant was decommissioned, the bombs were dismantled, the HEU was sent to the South African Atomic Energy Commission for storage and possibly for use as fuel in the Safari I research reactor. In 1991, South Africa acceded to the NPT and concluded a full-scope safeguards agreement with the IAEA. (Blix, 1995; Spector et al., 1995; Reiss, 1988; Jaster, 1985; de la Court et al., 1982.)

Argentina pursued a covert nuclear weapons program for many years, refused to adhere to the NPT, and did not sign the Treaty for the Prohibition of Nuclear Weapons in Latin America (the Tlatelolco Treaty). A gaseous diffusion enrichment plant was built. Construction of reprocessing facilities was pursued for some years but was suspended in 1990. A number of sites and facilities were developed for uranium mining, milling, and conversion, and for fuel fabrication. A missile development program was pursued for some years. Argentina's nuclear program was supported by a number of countries: power reactors were supplied by Canada and West Germany, a heavy water plant was supplied by Switzerland, and the Soviet Union was another supplier of nuclear equipment. Hot cells operated from 1969-1972, with no international safeguards; figures on the amount of spent fuel treated in the hot cells vary greatly. (Spector et al., 1995; Holdren, 1983; Spence, 1984; Poneman, 1985; de la Court et al., 1982.)

Brazil pursued a covert nuclear weapons program in response to Argentina's program. It developed a modest nuclear power program, enrichment facilities (including a large ultracentrifuge enrichment plant and several laboratory-scale facilities), a limited reprocessing capability, a missile program, a uranium mining and processing industry, and fuel fabrication facilities. Brazil was supplied with nuclear materials and equipment by West Germany (which supplied reactors, enrichment and reprocessing facilities), France, and the US. (Myers, 1985; Spector et al., 1995; Spence, 1984.)

The regional nuclear arms race between Brazil and Argentina has eased. Both countries have entered into a bilateral safeguards agreement; both have signed
and ratified the Tlatelolco Treaty; both have agreed to IAEA inspections in addition to those provided for under the bilateral agreement; and Argentina acceded to the NPT in 1995. (Spector et al., 1995.) Both Brazil and Argentina operate research reactors, but these reactors do not seem to have been directly involved in the weapons programs.

Romania ratified the NPT in 1970, but a covert nuclear weapons development program was pursued under the Ceausescu regime. Little information is publicly available on the weapons program, but it is known that hot cells were used for experimental plutonium extraction from irradiated research reactor fuel. After Ceausescu’s overthrow in 1989, the weapons program was terminated. Supply of HEU for a 14 MW Triga research reactor was terminated by the US in the late 1980s because of the possibility of diversion of HEU for weapons production; the reactor was shut down from 1989-91 and it was converted to enable use of low-enriched uranium (LEU) fuel. A nuclear power program has been in the planning stages for some years in Romania, with five power reactors under construction as at 1995. (Spector et al., 1995.)

Some effort has been expended towards a nuclear weapons capability in a few countries other than those already discussed. For example nuclear weapons research was carried out in Sweden until the late 1960s, in tandem with and under cover of a nuclear power program (Johannson, 1986; Reiss, 1988). Another example is Yugoslavia: according to recent revelations, laboratory-scale separation of plutonium once took place, although the amount was very small. In addition, large volumes of HEU were supplied by the USSR/Russia to fuel the 6.5 MW research reactor (RA) at the Vinca Institute of Nuclear Sciences in Belgrade. (ANSTO, 1997.)

Many other countries have the potential to develop nuclear weapons, with more or less effort and time, as judged by overall technical capacity and industrial infrastructure, and/or operation of reactors, and/or stocks of weapons-useable materials. These countries include Australia, Austria, Belgium, Bulgaria, Canada, Chile, the Czech Republic, Denmark, Finland, Germany, Hungary, Indonesia, Ireland, Italy, Japan, Mexico, the Netherlands, Norway, Poland, Slovakia, Slovenia, Sweden, Switzerland, and Spain. (Spector et al., 1995.) This is not to suggest that these countries are on the brink of becoming nuclear weapons states of course.
NUCLEAR WEAPONS AND "THE NEW WORLD ORDER"

This commentary focuses on the potential for further proliferation of nuclear weapons. Firstly I will summarise the current state of nuclear weapons programs around the world. The easing of tensions between the US and the (former) Soviet Union, along with partial reductions in their nuclear weapons arsenals, clearly reduces the threat of nuclear war. Nuclear weapons programs have been abandoned in a number of other countries in recent years, including South Africa, Brazil, Argentina, Romania, and Algeria. So too the nuclear weapons programs of Iraq and North Korea have been retarded, if only by force or coercion. On the other hand the five declared nuclear weapons states have no intention of completely dismantling their nuclear arsenals. The India-Pakistan-China situation is a nuclear hot-spot; and the precarious peace in the North Asia region is further complicated by other rivalries such as those between North and South Korea, and China and Taiwan. The Middle East is another nuclear hot-spot.

It is beyond the scope of this thesis to discuss the broad contours of post Cold War political development in any detail whatsoever, but the briefest summary is necessary since the future of nuclear weapons is intimately bound up with broader political developments.33

Any hopes that the collapse of Stalinism would usher in an era of peace and prosperity - a "New World Order" - have long since faded. The two Cold War superpowers have themselves been involved in military excursions in the 1990s, for example the US involvement in the 1991 Gulf War, and Russia's war on Chechnya. The collapse of Stalinism has "lifted the lid" on a number of long-suppressed regional tensions (e.g. the Balkans) and reshaped many other regional alliances and tensions (e.g. India-Pakistan-China).

The end of the Cold War has in some respects exacerbated the trend towards polycentrism, but simultaneously broad regional alliances are forming and reforming. The US remains the largest economic and military power, in both cases by far, and it has some advantages over other regional power blocs in that it is a single integrated state, not so liable to centrifugal forces. Nevertheless the capacity of the US to unilaterally shape the world continues to wane, as shown for example by declining US influence within NATO. Overall the US decline is serious but relative. Russia remains a powerful military and economic force, notwithstanding considerable decline on both fronts, and still has some influence in Eastern Europe if less than during the Cold War. Europe is emerging as an

33 Some aspects of the summary draw from Rees, 1990.
economic and military power bloc with greater independence from the US. And of course there are powerful countries shaping the Asian region, not least Japan and China.

In some respects the post Cold War world is similar to periods before and after World War I, when Germany, France, Russia, the UK, and the US vied for supremacy, with the instability of that competition heightened by unequal military and economic strength between the various powers. This parallel has its limits of course. It is complicated by factors such as the increasing importance of middle powers (e.g. a number of Middle Eastern and Asian countries) and the reshaping of relations between the imperialist powers and their former colonies. Another important difference is that there is now a much higher level of militarisation all around the world. The Iran-Iraq war illustrated these trends: both middle powers with nationalist regimes which replaced colonial control or subservient client regimes of major powers; both putting much effort into militarisation (including as yet unsuccessful covert nuclear weapons programs); both striving for regional control; and both manoeuvring in an environment in which no single nation state, within or beyond the region, has such hegemony as to be able to impose its will on the regional tensions.

Within the fluid situation of post Cold War politics it is not possible to predict with confidence the alliances and antagonisms that will emerge, nor which antagonisms will spill over into war. It can be said that, notwithstanding the effects of the collapse of Stalinism, the post Cold War world is and will remain marked by inter-state rivalry and competition, with the potential for political and economic conflict to spill over into military conflict. Some underlying fundamentals are still in place despite end of the Cold War, including the division of the world into sovereign states, the need for economic expansion as a basic condition of capital accumulation, competition for foreign markets and the tensions and conflicts arising from that, and ongoing economic stagnation.

In addition to international antagonisms, there are many countries, particularly those on the periphery of the capitalist system, where there is much potential for major domestic political upheaval, as the recent examples of Rwanda, Zaire, and Albania demonstrate. A number of countries with a significant nuclear infrastructure are also prone to domestic political turmoil with unpredictable consequences – examples here include South Korea and various Eastern European countries including Russia.
Given the fluidity of world politics, it is difficult to predict the impact of broader political trends on nuclear weapons proliferation and *vice versa*. Some general comments can be made however. Several political factors encourage efforts to acquire or produce nuclear weapons: nation states may want nuclear weapons to counter threats to national security, to increase their capacity to achieve by force political objectives outside their boundaries, or to increase regional or global influence through the political and economic leverage that can be gained by possession or pursuit of nuclear weapons.

Apart from the political considerations, there are technical and economic factors and obstacles. These obstacles are insurmountable only for the poorest, least developed countries. With time, money, and determination, many developing countries could develop nuclear weapons, as shown for example by the substantial progress made in India, Pakistan, Argentina, Brazil, and Iraq towards a nuclear weapons capability.

On the other hand the technical and economic obstacles are substantial, and very few countries have an independent capacity to produce nuclear weapons. Consequently international nuclear commerce has been an important factor in the spread and retardation of nuclear weapons. Nuclear trade has been complicated by the interconnections between civil and military nuclear expertise and equipment. Declining growth in the nuclear power industry in the 1970s, tied to economic stagnation, had important implications for nuclear weapons proliferation. As domestic markets dwindled, the establishment of export markets became all the more important for the viability of nuclear power industries. However export markets for nuclear power were also declining. Thus competition for markets was intense, all the more so given the increasing number of supplier countries. These developments exacerbated the conflict between non-proliferation goals and the pursuit of commercial profit in the nuclear power industry. Nuclear supplier countries such France, Canada, and West Germany strengthened their hand against the US by showing a greater willingness to sell sensitive nuclear materials and equipment. In this they were not alone – all or almost all nuclear exporting countries, not least the US, have been guilty to a greater or lesser degree. Of the countries being targeted by suppliers for commercial deals, the most receptive were precisely those most likely to harbour military ambitions. (Clausen, 1985; Camilleri, 1984; Potter, 1985.)

Many supplier states have sold nuclear materials or equipment to countries with nuclear weapons ambitions. France has supplied Brazil, Israel, Iraq, Iran, Pakistan, South Africa and Pakistan. West Germany has supplied Brazil, Argentina, South
Africa, and Iran. Canada has supplied Argentina and India among other countries. China has supplied Pakistan and Algeria among other countries. The Soviet Union supplied Argentina, Iraq, and India, and subsequently Russia has supplied Iran, Iraq, and India. This list is by no means exhaustive, nor does it give a sense of how this trade fed into weapons programs; suffice it to say that all of these deals may have assisted covert nuclear weapons programs and some of them certainly did.34

While the US opposed more than a few of the transfers just listed, it has itself been involved in similar deals - for example with Brazil, Pakistan, India, Israel, Iran, Iraq, and South Africa. Nor was the US averse to selling nuclear materials to countries which had not ratified the NPT until the late 1970s - as at 1975, no less than thirteen of the US agreements for nuclear co-operation were with non-NPT countries. (Camilleri, 1984, pp.245-249; Clausen, 1985.)

By the mid 1970s, the inadequacies of the NPT/IAEA non-proliferation regime (discussed below) were openly acknowledged by politicians and by the nuclear establishment. The implications of civil nuclear commerce for weapons proliferation were equally stark, not least with the 1974 test explosion in India. This led to the formulation of new proposals to prevent horizontal weapons proliferation, particularly in the US. During the Carter presidency, an elaborate mixture of unilateral and multilateral initiatives was proposed to prevent horizontal weapons proliferation. In 1978 some of the proposals formed the basis of a Non-Proliferation Bill. This set criteria for cooperation agreements and export licenses, such as attachment of full-scope safeguards agreements to all civil nuclear commerce, prohibition of reprocessing without US approval (where US-supplied materials or equipment was involved), and prohibition of third-party transfer without US approval. (Clausen, 1985; Camilleri, 1984, pp.255-257.)

However the US initiatives had only a modest impact on nuclear weapons proliferation - and that impact was as much positive as negative. The policy exacerbated the trend for other countries to further develop their own nuclear fuel cycle capabilities. Countries expanding their nuclear infrastructure included Canada, several Western European countries, Brazil, Argentina, South Korea, India, Pakistan, and South Africa. Some of these countries became exporters in their own right. Various alliances were formed, sometimes independently of the major capitalist powers, whether for civil or military nuclear programs. The result was a progressively more heterogeneous and competitive international situation,

34 For literature on nuclear commerce and nuclear weapons, see Spector et al., 1995; Reiss, 1988; and the contributions to Snyder and Wells, 1985.
which no single state could hope to control. (Clausen, 1985; Camilleri, 1984, pp.269-273.)

In many cases, sales of sensitive nuclear materials and equipment have been motivated simply by commercial profit and a desire to increase the viability and competitiveness of national nuclear power industries. In other cases nuclear commerce has also been embedded in larger strategic designs. International nuclear trade has been inextricably intertwined with geopolitical alliances and rivalries, with various colonial, neo-colonial, and imperialist relations drawn upon and reshaped through nuclear commerce. Examples include US efforts to promote its regional objectives in the Middle East by offering to sell nuclear reactors to both Egypt and Israel, and (wavering) efforts by the US, France, and West Germany to cement their relationship with Iran through nuclear power projects. In some cases – such as the deal between West Germany and Brazil – major capitalist countries sought to secure uranium supply in return for assistance in nuclear (weapons) development. (Spence, 1984.)

The collapse of Stalinism has had no significant impact on the overall status of nuclear power industries; nor has any other recent development. Fierce competition for foreign markets will remain the norm for the foreseeable future, and this will continue to complicate and contradict non-proliferation initiatives.

From what has been said it is clear that the conditions are in place for further horizontal proliferation of nuclear weapons. That said, there are numerous obstacles and disincentives to nuclear weapons development – and further disincentives to use existing nuclear weapons in conflict. As discussed the technical and economic obstacles are substantial if only rarely insurmountable. In addition there are political barriers to weapons development: the possibility of being subjected to military attack (ranging from pre-emptive strikes on nuclear facilities to nuclear attacks); the possibility of external sanctions or countermeasures (such as a regional arms race); the global non-proliferation regime which restricts somewhat the availability of necessary materials and equipment; and the possibility of internal opposition or revolt over the acquisition of nuclear weapons. (Holdren, 1983; Reiss, 1988.)

25 Among the candidates for future pre-emptive conventional strikes on nuclear facilities are some Arab states (e.g. Iran, Syria, Libya) by Israel, North or South Korea by one another, and Taiwan by China. (Arnett, 1995; Snyder, 1985.) Conventional strikes on nuclear facilities in Pakistan by India, or vice versa, are also conceivable although they might not count as pre-emptive. There were reports in 1984 that the Indian government was considering a pre-emptive strike on Pakistan's enrichment and reprocessing facilities. (Cronin, 1985.)
Here I will focus on various non-proliferation initiatives and regulatory regimes, the most important of which is the NPT/IAEA system. The NPT was born out of international nuclear diplomacy in 1968. It divides the world into five weapons states – the US, the UK, France, China, and Russia – and non-weapons states. The weapons states are bound not to supply other countries with nuclear weapons or other nuclear explosive devices, they are bound not to facilitate the efforts of any non-weapons state to acquire or manufacture nuclear weapons, and they are bound to move towards nuclear disarmament themselves. Non-weapons states are bound not to accept the transfer of nuclear weapons nor to manufacture them or to seek assistance in doing so. They also undertake to accept the safeguards and verification system of the IAEA, which is in effect closely linked to the NPT. One purpose of the IAEA is to monitor safeguarded materials and facilities to detect any diversion into military programs. As at 1995, the IAEA had 122 member states, and 188 countries had some form of safeguards agreements with the IAEA. (Booker, 1993; Spector et al., 1995.)

There are polarised opinions in relation to the NPT/IAEA non-proliferation system. Many commentators are highly critical, arguing that the NPT/IAEA system suffers from numerous limitations, contradictions, and loopholes. Among the most strident of the critics is Falk (1983, p.190), who argues that the defects in the world's non-proliferation regime make it "half-blind, toothless and mute".

Critics note that the safeguards provisions of the NPT and other such treaties have no relevance for countries that do not become signatories, with some notable non-NPT states being India, Pakistan, and Israel. It is advantageous for countries wishing to develop civil nuclear programs to accede to the NPT/IAEA system because it allows for freer non-military nuclear transfers. However the international marketplace for nuclear materials and services is so highly competitive that countries which have not signed the NPT have, on occasions, been able to find suppliers, even for sensitive materials with potential for diversion to weapons programs.

For countries which do accede to the NPT/IAEA system, this does not preclude a covert weapons program. In such cases, with Iraq being the obvious example, NPT status can absolve supplier states of moral responsibility for dubious sales. Recipient states, if members of the NPT, can also pressure supplier states because

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of the possibility that withdrawal from the NPT would encourage other states to do likewise.

Other limitations of the NPT/IAEA system can be listed as follows:

- the NPT allows participating countries to design, develop, and assemble the non-nuclear parts of nuclear weapons;
- signatories can withdraw from the NPT with just 90 days notice;
- countries are generally warned in advance of IAEA inspections, and such inspections do not preclude a covert weapons program. Diversions of small quantities of fissile material may not be detected by IAEA inspectors;
- IAEA inspectors do not usually have the authority to seek out undeclared or clandestine facilities or materials;
- there is the possibility of countries taking advantage of a safeguarded facility to build an unsafeguarded duplicate, as in Pakistan for example;
- there are some provisions for NPT parties to exempt some nuclear materials and facilities from safeguards - for example areas can be declared out-of-bounds to IAEA inspectors because of alleged radioactive contamination;
- IAEA safeguards are impotent against theft or sabotage of nuclear material, nor do they cover international transport of nuclear materials;
- the IAEA inspection program is under-resourced and sometimes incapable of adequately carrying out inspections; and
- the IAEA statute contains secrecy provisions which are interpreted broadly - weak excuses may be accepted as an explanation for discrepancies, depending on the circumstances, and those discrepancies are not necessarily revealed publicly.

However the NPT/IAEA system has its supporters (e.g. Blix, 1995). Even critics generally argue for a strengthening of the system, rather than its abandonment. While the above-mentioned criticisms of the NPT/IAEA are justifiable, it is equally true that the NPT/IAEA system has helped to stop or retard some covert weapons programs. The underlying philosophy is to accelerate and facilitate civil nuclear development and transfers, and to prevent weapons proliferation by imposing conditions on (non-weapons) NPT/IAEA member states such as a commitment not to pursue weapons programs and a willingness to open facilities to monitoring. It can be safely assumed that if the first part of this strategy (encouraging the spread of civil nuclear technologies) was pursued without the non-proliferation commitments and the monitoring, a greater number of countries would have developed nuclear weapons.
One premise of the NPT/IAEA inspection regime is that undeclared nuclear activities would be detected by intelligence activities, and thus the IAEA has historically played little or no role in the detection of undeclared facilities. After the 1990 NPT Review Conference, the potential to use the Special Inspections provisions of NPT/IAEA safeguards agreements has been taken more seriously - all the more so after the 1991 Gulf War and the discovery of the extent of the Iraqi nuclear weapons program. (Uranium Information Centre, 1995.) In addition, the NPT/IAEA safeguards regime has been strengthened in the 1990s with technical improvements to safeguarding procedures, tightened supplier-state export controls, increased United Nations Security Council involvement in enforcing non-proliferation measures, and the accession to the NPT/IAEA regime of a number of countries including Algeria, Argentina, China, France, South Africa, and a number of Eastern European countries. (Spector et al., 1995.) In 1995 the 178 NPT member states indefinitely extended the Treaty. The NPT commitment to nuclear disarmament by the declared weapons states was confirmed though without a timetable for disarmament.

In addition to the NPT/IAEA safeguards regime, there are a number of other international non-proliferation initiatives which warrant brief mention. Some supplier-state export control agreements are in operation. The NPT Export Committee (the Zangger Committee) was formed in 1974. Soon after, an overlapping group of suppliers, this one including France, was formed to control supply of sensitive nuclear materials - this was known as the Nuclear Suppliers Group (NSG) or the London Suppliers Group. Some of the proclamations stemming from these export control groups were ill-defined to say the least, such as the NSG guideline to exercise self-restraint in the transfer of sensitive materials and technologies such as enrichment, reprocessing, and heavy water. The NSG's guidelines did not require suppliers to require NPT adherence or IAEA inspections as a precondition for supply. (Camilleri, 1984, p.250-254.) As with the NPT/IAEA regime, some efforts have been made to tighten NSG guidelines in the 1990s. After the 1991 Gulf War, NSG export controls were broadened to cover a large number of dual-use items, and also included a requirement that future exports be conditional on the recipient countries accepting IAEA inspection of all their peaceful nuclear activities. This last provision effectively precludes nuclear commerce between NSG member countries and India, Israel, and Pakistan. (Spector et al., 1995.)

Various bilateral or regional treaties have been instituted over the years to prevent nuclear weapons development or to reduce stockpiles - these include treaties between the US and Russia, Brazil and Argentina, the 1986 Treaty of
Raratonga which includes a number of Asia Pacific countries, the South American Treaty of Tlatelolco, and the 1996 African Pelindaba Treaty.

In 1996, the United Nations General Assembly passed the Comprehensive Test Ban Treaty (CTBT), with 158 votes in favour, three against (India, Bhutan, Libya), and a number of countries abstaining or absent (including Syria and North Korea). It must be signed by 44 named nations before it comes into force, including India, Israel, and Pakistan. India has refused to sign the CTBT, citing the failure of the Treaty to establish a firm timetable for the elimination of existing weapons. Pakistan voted in favour of the Treaty but said it would not sign unless India did. Britain and Russia said they would not sign if entry-into-force provisions were changed, i.e. if the rules were changed. It seems likely that the CTBT will not achieve legal status because of the dissenters, but it is nonetheless likely to have a positive impact in preventing further weapons testing. (Hallam, 1996; 1996B; ANSTO, 1996.)

The CTBT is likely to further entrench the nuclear dominance of those countries which already have nuclear weapons, in particular countries with advanced weapons programs; they can move to simulated tests and sub-critical tests. Non-weapons states will find it hard to develop weapons without testing. Proliferants are likely to place greater emphasis on development of weapons types which can be developed with greatest reliability without testing (in particular HEU, gun-type designs) as opposed to complicated designs which would have low reliability without testing (e.g. multi-stage thermonuclear bombs). (Spector et al., 1995.) Similarly, efforts to limit or stop further production of weapons-grade fissile material will further entrench the position of those countries with existing stockpiles of HEU and/or plutonium.

2.4. RESEARCH REACTORS

THE HISTORY OF RESEARCH REACTORS
RESEARCH REACTORS AND NUCLEAR WEAPONS

In this section, the first task is to discuss in general terms the place of research reactors within the broader scope of nuclear development. Then I discuss the use of research reactors in covert nuclear weapons programs.
Research reactor programs serve one or more of three broad functions. Firstly, research reactors are often used in support of nuclear power programs - to develop expertise, test reactor materials or fuels, and so on. Secondly, research reactors can be used directly or indirectly in the development of nuclear weapons. Thirdly, research reactor programs have increasingly taken on a life of their own, being used for a plethora of civil scientific, medical, and commercial functions. The history and trajectory of research reactors are taken up in detail in a later chapter (6.3) on radioisotope production; for the moment some general comments will suffice.

Definitions vary, but research reactors are generally considered to include all reactors except commercial (and sometimes prototype) power reactors and dedicated weapons (plutonium) production reactors.

In the post World War II period, a great deal of research was conducted in support of nuclear power and weapons. This entailed the construction of a large number of research reactors including prototype, test, and experimental reactors as well as multipurpose research reactors. This developmental phase did not give way to later phases, such as commercialisation of nuclear power, in any neat manner. For some years a variety of nuclear power reactor types were under development, all of which required major research projects involving research reactors. Even once US light-water reactor technology began to dominate nuclear power industries - in the US and elsewhere - considerable effort was still invested in nuclear power research and much of this involved research reactors.

Any country embarking on a nuclear power program, regardless of the extent to which the facilities will be domestically produced or imported, must first develop an appropriate nuclear science and technology base and an administrative and regulatory infrastructure. Often this development will involve the purchase of one or more research reactors which can range from zero-power facilities to large test reactors. If the later development of nuclear power is planned, medium or high-power multipurpose research reactors are the most appropriate - they enable the training of a range of personnel, they can be used for research relevant to the proposed power program, they require the development of a significant regulatory infrastructure, and they can be used for sundry other scientific, medical, and commercial purposes. (Mooradian et al., 1972.)
The growth and spread of research reactors was impressive, with the number peaking at 373 operating reactors in 1975. Most research reactors were built in advanced industrial countries, but over 60 countries have built or purchased research reactors. Nuclear supplier states sought to stimulate and then supply new markets for nuclear power, and sales of research reactors were an important aspect of that strategy. Many developing countries acquired small research reactors, often on generous terms provided by supplier states intent on stimulating markets for nuclear power – in some cases research reactors were donated by supplier countries. Over 100 US research reactors were sold abroad, in many cases facilitated by generous financial loan arrangements from the US Export-Import Bank. (Spence, 1984, pp.82-83.) Other suppliers – such as Germany, the UK, France, and Canada – followed in the path of the US. The promotional wing of the IAEA has also played an important role in the development of nuclear facilities in developing countries including the transfer and operation of research reactors. Some developing countries went on to develop modest nuclear power programs, but most did not and only operate research reactors if any reactors at all.

Radioisotope production and nuclear medicine were bound up in these developments – such applications were prominent in the sales pitches for more than a few research reactor sales to developing countries (de la Court et al., 1982). As Pearson (1994, p.30) from Greenpeace puts it:

The application of nuclear technology in areas such as medicine and agriculture provides the nuclear industry with a foot in the door to developing countries. By pushing smaller scale, "benign" nuclear technologies, and the infrastructure and expertise needed to use them, these countries can be lured down the road to the big ticket items, such as nuclear power plants.

RESEARCH REACTORS AND NUCLEAR WEAPONS

Research reactor programs can be used, overtly or covertly, to assist in the manufacture of nuclear weapons in several ways. The most direct link is the use of research reactors for plutonium production. Another link is that HEU research reactor fuel can be diverted for weapons production. Another possibility is that HEU can be extracted from spent research reactor fuel. The operation of research reactors can also provide some justification for the development of enrichment and/or reprocessing facilities, which can facilitate weapons programs. More generally, research reactor programs involve the development of a nuclear infrastructure which lowers the barriers to weapons development.
It would be completely impossible to produce plutonium-239 weapons from some research reactors, such as zero-power test facilities. It would be extremely difficult to use many other research reactors to produce plutonium weapons because of insufficient production volumes or insufficient plutonium purity - for example many of the low-power reactors in developing countries would not be suitable. Nor are research reactors fuelled with HEU suitable for plutonium production.37

Similarly, the potential to use research reactor programs in support of HEU weapons development should not be overstressed. The fuel stockpiles and throughput of many HEU-fuelled research reactors are too small to be of much concern. And it would be difficult or impossible to use research reactors fuelled with LEU or natural uranium in support of an HEU weapons program (though these reactors are more suitable than HEU-fuelled reactors for plutonium production).38

Despite the above qualifications, research reactors can be and have been used in support of nuclear weapons programs. Even low-power reactors can be of concern. For example the Iraqi IRT-2000 research reactor, which originally operated at 2 MW but was later upgraded to 5 MW, could have produced sufficient plutonium for one weapon over a period of several years. This risk, albeit small, was amplified by the fact that IAEA inspections of the reactor were infrequent because of the low-risk status of the reactor. (Snyder, 1985.)

In general terms, the most useful research reactors for covert weapons programs are medium to high-power reactors fuelled with natural uranium or very lightly enriched uranium (thus producing significant quantities of plutonium-239), or medium to high-power reactors which use significant quantities of HEU fuel (which can be diverted before irradiation, or HEU can be extracted from spent fuel).39 Many other research reactors can be used for weapons-related research, or more generally to develop nuclear expertise. It is notable that research reactors operate in roughly twice the number of countries as power reactors: in 1996, 59 countries operated research reactors and 32 operated power reactors (ANSTO, 1996F; 1997).

37 However, as discussed in section 2.3, it is possible to "blanket" an HEU reactor core with natural uranium and thus generate significant volumes of Pu-239.
38 Definitions vary, but LEU is generally considered to be <20% uranium-235 by weight, with HEU containing 20+% uranium-235. Some categorisations also include medium-enriched uranium (MEU), with 20-50% uranium-235. A weapon could be produced with MEU, but it would be a cumbersome process and a crude device; HEU is far more suitable.
39 For general discussions on research reactors and nuclear weapons, see Wohlstetter et al., 1979, pp.167-169; Fainberg, 1983; Holdren, 1983; 1983B.
Sales of research reactors are an important part of the broader picture of dubious nuclear trade. The major capitalist powers have sold research reactors to a number of countries with weapons ambitions: recipient countries include India (sales and support from Canada, the US, the UK, etc.), Pakistan (US, France), Algeria (France), South Africa (US), Iran (US), Iraq (France), Israel (France), Argentina (US, West Germany), South Korea (US), Taiwan (Canada, US), and Brazil (US). (There is no evidence of serious pursuit of a nuclear weapons program in Chile, but research reactor sales and support to Chile by the US, the UK, and Spain could also be questioned.) The Soviet Union has also been involved in some questionable research reactor sales, including sales to Libya, Egypt, and North Korea. China has a long history of dubious nuclear sales; with respect to research reactors, China has sold two small research reactors to Iran, it supplied Algeria with the 10-15 MW Es Salam research reactor, and it is assisting Pakistan with the 50-70 MW research reactor at Khusab. Several other countries have developed reactor industries - such as Argentina and India - with further potential for domestic use of research reactors in support of weapons programs or exports of research reactors to countries with weapons ambitions. Thus India has used research reactors in support of domestic nuclear weapons development and has reportedly been negotiating the sale of a research reactor to Iran. Most research reactors in Argentina have been indigenously designed and built, and for some years there were plans to build a 70 MW research reactor in Argentina which would not be subject to any international safeguards and would have enabled plutonium weapons production without violation of IAEA safeguards agreements. While Argentina has struggled to establish a nuclear export industry, some sales have been made including the sale of a small research reactor to Algeria. (Poneman, 1985; Watford, 1993; Spector et al., 1995; Carnesale, 1981; de la Court et al., 1982.)

The most direct use of research reactors for nuclear weapons development is extraction of plutonium-239 from irradiated research reactor fuel. The two most important examples of this are India and Israel. In both cases, research reactors have been used in conjunction with reprocessing facilities to produce substantial volumes of plutonium for nuclear weapons. In Iraq, IAEA-safeguarded reactors have been used to produce small quantities of plutonium, and larger volumes would probably have been produced and separated if not for the bombing of Iraq's research reactors on four occasions from 1979 to 1991. In Romania, experimental plutonium extraction, using spent research reactor fuel, may have taken place in support of the covert weapons program prior to Ceausescu's overthrow in 1989. Similarly, there may have been covert plutonium separation in North Korea, probably involving irradiated fuel from the 5 MW(e) "Experimental Power

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Reactor" at the Yongbyon site. (It is a moot point whether this Experimental Power Reactor counts as a research reactor, a power reactor, or a dedicated plutonium-producing weapons reactor – suffice it here to note that the term research reactor can be a misnomer.) In Pakistan, one of the two operating research reactors, PARR-I, may have been used to produce tritium for advanced nuclear weapons despite being subject to IAEA safeguards, and the 50-70 MW research reactor under construction at Khusab may provide Pakistan with its first supply of unsafeguarded spent fuel. In Algeria, there may have been plans to produce plutonium for weapons in the 15 MW Es Salam research reactor, although that it less likely now that the reactor is under IAEA safeguards and Algeria has acceded to the NPT. In Taiwan, it was suspected that the Canadian-supplied TRR research reactor was being used in conjunction with a small reprocessing plant for weapons development; under pressure from the US, the reprocessing plant was dismantled in 1977 and the TRR reactor was shut down in 1987 although there are now plans to restart the reactor.40

Tied in with plutonium production is the question of reprocessing facilities for plutonium extraction. The longstanding view that reprocessing is a legitimate part of the nuclear fuel cycle – and perhaps a necessary step in the longer term – has legitimated the establishment of reprocessing facilities in a number of countries and has assisted in a number of covert weapons programs. The five declared weapons states all have substantial facilities for separation of weapons-grade plutonium. A number of other countries – including India, Israel, Iraq, and Pakistan – have sought help from advanced supplier states to develop reprocessing facilities. North Korea apparently succeeded in constructing a reprocessing facility without foreign assistance. In Argentina and Brazil, construction of reprocessing facilities was suspended. A number of other countries have expended some effort towards the establishment of reprocessing facilities, and in some cases, such as Taiwan and South Korea, this may have been associated with weapons ambitions (notwithstanding the substantial nuclear power programs in those countries). (Camilleri, 1984; Spector et al., 1995.)

In most of the cases listed above, nuclear power programs have provided the major rationale for developing reprocessing facilities, with research reactors being of less importance. That said, reprocessing facilities have certainly been used in several countries in support of covert weapons programs.

40 The main source for this information on plutonium production is Spector et al., 1995. See also the references listed in the survey of weapons programs in section 2.3. of this thesis. The comments on Taiwan are drawn from Independent Committee of Inquiry, 1984; Wohlstetter et al., 1979, pp. 168.
The use of hot cells - lead-shielded radiochemical laboratories with remote handling equipment for examining and processing radioactive materials - is more closely related to research reactors. Hot cells can, if adequately equipped, be used to extract plutonium from spent fuel. The simpler and cheaper the facilities, the lower the volume and the lower the purity (and thus the weapons-useability) of the plutonium. Hot cells are "dual-use" facilities: they can be used for radioisotope processing, and numerous other non-military purposes, as well as for plutonium separation. Thus for example there has been a dispute as to whether one of the facilities at the North Korean Yongbyon site is a "radiochemical laboratory" or a plutonium separation facility. Unsafeguarded hot cells, supplied by Italy, have been used in Iraq for plutonium separation. In Argentina, hot cells operated from 1969-1972 and may have been used to extract spent fuel. A small volume of plutonium was separated from hot cells in Romania. In Brazil, laboratory-scale reprocessing facilities were completed but are not known to have operated. A hot cell facility was built in Pakistan, with French and Belgian assistance, and might have been used for plutonium separation even though larger-scale facilities were also built. Had Algeria's covert weapons program proceeded, the existing hot cells could have been used for plutonium separation as well as for radioisotope processing. (Spector et al., 1995; Cronin, 1985; Snyder, 1985; de la Court et al., 1982.)

Civil nuclear programs - involving power and/or research reactors - are also implicated in the development of HEU bombs. There are three methods of using the cover of a civil nuclear program for HEU weapons production. One is diversion of imported HEU. A second possibility is extraction of HEU from spent reactor fuel. A third, less direct connection is that civil nuclear programs provide justification for the development of enrichment facilities. Generally a nuclear power program is a far more plausible rationale for the pursuit of a domestic enrichment capability than a research reactor program, because of the cost and complexity of enrichment facilities. In other cases enrichment is seen as a means of adding value to uranium exports. Justifications for the development of enrichment facilities cannot neatly be separated from each other. In Australia, for example, enrichment research was pursued for numerous reasons - adding value to uranium exports, doubts about the ongoing availability of HEU fuel for HIFAR, the possibility of enriched-uranium power reactors being introduced, and the research may also have been pursued to keep open the nuclear weapons option (see chapter 3.4).

Historically there has been more interest in, and concern about, the production of plutonium for covert weapons programs; plutonium was easier and cheaper to
produce than HEU. However improvements in enrichment technology have altered this balance somewhat. Another consideration is that weapons can be made from a simpler design using HEU.

Most of the countries which have pursued covert weapons programs have built or purchased uranium enrichment facilities or have pursued research into uranium enrichment. (Indeed most of these countries have also put some effort into plutonium production and separation, thus doubling their options.) In some cases, such as South Africa and Pakistan, a nuclear power program has provided legitimacy for the development of enrichment plants which have been used to produce HEU bombs. In other cases, such as Argentina and Brazil, a nuclear power program has provided legitimacy for the development of enrichment technology but the work has not progressed beyond the research stage, or enrichment facilities exist but have not been used to produce HEU. In a number of other countries, research reactor programs have been implicated in covert HEU weapons programs. One of the strategies pursued in Iraq was diversion of imported HEU fuel supplied for research reactors. In 1980, Iraq announced that IAEA inspections would be temporarily suspended because of the circumstances of the Iran-Iraq war, and 26 pounds of HEU were removed from the core of the low-power Tammuz II reactor and stored in an underground canal. Something similar happened during the 1991 Gulf War. So too domestic enrichment work was in progress before the bombing and/or dismantling of much of Iraq's nuclear infrastructure in the early 1990s. A centrifuge enrichment program may have been pursued in Iran - to the extent that there was any attempt to justify this covert research in relation to the civil nuclear program, it could have been justified for production of fuel for research reactors or for the planned nuclear power program. Israel has concentrated on plutonium weapons production but has made some progress in the development of enrichment technology. To the extent that there is any pretence that the Israeli nuclear program is a non-military program, it would be possible that enrichment work could be justified for the production of HEU for the IRR-1 HEU-fuelled reactor; alternatively the pretence of a nuclear power program in the longer term may be relevant. (Spector et al., 1995; Spence, 1984; Bellany, 1972; Holdren, 1983; Falk, 1983, ch.9.)

There are other cases where imported HEU research reactor fuel has raised concerns even if there has not been any diversion for weapons production so far as is publicly known. The supply of HEU to Libya by the Soviet Union (and now Russia) has been contentious. If there was a more serious pursuit of nuclear weapons in Sweden, diversion of HEU fuel, supplied by the US for the R2 research reactor, might have been a feasible option, safeguards notwithstanding. Just before
pulling out of Vietnam, the US removed 12-13 kg of 20% enriched uranium from the Dalat research reactor, which it had supplied. Supply of HEU research reactor fuel from the US has been suspended a number of times over the years because of concerns about the potential for diversion: there is no evidence of diversion of HEU in South Africa, but the US supplied 104 kgs of HEU research reactor fuel before supply was cut off in the mid 1970s; supply to Mexico was cut off for some months in 1978; supply to Israel was suspended in 1981; and supply to Romania was cut off from 1989. There are a number of other examples of supply of HEU research reactor fuel, or HEU targets for radioisotope production, being suspended or refused by the US. These instances reflect ongoing concern, dating from the 1970s, about the international trade in HEU and the weapons implications of the trade. (Jaster, 1988; Harby, 1988; Spector et al., 1995; de la Court et al., 1982.)

Leaving aside specific examples, it is widely acknowledged that research reactors are important in the HEU economy. The level of uranium enrichment for power reactors rarely exceeds 3-5% uranium-235, and this fuel is far short of the level of enrichment necessary for weapons production. Many research reactors, by contrast, are fuelled with HEU. In the 1950s and 1960s, low-power research reactors were built around the world using LEU fuel. LEU fuel was chosen in part because it is not suitable for weapons manufacture. However LEU fuels gave way to HEU, which can be used for longer in the reactor core, and can generate a higher neutron flux which is preferable for purposes such as fundamental research and materials testing. In addition, the use of HEU fuel facilitates the generation of high neutron fluxes and this facilitates radioisotope production; this was another reason for the use of HEU fuels. HEU became readily available and was used not only for high-power research reactors but also for low-power reactors for which LEU would have been sufficient if not ideal. (Muranaka, 1983.) The US has been the main supplier of HEU, since it had a near monopoly of enrichment facilities for many years, and has exported over 25 000 kg of HEU – most of this (85%) was sold to the 12 Euratom countries, but a total of 51 countries have received HEU for use in research reactors from the US. (Takats et al., 1993.)

The use of HEU fuel in research reactors has provided impetus for the production of and trade in HEU with implications for weapons proliferation. The weapons implications gave rise to the Reduced Enrichment for Research and Test Reactor (RERTR) Program, a US initiative which arose out of the 1978 Nuclear Non-Proliferation Act. The primary aim of the RERTR program is the conversion of HEU-fuelled reactors to enable use of LEU fuels. The implications of the HEU -> LEU reactor conversion program for radioisotope production will be taken up in chapter seven; for the moment my concern is with weapons proliferation. A
considerable proportion of HEU-fuelled research reactors in the US, or US-supplied research reactors in other countries, have been converted to LEU. Some in-principle agreement to support the program has also been given by Russia and China. These signs are promising, but it is likely that the connection between HEU-fuelled research reactors and weapons proliferation will be an issue for the foreseeable future. A significant number of reactors still use HEU fuel. Some reactor operators are refusing to convert reactors to LEU fuel – the technical logistics of reactor conversion are neither simple nor fully developed and the effect of conversion on reactor performance is a contested issue. There is little or no likelihood that weapons ambitions are influencing decisions in those countries where some reactor operators are refusing conversion (e.g. Belgium, the Netherlands, South Africa, the US). Nevertheless reactor conversion raises a familiar dilemma facing all attempts to deal with proliferation concerns with technical fixes – countries wishing to acquire a nuclear weapons capability using materials gained for or from research reactors are precisely those countries the least likely to be interested in the acquisition of or conversion to proliferation-resistant technologies. Another limitation of the reactor conversion program is that conversion to LEU will increase plutonium production.

As well as the potential for research reactors to be used for nuclear weapons production via the plutonium or HEU routes, research reactors can be used for weapons-related research – perhaps the most striking example is the 19 MW Purnima research reactor in India, which was essential for theoretical calculations relating to nuclear explosions and thus played an important role in the Indian nuclear weapons program including the 1974 test explosion (Reiss, 1988, ch.7). There would be many other examples of research being used for weapons-related research. This issue is greatly confused by the overlap between civil and military nuclear technologies – for example materials testing research is often ambiguous in its potential applications.

More generally, research reactor programs, as with nuclear power programs, require the establishment of a nuclear infrastructure, involving various nuclear fuel cycle technologies, technical expertise, the establishment of nuclear trade links, and so on. Development of this infrastructure can facilitate the later pursuit of nuclear weapons even if the original intention was only to pursue non-military nuclear development. Sometimes this has occurred through the intermediary of nuclear power: research reactor programs have been developed as a forerunner and/or an adjunct to nuclear power, and the power program is then entangled in a covert weapons program. Thus in a number of countries – e.g. South Africa, Pakistan, Argentina, Brazil – power programs have been used as cover for covert
weapons development, with little or no direct involvement of research reactors in the weapons program, yet in all these countries research reactors played an important role in the development of the nuclear infrastructure.\footnote{A related issue is whether it makes more sense to pursue a covert weapons program under cover of a nuclear power program or a research reactor program. This debate is taken up in \textit{The Bulletin of the Atomic Scientists} by Fainberg (1983) and Holdren (1983; 1983B).}

The indirect links between research reactors and covert weapons programs are complex and little is to be gained by commenting and speculating on all the cases where research reactors have, or may have been, indirectly involved in covert weapons programs. A number of points can be illustrated using the example of South Africa. There is no evidence that research reactors were used to produce plutonium for weapons in South Africa, nor that HEU research reactor fuel was diverted. Yet the two research reactors, Safari I and II, were probably of indirect value to the weapons program. They might have been used for weapons-related research - for example neutron generation and control research, or materials testing (Jaster, 1985). The operation of research reactors was certainly important in the development of a nuclear infrastructure in South Africa, and that development was certainly important for the weapons program. The termination of US supply of HEU research reactor fuel gave some impetus to, and justification for, the pursuit of a domestic enrichment capability, which was crucial to the weapons program. Lastly, as in Argentina, the supply of a research reactor (Safari I) to South Africa facilitated the later indigenous design and construction of a research reactor (Safari II) which was not under international safeguards (Jaster, 1985).

Since much of this thesis is concerned with the medical radioisotope industry, it is worth noting the connections between radioisotope production and covert weapons programs. One of the direct links between radioisotope production and weapons proliferation is plutonium extraction using hot cells. Another close link is that the use of HEU reactor fuel facilitates production of high specific activity radioisotopes\footnote{Specific activity refers to the ratio of the desired radioisotope to contaminants (which can include isotopes of the desired product).} - this was one of the reasons for the historical trend towards using HEU fuel, and it may be a reason some reactor operators have refused conversion to LEU fuel more recently (see chapter 7.7).

Another set of links between radioisotope production and covert weapons programs involves enrichment facilities. In Iraq, it was discovered in 1991 that large calutrons - electromagnetic isotope separation devices, also known as high-current mass spectrometers - were being used for uranium enrichment.
Calutrons are also used to enrich stable isotopes, which are used, among other purposes, as feedstock for the production of some medical radioisotopes. There have been concerns that a small, Chinese-supplied calutron might have been (and might yet be) used for uranium enrichment in Iran. (Spector et al., 1995.) As with electromagnetic enrichment facilities such as calutrons, other enrichment technologies, including lasers and gas centrifuges, can be used both for uranium enrichment and for the separation of isotopes for radioisotope production (Hardy, 1996).

Beyond the more-or-less direct connections between radioisotope production and covert weapons programs, there are more general connections. Medical radioisotope production is routinely promoted as one of the most beneficial uses of research reactors. This gives impetus and legitimacy to research reactor programs, despite the potential for covert weapons development. One notable example is Iraq, where the nuclear program was kick-started with a small research reactor and a radioisotope laboratory, both supplied by the Soviet Union.

As discussed in the following chapter, Australia is yet another country where a small-scale civil nuclear program, based on a research reactor, became entangled in a covert weapons program for a time. Moreover Australia is one of many countries where propagandising about the wonders of nuclear medicine, and thus the importance of reactor radioisotope production, has been used repeatedly as an ideological prop for a research reactor program.
CHAPTER THREE: NUCLEAR DEVELOPMENT IN AUSTRALIA

3.1. INTRODUCTION
3.2. THE EARLY YEARS
3.3. THE AUSTRALIAN ATOMIC ENERGY COMMISSION
3.4. NUCLEAR POWER, NUCLEAR WEAPONS, AND "PEACEFUL" NUCLEAR EXPLOSIONS
3.5. THE AUSTRALIAN ATOMIC ENERGY COMMISSION IN SEARCH OF A MISSION: 1970-1987
3.6. THE AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION
3.7. ANTI-NUCLEAR OPPOSITION IN AUSTRALIA
3.8. CONCLUSION

3.1. INTRODUCTION

This chapter analyses the history and current status of nuclear projects in Australia. The primary aim is to provide context for the analysis, in chapter four, of the HIFAR replacement controversy and in particular the 1992-93 Research Reactor Review. This chapter can also be read as a case study of issues discussed in the previous chapter, in particular the rise and fall of nuclear power and the intersection of civil and military nuclear programs.

There are two recurring themes in Australia's nuclear history - military concerns, and the troubled history of ANSTO and its predecessor the Australian Atomic Energy Commission (AAEC). The military concerns include active support of the nuclear weapons programs of the US and the UK, in particular through the hosting of British weapons tests and US military bases. In addition, there has been wavering interest in a domestic nuclear weapons capability, and a willingness to pursue civil nuclear projects in such a way as to lower the barriers to weapons development. A second focus in this chapter is the AAEC/ANSTO: from its historical role as the guardian of Australia's entry into the nuclear age, the AAEC/ANSTO has gradually been downgraded to just another public-sector civil science agency, though not completely and not without resistance. These two themes - the weapons connections, and the rise and fall of the AAEC/ANSTO - are summarised in the concluding section (3.8) of this chapter and are related to the HIFAR replacement controversy in chapter four.
3.2. THE EARLY YEARS

Until recently, the major sources of information on the history of nuclear development in Australia were Moyal's (1975) study of the AAEC, the selective sketches found in literature produced by nuclear or scientific agencies, and many studies, mostly by academics or activists, of particular issues such as the uranium mining industry or the British weapons tests. In 1992, Alice Cawte's *Atomic Australia* was published; it is a comprehensive history of many aspects of nuclear development in Australia and I draw from it substantially in this chapter.

A rudimentary, uncoordinated nuclear program took hold in Australia after World War II. The federal government played a leading role, as did a few high-profile scientists. Early initiatives included the establishment of nuclear advisory bodies, the establishment of a school of nuclear physics at the Australian National University, and some limited research by universities and science agencies into topics such as uranium geology. (Moyal, 1975; Cockburn and Ellyard, 1981; Cawte, 1992.)

There was little interest in the domestic construction of nuclear weapons in the post-war period. Certainly there were concerns and insecurities about defence – indeed there was a good deal of paranoia about perceived threats from the north. However there were also cost considerations and the perceived security afforded by alliances with the US and the UK. As Cawte (1992, ch.2) argues, nuclear policies were guided by a vision of national economic development. Energy sources, industry, and export markets were the major concerns. Australia was largely dependent on imported oil. Power production from coal was inefficient. Industrial relations problems in the coal mining industry seemed intractable and recalcitrant gas and electricity unions also figured in the equations. The potential of hydro-electricity had yet to be established. This uncertainty over power sources was a dampener on industrial development and there was great hope that nuclear power would save the day.

The lack of interest in a domestic nuclear weapons capability was not unanimous nor did it last. Moreover the interconnections between civil and military nuclear technologies complicate the issue: in the 1960s, when there was greater interest in a domestic nuclear weapons capability, this was primarily expressed through the pursuit of ostensibly civil nuclear projects to lower the barriers to weapons development.
With a limited industrial base and a small scientific establishment, the Australian state and emerging nucleocracy inevitably pursued nuclear development as a diplomatic exercise in acquiring overseas technology. Early efforts to procure nuclear technology from the UK, the US, or through the United Nations, were largely unsuccessful. It became clear that Australia would need some bargaining chips. Thus Australia supported the weapons programs of the UK and US through the hosting of British nuclear weapons tests, the hosting of US military bases, and the supply of uranium. (Cawte, 1992, ch.2; Moyal, 1975.)

Establishing a uranium mining industry was a priority during and after World War II. The aims were to provide for Australia’s future needs, to exchange Australian uranium for foreign currency and foreign nuclear technology, and to support the weapons programs of the US and the UK and to strengthen those alliances more generally. The federal government increased its uranium prospecting through the 1940s and 1950s, and offered generous incentives to encourage private prospecting. The various incentives were sufficient to spark a prospecting boom, reminiscent of the nineteenth-century gold rushes. Many hundreds of deposits were found, but only a few of these were sizeable. Moreover by the late 1950s, significant uranium deposits had been discovered overseas. The US had stopped stockpiling uranium for military purposes, and the UK had sufficient supplies. Only one Australian uranium mine was operating by 1964, and that only through government subsidy. (Cawte, 1992; Alder, 1996.)

In the early 1950s, Prime Minister Menzies unilaterally agreed to a British proposal to conduct weapons tests in Australia, partly in the hope that Australia would gain some nuclear expertise in return, and partly because of Cold War paranoia. From 1952, 12 weapons tests took place, firstly on Monte Bello Island, off the coast of Western Australia, then at Emu Field and Maralinga in South Australia. Bomb-related tests continued at Maralinga until 1963. The weapons tests resulted in considerable environmental impact and human injury to Aborigines and armed service personnel. Successive governments used legislated secrecy provisions to withhold information about the weapons tests, and then to frustrate compensation claims. The issue resurfaced in the late 1970s and led to a Royal Commission in the mid 1980s. Still it was another decade before the Australian and British governments agreed to pay some compensation to victims and to pay for a clean-up of the Maralinga area.43

43 For literature on the weapons tests, see Royal Commission into British Nuclear Tests in Australia, 1985; Milliken, 1986; Mayne, 1994; Independent Committee of Inquiry, 1984, pp.98-100; Gardner, 1988; Carter and Carter, 1983; Martin, 1980; Booker, 1993.
The hosting of US military facilities grew slowly but steadily in the post-war generation. The main reason for hosting the facilities was to strengthen the alliance with the US, but at times there was also some hope and expectation of assistance in the development of nuclear expertise and facilities in Australia. By the 1970s, the establishment of a number of US nuclear bases in Australia had tied Australians to the nuclear arms race. The most important bases are those at North West Cape, Pine Gap, and Nurrungar, all of which became operational in the late 1960s and early 1970s. These bases have had a plethora of functions over the years, among the most important of which are tracking missiles, communicating with US nuclear-armed submarines, monitoring arms control agreements, and broader espionage operations. The history of US bases in Australia is one of secrecy and deception. For example, proposals for upgrading equipment at the bases have routinely been developed without consultation with the Australian government or government departments. Some of these unilateral developments - such as a new satellite ground station at North West Cape - have been significant in terms of the functions and strategic importance of the facilities. It is also clear that some US Central Intelligence Agency (CIA) operations at Pine Gap have never been revealed to the Australian government, and there is considerable evidence that the facilities have been used to gather intelligence on Australian communications.44

The strategy of supporting the weapons programs of the US and the UK to facilitate civil nuclear development in Australia had only modest success in the 1940s - assistance amounted to little more than tokens such as the placement of seven Australian research fellows at the British Harwell institute. Nuclear technologies, such as power reactors, were far from mature even in the most advanced nuclear countries, and those countries were guarding nuclear expertise because of the military implications and to a lesser extent to gain commercial advantage in the nuclear power industry. In the late 1940s and early 1950s, considerable effort was put into the acquisition of an experimental power reactor from the UK. When Menzies was in London to discuss the first round of weapons tests, scheduled for 1952, he asked about the possibility of a joint program to build a large power reactor in Australia. The weapons tests went ahead, but assistance in developing a nuclear power industry in Australia was slower coming - the British government pointed to the agreement it had with the US and Canada not to divulge nuclear know-how without agreement from all parties. (Cawte, 1992.)

44 For literature on the US military bases, and the alliance more generally, see Ball, 1980; 1988; Ball and Mathams, 1983; Hayes et al., 1986, pp.409-421; Smith, 1982; Falk, 1983, ch.8; Spigelman, 1972, pp.46-50; Colmer, 1989; Kennedy, 1982.
3.3. THE AUSTRALIAN ATOMIC ENERGY COMMISSION

Despite some early set-backs, efforts continued to secure British assistance in the development of a nuclear power industry in Australia. In the early 1950s, an agreement was struck involving the sale of Australian uranium, from the Mary Kathleen mine in Queensland, in return for money and technical cooperation. This included a commitment from the British to assist in the design of a nuclear reactor and provision of materials for its operation. Weapons tests also figured in the negotiations; tests at Monte Bello Island had been conducted and agreement was reached on tests to be conducted at Emu Field and Maralinga. By mid 1952, a reorganisation of scientific and nuclear institutions and advisory bodies was underway in anticipation of nuclear cooperation with the UK. It was in this context that the Australian Atomic Energy Commission (AAEC) was established. (George and Walker, 1982; Cawte, 1992, ch.4.)

The 1953 Atomic Energy Act was administered by the federal Minister of Resources and Energy and empowered the AAEC (ASTEC, 1985, p.43):

- to undertake exploration for, and mining and treatment of uranium;
- to construct and operate plant and equipment for the liberation of atomic energy and its conversion into other forms of energy;
- to sell materials or energy produced as a result of the operations of the Commission;
- to carry out research and investigations in connection with matters associated with uranium or atomic energy, or in connection with other such matters as the Minister determines; and
- to arrange for the training of scientific research workers.

A three member Commission was established as a statutory authority under the Act. Its membership increased to five in 1958. With funding from the federal government, the AAEC began construction of a Research Establishment at Lucas Heights in the mid 1950s. Fifty scientists were recruited to the AAEC. The small group of scientists which had been attached to Harwell since 1947 joined the AAEC and formed the nucleus of its scientific staff. The Commission was able to maintain its own research team at Harwell from 1954. (Alder, 1996; Moyal, 1975; Baxter, 1963.)

The Act contained extremely strict security provisions which gave the government almost unlimited powers to act on the slightest suspicion of unauthorised release of nuclear information. The security provisions applied...
right across the nuclear fuel cycle: thus for example a union ban on the supply of
spare parts for mining equipment could theoretically lead to a seven-year jail
sentence. This legislation was intimidatory to employees and in later years to anti-
uclear campaigners. It was not repealed until 1987. In practice the major effect of
the security provisions was to stifle AAEC employees and ex-employees who
might otherwise have had more opportunities for constructive contribution to
public debates on nuclear matters. (Independent Committee of Inquiry, 1984, p.162;
Evans, 1986.)

Phillip Baxter soon emerged as the most prominent figure within the AAEC.
Baxter had played a role in the Allied nuclear weapons program during World
War II, producing Britain's first uranium hexafluoride in 1941. He later worked
on the chemical separation of plutonium at the Windscale plant in England. He
was part-time Chairman of the AAEC from 1953 to 1957, and full-time Chairman
from 1957 until he resigned from the AAEC in 1972. He was also worked for many
years at the New South Wales University of Technology. Baxter was an extremely
enthusiastic advocate of nuclear power, nuclear weapons, peaceful nuclear
weapons, uranium mining, in short of all things nuclear. He was very much a
technocrat, arguing for example that (purported) trends towards participatory
democracy in Western countries were a "dangerous heresy" that might bring
about the military dominance of the "planned-economy countries" (Baxter, 1975).
Like others of his time and his class, he was paranoid about national security –
this paranoia initially focused on Japan, then Indonesia, then China, and still later
the Soviet Union. As Venturini (1993) puts it, "This was Menzies' Australia: a
bastion of white British Imperialist Protestant Christianity – and racist to boot, the
'frightened country'." That racism was also evident in the lack of concern by
Baxter and others about the impact of weapons tests and uranium mining on
Aborigines. (Moyal, 1975; Martin, 1980; Baxter, 1975; Spigelman, 1972.)

By 1956, to draw from Cawte's (1992, pp.62-63) summary of the situation, Australia
had access to considerable foreign nuclear expertise, the AAEC had been
established, a uranium industry was established, nuclear tests had been conducted
in Australia thus improving (if only modestly) the bargaining position with
Britain, and the potential for domestic nuclear power generation was at a high-
point. Yet there was a darker side: improvements in the prospects for
conventional fuels in Australia made nuclear power less important; the uranium
mining industry was about to come unstuck; weapons testing and uranium
mining had damaged or destroyed the lives of more than a few Aborigines,
servicemen, and miners; and there was significant environmental destruction
and contamination at test sites and uranium mines.
The AAEC wanted a commercial nuclear power plant and it wanted it immediately. However no nuclear power station in the world fed a national electricity grid, and the economics of nuclear power were dubious. A research reactor seemed both appropriate and feasible: it would be a pilot plant in order to gain experience, to test design principles, and to provide research facilities. An agreement was struck in 1954 for a UK company to build such a reactor. The federal government approved and provided funding - £5.5 million over five years. The reactor was a 10 MW, heavy-water moderated, high-flux materials testing reactor. The UK Atomic Energy Agency agreed to supply enriched fuel rods, which it would redeem for reprocessing. (ANSTO, 1993D.)

Baxter wanted the reactor as close to him as possible - in fact he wanted it ten minutes from his University of Technology office in the densely-populated eastern suburbs of Sydney. However it was decided to locate the reactor at Lucas Heights, 20 kms south of Sydney. Partly this was because of safety concerns, not that they were paramount, and partly it was because isolation was seen as desirable for security reasons. The High Flux Australian Reactor, HIFAR, first went critical (i.e. achieved a sustained uranium fission reaction) on Australia Day, 26 January 1958. The reactor was in routine operation by 1960. (Cawte, 1992, ch.6.)

A second reactor, MOATA, achieved criticality in 1961. It was a low-power (originally 10 kW, later upgraded to 100 kW), graphite and water moderated reactor procured from the US. As with HIFAR, MOATA's design reflected plans to introduce nuclear power into Australia. It was permanently shut down in 1995, because of limited utilisation and high operating costs. (Anon, 1995C; ANSTO, 1993N; 1995-96.) MOATA was never as contentious as HIFAR - because it was so much less powerful - and need not be discussed further.

The AAEC research laboratories were completed in the early 1960s and included facilities for metallurgy, engineering, chemistry, radiochemistry, chemical engineering, and health physics. By June 1961 AAEC staff totalled 840. Various reciprocal research and training arrangements were in place with a number of countries including the UK, the USA, Canada, and some south-east Asian countries. (Moyal, 1975; Cawte, 1992, ch.6; Baxter, 1963.)

The principal justification for HIFAR was to develop the means for nuclear power generation through reactor design research, in particular the testing of reactor materials under extreme radiation and temperature conditions. The intention was to introduce natural-uranium power reactors and to fuel them with domestic
uranium, and thus the AAEC decided to embark upon a research program into the potential use of beryllium (or beryllium compounds) as a moderator in gas-cooled, natural-uranium reactors. Plans to use HIFAR for testing of beryllium moderators was well underway by the time HIFAR was in operation. Another reactor design was researched, based on liquid metal cooling, but it received less attention and was abandoned in 1958. (Moyal, 1975; Baxter, 1963.)

As the research plans proceeded, so too did plans to produce isotopes for medicine, industry, and agriculture. In 1956 the AAEC began active promotion of radioisotopes by establishing a Radioisotope Advisory Service. Yet radioisotope production was regarded as little more than a by-product of the research program. For example the production of cobalt-60 began because there was surplus reactor space until irradiation rigs for the research program were ready. All isotope and radiation research was lumped under the miscellaneous category of "Support and Associated Research". No more than 5-10% of the total workforce at Lucas Heights would be devoted to radioisotope research and production - nothing was to interfere with the beryllium research. Radioisotope production provided good opportunities for propaganda even if it was a marginal activity: in 1956 the head of the Commission's isotopes program published a book called the World of Radioisotopes (Gregory, 1956), and in 1957 an "Isotopes for Industry" exhibition was held in Sydney, attracting 20 000 visitors. (Alder, 1996, pp.8-9; Anon., 1968.)

Britain was less interested in supporting Australia's nuclear ambitions as the 1950s came to a close. The uranium glut had struck. The major weapons tests had taken place. As a result of these changed circumstances, Australia was left to continue the beryllium experiments on its own, whereas previously it had been a joint project. With the British feeding electricity from the Calder Hill plant into a power grid, there was some questioning of the need for reactor research in Australia. Thus the beryllium project was in some trouble before HIFAR was even operational, but the AAEC had already invested four years into the planning of the project, and there was a "can-do" attitude and a good deal of optimism and momentum within the AAEC. (Moyal, 1975; Cawte, 1992, ch.6.)

Coal production rose significantly from the mid 1940s, and continued to do so through the 1950s and 1960s. Domestic oil production began in the 1950s and steadily grew through the 1960s and 1970s. This was a considerable disincentive to pursue nuclear power, which was barely tested let alone proven through the 1950s. A further problem was the impact of the decline in the uranium industry. The AAEC was also generating ill-will with the government and the federal bureaucracy because of its questionable assessments on matters such as cost
estimates and the strength of overseas markets for uranium. Some changes were made in the organisation of the AAEC, to lessen its independence from the government and the bureaucracy. (Moyal, 1975.)

Although on the surface the beryllium research was going smoothly, the research was making little progress. By 1963, if not before, AAEC scientists were privately admitting that Australian reactor technology simply could not compete with developments overseas. Teams in both France and the US had investigated and abandoned beryllium moderator research. The development of nuclear power overseas was proving to be much slower, more expensive, and more difficult than most had anticipated. Thus the prospect of nuclear power reactors in Australia in the short-term was unlikely. Moreover American and British suppliers usually offered turn-key contracts and few countries were developing indigenous reactor technology. The rationale for the beryllium research, particularly given the poor results, was fading but no alternative project was evident. Eventually the beryllium research was wound down from the mid 1960s. (Alder, 1996; Moyal, 1975.)

3.4. NUCLEAR POWER, NUCLEAR WEAPONS, AND PEACEFUL NUCLEAR EXPLOSIONS

OVERVIEW
THE NON-PROLIFERATION TREATY
PEACEFUL NUCLEAR EXPLOSIONS
NUCLEAR POWER

OVERVIEW

A case might have been made for scaling back or abandoning a range of nuclear projects in Australia by the mid 1960s. The prospects for uranium mining looked glum, the failure of the beryllium research made it still less likely that domestic ingenuity could lay the foundations for a nuclear power industry, there was in any case little need for nuclear power given the discovery and exploitation of fossil fuel reserves, and support of US and British nuclear militarism had brought with it a host of problems. However there were established interests by the mid 1960s, in particular the AAEC. Lacking a raison d'être, the AAEC management wanted a power reactor regardless of the obstacles and regardless of the doubtful value of nuclear power to Australia, it wanted to use peaceful nuclear explosions for civil engineering projects, and there was also a push to develop a nuclear weapons capability. That much was no surprise: what was remarkable in the late 1960s was
the level of political support for these projects. This flurry of activity in the late 1960s clearly illustrates how a seemingly innocuous, small-scale nuclear program can, in a short space of time and under the impact of changing conditions, become something more sinister.

There was high-level interest in nuclear weapons before the late 1960s. It is worth tracing over this history since it is relevant to the arguments being developed, and since much of it has only recently come to light - largely thanks to Cawte's (1992) research and more recently with the declassification of government documents dating from the early to mid 1960s.

In the 1950s Baxter was openly arguing that one of the advantages of nuclear power was that it would open up the possibility of producing nuclear weapons. He was arguing for a reactor which could be converted fairly easily and cheaply for maximum plutonium production if necessary. He courted politicians and the military establishment. He might have expected a sympathetic ear given the Cold War paranoia of the time; indeed the defence and foreign policy establishment had shown some interest in acquiring nuclear weapons from the US. (US legislation had been passed enabling the stationing of nuclear arms in allied countries, and the ANZUS treaty further bolstered the possibility of US weapons being stationed in Australia.) Some politicians, including government Ministers, were also advocates of domestic nuclear weapons. However the general weight of opinion, among politicians and other arms of the state, was that there was no urgency and that the alliances with the US and UK would suffice. (Cawte, 1992, ch.6.)

Whatever the confidence in the US and the UK, sections of the Australian military establishment wanted nuclear bombs. The government's Defence Committee, comprised of the chiefs of the armed forces, approached the US. Very little came of the approach, just some vague promises to consider Australia if the US chose to station nuclear weapons in the region. The Defence Committee considered approaching the UK for the supply of tactical nuclear weapons, thinking that Australian support of the British weapons program would boost its chances. In 1958 an informal approach was made to buy bombers and tactical nuclear weapons from the UK, but to no avail. (Cawte, 1992, ch.6.)

Menzies and other leading figures in the government consistently denied that overtures were being made about the purchase of nuclear weapons overseas. However some within the government were openly advocating the acquisition of nuclear weapons - including John Gorton, who later became Prime Minister.
While interested in purchasing nuclear weapons, or having nuclear weapons stationed in Australia, defence planners were less interested in producing them - in part because of the cost, and also because of the implications for relations with allies, in particular the US. Thus Baxter's idea in the 1950s for a power reactor at Mount Isa, which could also produce plutonium to be stockpiled for weapons, came to nothing. (Cawte, 1992, ch.6.)

Similar attitudes prevailed through the early to mid 1960s, during which time the government was paranoid about Indonesia's role in the region (Sheridan, 1994). In 1962 a Defence Committee submission to Cabinet argued that a nuclear weapons capability would vastly increase Australia's defensive and offensive strength. However the Committee said that there was no immediate need for an independent nuclear weapons capability, and that in the short term it was more important to strengthen conventional forces. In the same year, Cabinet discussed the possibility of a feasibility study into the building of a power reactor at Lucas Heights. The Minister for National Development, William Spooner, said that the expertise gained through a power reactor project would be invaluable if a decision were made to build nuclear weapons. A submission to Cabinet by the AAEC also noted that a power reactor could provide plutonium for nuclear weapons. (Stewart, 1993.)

The willingness to entertain the nuclear weapons option was evident in the 1963 decision to buy F-111 bombers from the US; one reason for this decision was the potential to modify F-111s to carry nuclear bombs if required. Moreover their range of 2000 nautical miles made them suitable for strikes on Indonesia. (Stewart, 1994.)

In 1965 and 1966, the Minister for National Development, David Fairbairn, made submissions to Cabinet proposing a design and cost study into nuclear power. The 1966 submission canvassed the weapons connection, in particular the potential to use the expertise gained in a nuclear power program for the development of weapons. (Henderson, 1997.)

In 1965, the AAEC and the Department of Supply were commissioned to examine all aspects of Australia's policy towards nuclear weapons and the cost of establishing a nuclear weapons program in Australia. The AAEC, floundering at the time, would have to be maintained if the weapons option was to be pursued or even left open. Harold Holt, who replaced Menzies as Prime Minister in 1966, gave Baxter some indication that the government might approve construction of a power reactor. The beryllium project gave way to research into heavy-water,
natural-uranium reactors; still there was an expectation that power reactors would be fuelled with natural uranium from domestic deposits. (Cawte, 1992, ch.6.)

The AAEC also began a centrifuge uranium enrichment program in 1965. One reason for this program was doubts about ongoing supply of research reactor fuel. Another reason was the potential profit to be made through export of enriched uranium or even completed fuel elements. Tied in with this were nationalist ideologies, and ideologies of technological progress and sophistication as opposed to being a "quarry for Big Brother", to use the words of a former Chief Executive of the Commission (Alder, 1996, pp.30-31). A third reason for the enrichment research was to keep open the option of introducing LEU-fuelled power reactors and producing that fuel in Australia. (Hardy, 1996.)

The enrichment research was carried out in secret until the Commission made the project publicly known in 1967. The initial secrecy was for fear that public knowledge of the project would raise allegations of intentions to develop nuclear bombs. (Alder, 1996, pp.30-31.) Whether the enrichment research was initiated or pursued partly because of the weapons connection is open for speculation. Clearly there was some interest in and support for a nuclear weapons capability at the time, and a willingness to pursue civil nuclear projects in such a way as to leave the weapons option open. Baxter made the link between uranium enrichment and weapons production a number of times over the years (Cawte, 1992, ch.6). It is also worth making the (obvious) point that regardless of intentions, an enrichment plant certainly would have facilitated the production of HEU weapons if they were ever sought.

From the mid 1950s, the US entered into nuclear cooperation agreements with a number of countries. One such agreement was signed with Australia in 1956 although it had little consequence for technology transfer. (Cawte, 1992, pp.60-62.) In 1966, the US government wanted to transfer safeguards provisions associated with the agreement to the IAEA. The Australian government agreed, but only after being reassured by defence officials that IAEA safeguards would not preclude a nuclear weapons program. (Greenless, 1997.) The previous year, there were Cabinet discussions on the potential for nuclear transfers from France which would not be subject to safeguards (Henderson, 1996).

Despite the glut in the uranium market, the Minister for National Development announced in 1967 that uranium companies would henceforth have to keep half of their known reserves for Australian use, and he acknowledged that this
decision was taken because of a desire to have a domestic uranium source in case it was needed for weapons production. (Cawte, 1992, ch.6.)

There was a clear pattern through the 1950s and 1960s. There was sustained, high-level, and growing interest in a domestic nuclear weapons capability, but it was not seen as an urgent matter nor was there consensus on the issue. The government was not intent on developing nuclear weapons in the short term - it merely wanted to keep its options open.

The momentum continued to build in the late 1960s. Baxter was still an influential advocate of nuclear weapons, as were some other influential nuclear scientists and administrators such as Ernest Titterton. The now-defunct Democratic Labor Party (DLP), strongly Roman Catholic and fiercely anti-communist, alone among political parties of any substance past and present, advocated nuclear weapons development in official defence policy statements. The DLP polled between 5-10% at federal elections. The Returned Services League advocated a weapons program, though equivocally at times, and there was some support within the defence forces. (Martin, 1980; Cawte, 1992, ch.6.)

The growing momentum was fuelled by political developments overseas. The Menzies government was far more comfortable with the Suharto military dictatorship than it had been prior to the 1965 massacre and take-over by the Indonesian military. Nevertheless, the British had withdrawn from Malaya and there was concern about Soviet or Chinese communism spreading south. In 1964 China exploded its first nuclear weapon. The collapse of the 1954 Geneva agreement over Vietnam seemed imminent. There were doubts about the willingness of the US or Britain to provide military aid in the case of threats to Australia. There was particular concern to strengthen the alliance with the US, which partly explained Australia's involvement in the Vietnam War and the hosting of a growing number of US military facilities. (Bellany, 1972, chs.5, 7; Cawte, 1992, ch.6.)

THE NON-PROLIFERATION TREATY

In late 1967 Holt disappeared while swimming, and Gorton became Prime Minister. Gorton had openly advocated production or acquisition of nuclear weapons in the late 1950s. Within weeks of Gorton becoming Prime Minister, the US put forward a second draft of the NPT. Gorton was determined not to sign. That got a mixed reception: some such as Baxter were on-side but there were also opponents who held the view that the NPT should be signed to placate the US.
Gorton established an interdepartmental committee in which the AAEC was strongly represented. (Cawte, 1992, ch.6.)

When the United Nations General Assembly met in April 1968, the Australian position was one of obfuscation and general rejection of the NPT. The argument was put that Australia would not sign without greater conviction that the NPT would be effective. However that was a circular argument: by signing the Treaty Australia would be doing what little it could to strengthen non-proliferation initiatives. The government argued that signing the NPT would disadvantage Australia economically by retarding civil nuclear development - mention was made of the potential use of peaceful nuclear explosives for civil engineering projects, of the potential for the NPT to interfere with Australia's uranium trade (such as it was), and the impact of the NPT on indigenous nuclear research. Baxter argued that the intention of the NPT was to restrict all nuclear research and development, to the advantage of the US. There was some logic to the argument - the US had indeed played the non-proliferation card in order to strengthen its own economic hand in civil nuclear development after the war. Nonetheless these were arguments of "not inconsiderable gall" as Bellany (1972, p.106) argued, given the rudimentary state of Australia's nuclear program. There was no basis to the anti-communist fear-mongering in the argument that the NPT would enable communist espionage - the NPT made allowances for member countries to veto inspectors from particular countries. (Encel and McKnight, 1970; Anon., 1969.)

If the unwillingness to sign the NPT was partly because of an unwillingness to close off or complicate the nuclear weapons option, as it almost certainly was, then it was not a convincing argument even in those terms. Signing the Treaty would make it easier to gain assistance in the development of nuclear fuel cycle technologies such as enrichment, reactors, and perhaps reprocessing. Development of some of those technologies was essential if a weapons program was to be pursued, and that development would require foreign assistance. (Bellany, 1970; Anon, 1969.) It was not difficult for non-NPT states to find nuclear suppliers in the 1960s and into the 1970s, but a strategy of pursuing civil and perhaps military nuclear ambitions as a non-NPT state risked jeopardising the alliances with the US and the UK; as always, those alliances were seen to be vital.

Australian opposition to the NPT could only worsen regional relations, such as those with Indonesia, Japan, and China. By 1970, international rivalries had subsided somewhat. The US, Italy, and West Germany had adhered to the NPT, arms reduction talks between the US and the USSR showed some promise, and Sino-American talks had begun. Under those circumstances the refusal to sign
and ratify the NPT was even more "noteworthy and obscurantist" as Encel and McKnight (1970, p.17) argued.

During the two-year period that the government refused to sign the NPT, the Minister for National Development had admitted that a sticking point with respect to the NPT was indeed a desire not to close off the weapons option. In 1969, two further projects were announced, both with implications for weapons development – the Cape Keraudren peaceful nuclear explosion project, and two weeks later an announcement by Gorton that a nuclear power reactor would be purchased. (Cawte, 1992, ch.6.)

**PEACEFUL NUCLEAR EXPLOSIONS**

In early 1962, the US Atomic Energy Commission had, at the invitation of the AAEC, sent an expert to Australia to discuss the potential uses of so-called peaceful nuclear explosives (PNEs) in Australia. The following year, the federal Cabinet approved a proposal from the Minister for National Development that a team be sent to the US to find out more about PNEs. There was caution however, given that problems concerning the British weapons tests were surfacing for public debate at the time. (Pemberton, 1994.)

In the late 1960s the interest in PNEs was renewed and the AAEC set up a Plowshare Committee. Both the US and the Soviet Union established experimental PNE programs from the 1950s. It was argued that nuclear explosives could be suited for major engineering projects, such as widening the Panama Canal. However the economic and environmental aspects of PNEs were major concerns, as were the weapons proliferation implications. Apart from Australia, very few non-weapons states were interested in PNEs. Those that were – such as India, Brazil, and South Africa – were almost certainly interested in the military implications of a PNE program. (Findlay, 1990; Bellany, 1972, chs.5, 7; Warner, 1971.)

The most advanced plan in Australia was for a major nuclear excavation forming a harbour off the northern coast of Western Australia, at Cape Keraudren. The harbour was to facilitate a nearby mining venture. This project was conceived in the late 1960s. Most of the interest in using PNE's in Australia came from elsewhere – specifically, from the US Atomic Energy Commission. The AAEC was also an enthusiastic advocate of the use of PNEs in Australia - Australia would not have flirted with PNEs if not for the existence of the AAEC and the
consequent availability of nuclear expertise and the efforts of propagandists such as Baxter. (Findlay, 1990; Bellany, 1972, pp.40-41.)

The role of the Australian government in the Cape Keraudren project was, according to Findlay (1990), "incredibly naive". The project would clearly violate the Partial Test Ban Treaty to which Australia was a signatory. It was also hypocritical given Australia's condemnation of France for nuclear testing in the Pacific. The time-scale for the project was highly ambitious - because of a perceived urgency to trial PNEs to push ahead with the Panama Canal project. The project amounted to Australia being used as a guinea pig to determine the feasibility of massive civil nuclear explosions. The proposal was for five 200 kiloton explosions - by comparison the Hiroshima bomb was 12-15 kilotons. (Findlay, 1990; Bellany, 1972, p.41.)

The unwillingness of the government to sign the NPT, and the Cape Keraudren adventurism, were indicative of a broader problem: the AAEC, and Baxter in particular, had too strong a position in terms of providing advice to government, and the AAEC could not be relied upon to be "wholly impartial" as Bellany (1972, pp.106-107) argued. There was insufficient technical expertise within the government to counter specious technical arguments if such should be used by the AAEC. Moreover informed outside comment was restricted by the Crimes Act and the Atomic Anergy Act; thus many scientists who had worked at the AAEC were unable to provide independent commentary. (Anon., 1969.)

The Cape Keraudren project was abandoned in 1969, only three months after it was first announced. The reasons included some or all of the following: constraints imposed by treaties such as the Partial Test Ban Treaty and the NPT; an unwillingness to finance the project from the various interested parties; questionable profit-making opportunities from the mining venture near Cape Keraudren; an unwillingness from Japanese customers to purchase contaminated ore from the mining operations; concern in the US because of the Australian government's refusal to sign the NPT; and concern in some quarters about ecological damage and radiation hazards. The AAEC maintained a smaller Plowshare Committee after the Cape Keraudren project fell through. Various other possibilities were explored for the use of PNEs in Australia, but none of these plans reached fruition and the Plowshare Committee was disbanded. Some bizarre proposals, such as one from the Queensland Premier, Joh Bjelke-Peterson, to use PNEs to halt the progress of Crown of Thorns starfish in the Great Barrier Reef, only brought PNEs into further disrepute. (Findlay, 1990; Anon., 1969; Hutton, 1979.)
NUCLEAR POWER

Numerous proposals had been advanced through the 1950s and 1960s concerning the introduction of nuclear power. In 1969, the government announced that Australia's first nuclear power plant was to be built. In effect it would be a lead station, paving the way for the individual states to commission nuclear power plants in the future. (Alder, 1996, ch.9.)

Given the interest in developing a nuclear weapons capability at the time, it is hard to imagine that there was no interest in the pursuit of nuclear power to lower the technical barriers to nuclear weapons. Submissions to Cabinet had made the connection on several occasions over the years. Baxter and Gorton, the key proponents of the nuclear power plan, had supported weapons development at various stages. The NPT and PNE fiascos further indicated an interest in weapons development. And while it is true that there was a spate of orders for nuclear power plants around the world at the time, it was anything but clear that nuclear power was a necessary or desirable energy option for Australia given the substantial fossil fuel reserves.

A stipulation was imposed upon tenderers that the power reactor had to be capable of being fuelled with Australian uranium, with fuel elements made in Australia (Alder, 1996, ch.9). This stipulation was justified with appeals to nationalistic ideologies of technological self-sufficiency, but it can easily be read as suggesting an interest in weapons. In effect the stipulation meant that the reactor would be fuelled with natural uranium (e.g. the Canadian CANDU reactor type), or tenderers would be required to facilitate the establishment of an enrichment plant in Australia. Either way, Australia would be a step closer to a weapons capability and could pursue that option without the threat of overseas fuel supply being terminated. If a natural-uranium reactor was built, it would be preferable for plutonium production, and of course there would be no reliance on overseas enrichment services. If an enriched-uranium reactor was built, then the transfer of enrichment technology to Australia would facilitate, to a greater or lesser degree, the production of HEU for bombs, and the possibility of producing plutonium for bombs would also remain open.

Publicly, there was silence and evasion about the prospects for nuclear weapons. Even Baxter would not be drawn on the topic once the nuclear power project was underway, and Baxter (1975) and others from the AAEC (e.g. Alder, 1996) have insisted over the years that the power project was not pursued even in part.
because of the weapons connection. Yet even in 1969 Baxter (quoted in Anon., 1969B) made one of his characteristic statements:

_The growth of this (nuclear power) industry and the expertise and the facilities which it will create will provide a basis from which an Australian government, at any future date feeling that nuclear weapons were essential to provide this nation's security, could move with minimum delay to provide such means of defence._

In addition to the nuclear power proposal, the AAEC's enrichment research grew steadily through the 1960s and beyond, and the Commission had begun preliminary research into plutonium separation.⁴⁵ As with the nuclear power project, it is conceivable that the pursuit of enrichment and reprocessing research had nothing to do with weapons ambitions, but it seems more plausible to argue that there was a dove-tailing of civil and military nuclear ambitions.

Some problems faced the nuclear power project, such as finance, where the reactor would be built, and what would be done with the electricity. The states and territories were unenthusiastic. Power reactors were unsuitable for the smaller grids of the western and central states and territories, and there was little interest in the eastern states because of abundant supplies of conventional fuels. Jervis Bay, on the south coast of New South Wales, was selected as the site for the reactor - it was convenient in that it was commonwealth land. The federal government agreed to sell the electricity produced to New South Wales at below cost. (Moyal, 1975; Alder, 1996.)

In late 1969 a federal election was held. The Liberal/Country government held on but with a reduced majority. Within the Liberal Party the balance had swung back to those more economically minded and less concerned about declining US power in the Pacific and the implications of that for Australia. Given the election result it was only a matter of time before the question of the NPT surfaced again. Gorton decided to sign the NPT, protesting that it was not to be taken as a decision to ratify the Treaty and pointing out that the Treaty was not binding until ratified. Nor would the government ratify the NPT until its list of objections had been resolved. (Cawte, 1992, ch.6.)

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⁴⁵ Cawte, 1992, p.127. Cawte does not provide any information on the plutonium separation research. There was certainly some interest in reprocessing - for example in February 1971 the AAEC directed an employee to visit a European reprocessing plant on an information-gathering exercise. See Hardy, 1996, p.60.
The Australian Labor Party (ALP) opposition was generally supportive of the government’s plans to establish a nuclear power reactor. However by 1970 the ALP objected to some aspects of government and AAEC policy and procedure in relation to nuclear power. Contentious issues included the methodology by which site studies began only after tenders had been issued; the fact that the AAEC was the sole buyer, builder, borrower, and operator; and the obsessive secrecy surrounding the project. (Moyal, 1975.)

Preliminary site work began at Jervis Bay – $1.25 million was spent on roads, power, water, and houses for future employees. A display caravan was set up to inform and placate the residents of Jervis Bay; it was not informative nor did it placate opponents. There had been only scanty studies of issues such as site selection, environmental impact, safety issues and accident plans, waste disposal, the eventual decommissioning of the plant, and the comparative cost of nuclear and coal-generated power. Studies into these issues were rudimentary or non-existent and findings were not released. (Spigelman, 1972, pp.69-74; Cawte, 1992, ch.6.)

For various reasons including the largely bipartisan support of nuclear power, there was no mass public opposition to nuclear power at this time. However there was at least some public opposition, particularly around the proposed site at Jervis Bay. The South Coast Trades and Labour Council announced that it would refuse to assist in the building of the plant. (Falk, 1983, ch.11.)

Fourteen tenders were received from seven organisations from four countries – the US, the UK, West Germany, and Canada. The AAEC was strongly represented on the assessment committee which was established to evaluate tenders, as was the Electricity Commission of New South Wales. An American company, Bechtel, acted as consultants. A short list of four proposals was arrived at, and eventually the assessment committee recommended an LEU-fuelled steam-generating heavy-water reactor from a UK/German consortium. According to Alder (1996, ch.9), who was involved in assessing the tenders, there was little to separate the tenders on economic grounds, and the UK/German proposal was favourable in relation to the transfer of enrichment technology.

Gorton’s position as leader of the Liberal Party was under intense pressure and he resigned in March 1971. William McMahon succeeded him. McMahon was less enthusiastic about nuclear power than his predecessor. Reasons for this included concern over the financial costs; awareness of difficulties being experienced with

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46 All figures are in Australian dollars unless otherwise indicated.
reactor technology in Britain and Canada; recognition of strongly divided opinion within the AAEC; suspicions that the government was not being kept fully informed by the AAEC; and, according to Moyal (1975, p.376), "a personal reluctance on his part to identify with a nuclear policy that required types of uranium suitable for military purposes."

McMahon seemed prepared to proceed with the nuclear power project but he was more inclined towards an American tender - in part because of his desire to maintain friendly dealings with the US. The short-list of tenders was passed to Treasury which prepared a highly critical response. The comparison with respect to coal-generated electricity was extremely unfavourable, even making allowance for a premium price to bring Australia into the age of nuclear power. There was also less impetus for keeping the option of nuclear weapons production open given the change in the balance of forces within the Liberal Party. The project was deferred for twelve months in June 1971, and deferred indefinitely in June 1972. The Whitlam government did nothing to revive the nuclear power project from 1972-75. (Moyal, 1975; Cawte, 1992, ch.6.)

It took a decade or more for the AAEC to adjust to the abandonment of the Jervis Bay project; it did not consider the project to have lapsed in 1975, and in 1979 the AAEC reception centre still boasted a glossy display of the project with no suggestion that it had been abandoned. (Hutton, 1979).

Plans to develop nuclear power or nuclear weapons have never had as much high-level support as they did in the late 1960s and early 1970s, but the interest has never subsided completely. True to form, Baxter was advocating the establishment of a domestic enrichment plant through the 1970s for several uses including weapons production. (Martin, 1980, pp.48-49.) The financial costs associated with nuclear weapons were never likely to be insurmountable. Developing the technical and manufacturing expertise and facilities would have taken considerable time and effort, a significant but not prohibitive obstacle. The major barriers to nuclear weapons manufacture in Australia have been political. There were (and are) considerable doubts as to whether the advantages of acquiring nuclear weapons would outweigh negatives such as the possibility of sparking a regional nuclear arms race, or the possibility of threatening the alliance with the US. (Bellany, 1970; 1972.)

There were occasional signs of a renewed interest in nuclear power through the 1970s and into the 1980s, though this interest has faded. Almost all state and territory governments expressed interest in nuclear power at some stage, and
there was interest from some state electricity utilities. Some familiar elements of nuclear politicking were on display, such as wildly exaggerated predictions of future electricity demand; boastful comments by the Premier of Western Australia that a nuclear power plant would be enormously prestigious, adding to WA's "State of Excitement" image; and recognition that the capital-intensive nature of nuclear power was attractive when compared to the occasional industrial militancy in the coal industry. However there was strong public and union opposition to nuclear power, which fed into the mass anti-nuclear, anti-uranium movements of the late 1970s and early 1980s. The replacement of Liberal governments by the ALP in a number of states also put a dampener on proposals for nuclear power. (Falk, 1982, ch.11; Martin, 1984B; Hutton, 1979; Brotherton, 1979.)

### 3.5. THE AUSTRALIAN ATOMIC ENERGY COMMISSION IN SEARCH OF A MISSION: 1970-1987

By the time the ALP won the 1972 federal election, the AAEC was floundering, as it had been before the flurry of activity in the late 1960s. The AAEC had cost some $170 million (1972 value) over the previous two decades but had little to show for itself. (Cawte, 1992, ch.6.) The accession of the ALP to government initially had little consequence for the AAEC. There was little direction from the responsible Minister, nor even much communication between the Minister and the AAEC. Baxter retired from the AAEC in 1972, which further removed the Commission from political and public visibility. A major investigation and then a reorganisation of the AAEC took place from 1972 to 1974; but none of this was informed by, nor did it lead to, any explicit, major shift in objective. The review criticised the excessive secrecy of the AAEC and the over-classification of documents, but no steps were taken to enable greater public scrutiny and debate though the ALP had argued for such changes when in opposition. (Moyal, 1975.)

In 1975, Ann Moyal (1975, pp.382-383) summed up the AAEC thus:

> Basically the history of the Australian Atomic Energy Commission is an object lesson in the problems and dangers of closed government. At root it is a case study of the framing of a national nuclear policy through the influence of one powerful administrator surrounded largely by silent men. Moreover in the Australian environment, Sir Phillip Baxter's exercise of a monopoly of scientific advice on nuclear matters was compounded by the weakness in our parliamentary system in failing to make adequate information available to
the Opposition. Throughout, there was insufficient opportunity for public
debate and little for assessment and meaningful comment among the
scientific and public communities. Overall there was a disdain for public
accountability on the part of a major scientific establishment.

Despite the sense of drift, the AAEC was entrenched as the focal point for all
matters nuclear. In 1976, staff numbers reached a peak of 1354, of whom 1190
worked at Lucas Heights. The Commission had responsibilities in relation to the
uranium mining industry; it was involved in setting standards for ionising
radiation; it was one of the available authorities on the licensing and regulation of
nuclear facilities; it was the negotiating headquarters for Australia’s international
nuclear relations; and since the 1973 ratification of the NPT, it was the authority
for control and supervision of NPT safeguards. (Moyal, 1975.)

Notwithstanding the centrality of the AAEC, the range of institutions involved in
nuclear projects had expanded considerably. The Australian Institute of Nuclear
Science and Engineering was founded in 1956, and has played an important role in
linking the research efforts of the AAEC/ANSTO with Australian universities.
The Australian School of Nuclear Technology was founded in 1964 as a joint
venture between the AAEC and the University of New South Wales; it has
provided training for many Australian and overseas scientists in a range of
nuclear fields. A number of other universities have pursued nuclear R&D. The
Commonwealth Scientific and Industrial Research Organisation (CSIRO) is
Australia’s major scientific research and development organisation; many of its 40
divisions were involved in nuclear-related research by the mid 1970s. The
Australian Radiation Laboratory, part of the Commonwealth Department of
Health, played a significant role in the regulation of nuclear materials. The federal
government’s Bureau of Mineral Resources played a significant role in the
uranium industry. Several private companies also formed part of the nuclear
infrastructure by this stage; apart from private-sector investment in the uranium
industry, a number of companies were involved in nuclear projects such as
applied research or radioisotope support services. (AAEC, 1974.)

Through the 1970s the major area of work for the AAEC was at the front-end of
the nuclear fuel cycle - uranium mining, conversion, and enrichment. The
uranium mining industry underwent a revival from the late 1960s. By the end of
1970 more than 60 companies were exploring for uranium - more than twice the
number of the previous year. Some promising deposits were uncovered in the
Northern Territory, South Australia, and Queensland. (Falk, 1982, ch.11; Cawte,
1992, ch.7.)
The AAEC had been involved in every facet of uranium mining since its inception - exploration, mining, milling, conversion, safety and environmental regulation, securing export deals, and negotiating and overseeing safeguards agreements. Yet the Commission's involvement in the uranium industry varied according to government policy, no more so than during the 1970s. In October 1974, the federal ALP government announced that, through the vehicle of the AAEC, it would be the sole uranium marketing authority with a 50% interest in any venture resulting from discoveries by private companies. The AAEC would be the only organisation exploring for new deposits in the Northern Territory - thus the AAEC set up exploration operations from scratch, since many years had passed since it had been involved in exploration. The Commission became a partner in the Mary Kathleen mine in Queensland, the large Ranger mine in the Northern Territory, and it was also involved in a joint venture in the Ngalia Basin region of the Northern Territory. (Alder, 1996, ch.14; George and Walker, 1982; Brennan, 1985; Falk, 1982, ch.11.)

During 1975 the ALP was increasingly under siege. Nuclear power was once again in trouble around the world, which dampened prospects for uranium exports. Weapons proliferation concerns, highlighted by the Indian test explosion in 1974, gave further impetus to non-proliferation initiatives. An anti-uranium movement was gathering strength. There were opponents of uranium mining within the ALP; they were in the minority but sufficiently numerous and vocal to provide stiff opposition. Under pressure, the government established the Ranger Uranium Environmental Inquiry in mid 1975, which slowed uranium mining ventures even though the government was keen for sales to go ahead after some years of procrastination. The Ranger Inquiry was still in progress through the constitutional crisis of late 1975 which saw the dismissal of the Whitlam government and a landslide victory to the Liberal Party in the ensuing election. (Alder, 1992, ch.14; Falk, 1982, ch.11; Cawte, 1992, ch.7.)

From 1976 the Liberal government substantially reduced the role of the AAEC in the uranium industry. The Commission's exploration program was phased out, and its financial interest in a number of uranium mines was sold to private interests. The Commission's Uranium Branch was abolished in 1979, and then in 1982 the Uranium Resources Evaluation Unit of the AAEC was transferred to the federal government's Bureau of Mineral Resources. (AAEC, 1981-82; 1983-84; Alder, 1996, ch.16.)
The last major project for the AAEC was enrichment R&D. This work had expanded rapidly from its commencement in 1965. The Commission was restructured in the early 1970s to put greater emphasis on enrichment research. By 1977 - and perhaps earlier - the Centrifuge Enrichment Project Division (CEPD) was responsible for the Commission's largest research program. The CEPD acquired considerable expertise in enrichment technology, but it always remained some distance behind the larger R&D programs in several other countries. Thus there were repeated efforts to collaborate with overseas enrichment programs towards the establishment of a plant in Australia. These overtures were generally well received. Apart from whatever technological sophistication the CEPD could offer, Australia was attractive because of the availability of suitable sites for an enrichment plant, large uranium reserves, a high level of political stability, and relatively cheap and abundant reserves of fossil-fuel energy (an important factor since enrichment plants generally consume large amounts of electricity). (Hardy, 1996; Alder, 1996.)

Over the years, negotiations, and sometimes joint studies, were carried out between the AAEC and various overseas enrichment organisations and consortia - the US Atomic Energy Commission (and its successors), teams from Japan and France, the German-UK-Netherlands URENCO consortium, and the short-lived Association for Centrifuge Enrichment which involved seven European countries plus Canada, Japan, and Australia. The prospects for a collaborative venture were strong, but were never realised for various reasons such as changes in government and/or government policy, and fluctuating interest from potential overseas partners, some of whom developed facilities elsewhere. (Hardy, 1996; Alder, 1996.)

Several Australian companies were also interested in establishing facilities for uranium conversion (to uranium hexafluoride) and enrichment. In the early 1980s a "pre-feasibility study" was carried out into centrifuge enrichment technology by the Uranium Enrichment Group of Australia (UEGA), a joint venture formed by four Australian companies with the assistance of the AAEC. Plans for a full feasibility study were approved by government. There was considerable interest from overseas enrichment groups, and UEGA chose to collaborate with URENCO. However in 1983 the newly-elected ALP federal government put a stop to the venture. (Alder, 1996, ch.18; Hardy, 1996.)

By this time, enrichment work absorbed a quarter of the AAEC's research effort. Most of the effort concerned centrifuge enrichment, but there was also a small laser enrichment research project. The enrichment work was scaled down, under
direction from government, and it had terminated by 1985. For a year or two, the expertise and facilities developed through the enrichment work were redirected to enrichment safeguards projects. Proposals were developed within the CEPD to use the centrifuge enrichment facilities for separation of molybdenum isotopes, which would then be used as targets to produce radioactive molybdenum-99 for nuclear medicine. However nothing came of those proposals - by that time considerable resources had been invested in a molybdenum-99 production regime involving irradiation and processing of HEU targets. (Alder, 1996, ch.18; Hardy, 1996; Brennan, 1985; AAEC, 1981-82, p.14; 1983-84, p.11.)

A recent review of the AAEC/ANSTO divides its history into three phases (Bain International et al., 1994, p.4.). The first was the development of nuclear power, which lasted until the early 1970s. The second phase focused on uranium studies and centrifuge enrichment, which was terminated in the mid 1980s. In the third phase, the main purpose of the AAEC has been, as the review euphemistically notes, "less clear".

A series of reviews and reorganisations of the AAEC took place through the 1970s, including a major reorganisation of the Commission in 1974 and a reorganisation of senior management in 1978. In 1979 a committee of the National Energy Research Development and Demonstration Council (NERDDC) reviewed the research activities of the AAEC. The NERDDC review recommended a diversification of energy research to include non-nuclear energy. The AAEC had been conducting some limited non-nuclear research, including solar energy research, from the mid 1970s, but this work was limited by constraints imposed by the Atomic Energy Act. The terms of reference for the NERDDC review also mentioned commercial activities and spin-offs: from this point on commercial activities and collaborations would become increasingly important rather than tacked-on extras to the research program. (Hardy, 1996; AAEC, 1981-82, pp.52-53; George and Walker, 1982; Brennan, 1985.)

In 1980 the federal government announced that an interdepartmental committee would undertake a review of the 1953 Atomic Energy Act and related matters. The Uranium Advisory Council also undertook reviews of the Act in 1980-81. (ANSTO, 1993D, p.1.4.) In June 1981 the government announced that, as a result of the various reviews, it had decided that far-reaching changes to Commonwealth legislation in nuclear matters were required, as the Atomic Energy Act did not provide an appropriate basis for the development, regulation, and control of nuclear activities. (National Energy Advisory Committee, 1981, p.6.)
The legislative changes were a long time coming however. In the meantime, the government announced that direct government involvement in non-nuclear energy research and development should remain the province of the CSIRO. Consequently about one third of the AAEC's research staff was transferred to the CSIRO, including the entire Chemical Technology Division. A CSIRO facility was established adjacent to the AAEC's Lucas Heights facilities. (ASTEC, 1985, p.45; Alder, 1996; ch.16.)

The decision to restrict the AAEC to nuclear work was significant. As a past Chairman noted, "The moment for the creation of an Australian Energy Commission had come, and passed." (George, 1984.) How a revamped Australian Energy Commission would have dealt with energy issues, and within that the question of nuclear energy, is anyone's guess. It might have remained a white elephant, as the AAEC had arguably become, but a broader agenda for the AAEC might also have weakened and diluted its advocacy of dubious nuclear projects such as power reactors, PNEs, and weapons. The latter scenario was certainly a strong possibility if the AAEC was merged with the CSIRO, which was one option under discussion at the time.

With its reduced resources, the AAEC once again reviewed its programs and underwent a reorganisation. In 1982 the senior management structure at the AAEC was reorganised again, and research management was reorganised yet again in 1983. Some programs in chemistry, and isotope and radiation applications, were terminated or transferred to the CSIRO along with the solar energy research. Synroc, an experimental waste disposal technique, became a major focus. Synroc research began in 1979, and by 1985 it accounted for 15% of the research effort of the Commission. Some speculative work on nuclear fusion as a long-term energy source began in the early 1980s. The Commission's involvement in international safeguards and technical assistance was increased. More effort was put into bilateral and multilateral nuclear projects, especially with regional countries such as Indonesia, South Korea, Malaysia, and Thailand. Nuclear science programs continued in areas such as nuclear physics, materials, radioisotope applications, and environmental science. (George, 1984; Brennan, 1985.)

Radioisotope production assumed more importance in the scope of the AAEC's activities. Indeed radioisotope production had slowly assumed greater prominence within the scope of the AAEC's activities from the late 1960s. A national service for the production and distribution of reactor-based radiopharmaceuticals had been established in the 1970s. This growth was slow but not imperceptible: radioisotope production, for medicine in particular, had been
continually milked as a public relations winner, beginning even before HIFAR was operational. The commercial use of HIFAR was extended in 1985 with silicon irradiation on behalf of Japanese companies. AAEC expenditure for 1984-85 was $48 million, revenue from commercial operations was $2.5 million, and the Commission had a total staff of 1060. (George and Walker, 1982; Brennan, 1985; AAEC, 1983-84, p.4; ASTEC, 1985, pp.45-46.)

The various changes in the early to mid 1980s led to a degree of industrial unrest. This was in contrast to the early years of the Commission when industrial disputes were virtually unknown. A shortage of staff in some areas led to an increase in the incidence of demarcation disputes and also had an adverse effect on morale. Industrial unrest was exacerbated by the lack of a sense of direction in the AAEC, and the absence of an appropriate industrial relations strategy by the AAEC management. (AAEC, 1981-82, p.91.)

The AAEC noted in its 1983-84 Annual Report that several years of financial restraint had resulted in a marked decrease in the funds available for capital programs, to the point that the staff were not appropriately housed or equipped. The same complaint was made in the following years. (AAEC, 1983-84, pp.17-18; 1984-85, p.17; 1986-87, p.7.)

By the time that the Australian Science and Technology Council (ASTEC, 1984) was asked to review Australia's role in the nuclear fuel cycle in 1984, it was no wonder that a commentator asked what more a review could possibly say by that stage (George, 1984). Then followed the ASTEC (1985) review of nuclear science and technology in Australia.

The AAEC management was under siege through the 1980s, from tight-fisted and meddling governments, from unions, and from anti-nuclear activists. A number of specific incidents only made things worse. In 1983 significant quantities of gelignite and ammonium nitrate were found inside the AAEC's boundary fence along with three detonators. Several incidents occurred in 1984: the accidental release of 1.5-2.5 kg of uranium hexafluoride; improperly sealed isotopes were driven through Sydney for five hours, and the driver was exposed to the maximum radiation dose considered acceptable in a year; a ruptured pipe released 100 litres of radioactive sludge into stormwater drains with two workers contaminated, and no notification of the general public. (King, 1985.) Also in 1984, a threat was made to fly an aircraft packed with explosives into HIFAR a week later. The threat caused considerable media attention and concern in the local community. A person was charged and found guilty on two counts of causing
public mischief. (AAEC, 1984-85, p.77.) In 1985 it was reported that low levels of radioactive tritium had been leaking from the Lucas Heights facilities into two stormwater drains over the previous decade. Also in 1985, after vandalism of a pipe, radioactive liquid drained into Woronora river, and this incident was not reported for 10 days. In 1986 an act of vandalism resulted in damage to the sampling pit on the AAEC's effluent pipeline. This sparked widespread media coverage. (AAEC, 1985-86, p.15.) In 1987 a serious fire occurred in the charcoal filters of a hot cell, burning for nearly two hours with two workers contaminated. (Lucas Heights Study Group, 1986; 1993.) All through this period the problem of radioactive waste disposal was becoming increasingly embarrassing.

These were not happy days for the AAEC. It was time for a change of name, an eye-catching logo, and another review.

3.6. THE AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION

In November 1985 the Australian Nuclear Science and Technology Organisation (ANSTO) Bill was introduced into the Senate, and subsequently the ANSTO Act came into force in April, 1987. Thus ANSTO was born. In many respects the new legislation did not represent any fundamental break from the past; rather it reinforced and provided a legislative basis for a number of trends already evident.

In 1986, the Collins Committee was established by the Minister for Resources and Energy to review the AAEC. The review was timed to coincide with the formation of ANSTO and to provide the first ANSTO Board with some working ideas. The ANSTO Board adopted the majority of the recommendations - which was no surprise since three members of the Collins Committee were appointed to the Board. The Collins Committee argued that the AAEC had no clear objectives, too large an administrative effort, too many committees, that more effort was needed in commercial activities, and, inevitably, that another review was needed (Collins et al., 1986; Anon., 1987; AAEC, 1986-87, p.6.)

Some changes in activities occurred but still ANSTO's work was eclectic. ANSTO's functions were to include research, the provision of expert technical advice (primarily to government), the operation of national nuclear facilities, and the commercial marketing of products and services. The radioisotope operations were remoulded: Australian Radioisotopes was established as a commercial subsidiary attached to ANSTO. (AAEC, 1986-87, p.7.)
Some research into basic aspects of laser enrichment of uranium were restarted, although nothing on the scale of the previous enrichment R&D. A private company, Silex Systems (formerly Australian Nuclear Enterprises), has also pursued research into laser isotope separation processes in the past decade, and some of this work has been carried out in collaboration with ANSTO.47 (Hardy, 1996, ch.9.)

In addition to its nuclear work, ANSTO was empowered to undertake non-nuclear work at the discretion of the Minister for Resources and Energy, where that would be an effective use of its resources and would not unnecessarily duplicate activities being conducted elsewhere. That allowance seems not to have had any significant impact on ANSTO's work but it did ensure ongoing friction between ANSTO and the CSIRO.

The Collins Committee proposed a basic strategy for ANSTO which was "outward-looking, strongly interactive with other bodies, and directed towards the practical utilisation of nuclear science and technology for the benefit of Australia." This was typical of the discourse within which nuclear science and technology had become embedded. It has a number of elements. One was the multiplicity of nuclear applications, from termite removal to industrial gauges to decontamination of bee-hives. Tied in with the eclecticism was a perceived need to broaden the constituency for nuclear science: "The degree of involvement of outside organisations is particularly important for the future viability of ANSTO", the Collins Committee noted. (Collins et al., 1986.) Another feature of the new discourse was the compulsion to establish endless reviews, whether initiated by government or by the AAEC/ANSTO: this reflected the currency of managerialist ideologies and also the ideology of economic rationalism; it was indicative of the underlying lack of direction; and it was politically convenient for governments to establish reviews since that shifted the burden of decision-making to some extent and delayed the need to make contentious decisions, not least decisions concerning the future operation of research reactors.

Over the decades the AAEC/ANSTO had gradually lost its status as guardian of the coming revolution that was nuclear energy, and it was refashioned as one public-sector civil science agency among many. ANSTO competed for scarce resources with a host of other science and technology institutions. It adapted to this new environment to some extent, learning for example to be more competitive when applying for grants from outside funding bodies. However

47 In 1997 Silex signed an agreement with a US enrichment organisation (USEC), whereby USEC will examine the commercial potential of the Silex laser technology. (ANSTO, 1996F.)
ANSTO has also attempted to assert its special place within the public-sector science and technology infrastructure, in particular by playing up its role in foreign policy areas such as non-proliferation. This has been tied to objectives such as the acquisition of a new research reactor, and an ongoing struggle to avoid being amalgamated with the CSIRO.

Like all public-sector science agencies, and many others besides, government funding was insecure. Funding did not fall but nor was it increased. Funding for capital works was scarce, and expensive new toys such as a new research reactor were unlikely to gain approval in this climate. The other side of this coin was that there was considerable pressure on ANSTO to increase its revenue from sources other than government.

In order to cut costs, there was pressure to cut staff numbers and to increase the ratio of research and operational staff compared to support staff. Staff numbers fell through the 1980s. By mid 1976 AAEC staff numbers had peaked at 1354; by 1987 there were 1026 staff. (AAEC, 1986-87, p.6.) In the first years of ANSTO's existence the staff cuts continued; the government's requirement was that staff levels be reduced by 240 over the three years to 1990. The ANSTO Board agreed to the staff cuts in the expectation that significant increases would occur in the funds available to upgrade ANSTO's buildings and equipment. (ANSTO, 1987-88, p.7.) By mid 1994 there were 785 full-time staff and 46 part-time staff. Several major projects were completed during ANSTO's first few years, including the National Medical Cyclotron, a Business and Technology Park at Lucas Heights, a supercomputer, and a tandem accelerator. (ANSTO, 1993D, pp.1.3-1.4; 1993-94, p.54.)

The second component of the austerity drive concerned revenue raising. This was part of a broader drive to integrate public-sector science and technology with industry (Johnston, 1993). From 1988 ANSTO was able to retain revenue from commercial activities, an initiative designed to stimulate links between ANSTO and industry. In 1987 a target was set for ANSTO to earn, within five years, external revenue equal to 30% of its government appropriation. Similar targets were set for other organisations including the CSIRO. ANSTO's target had been reached in 1990-91, including revenue from Australian Radioisotopes. (ASTEC, 1994, p.3; ANSTO, 1993I, p.1.54.) The 30% revenue target was reached with a little help from the new "Prophecy" accounting system in which sales were recognised immediately upon issuing an invoice rather than actual collection of payments. (ANSTO, 1990-91, pp.59-60.)
An ASTEC (1994) review of the external earnings targets scheme said that the scheme had encouraged the development of links between ANSTO and industry and other research users - 373 private companies "interacted" with ANSTO (excluding ARI) between 1990-91 and 1992-93. These "interactions" seem to have grown exponentially such that nuclear gadgetry can be found in any nook, cranny, termite nest or bee-hive. A 1994 review of ANSTO argued, as had many reviews of the AAEC/ANSTO before it, that "ANSTO's mission has become increasingly complex, and activities have proliferated with no clear sense of focus or priority." (Bain International et al., 1994, p.4.)

ASTEC (1994) recommended against higher revenue targets because too much appropriation capital would be diverted to achieve the target, placing at risk intellectual capital, longer-term research, and "research programs of national importance and public good". ASTEC noted that there was a contradiction between public good and commercial research, and argued for increased accountability and minimising the less desirable effects of the external earnings targets. Undoubtedly the public good is a secondary consideration, if a consideration at all, as ANSTO refashions itself to make it attractive to paying customers. That said, from the point of view of nuclear critics a loss of intellectual capital at ANSTO might not be a bad thing; it could raise the technical and economic barriers to developing nuclear weapons, nuclear power, PNEs, or other such dubious projects. A similar point can be made about "research programs of national importance and public good": silicon doping and other such revenue-raising concerns are considerably more benign than much else that the AAEC/ANSTO has been involved in. On the other hand it is not a simple either/or situation: ANSTO's eclectic operations may be relatively benign but the nuclear expertise and facilities could be redirected into more contentious areas in future.

Another aspect of the drive to integrate ANSTO with industry was to change the governing Executive of ANSTO to include a majority of members appointed from outside ANSTO. Advisory Committees were established in each of the research programs, including representatives from industry, other science and technology institutions, and academia. Those changes were advertised as moves towards greater responsiveness and accountability to the "community". However only narrow sections of the community, in particular industry and science, have been included.

Married to the economic rationalism which has come to affect ANSTO is a managerialist, bureaucratic ethos. These various ideologies have come to permeate the public sector (Pusey, 1991). At ANSTO the managerialist ethos
manifests itself in many ways. One is the sort of bean counting that has ANSTO tallying its "interactions" with private enterprise. Other manifestations of the managerialist ethos include the focus on strategic and corporate plans, performance indicators, operational efficiency, external revenue targets and the like. The Collins Committee was well versed in this jargon: "The Committee believes that ANSTO should adopt a formal mechanism for setting its objectives, and institute appropriate corporate planning procedures for allocation of resources to programs to achieve these objectives, and to monitor its performance against the identified goals." (Collins et al., 1986.) Again the endless series of reviews is relevant, though they seem to generate more turmoil than "operational efficiency".

Collins, then Chairman of the ANSTO Board, noted in 1988 that: "In a climate where nuclear issues attract bad publicity, and where public attitudes towards nuclear matters are so negative, the challenge of ensuring ANSTO's survival in an appropriate, viable and effective form is no small one." (ANSTO, 1987-88, p.7.) The following year Collins was considerably more chirpy, mentioning the greenhouse effect and ozone depletion and arguing that "If nuclear energy is to play a more important role in the future energy generation of the world, Australia has the opportunity and the responsibility to contribute to that endeavour." This could be achieved by increasing uranium sales, he argued. He went on to accuse nuclear critics of being irrational, emotional, ill-informed, and politically-motivated. (ANSTO, 1988-89, pp.7-8.) This new zeal indicated that after a decade or so of being under siege from many directions, ANSTO was now on a more secure footing.

Associated with the 1987 ANSTO Act was the Atomic Energy Amendment Act, which repealed much of the 1953 Atomic Energy Act including the draconian security provisions. ASTEC (1985, p.74) saw that modification as facilitating greater efforts to propagandise about the "many important and peaceful applications of nuclear technology." Propagandising was nothing new to the AAEC/ANSTO, but in the past decade more effort has been put into open days, community forums (with a minimal exchange of significant information), glossy brochures and the like; this substitutes for genuine public accountability. One expression of this trend was the establishment of a Public Affairs Unit in 1990.

With some renewed zeal in the Organisation, and a boosted propaganda unit, ANSTO was better placed to renew its efforts to secure a replacement research reactor and this campaign duly gained momentum in the late 1980s and beyond. However the issue of radioactive waste disposal had become increasingly
contentious and was a major issue in the lead up to the 1992-93 Research Reactor Review. ANSTO confidently announced in 1987-88 that plans were in train to send 450 spent fuel rods to the US for reprocessing, and that a transport container, costing over a third of a million dollars, had been constructed for that purpose. (ANSTO, 1987-88, p.43.) In 1990-91 all that ANSTO could record in its Annual Report (p.66) was that developments were being monitored, an initial loading of HIFAR fuel rods had been prepared, and additional interim storage had been installed for HIFAR fuel rods. In addition a contract was negotiated with AEA Technology, Dounreay, Scotland, for reprocessing of 150 HIFAR fuel rods. Another waste issue concerned ANSTO's role in handling radioactive waste generated elsewhere in Australia. An attempt to move waste from the munitions factory of the Australian Defence Industries at St. Marys, Victoria, to the ANSTO facilities at Lucas Heights was successfully opposed in the NSW Land and Environment Court by the Sutherland Shire Council. The Court held that ANSTO did not have the power to deal with radioactive waste from non-ANSTO origins. As a result, the legislation governing ANSTO was amended. The ANSTO Amendment Act 1992 allowed ANSTO to store, manage, and process radioactive waste as a commercial activity with immunity from state/territory and local government laws. The new provisions were open-ended and highly contentious. Efforts to establish a national waste repository were stepped up at this time. (Senate Legal and Constitutional Legislation Committee, 1994.)

3.7. ANTI-NUCLEAR OPPOSITION IN AUSTRALIA

INTRODUCTION

THE NUCLEAR DISARMAMENT PARTY
RETREAT AND CO-OPTION
GREEN PARTIES
ECO-PAX IN THE 1990s AND BEYOND
OPPOSITION TO THE AAEC/ANSTO

INTRODUCTION

In this section I summarise anti-nuclear opposition in Australia from the mid 1970s to the present. The 1992-93 Research Reactor Review, and the HIFAR replacement controversy more generally, cannot adequately be understood without consideration of the trajectory of anti-nuclear opposition over this period.
Anti-nuclear opposition in Australia has to a considerable extent mirrored events overseas, but there have also been some distinctive features. Uranium mining and export has been the biggest concern, with the links between uranium export and weapons proliferation a major focus. Another notable and distinctive feature of anti-nuclear politicking in Australia was the important role played by the labour movement in the 1970s and 1980s; however that support has fallen away over the years.

A forceful anti-uranium movement developed through the mid 1970s. In nationally-coordinated demonstrations, the movement was attracting up to 50,000 marchers in the major cities. In Victoria alone, over 100 local groups opposed to uranium mining had been set up by the end of 1977. A number of groups had formed – Friends of the Earth (some of which were off-shoots from Greenpeace), the Movement Against Uranium Mining, Campaign Against Nuclear Energy, Uranium Moratorium (later superseded by Coalition for a Nuclear-Free Australia), and Campaign Against Nuclear Power. Some more established groups were involved, such as the Australian Conservation Foundation and the Wilderness Society. The common themes of anti-uranium campaigns were (and are) environmental hazards, the link between uranium export and weapons proliferation, and the impact of uranium mining on Aborigines and workers in the industry. There were two threads to the movement: mass opposition in the major cities, and opposition in the regions of the mines which has usually involved Aborigines. Along with the formation of a number of anti-nuclear, anti-uranium organisations, there was significant opposition to uranium mining and export by trade unions from the mid 1970s. (Martin, 1982; Falk, 1982.)

By 1977 the ALP had a formal policy opposed to uranium mining and export. Sections of the anti-uranium movement helped the ALP in marginal seats in the lead up to the federal election of December 1977. However this campaigning in marginal seats seemed to have little effect, and the Liberal government was re-elected. The anti-uranium movement faded for a time after this defeat; many activists left the movement while a number of groups effectively ceased to exist. Mass demonstrations in the late 1970s were large but in decline from the 1977 peak. Union opposition to uranium mining and export began to wane. (Falk, 1982, ch.11; Cawte, 1992, ch.7.)

In the early 1980s, the various strands of the peace movement picked up once again. Apart from uranium mining, issues taken up by the mass movement included weapons proliferation overseas, the US bases, the ANZUS alliance, French weapons testing in the Pacific, and the secret history of the British weapons
tests which was slowly coming to light. In 1984 peace marches were twice as big as the previous year, sometimes with marches a quarter of a million strong in the largest cities. These were backed up by industrial action and blockades and demonstrations at some of the uranium mines and US bases. Violence was rarely seen on the scale that was sometimes evident in Europe and North America, but state power was never far away, as demonstrated for example by mass arrests at demonstrations against the US bases. On top of the long-established groups, and the numerous groups that formed in the 1970s, there was further organisational development and coalescence in the peace movement. For example People for Nuclear Disarmament (PND) was formed in 1981 as a coalition of peace and anti-nuclear groups; the number of PND groups around the country had mushroomed to 65 within a year. (Goertzen, 1988; Hewett, 1982; Summy, 1987; Falk, 1983, ch.10; Friends of the Earth, 1986; Hallam, 1988; Ralfs and Miller, 1988.)

THE NUCLEAR DISARMAMENT PARTY

As in other countries, peace and anti-nuclear movements in Australia have lost ground because of illusions in mass social-democratic parties, in Australia's case the ALP. Among the more notable disasters was the 1966 federal election, in which many opponents of the Vietnam War actively supported the ALP; the result was that the movement was demobilised and demoralised and the ALP secured fewer votes than at any election since 1906 (Saunders and Summy, 1982). Then the anti-uranium movement lost energy after the federal elections in 1977 and 1980; much hope was put in an ALP victory which did not eventuate (Martin, 1989).

The "victory" of the ALP winning government in 1983 was even more demoralising since the new government reversed most of its progressive policies such as its opposition to uranium mining. (The government put in place a compromise policy which allowed only for the development of three, named mines; this policy remained in place from 1983 to 1996.) Anti-nuclear movements have had some limited success in winning over the ALP to certain positions on certain issues at certain times, but as Saunders and Summy (1982, p.26) note:

...... the cost of wooing the ALP has usually resulted in the need to adopt a lowest-common-denominator approach; analysis has been simplified and policy and tactics have been moderated in order to maintain and increase the support the movement has won from the party. Moreover, not only has the movement's ability to engage in radical critique and militant action been
compromised, but concomitantly the prospects for sustained future growth have been diminished.

The early performance of the ALP government led to a great deal of bitterness. At the 1984 ALP National Conference, the three-mines policy was established, and the conference gave support to the ANZUS Treaty, the US bases, and visits of nuclear warships to Australian ports. The major response of nuclear critics was to compete with the ALP in the electoral arena. Thus was born the Nuclear Disarmament Party (NDP). In less than six months the NDP had 8000 members, it had polled 650,000 primary votes (6.8%) in the federal election of late 1984, and an NDP candidate, Jo Vallentine, was elected to the Senate. (Christoff, 1985; Prior, 1987; Pakulski, 1991.)

In another six months the NDP had all but collapsed. From the start the NDP’s purpose was to contest the next federal election; it was in Christoff’s (1985, p.15) words "guerilla electoralism". The NDP drew considerable support from disgruntled members and former supporters of the ALP, it was very popular among young people, and a range of people and groups from the environmental and peace movements threw their weight behind the NDP election campaign. The Party had three planks to its platform (and no more): the closure of all foreign military bases in Australia; banning the stationing in Australia or the passage through Australian waters or airspace of any nuclear weapons; and the banning of uranium mining and export.

NDP election campaigning was frantic, and there was a good deal of exhaustion after the 1984 election (which returned the ALP to government). Since the NDP had been established to contest the election, its future direction was unclear. Some hoped it would evolve into something along the line of the German Greens. Other people had different ideas. The general and vague Party program was a blank page onto which many groups wrote their own ideologies and programs, and these proved too diverse and contradictory. The NDP had grown so quickly that issues of structure, accountability, policy, and the involvement of members of other parties had not been properly addressed. At a conference in April 1985, the Party was badly split over these issues. The charismatic rock star Peter Garrett led a walk-out of some of the leaders which signified the beginning of the end of the NDP. Jo Vallentine renounced her allegiance to the NDP. Membership declined rapidly and the NDP faded into obscurity.
RETREAT AND CO-OPTION

The ALP was certainly affected by the initial success of the NDP, but it did not adopt more progressive policies. Indeed it was soon after the 1984 election that the MX missile controversy flared up. Early in 1985 Prime Minister Hawke made a secret commitment to the US government to provide back-up facilities for the test landings in the Tasman Sea of two unarmed MX missiles. This information came to public notice, and provoked such a furore that Hawke was forced to reverse his decision in the next few days. (Sharp, 1985.) The MX missile controversy helped to put the US bases and the ANZUS alliance firmly on the political agenda of nuclear critics and the major political parties alike; the decision of the New Zealand government to ban visits by nuclear warships was seen by many as a model for Australia.48

A section of the ALP left faction resigned from the Party in the mid 1980s. Since then the left faction has been nothing more than a rump with bland policies and very little influence within the ALP. Perhaps the most significant change in the ALP was that its leadership became considerably more adept at co-opting social movements including eco-pax movements. This co-option took various forms. In general the main method of co-option was (and is) to offer leaders of the movements places in the bureaucratic sun, for example through state funding of conservative peak bodies (such as the Australian Conservation Foundation) and the involvement of movement leaders in formal processes such as the Environmentally Sustainable Development process. (Shannon, 1996.)

In the case of anti-nuclear movements, the ALP government appointed an Ambassador for Disarmament, who sometimes appeared to be primarily a spokesman for the government's policies on the US alliance and uranium mining (Diesendorf, 1987). A Nuclear Free Zone Treaty was signed in 1986 by the government, which also amounted to little more than a co-option of the movements. Such initiatives gave politicians the opportunity to appear to be making a contribution to non-proliferation, but issues such as the US bases and uranium mining and export were not negotiable. These projects also gave the leaders of the anti-nuclear groups something to do in a period when the movements were in decline – though the movements declined all the faster.

48 As Wills (1985) notes, the stance of the New Zealand government was little more than electoral populism: the government still supported US interests in the region, not least by continuing to host US intelligence bases. In retaliation to the banning of nuclear warships, the US cut a number of military and intelligence links with New Zealand, but much remained.

49 There was a good deal of coalescence between the various strands of the environmental and peace/anti-nuclear movements, hence the term eco-pax. See Pakulski, 1991.
because resources were diverted from important, topical campaigns such as uranium mining at Roxby Downs (Fricker, 1988; Martin, 1985).

The ALP’s task of co-opting anti-nuclear movements was made easier by three interconnected developments: the movements became increasingly disconnected from the working class and the unions; they were in decline from the mid 1980s onwards; and the broad political strategy of building and broadening the mass movement increasingly gave way to various dead-end liberal strategies.

The movements were increasingly disconnected from the working class and the unions. As economic stagnation and the associated capitalist austerity drive took hold from the mid 1970s, concern gradually shifted from environmental, nuclear, and foreign policy issues to jobs and the economy. With the ALP in government from 1983, the union movement was increasingly being drawn into the consensus conservatism of the business-union-government Accord process. Struggles around workplace issues were on the wane, as were struggles around broader social issues such as uranium mining. Many union leaders were only too happy to do the bidding of the ALP government because of the close historical links between union leaders and ALP politicians and their common class location in the labour aristocracy. Socialists were excluded or went into self-imposed exile from the eco-pax movements; other socialists had failed to see the anti-capitalist dynamic of the movements and had ignored them from the start. (McDonald, 1996; Shannon, 1996; Beresford, 1977.)

Working-class involvement in the movements declined, and the power that could be wielded through union activities such as strikes was all but lost to the social movements. In turn the movements distanced themselves from the working class and unions; less effort was made to involve unions and workers in campaigns. The movements became more bureaucratic and reformist and far easier to co-opt whether by the state or by capitalists (e.g. green consumerism). Building and broadening mass campaigns gave way to reformism and individualism – professional lobbying, letter-writing campaigns, petition drives and so on, all of which can be useful tactics in the context of the building of a mass campaign but have precious little impact by themselves. Some activists retreated entirely into the dead-end politics of lifestyle change.

These various trends are neatly summarised by Shannon (1996):

"With the labour movement hunkered down in defensive bunkers, resisting with more or less (mostly less) success the assaults of a desperate capitalist"
class during the 1980s recession, green strategies took on a wistful and ineffective hue. Green self-improvement versions of the Biblical injunction to 'change thyself' (half a brick in the toilet cistern, recycling, and so on), elitist Greenpeace heroics, green consumerism, and the perennial ballot box came to dominate the outlook of most of those with environmental concerns.

Universities were of course shaped by the capitalist austerity drive and the decline of the social movements. Milieux of movement activists and academics went into decline, as seen for example in the inward turn of STS. Theoretically, movement leaders and theorists, and some academics, constructed a intellectual edifice justifying the retreatist politics of the movements. The idea took hold that the working class was no longer the agent of social change, that it had come to form part of the "productivist core" (or similar notions) along with the ruling class and the state. Often this was (and is) linked to overambitious theorising about the possibility that the social movements might fill the void left by the "corporatised" working class (e.g. Touraine, 1981, 1988). Sometimes the "new" social movements as a whole are glorified - "neither left nor right but out in front" - and contrasted to the "old" labour movement. In other cases one or other of the new social movements is held to be the guardian of the new age. Thus the central argument of Babin's (1985) book on the Canadian nuclear industry is that "it is within the antinuclear movement that we find the starting point for the most important struggle in post-industrial society."50

GREEN PARTIES

From the mid to late 1980s, in Australia as in many other (predominantly capitalist) countries, leaders of the eco-pax movements formed green electoral parties. To some extent the green parties were an advance on the environmentalism of the 1970s, in that they went beyond simplistic lifestyle solutions, and they bridged local issues to international issues and environmental issues to social issues. The green parties were attracting significant numbers of people from the social-democratic parties and the mass movements. They sometimes threatened to disrupt the two-party systems typical in most capitalist countries, and more generally they had the potential to spur the growth of progressive movements both inside and outside the electoral arena. (McDonald, 1996.)

50 For more sober and convincing assessments of the social movements, old and new, see Burgmann, 1993; McDonald, 1996.
Many local green parties formed in Australia - there were 13 in New South Wales alone by 1991. However their early promise has not been realised. The political circumstances in which they were developing was not helpful, with the movements in decline and increasingly disconnected from workers and unions, the economy in stagnation and periodic recession, most of the small socialist parties in self-imposed exile, and the ALP becoming more adept at co-opting social movements. More than a few of the green-party leaders were (and are) opportunists and careerists - social movement superstars - and this was never likely to help. Early electoral successes immediately raised the question of the balance to be struck between electoral and campaigning work. Most of the leaders argued for a greater focus on electoral work, and by pursuing this approach the green parties have become disconnected from their extra-parliamentary campaigning base. This was exacerbated by the enactment, after a struggle, of a proscription clause which resulted in the expulsion of campaign-oriented activists such as those from the Democratic Socialist Party. (McDonald, 1996.)

The Australian Greens were launched in 1992, uniting all those green parties which wanted to be part of a national organisation and would agree to adopt proscription. This unification was of little significance however. Before and after the formation of the Australian Greens, the trajectory was towards a narrow electoralism. The various parties affiliated to the Australian Greens have generally had only limited involvement in campaigns around French nuclear testing, uranium mining, or woodchipping of native forests. Indicative of the trajectory was the decision of the Australian Capital Territory Greens (affiliated to the Australian Greens) to form a coalition government with the conservative Liberal Party in the mid 1990s. Thus the ACT Greens are dutifully implementing the ruling-class austerity drive and justifying this with appeals to the shibboleth of "stable government". (McDonald, 1996.)

ECO-PAX IN THE 1990s AND BEYOND

Of course the green parties have not been the only organised expressions of eco-pax politics in the past decade. A number of groups from the first wave of eco-pax politics in the 1960s and 1970s have survived, though in almost all cases they have minimal personnel and resources. Friends of the Earth (FOE) groups still exist - though numerous FOE groups folded in the early 1990s. Other groups such as Movement Against Uranium Mining, and People for Nuclear Disarmament, are in much the same situation as FOE - alive but struggling. The Wilderness Society has a paper membership of many thousands, but it has very few activists, it has become closely tied to the electoralist green parties in most states, and it has at best
a modest involvement in campaigns such as those against uranium mining or French nuclear testing. The Australian Conservation Foundation is in much the same situation – many thousands of paper members but very few activists and a thoroughly reformist perspective. The Democratic Socialist Party (DSP), and the youth group Resistance, are the major socialist forces still involved in eco-pax politics; they have considerable influence given their small size, but as was shown by the proscription of the DSP from most of the green parties around Australia, liberals currently have the upper hand in Australian eco-pax politics.

Another group which needs mention, as it is perhaps the most visible of all eco-pax groups, is Greenpeace. Greenpeace is well able to generate enormous publicity for itself and for the issues it takes up. In some campaigns, such as that against French nuclear testing in the Pacific, Greenpeace plays a major, multifaceted, and positive role.

However Greenpeace tends to operate in a bureaucratic and exclusive manner – its members, and the public at large, are encouraged to support the organisation with money but there is little room for active involvement. Thus for all its appearance of being at the cutting edge of radical eco-pax politics, Greenpeace is much the same as the Wilderness Society and the Australian Conservation Foundation – a very high paper membership but a very small number of activists and a liberal reformist perspective.

Some eco-pax groups established in the 1970s or 1980s have folded altogether. For example Campaign Against Nuclear Energy, which arose in the mid 1970s and used to have a membership of over 1000, ceased operating in 1987 because of debts and lack of personnel. (Ralfs and Miller, 1988; Fricker, 1988; Orzanski, 1989.) The Communist Party of Australia, which used to have considerable involvement in eco-pax campaigns and other social movements, collapsed in the early 1990s.

In the absence of mass movements, most of the eco-pax groups have necessarily functioned as pressure groups rather than as a movement core. While there is little eco-pax politicking beyond these groups, the waves of the eco-pax movements have left a reservoir of public anti-nuclear sentiment. This sentiment can flare up on occasions, For example, demonstrations against French weapons tests attracted tens of thousands of people in 1995. Another example was the National Peace Protest and Desert Festival at the US base at Nurrungar in 1993, which attracted nearly 1000 protesters despite the remote location. These radicalisations tend to be short-lived and shallow but are significant nonetheless. Both the social movement organisations, such as they are, and the reservoir of
anti-nuclear sentiment in the public, are of considerable significance to the debate over the replacement of HIFAR.

Pakulski (1990, p.58) offers the following diagram in which political openness refers to the ability of disaffected groups to channel grievances through state institutions, and political strength refers to the capacity of state institutions to respond to such pressure:

![Diagram of Political Openness and Strength]

I would locate the Australian eco-pax movements vis a vis the state somewhere between the assimilation and persistence categories in Pakulski's schema, though the assimilation has been more a co-option with little substantive shift in the policies and practices, let alone the structure, of state institutions including the major political parties.

While that pattern of persistence and co-option of eco-pax movements in Australia is likely to remain for the foreseeable future, there have been some significant changes in the political landscape. The capitalist austerity drive has stepped up another notch with the election of the Liberal/National Coalition to government in March 1996. This has provoked some reaction by some of the social movements and also by sections of the union movement. However the reaction has been sporadic, and the trajectory of the austerity drive vis a vis the defensive reaction cannot be predicted with confidence. The new government's nuclear policies, and the (tame) opposition to them, are discussed in chapter 4.5.

**OPPOSITION TO THE AAEC/ANSTO**

From its inception until the 1970s, there was little opposition to the AAEC. Reasons for this included the secrecy of the AAEC and the largely bipartisan support for nuclear technology from the major political parties. (Moyal, 1975.)

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51 Eco-pax movements in (West) Germany have fallen some distance short of creating a revolutionary situation, but the combination of rigidity/blockage and weak state responses led to massive and sometimes violent protests in the 1970s and 1980s.
Since then, the various operations at Lucas Heights, including the research reactors, have failed to mobilise opposition to the same extent as issues such as uranium mining and the US bases. However the AAEC/ANSTO's involvement in most of Australia's nuclear projects has never been lost on nuclear critics. Moreover there has always been considerable mutual support between different eco-pax campaigns and groups. For example groups such as the Movement Against Uranium Mining, Friends of the Earth, and Greenpeace, have all taken up a range of issues including uranium mining, the US bases, disputes over radioactive waste, and last but not least the issue of the future of research reactors in Australia. Similarly, organisations such as uranium mining companies have supported the replacement of HIFAR even where they have little or no direct interest in the construction of a new reactor.

As well as the broader opposition to the AAEC/ANSTO from the eco-pax movements, there has been more concentrated opposition from sections of the local population. The Sutherland Shire Environment Centre has consistently been involved in campaigns relating to the AAEC/ANSTO. The Lucas Heights Study Group, a residents action group, was established in the mid 1970s and has been involved in many campaigns over the years. Among the various issues taken up by the Study Group have been demands that residential development near the AAEC not be allowed; that there be greater accountability and less secrecy in the AAEC/ANSTO's operations; that HIFAR and MOATA be shutdown (for various reasons such as safety and environmental impact); that a waste repository be established and waste removed from Lucas Heights; that the discharge of liquid radioactive waste into the ocean cease; that the AAEC/ANSTO should undertake non-nuclear research and development; that a national cyclotron for medical radioisotope production be established; and that a health study should be conducted in areas adjacent to Lucas Heights. (King, 1985.) Apart from the long-standing issues associated with the AAEC/ANSTO's operations, such as waste storage and disposal, there has been considerable adverse publicity from time to time relating to specific incidents such as the escape of uranium hexafluoride in 1984, and the 1996 shipment of 114 spent fuel rods to Scotland.

3.8. CONCLUSION

One issue which emerges from Australia's nuclear history is the recurring theme of nuclear militarism. Initially this involved support of the weapons programs of the US and the UK through the hosting of British weapons tests, American military facilities (including nuclear bases from the late 1960s), and uranium supply. Then from the 1950s there was some interest in the purchase of nuclear
weapons from the US or the UK or the stationing of nuclear weapons in Australia. And through the 1960s, there was a greater willingness to entertain the idea of domestic development of nuclear weapons, most concretely expressed in the series of projects from 1969-71. The high-level interest in nuclear weapons faded quickly, along with most of the relevant projects, but national defence/security concerns continue to shape nuclear development in Australia including the HIFAR replacement controversy.

Australia's nuclear history is also the history of the AAEC/ANSTO and its transition from an institution of great political, economic, and even military importance, to its more modest role as a public-sector civil science agency.

The themes which have predominated in this chapter - the weapons connection, and the rise and fall of the AAEC - have been taken up in some recent literature on Australia's nuclear history. They receive emphasis in Alice Cawte's (1992) book *Atomic Australia*. Cawte is not the first writer to discuss the nuclear weapons issue, but her account is the most systematic and sustained analysis of the interest in a domestic weapons capability and the intersection of that with projects such as the Jervis Bay nuclear power project.

Cawte's analysis is based on detailed archival research - she analysed a considerable volume of unpublished literature such as Cabinet submissions from the government's Defence Committee, various government Ministers, and Phillip Baxter. Cabinet documents from 1962-66, released in the five years since Cawte's book, all confirm the general thrust of her arguments - that there was high-level political interest in the possibility of developing a nuclear weapons capability (though no decision to systematically pursue a weapons program), and a willingness to pursue ostensibly civil nuclear projects such as nuclear power to lower the barriers to nuclear weapons. In other respects Cawte's arguments are necessarily speculative. For example there is a great deal of circumstantial evidence to support the argument that the Jervis Bay nuclear power project was pursued, in part, to lower the barriers to nuclear weapons, even though there was no public admission along those lines. Overall, Cawte's analysis of the interest in a domestic weapons capability is convincing. It is also insightful in its linking of the weapons issue with the history of the AAEC. In particular, Cawte shows how the AAEC was floundering in the late 1960s and thus all the more willing to involve

53 Indeed the sudden silence was revealing. More information on the 1969-71 period will come to light around the turn of the century, with the release of classified documents under the 30-year rule on disclosure of sensitive government documents.
itself in the development of nuclear explosives, whether for peaceful or military uses – this insight is of some relevance to the HIFAR replacement controversy.

Cawte's book, and other literature on the weapons issue, has provoked some defensive responses from the nucleocracy. One such response is a book by Alder (1996), who was centrally involved in much of the AAEC's work from the Commission's creation until 1982. On the weapons issue, Alder (1996, pp.7-8) says that:

...... there was never any planning or work done by the AAEC towards the development of nuclear weapons in Australia ...... (All), repeat all, of the Commission's own work was directed at all times to the peaceful uses of Atomic Energy, and those who say otherwise are remoulding history to suit their own false views and political purposes.

Whether there was ever any research at the AAEC directly related to weapons is an open question that is not addressed in the existing literature (so far as I am aware) nor in this thesis. In some respects the question can be questioned: regardless of intentions, and regardless of whatever might have taken place at the AAEC in relation to weapons development, a fair percentage of the AAEC's ostensibly civil research, not least the power reactor research and the enrichment program, had obvious implications for weapons development even if that was not the aim.

Whether consideration was ever given to the potential to use HIFAR in a more direct manner towards the acquisition of nuclear weapons is also a matter of speculation. Consideration may have been given to extraction of plutonium from spent HIFAR fuel, although the reactor produces insignificant amounts of plutonium, and yields might still be insignificant even if plutonium production was maximised. Most probably the AAEC's plutonium extraction research, to the extent that it was concerned with weapons development, was pursued with a view to reprocessing fuel from the planned power reactor. In any case the Commission's preliminary plutonium extraction research seems not to have gone far. Consideration may also have been given to diversion of HEU fuel, or extraction of HEU from spent HIFAR fuel. Pursuit of any of these options may have jeopardised further supplies of HEU from abroad, which might have been one reason enrichment research was pursued.

54 See also Hardy, 1996. Like Alder, Hardy was employed by the AAEC/ANSTO for many years. Hardy's book is far more tightly argued than Alder's, but it only addresses the weapons issue in passing. Both books are focused on the AAEC's enrichment program.
More generally, Alder's (1996) polemic misses the point. He ignores Baxter's arguments, repeated over the years, that projects such as nuclear power and enrichment should be pursued in part to lower the barriers to weapons production. He ignores (or is unaware of) the overtures made by the federal government's Defence Committee to the US and UK in relation to acquisition of nuclear weapons. He says nothing about the AAEC's Plowshare Committee and the Cape Keraudren PNE project. He says nothing about the refusal of the government to sign the NPT in the late 1960s, and Baxter's role in that episode. He ignores the public advocacy of Gorton and several other politicians for a nuclear weapons "deterrent". He ignores other comments on the public record, such as the admission by the Minister for National Development in 1967 that it was government policy to maintain a domestic uranium source for weapons production. He says nothing about the intersection of civil and military nuclear programs overseas. To the extent that these issues are addressed by Alder, it is simply to assert that neither Baxter nor anyone at the AAEC supported weapons development or supported civil nuclear development in part to lower the barriers to weapons development. He repeatedly claims that those who claim otherwise are politically-motivated, anti-nuclear dogmatists whose arguments rely on dubious sources.

As for the rise and fall of the AAEC, Alder (1996, p.9) says the Commission did not "lose its way" at all:

...... what actually happened was that our political masters kept changing the rules. Not just once or twice, but over and over again. In retrospect, I believe the AAEC and its staff showed great resilience in the face of constant politically motivated changes, many of which were caused by ignorance-based dogma.

In short, Alder's (1996, p.79) thesis is that "Dogma won, over national interest." His vision (p.83) is for Australia to provide the world with "total nuclear fuel cycle services including reprocessing and waste disposal", and if the ignorant, politically-motivated dogmatists have their way, Australia risks invasion from Asian countries in need of uranium.
CHAPTER FOUR:
THE 1992-93 RESEARCH REACTOR REVIEW

4.1. INTRODUCTION
4.2. HISTORY OF REVIEWS
4.3. THE RESEARCH REACTOR REVIEW PROCESS
4.4. DEBATES AND FINDINGS
4.5. FURTHER DEVELOPMENTS

4.1. INTRODUCTION

This chapter covers the recent history of debates over the replacement of HIFAR, focusing on the 1992-93 Research Reactor Review (RRR). I begin by summarising the 20-25 year history of the AAEC/ANSTO's efforts to convince the government to approve and fund a new reactor. Then the politicking surrounding the RRR is discussed. Then I summarise the overall findings of the Review, and discuss a number of the debates taken up during the Review, although it is beyond the scope of the thesis to analyse all of the debates in any detail. I conclude this chapter with some discussion on developments since the Review.

Before proceeding, some comments on the place of this chapter in the context of the thesis and on different approaches that might be used to analyse the RRR and the HIFAR controversy more generally. My analysis draws from the contextual material of the previous two chapters; in other words the HIFAR controversy is treated as a microcosm of the ongoing history of nuclear development in Australia and abroad. This approach can be contrasted with two different approaches. One approach would be a positivist/technical analysis of the HIFAR controversy - this would probably go no further than an analysis of each of the sub-debates within the broader HIFAR controversy.

Another approach would be to rely heavily on constructivist STS/SSK concepts, still focusing on the various sub-debates but with much more attention given to the social dimensions. For example the SSK concept of interpretive flexibility could be used to show how, during the RRR, pro- and anti-nuclear partisans attempted to ascribe to their own knowledge claims the status of fact, and to ascribe to their opponents' "facts" the status of conjecture. One might also expect some consideration of the symbolic dimensions of nuclear energy - the fears some people hold about nuclear holocaust, efforts by pro-reactor partisans to counter that anti-nuclear symbolism, and so on. In sum one would expect that a typical STS/SSK account of the RRR would be insightful, but that it might give weight to
Winner's (1993, p.373) gripe that "All the emphasis (in social constructivism) is focused upon specific cases and how they illuminate a standard, often repeated hypothesis, namely, that technologies are socially constructed."

Both a technical/positivist approach and an STS/SSK approach to the RRR could be justified. Public-policy debates surrounding the HIFAR controversy could profit from further technical/positivist analyses of some of the sub-debates. An STS/SSK approach might also add to public-policy debates; for example some of the complex sub-debates might profit from a symmetrical SSK analysis, or to give another example an STS/SSK analysis might expose and critique technocratic (and anti-democratic) ideologies and their role in the HIFAR controversy.

My approach borrows from the two approaches just described: there is some technical analysis, although not many issues are explored in depth; and the analysis is also alert to STS/SSK insights. In addition, the following analysis draws from the broader, historical picture of nuclear development presented in chapters 2-3. That material provides some important insights. Generally, the HIFAR controversy is more than the sum of its component sub-debates, yet a technical/positivist analysis or a narrow STS/SSK analysis of the RRR might easily reduce the controversy to its sub-debates. More specifically, the HIFAR controversy is much better understood in light of the historical tension between the AAEC/ANSTO as an institution of key strategic importance versus the AAEC/ANSTO as one public-sector civil science agency among many. That tension, and its significance, could only be partially teased out of the material presented to and by the RRR panel; it is much better understood with some historical background. Similarly, a technical/positivist or STS/SSK analysis could scarcely even begin to consider the intersection of the HIFAR controversy with nuclear weapons issues, since there was hardly any explicit discussion on nuclear weapons during the Review (except for nuclear weapons programs overseas). Yet on the strength of the discussion on the use of research reactors in nuclear weapons programs in chapter two, and also drawing from the analysis in chapter three of the interest of sections of the Australian state and nucleocracy in a domestic nuclear weapons capability and their willingness to pursue civil nuclear projects to lower the barriers to nuclear weapons, the intersection of the HIFAR controversy and nuclear weapons issues can be analysed.

The contextual material of the preceding chapters is most useful when addressing the "national interest" sub-debate of the HIFAR controversy, one component of which is national defence/security. If the only purpose of the preceding two chapters was to throw light on the national interest sub-debate, it would be a case
of using a sledgehammer to crack a walnut. However the contextual material of chapters 2-3 also sheds light on other issues; in particular, the analysis of nuclear medicine and the medical radioisotope industry, in chapters 5-8, profits from a broad, historical understanding of nuclear development.

4.2. HISTORY OF REVIEWS

With the AAEC/ANSTO floundering for lack of purpose through the 1970s and 1980s, HIFAR became more important to its activities. Partly this importance was practical - for example as economic rationalism took hold, HIFAR was increasingly used for silicon doping, radioisotope production, and other functions to increase revenue. Partly the importance of HIFAR was symbolic - ANSTO (1991) admits as much itself in saying that the operation of a research reactor brings "international prestige and influence".

The AAEC began pushing for government approval and funding for a new reactor, or a major upgrading of HIFAR, in the mid 1970s. On several occasions, federal governments have referred the issue to review committees and deferred making a decision on the issue. In broad terms, the repeated deferrals of a decision on the issue can be seen as reflecting financial considerations and the dubious rationale for a new reactor. Public opposition has also been a factor: while governments in Australia have not been forced to radically alter nuclear policies in response to public opposition, they have at least been forced to adopt a more guarded approach.

In 1975 the AAEC initiated a preliminary study into the possibility of replacing HIFAR. The study was completed in 1978, at which time the government approved a submission to proceed with detailed design studies, site selection, and financial estimations. A French designed replacement reactor, costing $30-40 million, was under discussion. However the 1979 National Energy Research Development and Demonstration Council (NERDDC) review recommended that HIFAR should not be replaced in the short term, although it did say that there was a need for a research reactor and that HIFAR should be refurbished. (ANSTO, 1991.) This was just ten years after all the interest in nuclear power and nuclear explosions, yet more mundane issues - such as the relative merits of reactors and cyclotrons for medical radioisotope production - dominated the debate (Malone, 1979).

The NERDDC recommendation terminated the study for a new reactor. A program to refurbish HIFAR began at an estimated cost of $4.7 million over five
years. Much of the impetus for the refurbishment was that HIFAR did not comply with safety and reliability standards which had been adopted during the two decades of the reactor's operation. The refurbishment involved work on the containment building, emergency core cooling system, reactor instrumentation, and electrical power supply. Short of a new reactor, the AAEC wanted an upgrading of HIFAR including an increase in neutron flux, but most of the modifications the government was prepared to fund were not to upgrade performance but to improve safety. The refurbishment program continued through the 1980s. (AAEC, 1981-82, pp.52-53; ANSTO, 1989-90, p.58.)

The future of HIFAR – and the possibility of a replacement reactor – was back on the agenda in 1985. An ASTEC (1985, p.61) review argued that it was essential for Australia to be involved in nuclear science and technology, and to operate a research reactor, for the following reasons: economic advantages through transfer of nuclear technology to Australian industry; scientific advantages; social advantages in medicine and environmental science; and foreign policy advantages, which ASTEC related to "Australia's influence in the International Atomic Energy Agency and other influential forums concerned with aspects of the nuclear fuel cycle."

ASTEC considered three options: replacement of HIFAR with a reactor of at least equal neutron flux; replacement of HIFAR with a smaller 5 MW reactor combined with assurances of access to overseas high-flux research facilities; or further refurbishment of HIFAR. ASTEC argued for retention of HIFAR with a regular budget for upgrading and maintenance; it said that with refurbishment HIFAR could operate safely and efficiently into the 1990s. Modifications would include improvements to neutron beam instrumentation. Replacement of HIFAR with a reactor of at least equivalent flux was "not feasible in the present Australian economic climate", the ASTEC report said, and a 5 MW reactor would mean discontinuation of most of the "international standard" research programs carried out using HIFAR. (ASTEC, 1985, p.4, pp.69-70.)

The HIFAR refurbishment program continued through the 1980s and beyond. In 1989-90 an ongoing HIFAR "modernisation program" commenced, initially focused on the completion of seismic hardening work and a program of replacement of electrical instrumentation and protective signals. Again the emphasis was on safety rather than upgrading performance. (ANSTO, 1989-90, p.58.)
By 1990 the transition from the AAEC to ANSTO had been completed. In some respects ANSTO was on a more secure footing - government funding had become a little more secure and generous, enabling some capital works projects to proceed, and anti-nuclear opposition was in decline. On the other hand there was some industrial unrest at this time, and the safety of HIFAR was a topical issue. The issue of replacing HIFAR resurfaced. Collins, then Chairman of the ANSTO Board, declared that there was public discussion, "mostly of an uninformed nature", on the issue. ANSTO had commenced planning for a new reactor by this stage, and argued that a firm decision from government was essential within the next few years. (ANSTO, 1990-91, pp.5-8.)

One aspect of the science and technology policy debate in Australia by this time revolved around "big science". It was in this context that ASTEC undertook a review into major national research facilities. (The definition of these facilities rested on various criteria, one of which was capital cost of at least $5 million. Of the six major national research facilities operating at the time, one was HIFAR, and another was the National Medical Cyclotron.) In ASTEC, ANSTO had a strong ally. ASTEC's uncritical support of the AAEC and other facets of nuclear development in Australia had been made clear on a number of occasions through the 1980s, no more so than in the 1984 ASTEC report which was a whitewash of the uranium mining industry. ASTEC (1992) argued that a reactor to replace HIFAR should be one of seven priorities in terms of major national research facilities, narrowed from an initial list of 96 proposals. ASTEC estimated that a replacement reactor would cost $150 million. This was by far the most expensive of the proposals for major national research facilities; in fact it accounted for over half of the $275 million estimated total costs for the seven proposals.

The ASTEC review accepted ANSTO's rationale for a new reactor. However the issue was soon to be subjected to more searching scrutiny.

**4.3. THE RESEARCH REACTOR REVIEW PROCESS**

On 30 September 1992, the then Federal Minister for Science, Ross Free, announced the establishment of the Research Reactor Review (RRR) which was to cost $1.2 million. The Terms of Reference for the Review were as follows:

1. *Whether, on review of the benefits and costs for scientific, commercial, industrial and national interest reasons, Australia has a need for a new nuclear research reactor.*
2. A review of the present reactor, HIFAR, to include an assessment of the national and commercial benefits and costs of HIFAR operations, its likely remaining useful life and its eventual closure and decommissioning.

3. If the finding on 1. above is that Australia has a need for a new nuclear research reactor, the Review will consider possible locations for a new reactor, its environmental impact at alternative locations, recommend a preferred location, and evaluate matters associated with regulation of the facility and organisational arrangements for reactor-based research.

In assessing the environmental impacts of the facility, the Review will take account of the objectives of the Environment Protection (Impact of Proposals) Act 1974, as amended. In this regard the Review will schedule public hearings and call for submissions from any interested parties by advertisements in major newspapers.

The Review panel consisted of three academics. The Chairperson was Professor Ken McKinnon, then Vice Chancellor of the University of Wollongong and a member of the Prime Minister's Science and Engineering Council. The other panel members were Professor Anne Henderson-Sellers, Director of the Climatic Impacts Centre and Professor of Physical Geography at Macquarie University, and Dr. Tor Hundloe, a Commissioner of the Industry Commission and a former Director of the Institute of Applied Environmental Research at Griffith University.

Ross Free (quoted in Sutherland Shire Environment Centre, 1993) said that membership on the Review panel of persons with known views "would totally distort the open-minded basis from which the Review is beginning." Thus it was a bone of contention that Henderson-Sellers was on the Review panel. A member of ASTEC, she was a signatory to the 1992 ASTEC report which recommended the construction of a new reactor.

Although the terms of reference mentioned the 1974 Environmental Protection Act, the Review was not established under the Act. This aspect of the Review was criticised by opponents of a new reactor because it lessened the scrutiny which the proposal for a new reactor would receive. In particular it allowed for the Review to proceed without identification of a specific proponent for the new reactor although ANSTO was clearly the major proponent. Without being identified as the proponent, ANSTO was not required to reveal detailed and specific
information relating to the project, which obviously put opponents at a disadvantage. (Wallace, 1993.) The Sutherland Shire Council (1993B) asked the Review to direct ANSTO to place its case for a new reactor before the Review before asking for submissions from other parties. The Review refused: proponents and opponents alike were required to forward submissions by the same date. The Council suggested that the Review gather government documents relevant to the HIFAR issue, and make them available to the public; again the Review refused, suggesting that use be made of the Freedom of Information Act.

Another bone of contention was the time allowed for the presentation of submissions. The closing date for submissions was given as 18 December 1992, allowing just two and a half months to prepare submissions. This was clearly disadvantageous to opponents of a new reactor. ANSTO, with far more resources, was in a much better position to submit a substantial submission in a short space of time.

Genevieve Rankin, a Sutherland Shire Councillor (and later the Mayor), voiced a number of other objections about the Review not long after its inception. She complained that McKinnon was naive about funding and that other aspects of science would necessarily suffer if a reactor was built. She took issue with McKinnon's blaming of the Council for the existence of housing in the Reactor Buffer Zone surrounding HIFAR. She objected to the refusal of the Minister for Science to provide some funding to the Council to help with its input into the Review. Rankin (1993) summed up her objections thus:

*It is distressing to find the supposedly objective Chairperson with very fixed views that cannot be changed by the weight of evidence, and to find him pre­empting the outcome of issues before hearing evidence. ...... Your (McKinnon's) determination to continue the Review with no requirement for ANSTO to present detailed costings or specifications, and no resources to be made available to opponents of the proposal, and with a panel member (Henderson-Sellers) who has an already stated public position in favour of another reactor, has made meaningful participation by the mass of the Australian community who are directly affected by this proposal impossible. I believe these matters combine to a deliberate attempt to force another reactor on to our community as a fait accompli. Sutherland Shire Council's formal submission is an attempt to participate in good faith within the limits of local resources in your review on the assumption that there may at some future date be some indication that this process is more than a bureaucratic whitewash.*
Many thought it inevitable that the Review would give unqualified endorsement to a new reactor. The Council had considered boycotting the Review, but went ahead and prepared a submission. Prepared in haste, the submission was flimsy. Other opponents of a new reactor contributed first-round submissions which clearly showed the effects of a lack of time and resources. By contrast, ANSTO's numerous submissions totalled 1500+ pages. In addition, ANSTO hired a public-relations firm (Edelmans) to assist in the soliciting of submissions in favour of a new reactor.

Clearly the Review was not an even playing field. The federal government set the agenda, limited the time for submissions, and appointed personnel from the upper echelons of academic and science institutions to conduct the Review. That there was high-level support within the government for a new reactor was further indicated by pro-reactor submissions from almost every government department. The Review panel, in turn, seemed unwilling to alter the balance of forces.

The capitalist state does not speak with one voice: a number of local councils in the southern Sydney region were opposed to a new reactor (as were a number of local branches of both the Labor and Liberal Parties). Of particular importance was the active opposition of the Sutherland Shire Council. The Council and local community had been burnt before in accepting "expert" assurances: to give just one example, a meeting of the Council in 1955 was assured that there would be no release of radioactive material of any kind from a research reactor at Lucas Heights, and thus the Council had voted to accept the proposal without raising any objections. Moreover the Council's political teeth had been sharpened in other disputes: the Shire hosts a toxic waste dump and Australia's largest capacity waste tip along with ANSTO. (Wallace, 1993.)

As well as being centrally involved in the Review itself, the Council was a focal point for a broader campaign against a new reactor. The Council was a source of financial resources, administrative support, publicity, and technical expertise. The Council adopted a joint Council/community approach to the fight against a new reactor, which entailed a joint Council/community working group including groups such as the Sutherland Shire Environment Centre and the Lucas Heights Study Group. (Wallace, 1993.) Much more alliance building went on in a less formal manner.
While the various strands of the peace movement subsided through the 1980s, a number of social movement organisations remained. Groups such as Greenpeace and Friends of the Earth (FOE) presented the Review with substantial (second-round) submissions and involved themselves in other aspects of the campaign such as media work. Dozens of other organisations and individuals contributed to the campaign. The arguments put to the Review by the Council, FOE, Greenpeace, and many others, were notable in that they did not adopt a NIMBY (not-in-my-back-yard) approach: they argued that there was no case for a reactor anywhere in Australia. (Wallace, 1993.) As well as the social movement organisations, the mass movements of the 1970s and 1980s had also left a residue of anti-nuclear sentiment in the public, and that sentiment was tapped during the Review.

It had seemed that a decision in favour of a reactor was a fait accompli, but the situation began to change. The initial deadline for submissions was pushed back to February 1993, and supplementary submissions were accepted for several months after that. Over 400 submissions were received, about 40% opposed to a new reactor. The Council’s second submission to the Review was far more substantial than its initial submission, and included solicited papers from a range of consultants including academics, accountants, lawyers, and scientists, on topics such as safety issues, radioactive waste, and alternatives to a domestic reactor for medical radioisotope production and supply. Other groups forwarded second-round submissions that are also likely to have influenced the outcome of the Review. The Review (1993, p.3) said:

Some of these submissions contained a great deal of helpful material, especially those from ANSTO and the Sutherland Shire Council, both of which included consultant opinions. The Review also profited a great deal from the close attention given to ANSTO and Lucas Heights matters over a long period by concerned citizen groups, including the Lucas Heights Study Group, Greenpeace and Friends of the Earth. This input gave the Review a feel for community concerns and suggested many of the questions which were subsequently followed up through consultancies commissioned by the Review.

The Review travelled to all capital cities in Australia except Hobart and Darwin, hearing evidence from 150 people over 13 days of hearings.

The additional time also enabled opponents of a new reactor to mount a public campaign. The issue was taken up by sections of the environmental movement, featuring prominently for example in World Environment Day marches and
rallies in mid 1993. This campaigning may have had some impact on the Review panel. Certainly McKinnon, who had seemed inflexible on a number of issues, became more inquisitive as the Review proceeded. Henderson-Sellers' critical questioning of ANSTO belied her status as a member of ASTEC; in fact her performance as part of the Review panel was "not only entertaining, but highly confronting toward ANSTO" according to John Hallam of Friends of the Earth (1993C). The public campaign may also have had some impact on the federal government: it was clear that there was considerable support within the government for a new reactor, but ultimately it accepted the Review's recommendation to defer the decision for another five years or so.

4.4. DEBATES AND FINDINGS

OVERALL FINDINGS
THE NATIONAL INTEREST
MEDICAL RADIOISOTOPES
RADIOACTIVE WASTE
RADIOACTIVE EMISSIONS
ACCIDENTS AND EMERGENCY PLANS
REGULATION OF ANSTO
COST OF A NEW REACTOR AND COMMERCIAL OPERATIONS
SCIENTIFIC RESEARCH
PUBLIC OPINIONS

OVERALL FINDINGS

The Terms of Reference for the Review asked it to consider the scientific, industrial, commercial, and national interest arguments for and against a new reactor. The Review was much concerned to adopt an objective position, sorting facts from arguments and contention and basing its findings solely on the former. It further hoped to base its findings on an economic evaluation, which it conceived as encompassing financial evaluation and also attaching dollar figures to non-financial aspects such as the scientific benefits and the national interest. However in that sense the Review was over before it had begun: it proved impossible to attach dollar figures to national interest considerations or to the scientific benefits, and so the Review's overall conclusions were equivocal.

The Review (p.xx) said that "an economic analysis of the balance of benefits over costs is not positive, unless high values are arbitrarily assigned to the science and national interest components for either HIFAR or a new reactor." It further
argued (p.xiii) that "The Government ...... has taken a strong position on the importance of the national interest. Consequently it might want to make a positive decision about a new reactor for the same reasons and in the same way as it does for defence and other national interest issues, bearing in mind that a new reactor might cost no more than a new frigate or submarine." Thus the Review - which only had an advisory role in any case - gave the government some leverage to proceed with a reactor primarily on the basis of the national interest.

While giving the government the option of proceeding with a reactor on national interest grounds, the Review argued that a decision on a new reactor should be deferred for "about five years". A deferral of a decision on the issue seemed appropriate to the Review for several reasons. Firstly, the issue of radioactive waste disposal was crucial (p.xiv): "It would be utterly wrong to decide on a new reactor before progress is made on identification of a high level waste repository site." Secondly, the Review (p.xiv) argued that there was sufficient doubt as to the merits of reactors vis a vis alternative technologies for scientific research and radioisotope production to make it "prudent" to have some delay in making a final decision on a new reactor. Thirdly, the Review (p.xiii) argued that "There are no safety, health, community risk or other reasons to close HIFAR. A technical Probabilistic Risk Assessment (PRA) is desirable, to assess its remaining life potential, but its remaining life is not likely to be less than a decade."

There was some expectation that the Review would proceed to a second stage dealing with issues such as siting of a new reactor. However this did not happen because of the recommendation that a decision on a new reactor should be deferred.

In sum the recommendations of the Review (p.xiv) were that the government should:

- keep HIFAR going;
- commission a Probabilistic Risk Assessment to ascertain HIFAR’s remaining life and refurbishment possibilities;
- provide an additional $2 million per year for scientists to gain access to international advanced neutron scattering facilities;
- commence work immediately to identify and establish a high level waste repository;
- accept the financial implications of the fact that neither the current nor any new reactor can be completely commercial;
• accept in consequence that any decision on a new reactor or other neutron source must rest primarily on the assessed benefits to science and Australia's national interests; and
• make a decision on a new neutron source in about five years' time when the relative arguments relating to spallation sources, cyclotrons and reactors might be clearer, and when Australia's scientific neutron scattering performance is more evident.

To the list of recommendations was attached various conditions (p.xv):

If, at the end of a further period of about five years,

• a high level waste repository site has been firmly identified and work started on proving its suitability
• there is no evidence that spallation technology can economically offer as much or more than a new reactor
• there has been no practical initiation of a cyclotron anywhere worldwide to produce technetium-99m
• there is good evidence of strong and diverse applications of neutron scattering capability in Australian science, including many young scientists, and a complex of industrial uses
• the national interest remains a high priority

it would be appropriate to make a positive decision on a new reactor. The most suitable site would need to be identified.

If any one of these onerous requirements is not met, either a negative decision, or a decision to delay further, would be indicated.

The Review (p.xvi) made no clear recommendation on the possibility of maintaining or upgrading HIFAR; it said that a PRA would be required before those possibilities could be assessed. There was very little support from either pro- or anti-reactor campaigners for the options of maintaining or upgrading HIFAR. Opponents generally argued against having any sort of reactor anywhere. ANSTO was more equivocal but argued that to maintain HIFAR until 2025 would require something of the order of $152 million to ensure its safety and a performance upgrading would cost considerably more; a new reactor would be a better instrument and would cost about as much.
Now to consider the most important sub-debates taken up during the RRR. A number of these issues will be explored in greater depth in chapters 5-8, insofar as they relate to radioisotope production.

THE NATIONAL INTEREST

The issues debated during the Review did not leap out of thin air nor were they set in stone by the nature of research reactor technology. Rather the issues taken up - and those that received little or no attention - were functions of a web of social, historical, and technological factors, no more so than with the national interest debate.

Key players in the nucleocracy had explicitly made the links between civil and military nuclear technologies from the 1950s to the 1970s. People such as Baxter and Gorton made the links between nuclear power and weapons, and saw those links as an argument in favour of the development of nuclear power. Once weapons proliferation had become an important argument against nuclear fuel cycle developments, the debates shifted - pro-nuclear partisans such as Baxter began to downplay the connections between civil and military nuclear technologies. (Martin, 1980.) A related aspect of the shifting nuclear discourse in Australia was the transformation of the AAEC/ANSTO into a multifaceted civil science agency. This transformation has never been complete however, and the national interest debate is the current formulation of the debate about whether ANSTO is the guardian of Australia's entry into the nuclear age (or at least an institution of great strategic, political significance), or just one science agency among many.

The RRR (p.1) said that since Australia has no power reactors, it seemed "fairly natural" that the Review would be a focus for anti-nuclear groups:

While accepting this interest as natural, the Review had a constant battle to keep a clear distinction between the 'big' nuclear matters, power and weaponry, and the local issues of whether the High Flux Australian Reactor (HIFAR) at Lucas Heights has purposes and earns its keep sufficiently to justify a new one.

That view indicates some naivete with respect to the interconnections between the "big" nuclear issues and small-scale nuclear programs and research reactors. In any case the Review was obliged to deal with a number of "big" issues. These were, perhaps surprisingly, put on the agenda not so much by opponents of a new
reactor, but by proponents of the project who advanced a host of arguments under the rubric of the national interest.

ANSTO is considered by some to be a strategically important and unique institution by virtue of its nuclear fuel cycle expertise, and this expertise is said to be largely dependent on the operation of a research reactor. This expertise is said to improve Australia’s capacity to strengthen the international non-proliferation regime, and to provide the government and other arms of the state with intelligence and advice. These themes came through in the Review’s (p.2) comments that national interest issues connected to the operation of a research reactor concerned "how necessary it is to maintain some degree of nuclear capability to assist non-proliferation initiatives, to find out what others are doing, or to protect its own national interest if occasion demanded." Elsewhere the Review (p.97) identified four areas of national interest: national security; the provision of expert advice; the ability to influence international and regional nuclear affairs; and commercial opportunities arising from nuclear facilities in the region.

I will now take up various threads of the national interest debate. A number of these threads are cryptic and nebulous, none more so than an issue which received hardly any direct attention – the weapons connection.

THE WEAPONS CONNECTION

Literature on the possibility of an Australian nuclear weapons capability tends to focus on the post-war generation, and in particular on the flurry of activity from 1969-71. However the issue would still appear to be a sub-text in debates over nuclear development in Australia, submerged within the national defence/security component of the national interest debate.

The interest in and support for a weapons capability fell away through the 1970s, along with the nuclear power and PNE projects. Since that time, there has been little or no high-level support for the systematic pursuit of a domestic nuclear weapons capability. However there may be some support, within political, military, and nuclear institutions, for the view that nuclear weapons should not be ruled out and that Australia should be able to build nuclear weapons as quickly as any neighbour that looks like doing so. This current of thought was evident in a leaked 1984 defence document called The strategic basis of Australian defence policy. The document implied that the government could simply disregard the NPT if it decided to develop nuclear weapons – which as Martin (1984B) notes
does not sit well with the government's heavy reliance on the NPT as the guarantee against military use of Australian uranium exports.

There was very little open discussion during the RRR about the potential to use HIFAR or a replacement reactor directly or indirectly in support of nuclear weapons. There were some cryptic references by the Review panel itself; for example it is not clear that reference to "national security" refers only to such issues as maintaining a role in the IAEA, nor is it clear what is meant by asking "how necessary it is to maintain some degree of nuclear capability ...... to protect its own national interest if occasion demanded", and the Review's comparison of a research reactor with a frigate or a submarine must have raised some eyebrows.

The weapons connection was not taken up by anti-reactor campaigners to any substantial degree. Perhaps the only exception was a comment in the submission of the Lucas Heights Study Group (1993):

We contend that indeed there is a possibility that a new reactor could be used for weapons research and production, depending on the policy of future Governments and the course of world events in the next 50 years. Certainly weapons research was carried out at the AAEC in the 60's. Such research would effectively make the establishment a target in time of war, hence the extreme security on site during the Gulf War.

In submissions from ANSTO and from government departments, there was no mention of the weapons connection (so far as I am aware), nor even any cryptic references such as those offered by the Review. It is however possible that there remains some support within political, military, and nuclear institutions for the view that weapons development should not be ruled out. The leaked 1984 defence document is suggestive, and it is worth noting that it would be seen as counter-productive as a political/diplomatic manoeuvre for such views to be publicly expressed if indeed they are held.

A private submission to the Review (Watford, 1993) was perhaps indicative of what could be a broader sentiment in political, military, and nuclear circles. This submission argued the following case. Australia should not develop nuclear weapons in the foreseeable future, one reason being that it could lead to a regional nuclear arms race. However the time may come when it would be necessary or desirable to develop nuclear weapons and to this end a civil nuclear program must be maintained. While it would not be practical or desirable to attempt to achieve civil or military nuclear parity with India or China, a civil nuclear
program at least the equivalent of other countries in the Asian region should be maintained. Moreover nuclear development in Australia should be boosted by resumption of work on uranium enrichment; this would add value to uranium exports and also facilitate weapons development. As a minimum step towards halting the decline of nuclear fuel cycle expertise, HIFAR must be replaced (Watford, 1993):

The statements made by ANSTO and others concerning national security are not overstatements or exaggerations. The replacement of HIFAR as proposed is the absolute minimum that can be done through the civil nuclear industry to protect Australia’s national security in the total sense, as well as the more limited sense of defence.

While there may be ongoing degree of interest in a nuclear weapons program, this should not be overstressed. It is extremely unlikely that any Australian government would pursue a weapons program in the foreseeable future barring a dramatic shift in international circumstances. There are many reasons for this, such as the possibility of sparking a regional nuclear arms race, the inappropriateness of nuclear attack as a response to any conceivable threat to Australian sovereignty, the possibility that a weapons programs would threaten the US alliance, cost considerations, and so on. Thus if there is any interest in a weapons program, this interest would go no further than leaving open the weapons option as a longer term contingency.

So much for speculating about possible high-level support for the maintenance of nuclear fuel cycle expertise to lower the barriers to nuclear weapons. Now to comment on how a HIFAR or a replacement reactor could facilitate weapons development in Australia.

Each of the fuel rods irradiated in HIFAR contains only about 0.5 grams of plutonium (Coleby, 1986). Even with 1600 spent fuel rods accumulated over the best part of 40 years, the total volume of plutonium stored at Lucas Heights is about $1600 \times 0.5g = 800$ grams. This is just one tenth of the 8kg figure which is often put forward as the minimum required for a bomb – 8kg of plutonium is one "significant quantity" in nukespeak. Cruder devices could be made with a smaller volume, and high levels of technical sophistication can off-set limitations imposed by low volumes of fissile material. For example Spector et al. (1995) argue that a country with a high technical capability could build a 20 kiloton bomb with as little as 3kg of plutonium-239 or 5kg of HEU, and a 1 kiloton device might require half these amounts. Even so, it would be a cumbersome exercise to extract
800g of plutonium from 1600 fuel rods, all the more so since there are no reprocessing facilities in Australia. Any effort to use spent fuel rods supplied by the US and the UK in support of a weapons program would almost certainly meet with extreme opposition from those countries.

Plutonium production could be maximised by reducing the fuel irradiation time in HIFAR or a replacement reactor. If LEU is used for a new reactor, as is proposed, then this could be a net positive in terms of reducing the potential for weapons production given that HEU is of considerable concern with respect to weapons proliferation. However LEU reactors are more efficient plutonium producers and thus increase the feasibility of production of plutonium weapons.

HEU weapons construction may be a more feasible route, either by diversion of fresh fuel or extraction of HEU from spent fuel. For uranium-235, 25kg is one significant quantity (SQ) and the inventory of spent fuel at Lucas Heights contains over 5SQ of uranium-235 (Australian Safeguards Office, 1993). Fresh fuel stocks are maintained at less than 1SQ (Australian Safeguards Office, 1993). Diversion of fresh fuel would almost certainly result in termination of fuel supply from abroad, unless the diversion went undetected. Alternatively, the AAEC/ANSTO's enrichment research could be restarted. The Liberal/National Coalition government has evidently ruled out a resumption of enrichment research (Uranium Information Centre, 1996).

Extraction of HEU (or plutonium) would require reprocessing facilities. The government was considering the possibility of establishing a domestic reprocessing plant as at early 1997, with a view to reprocessing spent fuel from HIFAR, and perhaps also from a future reactor. It would be highly speculative, and perhaps even a little paranoid, to suggest that the weapons connection is a significant factor in the government's deliberations on a reprocessing plant. Apart from providing some sort of solution to the problem of ridding ANSTO of stockpiles of spent fuel rods, a reprocessing plant would enable a commercial-scale demonstration of Synroc, the glass encapsulation technology which has been under development in Australia since the late 1970s. That said, with a new, high-power research reactor and a reprocessing plant, it is likely that significant quantities of plutonium could be produced and separated, or that fissile uranium-233 could be produced (by irradiation of thorium) and separated. In addition, large quantities of HEU could be separated from spent HIFAR fuel.

If a nuclear weapons program was pursued, many other factors would need to be considered other than the relative feasibility of HEU or plutonium bombs. These
factors would include supply of reactor fuel, suspension or maintenance of NPT/IAEA membership, delivery systems, the many technical and engineering aspects of weapons development other than production of fissile material, and so on.

Apart from the possibility of HIFAR or a replacement reactor being used directly for weapons development, there are the indirect links. A new reactor could be used for weapons-related research. More generally, nuclear fuel cycle expertise developed through the operation of a research reactor lowers the technical and economic barriers to weapons development. A related issue is the strident pro-nuclear stance that is common among people and institutions directly involved in nuclear development – Phillip Baxter is the classic example of this – and their potential role as a political constituency for nuclear weapons.

From a stand-point of unqualified opposition to nuclear weapons, the weapons connection is a legitimate argument against the operation of research reactors - though of course other arguments need to be considered also. It should be noted that proponents and even qualified opponents of nuclear weapons could easily agree with the premise but not the conclusion; in other words the fact that the operation of a domestic research reactor lowers the barriers to nuclear weapons can be seen as an argument in favour of a new reactor, "just in case".

INTELLIGENCE, INFLUENCE AND ADVICE

The major overt component of the national interest debate during the RRR was whether a reactor is required to maintain nuclear expertise, and whether such expertise facilitated Australia's capacity to influence international non-proliferation initiatives and to procure and process information relating to overseas nuclear developments. More generally, the Review (1993, p.2) asked "whether Australia could exert better influence in such issues as non-proliferation by remaining an active member of the international nuclear community or by working from outside".

One of the arguments was whether operation of a research reactor was essential to maintain Australia's designated seat on the Board of the IAEA - an argument with some history, dating at least from 1985 (ASTEC, 1985). While arguing for a continuing role in international nuclear forums such as the IAEA, the Review (p.102) was more sceptical about the need for a domestic reactor to secure Australia's designated position on the IAEA's Board of Governors. It referred to comments by the IAEA which suggested that other issues were more important,
such as Australia's role as a major uranium exporter and Australia's significant contribution to IAEA technical assistance programs. The Review also mentioned the example of New Zealand, which does not operate any reactors but still has periodic representation on the Board for a minimum of two years out of six, on a rotating basis.

The Review also touched upon some other issues relating to the IAEA, if only to note comments made by opponents of a new reactor. These issues include the extent to which Australia has influence on the IAEA Board given that the Board has no less than 35 members; whether Australian representatives on the Board actively promote non-proliferation or whether their interest is more in technical assistance programs which might expand potential markets for Australian uranium; and whether Australia might lose its designated place on the Board regardless of the operation of a research reactor, given the advancement of nuclear programs in regional countries such as Indonesia, Malaysia, and Thailand. The Review said there was no real data on how Australia would suffer in influence or any other way if it were not a designated Board member. There might even be advantages, the Review said, in not being so closely identified with some of the IAEA's stances. (RRR, 1993, pp.100-103.)

The most substantial submission in relation to intelligence, influence, and advice, was that of the Commonwealth Department of Foreign Affairs and Trade (DFAT). The DFAT considered national security to be the key plank of the national interest. It said that it was government policy to keep the world and in particular the region free of nuclear weapons, and pursuit of this policy required access to "objective" information. The DFAT argued that operation of a research reactor was essential to maintain expertise for purposes such as monitoring nuclear materials exported from Australia (e.g. uranium) and keeping informed about the "clandestine practices of certain countries". The DFAT also argued that the expertise gained through operation of a research reactor made it easier to "assess quickly and independently any nuclear terrorist threat in Australia or to Australia's interests abroad." The DFAT also said that the operation of a research reactor assisted in the provision to government of commercial advice.

The claim from the DFAT that it is dependent on ANSTO for "objective" advice was at best naive given the AAEC/ANSTO's history of advocacy of and/or involvement in everything from nuclear weapons to "nuking" termite nests. As Greenpeace (1993) argued, ANSTO is "part of an industry deeply committed, both emotionally and career-wise, to the expansion of the global nuclear industry ".

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It is difficult to see the logic in the DFAT's argument that operating a research reactor helps in assessing nuclear terrorist threats or the "clandestine practices of certain countries". There might be examples when ANSTO is able to provide useful information, concerning for example the technical aspects of safeguards or covert weapons programs. However those instances are likely to be infrequent. No concrete examples were given to back up the claims made in relation to intelligence, influence, and advice. Security and intelligence networks are of far greater importance than any information ANSTO could provide, and it is unclear that any information provided by ANSTO would be crucially dependent on the skills associated with operation of a domestic reactor. Moreover a research reactor could itself be targeted by terrorists - ANSTO has indeed been subject to terrorist or sabotage threats in the past.

The DFAT's argument that operation of a research reactor is essential to maintain expertise for purposes such as monitoring nuclear materials exported from Australia is difficult to assess. Such monitoring is largely dependent on the IAEA regime and the monitoring provisions associated with bilateral safeguards agreements. Certainly some AAEC/ANSTO staff have been involved in these activities. Whether their proficiency is markedly increased through experience with the operation of HIFAR is another matter. It is difficult to imagine that this experience would be of much use in the monitoring of uranium, which is the only export requiring safeguards monitoring (and then only after conversion to uranium hexafluoride). Experience with HIFAR would be of use when inspecting reactor facilities, as some AAEC/ANSTO staff have done through the IAEA; but again, this experience may not be crucial nor has it been established that the IAEA safeguards regime would be much the poorer without the handful of Australian inspectors who have been involved in overseas reactor inspections over the years.

As for commercial advice, another point raised by the DFAT and other government departments, these issues were not spelt out clearly but uranium would be the principal concern. Presumably the argument is that HIFAR-related expertise enables engagement in activities such as regional nuclear cooperation projects; in the process knowledge is gathered, friendly and cooperative relations established, and this can facilitate uranium sales. It is not in ANSTO's charter to act as a sales agent for uranium mining companies, and in any case it could continue in the absence of a domestic reactor.

The Review largely accepted the view that operation of a reactor was important for purposes such as gathering intelligence and providing advice to government. For example it said (pp.97-98) that the
DFAT has a key role in assessing the impact of nuclear activities, which could pose risks directly for Australian territory or for Australians generally, whether accruing in our region or worldwide. Its concerns that a replacement for HIFAR was needed in the national interest to keep abreast of nuclear science and technology had to be given very considerable weight.

In short the Review accepted the cryptic and unsubstantiated arguments put forward by institutions such as the DFAT in relation to intelligence, influence, and advice; this despite claiming (p.2) that it was appropriate to be "particularly sceptical" about claims made for the national interest, "because claims of national standing or influence are so often overstated all around the world."

Along with the DFAT, numerous other federal government departments and agencies supported a new reactor and claimed to be dependent on ANSTO to some extent for policy advice. These submissions dealt with issues such as nuclear safeguards, nuclear regulation, radioactive wastes, visiting nuclear warships, off-shore nuclear accidents, occupational and public health, and radiation protection. Most of these submissions argued that the continued operation of a research reactor of a significant power level was important for the provision of expert advice. (RRR, 1993, pp.99-100.) The CSIRO (1993) said that ANSTO's expert knowledge in nuclear and related sciences allowed Australia to take a technologically-advanced position in the provision of advice to the Pacific Rim, to maintain a sophisticated position in negotiating defence agreements, and it facilitated technical sophistication in the handling of radioactive materials which is important given Australia's uranium mining and export industry.

The CSIRO (1993) also said that a new research reactor would allow Australia to be strategically placed should Australia ever need to develop nuclear power. This was one of only a very small number of submissions to refer to the potential for future development of nuclear power.

As with the DFAT submission, it was not convincingly demonstrated in the submissions of government departments and agencies that ANSTO's nuclear expertise is indispensable for the various purposes mentioned, nor that the operation of a research reactor was essential for the maintenance of that expertise.

55 The Departments of Industry, Technology and Regional Affairs; Primary Industries and Energy; Environment, Sport and Territories; Health, Housing and Community Services; and Defence. The agencies included the CSIRO, Australian Safeguards Office, Australian Radiation Laboratories, the Commonwealth Environment Protection Agency, the Office of the Supervising Scientists, the Office of the Chief Scientist, and the Office of National Assessments.
A related aspect of the national interest debate concerns technical assistance projects. The AAEC/ANSTO has played an active role in nuclear technical assistance projects, mostly involving regional countries. This involvement operates through the IAEA, the OECD Nuclear Energy Agency, the United Nations Development Program, and a number of bilateral nuclear cooperation projects. (Commonwealth of Australia, 1995, pp.181-182.) Another channel for this benevolence is the International Conference for Nuclear Cooperation in Asia; ANSTO (1991) says this forum covers some projects which could not proceed through the IAEA because of weapons proliferation implications. Technical assistance projects are wide-ranging - nuclear medicine, nuclear safety, waste management, radiation protection, safeguards, occupational health and safety, environmental protection, transport of radioactive material, hydrology, food irradiation, tracer technology, radiation sterilisation, use of research reactors, HEU -> LEU reactor conversion, reactor physics, fusion, and databases. (Henderson, 1987.)

The reasons given by ANSTO (1991) for its involvement in technical assistance projects are the familiar national interest arguments: influencing bodies such as the IAEA to discourage weapons proliferation; obtaining nuclear information from other countries which would otherwise be more limited; and opportunities for commercial profit. Predictably, it was argued in a number of submissions to the RRR that ongoing involvement in technical assistance projects required the operation of a domestic research reactor. I will return to this issue in chapter 9.2.

MEDICAL RADIOISOTOPES

The debates about radioisotope production and supply during the RRR were very similar to those that had surfaced on several occasions from the late 1970s. To give just one example, ASTEC (1985, p.4) put forward a set of arguments in 1985 that were just the same as arguments put to the RRR by advocates of a new reactor:

"A range of radioisotopes currently produced at HIFAR is used in medicine, industry and applied research in many fields. ASTEC believes that the domestic production of radioisotopes should continue so that Australian patients can benefit fully from the diagnostic techniques of nuclear medicine. If domestic production were to cease, patients would be vulnerable to the interruption of the supply of radioisotopes from overseas and also would be deprived of diagnostic techniques which utilise short-lived radioisotopes which cannot be imported. A nuclear reactor cannot be replaced by a"
cyclotron for radioisotope production because some of the radioisotopes which are made by a nuclear reactor cannot be made by a cyclotron, and others can be made by a cyclotron only with great difficulty.

While on the surface these debates have changed little over the years, at a broader level there has been a significant shift. Radioisotope production has become more important in the scope of the AAEC/ANSTO's activities and more central as a justification for the existence of a nuclear agency and the operation of a research reactor. In other words, the debates about radioisotope production have not changed much but they have become more important components of the overall controversy as to whether a domestic reactor is necessary.

The Review (ch.8) took up the issue of radioisotope production and supply in considerable detail. The focus was on medical radioisotopes since the vast majority of radioisotopes produced using HIFAR are for nuclear medicine as opposed to industrial or research uses. Radioisotope production and supply was clearly an important debate: for example one of the three main reasons the Review argued that the decision on the replacement of HIFAR be deferred was the possibility that cyclotron technology might develop rapidly in the following years, in which case there may not be a case for a reactor for radioisotope production, in which case the overall balance might swing towards the non-replacement of HIFAR. Of course many other issues were also important: for example the issue of waste disposal was crucial, and debates over scientific research were very important given that research would be the major use of a new reactor. Suffice it to assert that the radioisotope issue was given much attention by the Review, and it also featured prominently in written and verbal submissions to the Review.

The Review considered various options for future procurement of medical radioisotopes. One was a greater reliance on imports. It discussed issues such as reliability of supply and the relative costs of imported versus domestic radioisotopes. The Review's conclusions (p.95) on this issue were vague and somewhat contradictory. It noted that many countries have either overcome the problems associated with reliance on imported medical radioisotopes, or found them not to be a problem, but then the Review goes on to say that "The Review is persuaded that the presence of a domestic source of supply is an important feature of the current high standard of services in nuclear medicine."

The emphasis in most submissions to the Review, for or against a new reactor, was on cyclotron versus reactor radioisotope production; the possibility of greater reliance on imported radioisotopes received considerably less attention. This
emphasis on cyclotrons versus reactors was reflected in the Review's findings. The Review (p.xvii) was non-committal about the prospects for cyclotron production of radioisotopes as an alternative to reactor production. It focused on the possibility of cyclotron production of technetium-99m, which is used in 80-90% of nuclear medicine procedures:

*Cyclotron technology is evolving quickly, but the debate about whether technetium can be produced successfully in cyclotrons ...... is not resolvable at this time. There are no current cyclotrons producing technetium and no plans anywhere to construct a large enough cyclotron for this purpose.*

The Review (p.88), comparing reactors and cyclotrons for medical radioisotope production, said:

*The Review neither could, nor would want to, pronounce one source better than the other. It does, however, need to reiterate the conclusion it must draw on the evidence to this point, that a reactor-based source will continue to be essential as far ahead as can be foreseen, if Australia's need for medical isotopes is to be met domestically.*

Henderson-Sellers (1993, p.810), during verbal submissions, said:

*I think the thing that has impressed me most as we have read through all of the submissions and have travelled around the country is not only the fluency and the highly articulate nature of the submissions from the medical fraternity but also I think their almost complete internal consistency - and that is very right and proper; they are all telling the same story I believe and I have no reason to believe it is not the truth.*

However Henderson-Sellers (p.811) then went on to ask whether the medicos were perhaps well-briefed enthusiasts. Certainly ANSTO solicited submissions from medical institutions, as did the public relations firm it hired. Indeed two submissions from independent medical institutions in different countries were identical; whether they briefed each other, or whether both institutions (and perhaps others besides) were given a helping hand by ANSTO, or the public relations firm hired by ANSTO, is open to speculation.56

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56 The two institutions are the Isotope Department, Nuclear Energy Unit, Malaysia; and Eastern Technical Services, Hong Kong.
Nuclear medicine practitioners were keen to support a new reactor because their careers are dependent on security of supply of radioisotopes. So too they have a financial stake in the matter: they are concerned that in the absence of a domestic reactor, radioisotope prices might increase but Medicare Schedule fees would not reflect the increased costs. Though supply might be equally secure and inexpensive in the absence of a domestic reactor, there seems to be a genuine belief among nuclear medicine practitioners that it is very much in their interests for there to be a domestic reactor source. ANSTO has played a major role in cultivating that belief.

**RADIOACTIVE WASTE**

In Australia, as in so many other countries, the political fall-out from radioactive waste problems is proving to be one of the major impediments to further nuclear development. There are no long-term repositories for any form of radioactive waste. Some modest progress had been made towards the establishment of a national repository for low-level waste (LLW) and intermediate-level waste (ILW). A short-list of eight potential sites has been arrived at; however there are many obstacles and progress has been very slow. Lucas Heights is by far the largest radioactive waste storage site. LLW and ILW is also held at about 50 interim storage sites around Australia; in many cases it is held in buildings that were not designed or located for radioactive waste storage (Anon., 1995). In 1994 ANSTO transferred 10 000 drums of LLW to Woomera in South Australia. The Woomera storage site is supposed to be temporary.

Still less progress has been made with respect to a high-level waste (HLW) repository. Roughly 1600 of the 1800-1900 spent fuel rods from HIFAR are stored at Lucas Heights, with the remainder having been shipped overseas for reprocessing. As at early 1997 the government was deliberating on three options. One is the construction of a domestic reprocessing plant. Another option - for some or all of the 700 or so rods of US origin - may be shipment to the US for reprocessing. It may also be possible to ship some or all of the 900 or so UK-supplied rods to the UK for reprocessing.57

The Review (pp.xiv, xxii-xxiii) gave ANSTO little reason for comfort in relation to its waste problems:

> A crucial issue is final disposal of high-level wastes, which depends upon identification of a site and investigation of its characteristics. A solution to

57 For an update on waste issues, see chapter 10.
this problem is essential and necessary well prior to any future decision about a new reactor. ..... It would be utterly wrong to decide on a new reactor before progress is made on identification of a high level waste repository site.

The Review (p.xx) noted that the costs of HLW disposal will be very high, and will include identification of a suitable site, construction of a repository, and transport of HLW. The Review (p.xxiii) also laid to rest ANSTO's notion that 1600 or so spent fuel rods stored at Lucas Heights are a financial asset:

The spent fuel rods at Lucas Heights can only sensibly be treated as high level waste. World opinion is moving in the direction of favouring the conditioning and direct disposal of spent fuel rods in preference to reprocessing. In any case, maintenance of the view that reprocessing is the best option inevitably involves return to Australia of by-product high level liquid wastes, making a national high level waste repository an inescapable concomitant of having any kind of nuclear reactor. The pretence that spent fuel rods constitute an asset must stop.

Apart from the environmental and financial aspects of waste storage, there are also weapons implications. As discussed previously the spent fuel at Lucas Heights contains over five Significant Quantities of uranium-235. HEU extracted from the spent fuel rods could conceivably find its way into nuclear weapons. A related issue is safeguarding - there are ongoing debates around the world over the safeguarding of radioactive wastes, concerning for example when wastes pose a sufficiently small proliferation risk that it is appropriate to terminate safeguarding procedures. That debate has financial implications, and it also has public health and safety consequences relating to the logistics of safeguarding procedures. (Linsley and Fattah, 1994.)

Of particular relevance to this thesis is the extent to which radioactive waste generation at Lucas Heights is associated with radioisotope production and processing. ANSTO was keen to advertise to the RRR the connection between medical radioisotope production and processing and waste: the first sentence in its submission on radioactive waste announced that the principal source of radioactive waste at Lucas Heights is from the production of radiopharmaceuticals. (ANSTO, 1993J, p.5.1.) ANSTO (1993P, p.9.1) was also at pains to point out that increased rates of waste generation from a new reactor would result solely from increased radioisotope production and processing.
Presumably ANSTO imagines that making the connection between waste generation and nuclear medicine will quell concern - waste generation serves a good purpose, it is a necessary evil. This tactic seems not to have had any effect on the Review panel. It is notable that, in early 1997, the same tactic was deployed by the Minister for Science and Technology, Peter McGauran. HIFAR is fuelled with 30-40 fuel rods each year, and McGauran said that "During this year more than 260 000 Australians will have a nuclear medicine procedure. ..... As a result of these procedures, some 35 spent fuel rods are generated by the Lucas Heights research reactor every year." The main point here is McGauran's linking of waste and medicine; in addition he would have us believe that all of the spent fuel rods are the result of radioisotope production despite the many other uses of HIFAR.

With respect to HLW, about 5-10% of the 1600 or so spent fuel rods can be attributed to medical radioisotope production. In addition, some HLW is generated during the production and processing of uranium fission-product radioisotopes such as molybdenum-99 (Mo-99). According to Egan et al. (1993; 1994), HLW is produced in radioactivity quantities 20 times greater than the Mo-99 yield, and the total volume of HLW at Lucas Heights from Mo-99 production is estimated to exceed 370 000 GBq (about 10 000 Ci).

As for LLW and ILW stored at Lucas Heights, the majority of these wastes result from radioisotope production and processing: all the liquid ILW, 70% of the solid ILW, 90% of the liquid LLW and 80% of the solid LLW (ANSTO, 1993J).

ANSTO claims that improved reactor technology would minimise the generation of waste by a new reactor. However the fact remains that a suitable long-term repository for any form of radioactive waste has yet to be established and producing more waste will only add to the problem. In relation to the improved technology of the proposed new reactor, ANSTO (1993P, p.9.1) said "The clear conclusion from this is that waste management is a favourable factor as regards any potential public impact from a new reactor." Such an argument is a nonsense and an obfuscation. One wonders what ANSTO's response might be to a serious HIFAR accident - that much experience was gained in disaster management and the accident was clearly a favourable factor as regards a new reactor?

58 Questions Without Notice, House of Representatives, 6 March.
59 Approximately 10% of HIFAR's neutrons are used for medical radioisotope production, less in earlier years and decades, hence this rough figure of 5-10%.
60 GBq (gigabecquerels) and Ci (curies) are measurements of radioactivity. 1 GBq = 0.027 Ci.
RADIOACTIVE EMISSIONS

There are several issues relating to radioactive emissions from routine operations at Lucas Heights. These include debates about the actual levels and nature of emissions, the public and occupational health implications, the environmental impact (which feeds back into public health issues), the adequacy of standards in relation to permissible emissions, and the methods by which standards are determined and emissions are monitored. These issues are complex and hotly contested. Some of the issues are clouded by a paucity of data; the lack of information is itself a bone of contention, with repeated calls over the years for studies into issues such as the public health impact of HIFAR emissions having mostly gone unheeded.

The Review (p.xx, 177) concluded that radioactive emissions from Lucas Heights are minimal and within international standards. The Review said that if there is a problem, it is simply one of a lack of trust and information.

As for occupational health, the Review’s (pp.191-192) benign picture was at odds with claims made by opponents of a new reactor. Opponents pointed to an article appearing in The Australian in 1990 concerning Dr. Arthur Tucker, who worked at the AAEC from 1964 to 1985. Tucker claimed that on numerous occasions his studies into staff health were obstructed or his findings kept secret. He said that he had been directed to stop his studies into possible links between the use of metals such as beryllium and the lung disease sarcoidosis, and that his research results were not published. Tucker also claimed that his later attempts to reinforce his studies with similar work were thwarted as funds, staff, and facilities were withdrawn. He also claimed that important reference materials were burnt by the AAEC. (Kennedy, 1990.)

The Review’s (p.205) conclusion on the public health impact was that “it is very unlikely that any relationship exists between the current reactor HIFAR and community health in the Sutherland Shire.” The Review (pp.146-148) claimed that the risks of radiation-induced cancer are relatively low and are well studied and well documented and form the basis of all radiation protection standards and systems. Elsewhere (p.184) the Review acknowledged that the epidemiological research, and the radiation protection standards and systems, are hotly contested within and beyond scientific and regulatory institutions. In their submissions to the Review, the Sutherland Shire Council (1993B) and the Sutherland Shire Environment Centre (1993) pointed to overseas studies showing greater than expected numbers of cases of leukaemia around UK nuclear facilities at Dounreay,
Sellafield, Harwell, Aldermaston, and Burghfield. The Review (p.184) noted that other studies had found no increased leukaemia incidence around nuclear facilities, and then extracted itself from the debate by saying that "Clearly this debate among epidemiologists will continue." Given that equivocation, it was surprising that the Review was so confident as to say that it is "very unlikely" that HIFAR emissions have any impact on public health.

Leaving aside debates over the impact of routine emissions, a number of accidents have resulted in releases of radioactive materials to the environment, some of which also had consequences for public or occupational health and safety (see chapter 3.5).

A considerable proportion of the radioactive emissions associated with ANSTO's operations result from radioisotope production and processing. Liquid and gaseous emissions result from reactor operation - one purpose of which is radioisotope production - and there are also substantial emissions from radiopharmaceutical processing. (RRR, 1993, p.17.) Of the total number of ANSTO staff on the dosimetry service in 1991-92, the 19% of total staff working in close proximity to HIFAR or working for Australian Radioisotopes (ARI) accounted for about 72% of the aggregate whole body dose of ANSTO employees. ARI staff accounted for 35% of the total radiation exposure to all ANSTO employees although ARI has only 8% of the total staff. For ARI staff the mean whole body dose was 4.84 mSv, and the aggregate whole body dose was 0.300 person-sieverts. (RRR, 1993, p.187.)

Just as ANSTO likes to link radioactive waste and nuclear medicine, so too Walker, then an AAEC employee, linked radioactive emissions to nuclear medicine (Walker, 1985, italics in original):

*Using the most pessimistic assumptions*, it would take over a hundred years of routine emissions of radioactivity from Lucas Heights to produce one 'extra' cancer in the whole population of Sydney. Yet, each year more than 70,000 Australians receive medical treatment using radiopharmaceuticals produced at Lucas Heights. Even a small success ratio for these diagnostic and therapeutic treatments puts the balance overwhelmingly in favour of Lucas Heights.

Walker's comments contain numerous debatable assertions; suffice it here to note that linking radioactive emissions and nuclear medicine is seen to be a useful public-relations manoeuvre.
ACCIDENTS AND EMERGENCY PLANS

Inevitably there were conflicting opinions as to the safety record of research reactors during the RRR. Pro-nuclear campaigners such as ANSTO argued that the safety record was excellent. The Review (p.13) largely accepted that view: "Research reactors are operated under the general nuclear code of seeking maximum safety. Their record of safety is excellent. There have been very few accidents and even fewer involving loss of life." The Review (p.13) referred to a 1980 report by the US Oak Ridge National Laboratory (ORNL) which listed nine accidents involving prototype power reactors or experimental reactors, and a further three involving multipurpose research reactors (Bertini et al., 1980). The multipurpose research reactor accidents were two accidents involving Canadian research reactors (see chapter 6.2 of this thesis), and a fuel element melting at the ORR reactor at the ORNL in 1963. None of these three accidents at resulted in any immediate deaths but the longer-term effects are disputed. The Review (p.13) went on to say that there has been only one further report of a research reactor accident since 1963, which occurred during refuelling of a critical assembly reactor in Argentina in 1983 and caused one death.

Some of the accidents not mentioned by the Review, or by ANSTO (1993L), presumably because they involved experimental research reactors rather than multipurpose reactors, are as follows. In 1955, the Idaho Falls EBR-1 research reactor suffered a partial core meltdown which destroyed it. In 1958, the research reactor at the Boris Kidric Institute in Yugoslavia overheated; six scientists were irradiated and transported to France for treatment, with one death. A power surge accident occurred at the 3 MW research reactor (SL1) at Idaho on 3 January 1961. The reactor blew up and three operators were killed. (Vallentine, 1992.)

The argument was put to the Review that accidents are more common in multipurpose research reactors than in power reactors because there are more frequent start-ups, shut-downs, fuel and rig movements, and more opportunities for human error. These arguments were drawn from industry literature and so could not easily be refuted. On the other hand there was no dispute that, in general, accidents involving power reactors pose a far greater risk to the general public because of the far greater volumes of fissile material used to fuel power reactors. (RRR, 1993, p.228.)
On the safety of HIFAR, the Review (p.xxi, p.159) said:

*Despite the many submissions questioning the safety and health aspects of the operation of HIFAR, the evidence strongly supports the view that HIFAR operates safely by an adequate margin, well within international safety standards. ...... The risks to the people living in the Sutherland Shire are very much less than the risks of traffic accidents, lightning strikes, bushfires, and several other forms of natural hazards. ...... On the evidence, the Review accepts that the likelihood of ...... a serious event is remote and that, in the unlikely event of such an accident to HIFAR, the radiological consequences would be small.*

The data and issues relating to the safety of HIFAR are ambiguous and contested and cast at least enough doubt on the matter to query the benign view presented by the Review and by ANSTO. In fact despite the above comments the Review argued that a Probabilistic Risk Assessment (PRA) should be carried out to ascertain HIFAR's remaining lifespan and to provide additional safety assessments.

ANSTO's critics, in particular the Sutherland Shire Council and Friends of the Earth (FOE), entered into a technical debate with ANSTO and the Nuclear Safety Bureau regarding the safety of HIFAR. FOE (1993B) claimed that HIFAR's control systems, in particular the cooling system, are problematic - that HIFAR has leaking thermal shield cooling coils, heat-exchanger leaks, and reactor instrumentation connected to an "uninterruptible" power supply that has never worked. FOE claimed that HIFAR's emergency backup shutdown system is inadequate, consisting of two "safety rods" well outside the core and able to absorb only 0.5% of the radioactivity. FOE said that there are doubts about the reliability of the unusual signal-arm safety absorbers, a significant problem since a loss-of-control-arm accident could result in a power surge leading to melt-down of the reactor core. Finally, FOE noted that HIFAR's core is surrounded by graphite, the material which burnt fiercely out of control at Chernobyl.

Some revealing history surfaced during the Review concerning disputes over HIFAR safety issues. In the late 1980s, senior engineers employed by ANSTO wrote to the Federal Minister for Science and Energy, asking for a full external safety audit. This request was made with the support of the Association of Professional Engineers of Australia (APEA), but the Minister did not agree to the audit. The engineers were acting in response to a series of operator-error incidents over a protracted period of time, some of which were serious incidents with direct
safety significance. As well as approaches to the government, the engineers had tried to initiate action through ANSTO, regulatory authorities, and the courts, but without success. (Darroch, 1990; Friends of the Earth, 1993B.)

Finally, in 1989, ANSTO commissioned a safety review by Atomic Energy of Canada Ltd. (AECL) which presented its report in 1990. AECL reported that the safety culture at ANSTO was inadequate. The report dealt with numerous problem areas: inadequate training for key reactor operating personnel; inadequate operating manuals; inadequate reviews, testing and inspection; poor health and safety practices; improper waste management; inadequate emergency arrangements; and a vital emergency core cooling system which was compromised resulting in unnecessary danger for two years. The AECL Review also said that during the past one to two years, there had been virtually no work done on improving the reactor, upgrading the training programs for reactor operators, improving the reactor maintenance program, or developing quality assurance systems. The AECL report said that in the light of past performance, there was reason for concern as to how future changes would be managed. That concern seems to have been well founded: ANSTO's response to the AECL report was an "Action Plan" which, according to some employees, failed to even address many of the problems let alone propose workable solutions. Subsequently the APEA gave the Nuclear Safety Bureau a report of alleged deficiencies and argued that HIFAR should be shut down pending a further independent inquiry; the Bureau reviewed this document but recommended to the Minister that no action be taken. (Darroch, 1990; Friends of the Earth, 1993B.)

Another safety-related debate is emergency planning, which is all the more important given that all exits from Lucas Heights are on narrow roads with bridge crossings, and given that 200,000 people live in the Sutherland Shire with 30,000 people living within a few kilometres of the reactor. At the time of the RRR, the most recent version of an emergency plan was still under development, which the Review said was an "unacceptable situation" (pp.165-166). Over two years after the completion of the RRR, ANSTO finally released a community leaflet for local residents advising them what to do in case of an emergency at the ANSTO facilities. The community leaflet was vague, uninformative, and inadequate according to a member of the Sutherland Shire Environment Centre (Priceman, 1996). Clearly ANSTO is concerned about the adverse publicity associated with acknowledging the possibility of a major reactor accident.
REGULATION OF ANSTO

Regulation is multifaceted, involving siting, design, commissioning, operation and decommissioning of nuclear facilities; transportation and management of nuclear materials; setting standards for ionising radiation doses to workers and the public; and monitoring of emissions. (Research Reactor Review, 1993, p.227.) These issues are clearly important but only the briefest summary follows.

The major nuclear regulatory agencies in the past decade have been the Nuclear Safety Bureau (NSB) and the Australian Safeguards Office (ASO). From the early 1980s, the AAEC/ANSTO gradually tightened its own regulatory procedures, if only to dampen criticism and to prevent a tighter and more independent regime being imposed by government. However, even when the NSB was made a statutory authority in 1992, problems of excessive self-regulation remained. For example, even after 1992 the authorisation to operate ANSTO was issued by the ANSTO Board not by the NSB. (RRR, 1993, pp.231-232.) Another problem has been the transfer of staff to and from ANSTO, the NSB, and the ASO. The Review (p.230) said that perceptions of potential conflicts of interest arising from secondments of ANSTO staff to the NSB and the ASO were "well based".

The Review (pp.xxiii-xxiv) said that the regulatory regime for the nuclear industry in Australia is unduly fragmented and unclear, and the scope of responsibility of the NSB is too limited. It said that ANSTO's Ministerial direction should be to a Minister different from the one responsible for reactor operations and regulation. It said the arrangement whereby ANSTO operates under an authorisation issued by the ANSTO Board, rather than a licence issued by the regulatory body, is inconsistent with IAEA international principles and requirements. It said there is scope for rationalisation of the separate safety and safeguards regulatory regimes. It said the regulatory authority should have unambiguous and effective sanctions powers, to ensure that conditions set by the regulatory authority are met by ANSTO.

In short, the Review agreed with many nuclear critics that ANSTO was inadequately regulated. Following the Review a governmental interdepartmental committee was established to review nuclear regulation in Australia. (Wallace, 1993.) In 1995, the Nuclear Safety Bureau was merged with the Australian Radiation Laboratory to form the Australian Institute for Radiation Protection (AIRP). The AIRP has responsibilities for regulating ANSTO, including the licensing of HIFAR and exposure to radiation, and ensuring compliance with
safety standards. The AIRP was made responsible to the Minister for Health. (ANSTO, 1993-94, p.11.)

COST OF A NEW REACTOR AND COMMERCIAL OPERATIONS

Over the years, claims have been routinely advanced about the economic benefits of operating a research reactor. However the arguments are shallow: as the Review argued (chs.10-11), a new reactor is certain to be an economic burden even allowing for revenue-raising ventures such as silicon doping and radioisotope sales.

Estimates of the cost of a new reactor put to the Review (ch.10) varied widely. The figure put forward by ANSTO was $150 million, but that figure did not include the reactor components which could be produced in Australia. The Review (p.xvii, ch.10) argued that the proposed new reactor would cost not less than $250 million, and decommissioning and waste disposal costs would be extra. Decommissioning HIFAR will cost anywhere from $27-192 million depending mainly on whether it proceeds in the near future or is left for a period of up to 50 years. Then there are costs - running into the tens or hundreds of millions of dollars - for disposal of the radioactive waste generated by HIFAR and any future reactor, and the eventual decommissioning of any future reactor.

It goes without saying that in a protracted period of global economic stagnation, funding is a key issue - perhaps more likely than any other issue to sway government towards a decision not to replace HIFAR. That the capital costs of a new reactor could be spread over a decade or more would be little consolation. It is also worth noting that influential science and technology organisations, in particular the CSIRO (1993), are concerned that funding for a new reactor not come at the expense of usual science funding.

The major HIFAR-related commercial activities at Lucas Heights are radioisotope production and silicon doping, with other relatively minor revenue from other irradiation and neutron-activation activities. On ANSTO's commercial activities, the Review (p.xviii) said ANSTO's efforts to generate commercial revenue had been successful with many new but as yet immature activities. On the other hand the Review (pp.26-27) found that, in Australia as elsewhere, the links between neutron sources and industry were not yet as pervasive and deep as the evidence of scientific usefulness suggested they ought to be. The Review also noted that industry rarely contributes to the costs associated with research reactors operations.
The Review (p.25) argued that there are strong arguments for Australia to maintain a neutron source, without which "Australia would lock itself out of several rapidly advancing areas of science." However the Review was inconsistent. In relation to the question posed by the Terms of Reference, whether the science at ANSTO is of sufficient distinction and importance to Australia to warrant a new reactor, the Review said (ch.6):

The Review is not convinced that that is the case – at least not yet. ...... Nobody advanced the view that Australian scientists working at HIFAR are at the cutting edge of science. .... a picture of a vibrant field of science, energised by young people excited by the challenges and opportunities, did not emerge. ...... The Review was not even convinced that (reactor-based) science has been a major focus of ANSTO activity. The full flowering of recent vigour might not be evident yet in publications, but at present the case for a new reactor on science grounds cannot be sustained, however compelling the need for such science.

Another debate concerned the relative merits of various neutron sources and accelerators. These debates were complicated and various permutations were considered. The Review (pp.48-49) concluded that the "jury was out" on too many issues relating to non-reactor neutron sources:

Rapid advances in the technology of accelerator based spallation sources may make such a source a worthwhile consideration, if scientific purposes are to be the key reasons for a new reactor. A spallation source would be unlikely to cost less than a new reactor. If a spallation source were to be chosen, a small reactor of about one megawatt power for the production of radioisotopes would also be necessary, unless advances in cyclotron technology make that avenue the preferable course.

The Review (ch.5) also discussed options such as increasing access of Australian scientists to overseas facilities, and floated the idea of developing a regional neutron source in collaboration with other countries.
The Review commissioned two surveys of public opinions about ANSTO and HIFAR, one by Reark Research (1993) and the other by Roy Morgan Research (1993). Both surveys were very much exploratory, involving only a small number of people. The Roy Morgan survey found that nuclear issues in general, and the nuclear reactor at Lucas Heights in particular, are not top-of-the-mind concerns for people regardless of where they live. Medical applications of radioisotopes generated the most positive reactions from respondents.

The Reark Research (1993) survey amounted to nothing more than an exercise in pro-ANSTO push-polling. It said there was no top-of-the-mind concern about the proposed new reactor, even in the Sutherland Shire, but "This does not, of course, mean that concern could not be fanned by activist groups." It said that because there was little understanding about research reactors or the levels of risk they entail, and because of the paucity of "rational" discussion, many would spontaneously vote against a new reactor, preferring to err on the side of safety. Thankfully, when a "rational" approach was taken and when respondents were allowed themselves to weigh up the advantages and disadvantages, they almost unanimously voted "yes": "The respondents were far more rational and willing to have an open mind than might have been assumed from the more extremist views that have appeared both in the press and via the local council in the case of Sutherland Shire, as well as from those who have presented submissions to the Reactor Review."

That the Review received about 150 submissions opposed to a new reactor, and in many cases critical of other aspects of ANSTO's operations, would seem to indicate a modest level of public opposition at least; roughly 40% of all submissions were opposed to a new reactor. The Sutherland Shire Council (1993C) claimed that 81% of local residents were opposed to a new reactor, but without providing any basis for the claim. More recently, a newspaper report says that a recent survey commissioned by ANSTO found that people living near HIFAR "expressed overwhelming support for a new reactor to be built somewhere remote from human settlements." (Beale and Dayton, 1997.)
4.5. FURTHER DEVELOPMENTS

PROPOSALS TO MERGE ANSTO WITH THE CSIRO
THE BAIN REPORT AND ANSTO's MISSION REVIEW
THE HIFAR REPLACEMENT CONTROVERSY

Before the RRR had even finished, the merry-go-round of reviews and reorganisations was underway. Proposals to merge ANSTO with the CSIRO were on the agenda. Such proposals had surfaced in the early 1980s and perhaps before that. In 1986 the Collins Review addressed the issue of the organisational separation of ANSTO and the CSIRO in 1986. It said there were no scientific reasons for their separation but there were non-scientific reasons (Collins et al., 1986):

For better or worse, nuclear energy occupies a special position in the minds of humanity. Attitudes within the community towards nuclear energy, including nuclear science and technology, have developed which are strongly polarised and firmly argued, in many cases without a very sound logical basis. ANSTO, with its responsibility for nuclear science and technology can be seen in the social and political context to have a unique set of problems and challenges which are not scientific or technological, but political, social and philosophical.

The organisational separation of ANSTO and the CSIRO dove-tails with the HIFAR replacement controversy - the operation of a research reactor provides a rationale for a greater degree of independence for ANSTO. Conversely, if ANSTO was absorbed into the CSIRO, the advocacy for a new reactor might be more diffuse - it is notable for example that the CSIRO (1993) said in its submission to the RRR that it could not support a new reactor if funding was not additional to usual government science funding. Incorporating ANSTO within the CSIRO would be a further step in the transition of the AAEC/ANSTO from being the main exponent of Australia's manoeuvring in the global nuclear arena to being just another public-sector science agency.

National interest arguments also intersect with the issue of the separation or merging of ANSTO and the CSIRO. Thus in 1989-90, Collins, arguing for a new reactor and also for ANSTO's organisational independence from the CSIRO, said (ANSTO, 1989-90, p.8):
The international role played by the Australian Government in nuclear matters, particularly nuclear non-proliferation, demands a high level of scientific and technological support which can be readily identified. Australia's voice in the nuclear debate has a much greater importance than might be inferred from our participation in the nuclear fuel cycle. The strength and credibility of Australia's position rests directly on the infrastructural, scientific and technological capability which exists in ANSTO.

In 1993 the Minister for Science and Technology proposed absorbing ANSTO into the CSIRO, with the objective of cutting costs. ANSTO management was hostile to the idea. CSIRO management had no interest in being lumbered with a Trojan horse along with problems such as radioactive waste management, HIFAR decommissioning, and doubts about the commercial viability of a number of ANSTO's ancillaries and joint ventures. ANSTO's critics, such as Friends of the Earth, supported the merger. (Pockley, 1993; 1993B; ANSTO, 1993-94, pp.8-9.)

The uncertainty surrounding the proposed merger resulted in major initiatives being put on hold at ANSTO. The merger did not proceed, with the government deciding to take a non-legislative route to achieve closer links between ANSTO and the CSIRO. A new ANSTO Board, including some members of the CSIRO, was appointed in December 1993. The new ANSTO Board set up another review, and another one after that.

THE BAIN REPORT AND ANSTO's MISSION REVIEW

A review was commissioned by the ANSTO Board in late 1993 to review ANSTO's operations. The review was carried out by three organisations, Bain International Inc., Batelle Memorial Institute, and Pacific Northwest Laboratories, and the report (the Bain report) was released in 1994. (Bain International et al., 1994.)

The Bain report proposed a rationalisation of ANSTO's activities, with some activities to be transferred and some to be stopped altogether. The remaining activities would fall within a number of "Key Research Areas" including radioactive waste management, safety of nuclear installations, resource processing and elimination of radionuclide contamination, applied accelerator technologies, and environmental and industrial applications of radionuclides. The report recommended discontinuing all nuclear physics applications, and transferring some environmental science activities to more appropriate agencies. It also
recommended that nuclear medicine programs including the Biomedicine and Health research program, Australian Radioisotopes, and the National Medical Cyclotron, be transferred out of ANSTO. (Bain International et al., 1994.)

The Bain report devoted considerable space to arguing for a new reactor to replace HIFAR. The national interest was high on the agenda. The report said the government places high priority on "influence and independence" in matters across the nuclear fuel cycle. Independence was equated with independence from other countries such as the US in matters such as nuclear expertise and intelligence gathering and analysis. The report (p.18) lists the elements of ANSTO's involvement in "supporting nuclear policy across the fuel cycle": underpinning an influential role in international bodies such as the IAEA and the OECD Nuclear Energy Agency; intelligence assessment of nuclear proliferation and safety issues; formulation of nuclear policy; developing bilateral safeguards agreements to enable responsible export of uranium; safety programming and control for nuclear powered warships in Australian ports; and environmental assessment and clean-up of radioactive sites (such as Maralinga and the uranium mines). (Bain International et al., 1994.)

The Bain report argued that to support the government's nuclear policies, ANSTO needed the experience derived from operation of a research reactor. It made cryptic statements (pp.100-101) such as that "..... as a reaffirmation of Australia's commitment to nuclear technology, it (a new reactor) would enhance the nation's worldwide and regional status and provide a continuing capability to effectively monitor nuclear developments." The report (p.98) argued that:

The wide range of skills, expertise and experience inherent in the continued safe operation of HIFAR and the research carried out on it enables ANSTO to provide sound, objective advice to the government. This, in turn, helps government to interpret and respond to the nuclear issues and possibilities by which it is confronted. It also provides government with a strong position and a credible voice in the international setting. For instance, understanding and adhering to the IAEA standards and procedures for operating nuclear reactors and handling radioactive material is of particular relevance to Australia, given the nation's position as a signatory of the Non-Proliferation Treaty and its stance as a strong proponent of non-proliferation internationally. Therefore, through its operation of a research reactor, ANSTO is able to contribute to the support of government's nuclear science policies and international obligations.
As discussed in chapter 4.4, these arguments are mostly overinflated. There is a remarkable degree of circularity and tautology in the argument that a research reactor is necessary to enable ANSTO to understand and adhere to standards and procedures for operating nuclear reactors.

The Bain report (p.100) considered four options - building a replacement reactor, upgrading HIFAR, running HIFAR down, and building a different machine such as a spallation source - and opted for the first option. The report (p.100) said that more detailed costings of a replacement reactor have been carried out since the RRR. The estimated total is $425 million over the new reactor's life of 40 years, which would include construction, operation, maintenance, and decommissioning costs, and that figure would take into account off-setting revenue. The report reproduced without critical commentary some creative accounting provided by ANSTO to the effect that a saving of $23 million could be made if a decision on a replacement reactor was made in mid 1996, instead of waiting the five years recommended by the RRR, because of reduced capital costs, and costs saved by operating HIFAR for two less years. Better still, if in addition to a decision being made in 1996 instead of 1998, the construction schedule for a new reactor was reduced from ten to eight years, a total cost saving of $66 million could be made, largely because of savings of $40 million in costs relating to HIFAR. There is no mention of the potential savings of hundreds of millions of dollars by abandoning the project altogether.

The Bain report did not seriously address the various objections to a new reactor. For example its comments (p.105) on radioactive waste comprised nothing more than a throw-away comment that the disposal of high-level waste is a crucial issue and one which ANSTO should be involved in addressing. The report (p.100) also advanced the circular argument that a new reactor would enable the broadening of waste management expertise. The Bain report had even less to say about issues such as the safety and environmental impact of HIFAR or any future reactor.

ANSTO's response to the Bain review was, naturally, to set up another review, this time an internal Mission Review. In response to the Mission Review, several recommendations were implemented by the ANSTO Board including:

- termination and redirection of several research projects to better reflect core activities;
- a series of measures, including capital improvements, to ensure the continuance of Australian Radioisotopes as a business under ANSTO management;
• continued biomedical research by maintaining 1) a research capability to support the development and production of commercial and potentially commercial radioisotopes and radiopharmaceuticals, and 2) a capacity to produce labelled ligands in support of a national program of emission tomography research;
• the appointment of a Director of Business Collaboration for improved communication with industry and other users of ANSTO's research and development and services;
• the appointment of a Canberra Liaison Officer to provide day-to-day communication with government departments, to better enable ANSTO to stay abreast of political developments and to play a role in shaping nuclear science policy; and
• implementation of a range of structural changes to ANSTO to facilitate improvements in effectiveness and efficiency.

It is notable that ANSTO has maintained its central involvement in medical radioisotope production and nuclear medicine more generally, contrary to the Bain report's recommendation that the Biomedicine and Health research program, Australian Radioisotopes, and the National Medical Cyclotron, be transferred out of ANSTO. Even if those transfers had taken place, ANSTO would still have a central role in medical radioisotope production for so long as it operates a reactor, but all the same it is to be expected that ANSTO will maintain as significant a role in nuclear medicine as it possibly can given that such activities provide an important ideological buffer against nuclear critics.

THE HIFAR REPLACEMENT CONTROVERSY

In late 1994 there was considerable debate and media comment on proposals to build a research reactor in Kalgoorlie, Western Australia. The area had been short-listed by the federal government as one of eight possible sites for a national radioactive waste repository. Consequently there seems to have been some back-room bargaining – a reactor might be built in Kalgoorlie if a repository could also be built in the area. The Western Australian government made several cryptic and sometimes contradictory statements about the alleged proposal. ANSTO, which has a strong preference for a new reactor to be built at Lucas Heights, seems to have been opposed to the idea of a reactor being built in Western Australia, saying there was no basis to such speculation and pointing to the RRR recommendation that a decision be put on hold until 1998. After a month or so, speculation about the proposal died down. (Rocchi, 1994; Davison, 1994; Rae, 1994.)
The most significant change in the political landscape since the Research Reactor Review was the election of the conservative Liberal/National Coalition in the 1996 federal election. An open-slather uranium policy has been put in place, and several mines are set to open or re-open as a result. The missile tracking station at Pine Gap is to be upgraded and the treaty that governs its use is to be extended for a further 10 years beyond the scheduled closure date of 1998. The Nurrungar base is to be closed in the year 2000 because of outdated and redundant facilities. The Coalition government has agreed in principle to a US proposal to establish a relay ground station for a US space-based ballistic-missile early warning program. (Sheridan, 1996.) Nuclear power has been ruled out by the Minister for Science and Technology, as has a resumption of enrichment research (Uranium Information Centre, 1996).

There has been no clear indication from the Coalition government in relation to HIFAR and a possible replacement. One pointer may lie in the decision of the government to cut every area of public spending (including science) with the one exception of defence spending. To the extent that ANSTO is seen as just another part of the science and technology infrastructure, it will not be immune from cuts and it may not get its new reactor. However despite the trend over the past two decades to view Australian nuclear technology in just those terms, there are still aspects of nuclear science which are seen to be of considerable significance in relation to foreign policy and security. To the extent that ANSTO and its allies can convince the government of the benefits of a new reactor in terms of foreign policy, military intelligence and security, and the sundry other aspects of the "national interest" discourse, they will be on firmer ground, all the more likely to secure government approval and funding for a new reactor.

ANSTO has been saying for some years - at least since 1990 and probably before that - that it is imperative that a decision on a new reactor be made as a matter of urgency. This view is now widespread. The Nuclear Safety Bureau says that it will not authorise ANSTO to operate HIFAR beyond 2003 unless a major upgrade of safety-related equipment is carried out. ANSTO says that if an upgrade is to be carried out and completed by 2003, it must begin in the 1996-97 fiscal year. (ANSTO, 1995-96.) Alternatively, if a new reactor is to be built, it will take something like 8-10 years to build. Continuity of ANSTO's reactor-based programs may be interrupted even if a decision to proceed with a new reactor is made soon. In any case it is widely accepted that there is some urgency to the matter.

In early 1997 there were media reports concerning the future of HIFAR and the possibility of a replacement reactor. An interdepartmental committee review has
evidently been reviewing the issue, including officers from the federal Departments of Science and Technology; the Environment; Health; and Foreign Affairs and Trade. The committee's review was held in secret with no requests for public submissions. (Rees, 1997.)

The (reported) deliberations of an interdepartmental committee raises questions about decision-making procedures and levels of public input and accountability. A few comments follow on these topics, although I will not go into any detail. A decision to proceed with a new reactor would almost certainly have to satisfy the Environmental Protection (Impact of Proposals) Act 1974. (The RRR was not formally established under the terms of the Act, but if the Review had recommended that a replacement reactor should be built, a second stage, concerning issues such as siting, would probably have had to satisfy the Act.) An attempt to circumvent that Act would be likely to generate considerable controversy and opposition within and beyond the federal parliament, and could be subject to legal challenge. In any case letters I have received from successive Ministers for Science and Technology, including the current Minister, are unequivocal on the point that the Environmental Protection Act would be satisfied.

The Act allows for one of four levels of assessment. The most closed option is examination of an issue by the relevant government Department - from conversations with personnel from the Department of Industry, Science and Technology, and from ANSTO, it appears unlikely that this level of assessment will be pursued in relation to the HIFAR replacement issue. There are two intermediate options involving an Environmental Impact Statement or a Public Environment Report; these provide for some level of public input though they are not nearly as open as a public inquiry. The final level of assessment is a public Commission of Inquiry.

It seems likely that one of the intermediate options will be pursued, involving either an Environmental Impact Statement or a Public Environment Report, with some level of public input. Nevertheless the Environmental Protection Act is sufficiently open-ended that there is considerable scope for government to manipulate the process to minimise public input if that is its intention. A 1996 letter from Peter McGauran, the current Minister for Science and Technology, suggests that the intention may indeed be to minimise public input. McGuaran writes that the RRR said that a decision on the issue should be made in about five years time, but that it "did not recommend that a new inquiry be undertaken." However the Review (p.4) did indeed say that "if, at some later stage, a new reactor
is envisaged, it should be assessed by a new panel possibly operating within the Environmental Protection (Impact of Proposals) Act."

McGuaran says the government will make a decision on the replacement of HIFAR in 1997 or early 1998. His public statements have been non-committal to some extent, but he has argued that there is a good case for a reactor. Most of his comments in support of a new reactor have concerned the production of medical radioisotopes:

We have full support for ANSTO and what it does. It plays a crucial role in Australia for both health and manufacturing terms. So many thousands of Australians owe their lives to the research carried out at ANSTO. Remember that ANSTO is Australia’s only producer of radioisotopes …..

A senior NSW Liberal Party politician, and the federal Democrats, are calling for a Senate inquiry into the future and possible relocation of the Lucas Heights facilities. (Hogarth and Cleary, 1997.)

HIFAR's age is creating a sense of urgency surrounding the issue of its refurbishment or replacement. The issue of what to do with the spent fuel rods at Lucas Heights, and the issue of waste management more generally, is even more pressing. This is because ANSTO is likely to run out of storage space for spent fuel rods in late 1998, and also because of the political backlash that would probably greet a decision to proceed with a new research reactor before some sort of solution (however temporary and inadequate) is found to ANSTO's radioactive waste problems.

I will finish this chapter with some comments on the state of anti-nuclear opposition. Opposition to the open-slather uranium policy and the reinvigorated US alliance has generally been tame. However there is still a large reservoir of anti-nuclear sentiment that could be mobilised against future nuclear projects, as demonstrated by the massive opposition to French testing in the Pacific in 1995. Another variable is the Sutherland Shire Council, which was so important in the campaign during the RRR. The make-up of the Council has changed. The Liberal Party now has a dominant position following Council elections in 1995. That may result in a less critical attitude to ANSTO's operations, and it may affect the

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61 As discussed in the postscript to this thesis (chapter 10), in September 1997 the government announced a decision to replace HIFAR. However the decision is subject to an assessment under the Environmental Protection Act 1974, and it is also subject to an investigation by a Senate Committee.

62 Matters of Public Importance, 5 March, 1997. See also McGuaran, Questions Without Notice, House of Representatives, 6 March.
outcome of the controversy over the replacement of HIFAR. On the other hand some Liberal Party members were opposed to a new reactor at the time of the RRR: it remains to be seen what role the Council will play in the controversy in the coming years.
CHAPTER FIVE:
THE RADIOISOTOPE INDUSTRY:
INTRODUCTION AND HISTORY

5.1. INTRODUCTION
5.2. THE HISTORY OF RADIOISOTOPE PRODUCTION AND NUCLEAR MEDICINE

5.1. INTRODUCTION

The empirical scope and organisation of chapters 5-8 centres on the evaluation of the relative merits of a new reactor in Australia for radioisotope production versus alternative options. If HIFAR is permanently shut down without replacement, any combination of four options is possible. There could be greater reliance on domestic cyclotron production of radioisotopes. A second possibility is greater reliance on imported radioisotopes. For radioisotopes not amenable to domestic cyclotron production or importation, there are two further options: using alternative radioisotopes or non-radioisotope medical technologies. All these options would almost certainly be pursued to a greater or lesser extent in the absence of a domestic research reactor; they are not mutually exclusive. Indeed at the moment there is some usage in Australia of domestic cyclotron radioisotopes, imported radioisotopes, and diagnostic and therapeutic technologies which compete with nuclear medicine, along with HIFAR-produced radioisotopes.

In this chapter I briefly summarise the history of nuclear medicine. This summary focuses on the central role of nuclear agencies in the development of nuclear medicine, and the integration of radioisotope applications into the clinical practice of medicine, primarily in the field of diagnostic imaging. Chapter six presents empirical material on reactor radioisotope production around the world. Chapter seven presents an analysis of the global radioisotope industry, taking up a range of topics: radioisotope demand; production levels; the level of industry concentration; vertical integration; private and public sector involvement; dedicated production facilities; the links between radioisotope production and nuclear development more generally; technical innovations; and radioisotope production using cyclotrons and linear accelerators. On the basis of the material presented in chapters 5-7, the question of future radioisotope production and supply in Australia is addressed in chapter eight.
ANALYSING NUCLEAR MEDICINE AND THE RADIOISOTOPE INDUSTRY

One way of proceeding with an analysis of future radioisotope production and supply scenarios for Australia would be to consider each medical radioisotope currently produced by HIFAR, collating information on the feasibility of importation, domestic cyclotron production, or replacement with alternative radioisotopes or non-radioisotope procedures. However this analysis proceeds from a different direction, from a broader analysis of global production of and trade in radioisotopes. Such a general understanding is essential for an adequate assessment of future supply scenarios for Australia, and it provides a framework from which analysis of any specific radioisotope can proceed. The only radioisotope discussed in detail is technetium-99m (Tc-99m) and its parent radioisotope molybdenum-99 (Mo-99). Tc-99m is used in 70-80% of all nuclear medicine procedures.

There is very little academic work concerning nuclear medicine or the radioisotope industry, and the few studies that exist are more useful for information than insight (e.g. Russell, 1979; Hamilton, 1982; Bronzino et al., 1990, ch.7). Social analysts of nuclear industries rarely say much about the radioisotope industry. In some studies, radioisotope production is discussed in the context of the various industrial, medical, and research activities of nuclear agencies (e.g. Moyal, 1975). Such studies give some insight into the links between radioisotope production and other aspects of nuclear programs. However that alone is insufficient for my purposes since many aspects of the radioisotope industry - such as processing, transport, and marketing - involve institutions other than nuclear agencies and social and economic dynamics other than those which shape the nuclear industry.

Nor is there much of relevance in the medical sociology literature. This literature tends to focus more on the use and consumption of medical technologies, less on production and trade. Studies of medical use and consumption take up issues such as the development of usage organisations and practices, professional strategies used to advance or retard the development of a particular technology, and medical technology evaluation. Some of this literature is useful. For example use/consumption studies bridge into studies of technology regulation and evaluation, in which the roles of state institutions and private companies come into view alongside the more common focus on medical personnel and institutions. Moreover there is interaction between production and consumption, supply and demand: for example professional struggles (turf battles) over the use of medical radioisotopes have consequences for radioisotope demand which, in
turn, affects production. However in the following analysis I do not look closely at the level of professional practice, or medical micropolitics more generally; the issue of future radioisotope supply scenarios for Australia invites an analysis focused largely on the levels of radioisotope production and trade.

There are some sociological analyses of medical imaging modalities such as x-radiology, computerised tomography, and magnetic resonance imaging (e.g. Littrell, 1989), and there are hagiographic "in-house" histories of all of them. Once again the focus is generally on the use and impact of imaging technologies rather than production and trade. Nuclear medicine tends to be given little or no attention in this literature. A typical example is Hamilton's (1982) *Medical Diagnostic Imaging Systems*, a study of a range of imaging technologies including nuclear medicine. This book has much useful information and some useful insights but it lacks any clear overall analysis of medical imaging and it deals only with the US market. Hamilton's book illustrates another blind-spot in the literature: the discussion on nuclear medicine is focused solely on imaging equipment and computers, with no discussion at all on radioisotope production and trade. Another illustrative example is the lengthy and largely descriptive account of medical imaging in Bronzino et al. (1990, ch.7). Insofar as this account moves from description to analysis, the concern is with "lumpy" investment decisions and other issues which concern imaging equipment not radioisotopes; the comments on radioisotope production are brief and purely descriptive and technical.

Medical sociology bridges into studies more clearly identifiable as STS-inspired. Once again the STS literature dealing with medical imaging technologies is of little value for this thesis. Barley's (1986) analysis of the introduction of computerised tomography scanners into two different hospital radiology departments is illuminating in its analysis of the different social dynamics occasioned by computerised tomography *vis a vis* the division of labour in radiology – but the work is narrow in scope. Similarly, the historical analysis of the development of cyclotrons by Baird and Faust (1990) is narrowly focused. Their aim is to urge a conception of scientific knowledge broad enough to include scientific instruments and instrumental techniques; that is, a conception of scientific knowledge which includes but goes beyond theory. That may be of some interest in relation to the construction and negotiation of boundaries between science and technology, but it has no relevance for the questions to be addressed in this thesis. The analyses of the historical development of ultrasound by Yoxen (1987) and Koch (1993) offer some useful insights – concerning for example the
transfer of military technology to medicine - but mostly they rehash the well-worn themes of constructivist technology studies.

An STS analysis which is certainly of use is Stuart Blume's (1992) *Insight and Industry*. As discussed in chapter one, Blume's book does not directly address nuclear medicine but the overall analysis of medical imaging is useful and suggestive. Blume's analysis needs to be reworked in relation to the radioisotope industry. Blume emphasises the evolution of an interorganisational structure at the centre of which are the symbiotic interests of the producers (manufacturing companies), purchasers (mostly hospitals), and users (radiologists) of imaging equipment. A major difference between the radioisotope industry and the medical imaging equipment markets analysed by Blume is the central involvement of state-controlled nuclear agencies in radioisotope production. Whereas Blume's analysis draws primarily from theory on the economics of innovation, and from medical sociology, an analysis of the radioisotope industry will also need to be alert to the sociology of nuclear development.

Of direct relevance to this thesis is the analysis of the global radioisotope industry by Frans Berkhout (1993), an academic who has written widely on nuclear issues. His study was commissioned by the Sutherland Shire Council for inclusion in the Council's submission to the Research Reactor Review. Berkhout analysed the level of concentration and competition in the radioisotope industry, and he made projections about future production levels. His analysis is particularly useful in relation to radioisotope processing and retailing - in this domain he discusses the changing structure of the industry, such as the shift towards regional radiopharmacies and unit-dose supply of radiopharmaceuticals to hospitals, and the vertical integration of the industry. Berkhout's study is brief, and it is focused exclusively on the Mo-99/Tc-99m industry, but it is useful nonetheless - all the more so since it was focused explicitly on the issue of future supply of the Australian market.

In view of what has been said, analysis of the radioisotope industry must take account of the following broad features. Firstly, analysis of the economics of the industry is essential. Radioisotope production is often carried out on a non-commercial basis, but international trade is invariably carried out on a commercial basis even where production is largely controlled by state institutions. Secondly, the important role of nuclear agencies in radioisotope production must be considered. Thirdly, the idiosyncrasies of medical markets - for example the insulation of both sellers and buyers from price signals as a result of third-party payment systems - must be considered.
One last aspect of the analysis that should be mentioned is that for the most part I assume the value of nuclear medicine and focus on the evaluation of alternative production and supply scenarios. This is the approach adopted in virtually all discussion on nuclear medicine in relation to the HIFAR replacement controversy, whether from proponents or opponents of a new reactor. However the issue is reframed at various stages in the following chapters, with some critical analysis of the importance of nuclear medicine and its alleged irreplaceability vis a vis alternative medical technologies. Thus some issues are addressed which arise from structural critiques of medicine under capitalism - in particular iatrogenesis and overuse. As for alternative technologies, claims that nuclear medicine is unique as a functional diagnostic imaging technology, and thus immune from competition in this medical domain, are scrutinised, and other aspects of competition between imaging modalities are discussed. I also scrutinise the claim that research reactors and cyclotrons are complementary rather than competing radioisotope sources.

5.2. THE HISTORY OF RADIOISOTOPE PRODUCTION AND NUCLEAR MEDICINE

RADIOISOTOPES: THE NUCLEAR CONNECTION
THE POST-WAR DEVELOPMENT OF MEDICAL IMAGING MODALITIES
NUCLEAR MEDICINE AND THE RADIOISOTOPE INDUSTRY

This section summarises the history of radioisotope production, nuclear medicine, and the broader context of medical imaging modalities. There is no need in this thesis for a detailed history of these issues, and the following comments serve mainly to provide some context for subsequent chapters and to flag some issues that will be taken up in those chapters.

RADIOISOTOPES: THE NUCLEAR CONNECTION

From the discovery of radioactivity in the late nineteenth century until the 1930s, the only radioisotopes available for medical (or any other) purposes were naturally-occurring radioisotopes such as radium, polonium and radio-lead. Most of these radioisotopes were (and are) rare, and methods for separating them were crude. Consequently the use of radioisotopes for medical purposes was uncommon and experimental.
From the early 1930s, the development of artificial radioisotopes first took place with the construction of a range of particle accelerators including cyclotrons. The use of radioisotopes in medicine expanded. However radioisotopes were still hard to get through the 1930s. Particle accelerator technology was in its infancy. Some accelerators in the US were used for uranium enrichment for weapons production during World War II, and the three that existed in Japan were destroyed by the invading US army in late 1945. From the late 1920s until World War II, a nexus had formed between particle accelerators and nuclear medicine, then during the war accelerators were linked to nuclear militarism. These links were remoulded during and after the war. Some ongoing effort was expended on the development of particle accelerators, but they were developed primarily for physics research including military research. Far more effort and funding was expended on the development of fission technology using nuclear reactors. (Brodsky et al., 1995; Stelson et al., 1995; Boyd and Lane, 1973; Sasaki, 1995; Freeman, 1981, ch.4; Cockburn and Ellyard, 1981, ch.9.)

The production of medical radioisotopes became a subsidiary function of nuclear research reactors. Inevitably, the US was at the forefront of reactor radioisotope production. Of the 65 research reactors in operation in 1957, only 10 were outside the US (Coleby, 1987). The UK also produced reactor radioisotopes from the mid 1940s. Not long after, research reactors were being used in the Soviet Union for radioisotope production. Other countries with plans to develop nuclear power and/or weapons also had a need for research reactors. As research reactors become more widespread, so too did reactor radioisotope production.

With perhaps just one exception – a small reactor built in the US for cancer treatment and limited radioisotope production – research reactors were not built specifically for medical purposes (Anon., 1959). Although medical radioisotope production was a secondary concern, artificially-produced radioisotopes were more widely available after World War II. There was a deluge of papers, speakers and publicity; over 3000 articles were published relating to medical uses of radioisotopes from 1945-50 around the world. (Croll, 1994; Bindon, 1988; Brodsky et al., 1995; Coleby, 1987.)

Without the development of nuclear weapons and power programs, nuclear medicine would not have become integrated into medicine so rapidly, and may not have become a widespread medical application at all. Medical radioisotope production was a secondary function and sometimes marginalised because of the priority accorded to nuclear power and weapons research. Yet nuclear agencies were keen to support the development of nuclear medicine, which served an
important ideological, legitimating function. The production of medical radioisotopes was accompanied by much publicity focused on finding a cure for cancer and spiced with swords-to-ploughshares rhetoric. (Kotz, 1995.)

Financial incentives had little to do with the early development of nuclear medicine: there was little or no profit to be made in such an immature market. Radioisotopes were typically supplied at little or no cost – this occurred not just in the capitalist countries pursuing major nuclear power and/or weapons programs, but also in countries with modest nuclear research programs such as Australia and a number of Latin American countries (Touya, 1987). Even before the end of the 1940s, some private companies had carved out a niche as intermediaries between bulk radioisotope producers (i.e. nuclear agencies) and users (hospitals), but these companies did not play a significant role for some decades.

The radioisotope industry can usefully be considered as a product of the symbiotic interests of nuclear agencies and medical professionals. More broadly, class interests were also at work, even if the profit motive was not an important driving force. As well as serving as an ideological prop for the nuclear industry, radioisotope production and nuclear medicine fitted neatly with the ideologies of technological and medical progress that were so prominent in the post-war decades. These various ideologies were evident in the rhetoric surrounding radioisotope production and nuclear medicine, such as the boastings of a former director of the Oak Ridge National Laboratory about the Laboratory's role in "saving lives and money with isotopes" (Weinberg, quoted in ORNL, 1996):

If at some time a heavenly angel should ask what the laboratory in the hills of East Tennessee did to enlarge man's life and make it better, I dare say the production of radioisotopes for scientific research and medical treatment will surely rate as a candidate for very first place.

Much was made of the potential for radioisotopes to be used to cure cancer, but nuclear agencies, governments, and the capitalist media were far slower to acknowledge the dangerous and iatrogenic effects of radiation – whether from weapons tests, reactor emissions, uranium mining or medical radioisotopes – and nuclear critics were routinely accused of being communists (Wasserman et al., 1982, ch.7).

For hospital managers/boards and doctors, the main motivations for involvement in nuclear medicine were profit and prestige. Several specialties within medicine began experimenting with radioisotopes: "The added prestige,
training opportunities and facilities for clinical research which isotopes bring to these special units is considerable." (McRae, 1963.) Much could be said about the turf battles between different medical specialties and different occupations for control over nuclear medicine, but that would serve little purpose in this thesis.

The symbiosis between nuclear agencies and medical institutions works both ways. There is a long history of medical practitioners and researchers giving verbal support to the development of nuclear power, weapons and so on. Thus Wagner and Ketchum (1989), nuclear medicine specialists, blow the trumpet not only for medical uses of radiation but also for nuclear power. Brodsky et al. (1995, p.813) claim that the bombing of Nagasaki and Hiroshima "seems to have saved millions of lives", talk about "environmentally clean and safe nuclear power and radioactive waste disposal", and are hostile to nuclear critics. Medical personnel and institutions sometimes strayed from the topic of radioisotope supply in submissions to the Research Reactor Review – for example the Flinders Medical Centre (1993) argued that HIFAR is an "important and prestigious" national facility, and failure to build a new reactor would result in a loss of international status which could be seen as an indicator of Australia's continued slide towards "banana republicanism" and third-world status.

In other cases the support of medical personnel and institutions is more tangible, such as through their involvement in radiation dosimetry research and regulation; this encompasses medical radiation along with many other radiation sources such as reactor emissions and uranium mining. (Stelson et al., 1995; Gofman, 1990).

The most sinister aspect of the symbiosis between medicine and nuclear programs was a series of radiation experiments carried out in the US from 1944-1974. The experiments were funded by a range of institutions including the Defence Department and the US Atomic Energy Commission. At least 31 contentious radiation experiments have come to light, affecting up to 800 people. Dozens of people, including prisoners, mental patients, children, and pregnant women, were injected with small quantities of plutonium. Some cancer patients were injected with uranium – to test the effects of uranium on tumours and/or to determine safe levels of exposure among uranium miners. Between 1961 and 1972 the military sponsored work in which at least 87 cancer patients were irradiated to test the effects of radiation on cognitive and emotional processes. Justifications given for some of the experiments referred to Cold War paranoia and overlapping notions of subjecting a few individuals to risks for the good of society as a whole. In addition to tests performed directly on individuals, a number of tests were
conducted involving the deliberate release of radiation into the atmosphere. (Roberts, 1994; Rhein, 1994; Advisory Committee on Human Radiation Experiments, 1996.) Predictably, the nuclear medicine community has tried to distance itself from these experiments despite the involvement of the medical profession - thus an article on the topic in *The Journal of Nuclear Medicine* was titled "Not Nuclear Medicine" (Miller, 1994B).

Far more widespread than military-medical experiments was the misuse of radiation (radioisotopes and x-rays) as a result of corporate and medical profiteering, tied in with ignorance about the iatrogenic effects of radiation and a willingness to use medical patients as guinea pigs for experimental procedures without informed consent. Questionable experiments carried out in Australia in the 1940s and 1950s, which have received some publicity recently, belong to this category of misuse (Bonnyman, 1994).

While nuclear medicine personnel and institutions have generally been staunch allies of all things nuclear, there has been the occasional dissent. For example in 1978, 74 doctors and scientists involved in nuclear medicine in Australia sent a petition to the federal government expressing their concern, and urging a cautious approach, to nuclear power on the grounds of waste disposal, radiation, pollution, and genetic risks. The petition was a response to attempts by the Citizens for Uranium Export to lobby doctors to support uranium mining and export. (Williams, 1978.) In 1993 the International Physicians for the Prevention of Nuclear War called for a boycott on Siemens medical equipment (which includes nuclear medicine equipment) because of aspects of the company’s involvement in the nuclear power industry. Siemens denies the boycott is having an impact but "industry sources" say it is, particularly in Europe, according to a reporter in the Movement Against Uranium Mining’s magazine *The Third Opinion*. (Anon., 19961.) Another falling out followed from the attempt of the Canadian Control Board to raise permissible radiation levels for workers and the public in 1983-84. All the major unions representing Canada’s 200 000 radiation workers, including medical radiation workers, banded together to oppose the changes which were subsequently dropped. (Babin, 1985, p.17.) One further example is the work of a number of dissident doctors and scientists working in the field of radiation research and regulation (see chapter 8.3). Little is to be made of these examples; they are rare exceptions and there is no sign that the bonds between nuclear medicine and nuclear agencies are becoming more troubled with time.

Despite the support of nuclear agencies in the development of nuclear medicine, and the much greater availability of radioisotopes from research reactors after the
war, nuclear medicine was still a small and weakly-established branch of medicine through the 1950s and early 1960s. Radiation detection equipment was rudimentary and only a handful of applications for radioisotopes had been developed such as the use of iodine-131 for thyroid disorders, chromium for labelling red blood cells, potassium-32 treatment for leukaemia, and cobalt treatment for megaloblastic anaemia. (Kotz, 1995.)

THE POST-WAR DEVELOPMENT OF MEDICAL IMAGING MODALITIES

From the 1890s until the late 1950s, x-radiology was the only medical imaging modality to have progressed beyond a rudimentary stage of development. A thriving industry had developed around x-radiology. Companies manufacturing x-ray equipment were generally satisfied with incremental innovations. Radiologists gradually carved out a secure and comfortable niche within the division of medical labour, and were sufficiently challenged by incremental innovations. In short there was not much impetus for radical innovation in medical imaging. Nevertheless, changes were looming.

Capitalist economies around the world experienced protracted growth in the post World War II generation. Medicine was one sector for capital investment, and companies were in a better position to be risking investment in the development of expensive new technologies. Hospital boards/managers were willing to support the introduction of new technologies, which promised profit and prestige. At the level of medical practice, private and public-sector third-party payment systems were developed and thus there was little or no incentive for doctors or patients to limit the use of medical procedures. (Russell, 1979; Gelijns, 1989; Littrell, 1989; Hancher, 1989; Blume, 1992.)

A variety of professionals gained scientific expertise during World War II and this impacted upon civil science and technology after the war. Atomic research was a major priority in a number of countries in the post-war period; this facilitated the further development of nuclear medicine and was also important in the development of other imaging technologies such as magnetic resonance imaging, ultrasound, and thermography. (Blume, 1992, pp.72-74; Yoxen, 1987.)

With the transfer of military technology and an external environment in many ways conducive to the introduction of new technologies into medicine, there was ample opportunity for the development of new imaging technologies. Industrial and professional interests went to work on a range of technologies; several were successfully integrated into the interorganisational structure of medical imaging.
though inevitably there were some failures such as thermography. Ultrasound and nuclear medicine, and to a lesser extent thermography, had taken shape by the 1960s. Computerised tomography (CT) scanning was just emerging; it was born of and into the world of complex electronics and computers. Developments in those fields opened up possibilities for new imaging technologies and also greatly influenced the speed and scope of existing technologies including nuclear medicine. (Blume, 1992, pp.72-73, 157.)

Diagnostic tests of various sorts have been among the fastest growing areas of medicine (Hamilton, 1982; Pinckney, 1985; Nelkin and Tancredi, 1989). Despite the rhetoric among doctors that verbal consultation and physical examination are the cornerstones of diagnostic medicine, diagnostics has become wedded to a range of technologies. As Kothari and Mehta (1988, p.185) put it:

*Given the ever-expanding arsenal of computerized electronic gadgets - CT scan, auto-analyser, PET scan, NMR scan, ultrasonography - the modern medical man looks like a supersleuth, a Sherlock Holmes backed by a Watson carrying with him the latest off the IBM assembly-line.*

While professional and industrial interests were at the centre of the development of imaging modalities, the role of the capitalist state was also crucial. This support operated at different levels. State funded and/or controlled institutions such as regulatory agencies, health departments, and public hospitals were directly involved in research, regulation, and the application of imaging technologies. The state provided considerable financial support for research and development of new imaging technologies. Typically private-sector research, then as now, focused on incremental innovations whereas the state played a greater role in radical innovations (which may be taken up by private enterprise). (Hamilton, 1982, pp.199-200.)

The various arms of the capitalist state have contradictory goals with respect to medical technologies. The state has an overall interest in maintaining a growing economy and within that a viable medical industry. State support of medicine also serves in the reproduction of labour power, and it dampens political unrest. However the substantial growth of medical spending by the state is seen as an economic burden which must be checked, particularly in the past generation in the context of economic stagnation and the associated austerity drive. This can lead to attempts to control the use of medical technologies and to limit the introduction of new technologies. Thus there are conflicting agendas: promoting a
profitable industry conflicts with regulatory goals such as setting safety standards and keeping costs under control. (Renaud, 1975; Hancher, 1989.)

NUCLEAR MEDICINE AND THE RADIOISOTOPE INDUSTRY

Nuclear medicine caught the wave of development of medical imaging technologies. Thus in Australia, the late 1960s and early 1970s was the "honeymoon period" for nuclear medicine according to the Foundation President of the Australian and New Zealand Society for Nuclear Medicine (Lander, 1972). Interest was growing among doctors, other professionals, hospital administrators, the general public, politicians, and private enterprise. The media was giving "considerable time and space" to nuclear medicine. "Charitable Foundations" and community organisations dug deep to finance nuclear medicine units, and some "outstanding" contributions came from "altruistic individuals". Whatever the motives, there was also some corporate benefaction - for example Searle Nucleonics donated a gamma camera for clinical research. In the two years to 1972 the number of nuclear medicine gamma cameras in Australia rose from two to fifteen and there was also a marked rise in the number of rectilinear and conventional single-headed scanners. (Lander, 1972.)

The earliest uses of medical radioisotopes were therapeutic (and often iatrogenic) - radioisotopes supplied energy rather than information. Until imaging equipment was developed from the 1950s, nuclear medicine was limited to either therapeutic procedures or diagnostic tests of function and flow which generally required sampling body tissues and fluids to determine the distribution of radioactivity, or alternatively the use of simple external counters to detect and quantify radiation levels. Diagnostic procedures gradually became the most frequent application of nuclear medicine. Within the field of diagnostic nuclear medicine, tissue sampling and external quantitative scanning gave way to nuclear imaging. This was facilitated by the development of increasingly sophisticated scanners, research into radiopharmaceuticals which localise in specific organs, and computer technology. (Ganatra and Nofal, 1986; McRae, 1963.)

Rectilinear scanners were the first pieces of equipment used for nuclear imaging. These scanners, introduced in the late 1940s, gradually gave way to gamma cameras from the late 1950s. Both work on the same principle - activation by radiation striking a crystal, usually a sodium iodide crystal. However gamma cameras produce a film without having to scan the patient physically, they can be used for dynamic studies whereas rectilinear scanners cannot, and they give superior resolution to rectilinear scanners. (van Herk, 1986; Ganatra and Nofal,
By the end of the 1960s, gamma cameras were being produced on a commercial scale, often by the same companies involved in the development of equipment for other imaging modalities. A range of increasingly sophisticated imaging cameras has been introduced based on the sodium iodide scintillation crystal – the rectilinear scanner, the gamma camera, the whole body imager or multocrystal scanner, and the single photon emission computed tomographic (SPECT) scanner. (Hamilton, 1982, pp.19-25.) The development of gamma cameras significantly expanded the range of applications of nuclear medicine; similarly, the new generation of gamma cameras, particularly those equipped with SPECT, resulted in a resurgence of nuclear medicine in the 1980s. (Carretta, 1993; Hamilton, 1982, p.35.)

Major advances in computer data acquisition and analysis also took place from the late 1960s, with significant implications for nuclear medicine. (Croft, 1990; Dugdale, 1974; Flakus, 1981.)

Radioisotope production technology underwent considerable growth and development from the 1960s. Reactor radioisotope production involves reactor irradiation facilities, post-irradiation handling and processing (mechanical and chemical), measurement, dispensing, packing, and transport. Innovations took place across the spectrum of these activities. The development of a wider range of radiopharmaceuticals, along with freeze-dried radiopharmaceutical kits which required a minimum of preparation at the hospital, facilitated the growth of nuclear medicine; no longer was it confined to large hospitals with direct access to a radiopharmacy. Such innovations have also facilitated the gradual spread of nuclear medicine to private clinics. (Khafagi, 1992.)

The development of a number of generator systems was particularly important, with the desired radioisotope being "milked" from the longer-lived parent radioisotope at or close to the point of use; this meant that transport time and distance was less of an obstacle. Technetium-99m, drawn from Mo-99/Tc-99m generators, became established as the most common diagnostic imaging radioisotope. This entailed research and development across a range of areas - HEU target technology, target processing, generator technology, and conjugation of Tc-99m with a range of molecules to produce an ever-wider range of Tc-99m radiopharmaceuticals. Whereas in the formative years of nuclear medicine doctors would take whatever radioisotopes they could get, Mo-99/Tc-99m became the radioisotope of choice and supply of this radioisotope became increasingly important. (Stelson et al., 1995; Webb, 1988, pp.10-12; Egan et al., 1994.) Although Tc-99m rapidly became the dominant radioisotope for diagnostic studies, the range
of radioisotopes used in nuclear medicine increased considerably; some important developments were the use of gallium-67 from 1969, thallium-201 (1975), and fluorine-18 (1979). (Egan et al., 1994; Khafagi, 1993.)

Whereas the development of other imaging modalities depended primarily on the symbiotic interests of manufacturing companies and doctors, the symbiosis in radioisotope production and supply was between public-sector nuclear agencies and doctors. A consequence of this was that financial interests were not nearly so important as with other imaging modalities, as indicated by the supply of radioisotopes free of charge. Over the decades this has changed, through two main processes. Under the impact of economic rationalism, nuclear agencies have commercialised radioisotope production and marketing. The practice of supplying radioisotopes at no cost became less frequent though there remains a considerable degree of subsidisation. Secondly, private companies have played an increasingly prominent role in the radioisotope industry.

From the early post-war years a pattern was set in relation to the involvement of private companies in the radioisotope industry. The pattern was (and is) for nuclear agencies to produce radioisotopes and private radiopharmaceutical companies to assume intermediary roles - processing, packaging, transport, and finally supplying radioisotopes to hospitals. This pattern remains the norm today. The radiopharmaceutical companies are involved in, or have links to, the pharmaceutical industry, and they generally supply hospitals with radioisotopes and pharmaceuticals or with pre-mixed radiopharmaceuticals. The radiopharmaceutical companies have significantly affected the radioisotope industry in a number of ways. They have played a role in product research and thus increased the number of products being used in nuclear medicine. They have consolidated and expanded the market for medical radioisotopes, in the process securing nuclear medicine's place within the field of diagnostic imaging. They have developed global supply chains: domestic producers increasingly find themselves in competition with foreign suppliers. They act as a significant constituency for public-sector radioisotope production (except when it competes with their own radioisotope production operations). A number of radiopharmaceutical companies own and operate cyclotrons dedicated to radioisotope manufacture, and some of the larger companies have begun to play a greater direct role in reactor radioisotope production in the past decade.

As well as the movement of radiopharmaceutical companies into radioisotope production, they have also assumed more of the functions previously carried out in hospitals and now supply doctors with ready-to-use doses of radiopharma-
ceuticals. In short, the divisions within the industry – bulk radioisotope production (nuclear agencies), intermediary processing and transport (radiopharmaceutical companies), and final processing (hospitals) – have become far less neat.

The growth of a number of imaging modalities has slowed over the past 10-20 years. At the broadest level this has been a consequence of economic forces, with capitalist economies moving in and out of recession. There has been less opportunity for the development of new imaging modalities, with the cost of developing new advanced systems having increased considerably. Market saturation has occurred with some modalities, forcing some companies out of the imaging industry. Another check on the growth of imaging modalities has been cut-backs in government funding for R&D, and the various methods used by governments to limit health-care spending, with expensive technologies being an obvious target.

Radioisotope production has not been affected in the same way as other aspects of the medical imaging industry, for reasons such as the primacy of public-sector nuclear agencies in radioisotope production (and their partial immunity from market forces), and the need for ongoing radioisotope supply which makes market saturation less of a problem in comparison with imaging equipment. Nevertheless radioisotope production has felt the squeeze. Despite the fact that most of the 60+ countries to have operated research reactors have used them for radioisotope production, among other purposes, the commercial export trade has always been far more concentrated. There are many reasons for this, such as the modest size of the world radioisotope market and the inadequacy of many research reactors for production of high specific activity radioisotopes. In the early 1990s the concentration was such that a Canadian company supplied almost all of world demand for Mo-99; if there had been protracted problems with that operation there could have been a major worldwide shortage of Mo-99/Tc-99m.

The Research Reactor Review (1993, p.91) neatly summed up the current, messy situation in the radioisotope industry. It said that the global radioisotope market is in a very dynamic state, and there is no certainty how things will change. All aspects of supply, logistics, usage, and price are in flux. Enough reactors exist to supply or even over-supply the market depending on priorities of reactor usage. The Review said that the one predictable variable is that demand for radioisotopes will increase, but even that is questionable in the medium to long term as will be discussed in chapter seven.
6.1. INTRODUCTION

In the absence of a research reactor in Australia, domestic cyclotrons will be able to fill the void to some extent for supply of medical radioisotopes, and perhaps in time cyclotrons will supersede reactors for radioisotope production. In addition, there would almost certainly be greater reliance on alternative medical technologies, in particular diagnostic imaging modalities other than nuclear medicine, in the absence of a domestic reactor. Despite these alternatives, there would certainly be considerable reliance on imported reactor radioisotopes in the absence of a domestic reactor, at least until such time as non-reactor production methods are further advanced.

Whether a substantial reliance on imported radioisotopes is feasible depends on reactor radioisotope production overseas. Since the global radioisotope industry is in a state of considerable flux, and information on the industry is scarce, a detailed look at overseas reactor radioisotope production is necessary and that is the purpose of this chapter. Firstly, the major radioisotope producers and exporters are discussed. Then I turn to smaller radioisotope production operations, which necessitates some general discussion of research reactors around the world, followed by regional summaries of reactor radioisotope production.

SOURCES OF INFORMATION

As discussed in chapter 5.1, there have been hardly any critical analyses of the radioisotope industry (or nuclear medicine). Several reasons can be suggested for this. Firstly, the radioisotope industry is modest in scale. Similarly, nuclear medicine accounts for only a small percentage (about 5-10%) of diagnostic imaging procedures, and therapeutic nuclear medicine is even less common, generally accounting for just 1-2% of all nuclear medicine procedures. (Styles, 1993; Ell, 1992.) Secondly, the radioisotope industry is fundamentally different to the industries associated with medical imaging equipment (in particular cameras and...
computers), and thus tends to be ignored in the literature on medical imaging and even in the literature on nuclear medicine. Thirdly, inertia has no doubt played a role - there have been hardly any attempts to even begin to analyse the radioisotope industry and this has become self-perpetuating. A fourth reason is that the industry is difficult to analyse because it is complex, fluid, and fragmented.

A fifth reason for the paucity of analyses of the radioisotope industry is that it is difficult to compile empirical information on the industry. Partly this is because of the fluid and fragmented nature of the industry. Another reason is that, despite the large number of radioisotope producers around the world, there are very few organisations involved in the commercial production and export of the most common medical radioisotopes, in particular Mo-99. Thus the industry is, at one and the same time, fragmented and concentrated. As Berkhout (1993) and Travelli (quoted in Rojas-Burke, 1993D) note, organisations involved in the commercial radioisotope industry are few in number and reluctant to divulge information on their activities. Apart from commercial confidentiality, another factor limiting access to information is the culture of secrecy which has traditionally surrounded nuclear agencies to a greater or lesser extent. I suspect that a third reason that a number of organisations have refused or ignored my requests for information is a simple lack of interest in the academic pursuits of an Australian PhD student. One final difficulty has been language barriers, which have limited and confused some communications.

A number of organisations have more detailed information on radioisotope production around the world than the following survey, but have not been prepared to provide me with that information. The following survey is, as far as I know, the most comprehensive one available in the publicly-accessible literature.

The secrecy of commercial radioisotope producers is not absolute - many organisations have responded to my requests for information. In addition, much information is available in publicly-accessible literature such as professional journals. Nevertheless, lack of information is certainly a limitation. In a volatile industry where the future of just one (existing or planned) reactor can have ramifications for radioisotope users around the world, it is of course important to pay attention to the accuracy, currency, and comprehensiveness of information. My approach has been to put considerable effort into the acquisition of information, and to make it clear when information gaps cast doubt on the analysis.
Specifically, the research strategies used to compile information for chapters 6-8 are as follows:

- analysis of books, journal articles (especially the nuclear medicine journals), annual reports and other literature from nuclear agencies and radiopharmaceutical companies; and
- phone calls and written correspondence with a wide range of people involved in radioisotope production and processing (i.e. nuclear agencies and radiopharmaceutical companies) in Australia and overseas, and to a lesser extent with (nuclear and medical) researchers and doctors practising nuclear medicine.

My primary concern has been to compile comprehensive, current and accurate information on the major global radioisotope producers, which supply well over 95% of the world market for medical radioisotopes (see section 6.2). Despite some minor information gaps, this has been achieved.

In addition, I contacted nuclear agencies and/or radioisotope companies in all countries operating medium or high-powered research reactors, asking for (further) information on radioisotope production and supply. Approximately 50% of these requests were answered. While there are information gaps as a result of the failure of some agencies/companies to respond, these gaps do not significantly detract from the survey in this chapter or the analysis in chapter seven: sufficient information has been obtained on the major global producers, and the available information on other producers is adequate for my purposes.

6.2. THE MAJOR RADIOISOTOPE PRODUCERS

NORDION INTERNATIONAL
INSTITUTE NATIONAL DES RADIOELEMENTS
MALLINCKRODT
AMERSHAM
SOUTH AFRICAN ATOMIC ENERGY COMMISSION

NORDION INTERNATIONAL

In 1948 the Canadian government created a nuclear agency, Atomic Energy of Canada Limited (AECL). Thus began the development of a major nuclear power industry. The Radiochemical Company, formed as part of AECL, expanded and diversified its operations and gradually became the world’s leading supplier of radioisotopes and nuclear-based industrial products. In 1988, as part of a broader
trend towards divestment and privatisation of government activities, AECL was restructured and the Radiochemical Company was privatised and renamed Nordion International. (ANSTO, 1993F, Annex 7.1.1.)

The NRU research reactor, which AECL uses to supply Nordion, is located at AECL’s facilities at Chalk River, Ontario. Nordion is based in Kanata, Ontario. It has approximately 700 employees, with a further 100 employees based at Nordion’s European headquarters in Belgium. (ANSTO, 1993F, Annex 7.1.1.)

As at 1993, Nordion was owned by the following groups: 80% by MDS Healthcare; 14.9% by Amersham; and the remaining 5.1% owned by former Radiochemical Company employees. MDS bought Amersham’s 14.9% share in March 1995 for $C 17.6 million. (MDS Healthcare, 1995.)

MDS revenue in the fiscal year 1994-95 was $C 689 million – but that figure represents sales across a range of medical and life science technologies, not just radioisotope sales. (Anon., 1996C.) Nordion and AECL Annual Reports mentioned radioisotope sales of $C 162 million in 1991/92, with 23% annual growth.63 (ANSTO, 1993F, Annex 7.1.2.)

Nordion has a small number of subsidiary or affiliated organisations: Cyberfluor Inc (100%); Medgenix Diagnostics (100%); Nordion Europe (100%); and Resolution Pharmaceuticals Inc. (50%). (ANSTO, 1993F, Annex 7.1.1.)

The extent of Nordion’s current activities in Europe is unclear. In 1994 MDS/Nordion sold "certain contracts and intangible assets" relating to its European radiopharmaceutical business to Du Pont. Thus Du Pont has assumed sales and marketing responsibilities in Europe, with bulk supply from Nordion. (MDS Healthcare, 1995.) Nordion (1994) says it is supplied with some radioisotopes from four European reactors, which almost certainly ties in with an arrangement it has with the Belgian Institute National des Radioelements (IRE) for back-up supply. Nordion also has an a supply agreement with the operator of the Belgian BR-2 reactor (discussed below).

Over 90% of Nordion’s sales are to export markets in more than 100 countries. All of Nordion’s production and processing facilities are located in North America and Europe, but supply chains stretch all around the world. Nordion supplies about two thirds of the world demand for reactor radioisotopes – including Mo-99

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63 It is highly unlikely that this growth rate has been maintained. In the early 1990s, Nordion profited from the closure of a number of reactors used by its competitors.
and cobalt-60. Nordion also markets cyclotron radioisotopes. At its Vancouver site, Nordion operates two cyclotrons which are dedicated to radioisotope production, and Nordion also has access to the large production and research cyclotron operated by TRIUMF (Tri University Meson Facility) in Vancouver. Another two cyclotrons operate at Nordion's Belgian facilities. (Nordion, 1994.)

As well as supplying bulk radioisotopes, Nordion produces a "growing line of finished radiopharmaceuticals". As with other major radiopharmaceutical companies, Nordion has close links with pharmaceutical producers including some of its subsidiary organisations. Nordion also produces a range of clinical and research irradiator and over half the world's gamma radiation processing equipment. (ANSTO, 1993F, p.7.4, Annex 7.1.1; Nordion, 1994.) In short Nordion is a major producer of radioisotopes and equipment for medical and industrial purposes.


Nordion has relied on two reactors in Canada, NRX and NRU, which are owned and operated by AECL. (ANSTO, 1993F, p.7.4.) The National Research Xperimental (NRX) reactor was built in 1947. It was essentially a pilot factory for the production of plutonium, which was supplied to the US until 1963 (Babin, 1985, pp.35-44). NRX was involved in an accident in 1952. A power excursion destroyed the core of the reactor, causing some fuel melting. The core of the reactor was buried as waste. Hundreds of US and Canadian servicemen were ordered to participate in the clean-up. (Edwards, n.d.) According to ANSTO (1993L, pp.3.16-3.17), the accident led to a significant release of radioactivity, but there were no reported injuries. NRX was rebuilt and operated until early 1992 when it was permanently shut down. It was used for radioisotope production at various stages of its life, primarily as a back-up to NRU.

The National Research Universal (NRU) reactor first went critical in late 1957. In 1958 there was a fire in the NRU reactor which badly contaminated the inside of the reactor building with some release of radioactivity outside the building.
Several fuel rods overheated and ruptured, one catching fire. The ventilation system was jammed in the open position, thus allowing the spread of radioactivity down-wind from the reactor site. The burning fuel rod was extinguished by a relay team of scientists and technicians running past the maintenance pit and dumping buckets of wet sand on it. Over 600 men were involved in the clean-up. AECL claims that very few men were exposed to radiation doses exceeding the then permissible levels. It also claims that no adverse health effects were caused by the exposures received. The methodology for this second conclusion was the ostrich technique: no follow-up studies were carried out, the men involved in the clean-up were told to observe strict secrecy about the operation, claims that adverse health effects were linked to the clean-up were vigorously denied, and AECL has refused to supply information that would assist in the location of men involved in the clean-up and thus facilitate follow-up studies. (Edwards, n.d.)

After this inauspicious beginning, NRU has had a less troubled history, though not one without incident. Recently AECL was boasting that NRU had achieved 1000 days of operation without a shut-down of more than 130 hours (AECL, 1994-95). A high-power (135 MW), high-flux (4.0 x 10^{14} neutrons/cm^2/second) reactor, fuelled with 20% LEU fuel, NRU is well suited for radioisotope production. NRU produces most of Nordion's radioisotopes, with a smaller volume coming from European reactors. Indeed NRU alone is capable of producing two times the world requirements for medical isotopes including Mo-99 (Nordion, 1995, pers. comm.). As well as being used for radioisotope production, NRU is used extensively for testing of fuel and reactor components for power reactors (ANSTO, 1993L, p.3.10).

Because of its role as the production facility for a high proportion of world demand for radioisotopes, there has been concern that problems with NRU could lead to radioisotope shortages around the world. Serious, protracted shortages are less likely now, because a number of commercial producers have entered or re-entered the market in the past few years, but in the late 1980s and early 1990s the situation was precarious. A number of reactors used for commercial radioisotope production, including Mo-99 production, were permanently shut down within the space of two years. These included the DIDO and PLUTO reactors in the UK, Nordion's NRX reactor, and the reactor in New York, owned by the Cintichem company, which supplied about half the US Mo-99 market (the other half supplied by Nordion).

Since the late 1980s, when NRU assumed such importance, AECL managed to maintain continuous supply of radioisotopes, except for one or two brief periods.
which caused no significant shortages. In 1988 the US Department of Energy (DOE) stopped supplying HEU targets for a few weeks but this did not stop production (Harby, 1988). In January 1991, AECL stopped production for two days due to a leaking coolant pipe in the reactor building. In October 1991, there was no problem with supply from AECL but there was a labour strike at Nordion, during which company managers processed radioisotope products. In a labour dispute at AECL in July 1992, management and union officials reached a settlement only hours before the 150 reactor operators at the Chalk River facilities were set to strike. (Rojas-Burke, 1992.) In April 1994 a fuel rod became stuck in NRU. Production stopped for five days. Nordion maintained shipments by calling on its back-up agreement with IRE in Belgium. (Rojas-Burke, 1995.) In mid 1995, a mechanical system in NRU jammed and the reactor had to be shut down for repairs. Operation resumed within a few days. Once again Nordion drew on a back-up agreement with a European producer (probably either IRE or the Belgian reactor operator SCK-CEN) to maintain supply. (Seidel, 1995.) Plans were developed for a major refurbishment of NRU which would allow it to operate well beyond its 50th birthday in 1997. These plans were dropped however, and NRU will be permanently shut down early in the next century. Nordion has explored the possibility of securing contracts for bulk radioisotope supply (in particular Mo-99) from overseas reactors. The mutual back-up agreement with IRE was struck in 1993. Nordion has also considered collaboration with nuclear agencies in the US (Oak Ridge National Laboratory) and Peru, but these negotiations led to nothing. During the threatened 1992 strike at AECL, Canadian embassy officials, among others, were negotiating possible shipments of HEU targets to Indonesia for irradiation then shipment back to Nordion for processing. In addition to some supply from Belgium, this may have averted supply shortages in the case of a strike. (Rojas-Burke, 1992.)

Nordion's main strategy to maintain its market position beyond the operating life of NRU has been to pursue the construction of new reactors in Canada. When Nordion was privatised in 1988, an agreement was reached for AECL to supply Nordion with radioisotopes for 23 years, extending to the year 2011. (MDS Healthcare, 1995.) In 1990, AECL began construction of a Maple-X research reactor which was to be dedicated to radioisotope production. AECL reportedly spent $C 40 million on the Maple-X project, but by the mid 1990s the reactor itself had not been built and AECL decided to abandon the project, claiming that market demand for radioisotopes was insufficient to justify the costs. (Radioactive waste disposal problems may have been another factor.) Nordion and MDS Healthcare took AECL and the Canadian government to court over the issue. An out-of-court
agreement was finally reached in mid 1996. Under the 20 year agreement, the Canadian government will directly provide $C 5 million for the construction of two 10 MW Maple reactors and further radioisotope processing facilities, and it will provide a fully-repayable, interest-free $C 100 million loan to MDS/Nordion. The second Maple will be a back-up facility. AECL will also contribute $C 12.5 million to the $C 140 million project. Thus the project is to be funded mostly by MDS/Nordion, but with considerable support from the government and AECL. The reactors are to be built at Chalk River by AECL, and operated by AECL under overall management from Nordion. The first Maple is expected to begin operation in 1999 and the second a year later. NRU will not be shut down until the Maples are operating. (AECL, 1996; Anon., 1994D; 1996C; ANSTO, 1996B; Nordion, 1995, pers. comm.)

The Maples will mainly be used to produce Mo-99, but may also produce other radioisotopes such as cobalt-60, iridium-192, iodine-131, and iodine-125. Market demand will determine volumes and variety. The 10 MW Maples are considerably less powerful than NRX and NRU in terms of megawattage, but with advances in technology, and the Maples being purpose built for, and dedicated to, radioisotope production, Nordion will have the capacity to remain a major producer and exporter of radioisotopes. In fact Nordion is likely to have the reactor capacity to supply the entire world demand for Mo-99 for some decades to come, but with competitors emerging its share of the market has already dropped and may continue to do so. (Lewis, 1996; Anon., 1996C; Rojas-Burke, 1995.) The (new) agreement between AECL and Nordion expires in 2016 but it can safely be predicted that the Maples will continue to be used for commercial radioisotope production well beyond that date. According to MDS, the Maples will ensure reliable, uninterrupted supply "well into the next century". (Anon., 1996C.)

As at 1993 the plan was to fuel the Maple-X reactor with 93% enriched HEU fuel supplied by the US (INSC, n.d.). Whether that is still the intention is unclear, but it goes against the trend towards the use of LEU fuels for research reactors because of the weapons implications of the HEU economy, and Canada is reliant on the US for enriched fuel since it has no enrichment facilities of its own.

The profitability of the Maple venture cannot be assumed. AECL appears to have its doubts. According to an Amersham representative (quoted in Anon., 1995E), Nordion would not break even on their investment in the Maple reactors and processing facilities for at least 15 years. Recently Nordion increased prices to generate funds to pay for its investment. The price increase was expected to be
"40% or less" for Mo-99 according to a Nordion representative (quoted in Anon., 1995E).

Evidently, neither the radiopharmaceutical companies nor users (hospitals, clinics) have objected to Nordion's price increase, even though they are operating in an environment of economic constraint. The return for the price increase is greatly increased, long-term security of supply. Moreover bulk Mo-99 accounts for only 30-60% (depending on generator size) of the cost of manufacturing Mo-99/Tc-99m generators. (Rojas-Burke, 1995.) Thus increases in the price of bulk Mo-99 do not lead to directly proportional increases in generator costs - the expectation was that Nordion's expected 40% price increase would lead to generator price increases in the order of 20-25% for large generators, 8-10% for smaller generators, and 6-7% for unit doses of Tc-99m. The price for bulk Mo-99 breaks down to just a few dollars for each Tc-99m procedure. Some less commonly used radioisotopes (e.g. iodine-131) are far more expensive per unit dose, and the pharmaceuticals (localising agents, etc.) which are tagged with radioisotopes comprise a considerable proportion of overall costs. Overall, it was expected that the price increases for Mo-99 would have only a modest impact on overall radiopharmaceutical budgets - about 3% for large nuclear medicine departments and up to 7% for smaller departments. (Anon., 1995E; Rojas-Burke, 1995.)

Nordion is largely reliant on Canadian reactors. It also draws from the Belgian BR-2 reactor which is owned and operated by the Belgium Nuclear Research Centre, SCK-CEN. ANSTO (1993F, Annex 7.1.1) says that Nordion has an exclusive supply agreement in relation to the BR-2 reactor. It is a high-flux (up to 10^{15} n/cm^2/sec), high-power (100 MW) materials testing reactor using 93% HEU fuel, with facilities for simultaneous irradiation of up to nine targets for radioisotope production. (Koonen, 1995.)

BR-2 first went critical in 1961. A major refurbishment of the reactor began in 1995. This has taken place under the oversight of SCK-CEN. The refurbishment has more to do with safety and regulatory concerns than performance upgrading. Operation was expected to recommence in April, 1997. Future radioisotope production will depend on several factors. One is conflicting demands. According to SCK-CEN (1997, pers. comm.), production of radioisotopes "will continue after the refurbishment if compatible with the operating regime". However it is unlikely that BR-2 will be so overwhelmed with conflicting demands that radioisotope production will cease altogether. The reactor will remain capable of substantial radioisotope production when it is restarted, and SCK-CEN (1997, pers. comm.) expects to recommence Mo-99 production. Another variable is demand. A
number of substantial commercial Mo-99 production ventures have begun in the past few years, and thus the main role of BR-2 may be as a back-up. If there is little demand for Mo-99, BR-2 may be used for production of other radioisotopes. It has been used to produce iodine-131, xenon-133, cobalt-60, and others on demand (SCK-CEN, 1997, pers. comm.). The operating regime will be reduced from 168 days per year (8x21) to about 105 (5x21), and this may be disadvantageous for radioisotope production, especially for short-lived radioisotopes for which continuity of production is particularly important. BR-2 is expected to operate until about 2010-2015 (Gubel, 1995).

Nordion is able to use its strong position in the Mo-99 market to advantage. For example Du Pont, a major radiopharmaceutical company, signed an agreement in the early 1990s which commits it to using Nordion as sole supplier of bulk Mo-99 for 10 years. (Rojas-Burke, 1992; MDS Healthcare, 1995.) Nordion has a history of being aggressive in the marketplace. It is likely to be still more aggressive in future given the scale of its recent investment and the increasingly competitive environment in which it will be operating.

INSTITUTE NATIONAL DES RADIOELEMENTS

A European firm, the Institute National des Radioelements (IRE) has been a supplier of Mo-99 and other radioisotopes since 1978. IRE operates a plant in Belgium. This plant relies on reactor irradiation of targets in four European research reactors; the targets are purified and processed in Belgium. (Anon., 1994B.) According to one report the four reactors are Osiris (France), HFR (probably the 57 MW French HFR reactor), Siloe (France) and Petten (the Petten HFR reactor in the Netherlands) (Iturralde, 1996). Evidently the Belgian BR-2 reactor is not one of IRE's sources but that is not certain.

The exact relationship between Nordion Europe, IRE, and the operators of the four European research reactors cannot be pieced together with certainty - available information is incomplete and sometimes contradictory. According to Berkhout (1993), IRE is part-owned by Nordion. Certainly there is a back-up agreement between Nordion and IRE. Apart from the back-up agreement, it seems that Nordion Europe distributes most of IRE's radioisotope products, negotiating distribution agreements and market prices with potential consumers (Anon., 1994B). The four European reactors which Nordion (1994) says it draws from are almost certainly those which IRE draws from. Whether Du Pont has taken over any of these functions from Nordion Europe is unclear but it is quite likely.
Several years ago, IRE's weekly production was just over 1000 Ci/week of Mo-99 with possible production of up to 3000 Ci/week. (Anon., 1994B.) Thus IRE's annual output was roughly 50 000 Ci or close to 10% of world production (up to 30% at maximum production).

MALLINCKRODT

Mallinckrodt was formed in the 1880s as a chemical company. It began its involvement in medical products in the early 1900s - an x-ray contrast medium was one of its major medical products. Mallinckrodt was also involved in the uranium industry from World War II to 1967, especially in enrichment. (Mallinckrodt, 1996.)

Based in the Netherlands, Mallinckrodt has total global sales (as at the mid 1990s) of about $US 2 billion p.a. in three divisions - Mallinckrodt Chemical, Mallinckrodt Medical and Mallinckrodt Veterinary. A series of mergers and takeovers affected Mallinckrodt in the 1980s and 1990s. About 10 000 people are employed worldwide. Mallinckrodt Medical is responsible for about half of total staff and sales ($US 1 billion in fiscal 1995). (Mallinckrodt, 1996.) Radiopharmaceutical sales were $US 160 million in 1991 (ANSTO, 1993F, Annex 7.1.3). The rest of Mallinckrodt Medical's sales are spread across a range of products such as x-ray contrast media and pharmaceuticals (some of which are supplied as "cold kits" to be mixed with radioisotopes in hospitals).

Mallinckrodt has radioisotope processing facilities in the US (St. Louis) and at Petten in the Netherlands. Over two dozen nuclear medicine products are marketed, and Mallinckrodt is also involved in research leading to new products. (ANSTO, 1993F, Annex 7.1.3.) As well as its involvement in reactor radioisotope production and processing, Mallinckrodt operates two cyclotrons at the Petten site, one in operation since 1966 and another completed in 1993. Thus Mallinckrodt produces and processes a range of reactor and cyclotron radioisotopes including Mo-99/Tc-99m generators and radiopharmaceuticals based on gallium-67, indium-111, iodine-123, iodine-131, phosphorus-32, rhenium-186, thallium-201, xenon-133, and krypton-81. Mallinckrodt has traditionally played a greater role in radioisotope processing and retailing rather than production. In the US it operates Diagnostic Imaging Services, a network of regional radiopharmacies that supply pre-mixed, ready-to-use radiopharmaceuticals. (A similar network of radiopharmacies probably operates in Europe.) Another facet of Mallinckrodt's involvement in the industry in the US is a subsidiary called Nuclear Medicine
Associates, a team of medical physics consultants who offer expert advice on issues such as federal licensing. (Mallinckrodt, 1996.)

Until recently Mallinckrodt has relied on Nordion for supply of bulk Mo-99 and other reactor radioisotopes. From the early to mid 1990s Mallinckrodt has brought to fruition a project to produce its own reactor radioisotopes. The reactor is the HEU-fuelled High Flux Reactor (HFR) at Petten, which first went critical in 1961. It is one of the few high-power (45 MW), high-flux (2.7x10^14 n/cm^2/sec), materials testing reactors still in operation in Europe. (Anon., 1994; IAEA, 1994.) Most of the impetus for this project has been Mo-99 production, but some other radioisotopes are also produced.

Along with Mallinckrodt, two other organisations are involved in the Petten nuclear facilities. One is the Energy Research Foundation ECN, which is involved in research and development connected to various energy systems. The other is the Joint Research Centre (JRC) of the European Commission, which uses HFR for research, in particular for high-temperature materials research. The JRC (formerly Euratom) is the owner and licensee of HFR but operation is entrusted to ECN. (Mallinckrodt, 1996.) ANSTO (1993L, pp.3.24-3.25.) says that 13% of HFR usage is devoted to radioisotope production, without specifying how this figure was arrived at.

Mallinckrodt's HFR venture almost certainly required some modification to the reactor to facilitate target irradiation. It seems that a more expensive and complicated aspect of the project was the building of facilities to process irradiated HEU targets (for Mo-99, iodine-131, etc.). The processing plant is adjacent to the reactor, with two lines of five hot cells for separation of Mo-99 from irradiated targets. The targets are then returned to the UK for reprocessing. According to Mallinckrodt (1996), the Mo-99 plant was built "together with ECN". According to another report, Mallinckrodt formed a corporation with the Dutch government's Radioactive Waste Research Centre to construct the plant (Anon., 1994C). This Radioactive Waste Research Centre probably refers to ECN.

The financial relationship between Mallinckrodt, ECN, and the JCR is unclear, but the project seems to have worked to the advantage of all three organisations. Mallinckrodt has acquired a reactor production facility without having to start from scratch. The JCR and ECN benefit from Mallinckrodt's involvement because radioisotope production represents the main source of income from work from third parties, and this is a "strong support" for the future of HFR (European Commission, 1996).
Vermeeren (quoted in Anon., 1994), General Manager of Mallinckrodt's nuclear medicine division, said that the company was reluctant to get involved in bulk Mo-99 production, mainly because the use of HEU (used as targets) is highly regulated, and also because of the costs associated with handling and storage of high-level waste. On the other hand as a major supplier of Mo-99/Tc-99m generators and radiopharmaceuticals, having its own production facility potentially had cost and security-of-supply advantages. Moreover the HFR reactor was available for use, and a company was already operating to remove high-level wastes from the Petten site. (Anon., 1994; Mallinckrodt, 1996.)

Over the years Mallinckrodt has become a major supplier of radioisotopes and radiopharmaceutical products to the European and US markets. Using HFR, Mallinckrodt supplies over 60% of European demand for medical radioisotopes – this amounts to 5 million procedures p.a. (European Commission, 1996). In addition, Mallinckrodt supplies about 20% of the Mo-99 market in the US. Overall, it supplied about 25% of the world Mo-99 market as at 1995. (Rojas-Burke, 1995.)

In 1996 Mallinckrodt was the second largest commercial producer of medical radioisotopes in the world, after Nordion, and it may maintain that position for some years to come. It is not likely to challenge Nordion's dominance for the simple reason that it seems not to be interested in competing with Nordion. According to Vermeeren (quoted in Rojas-Burke, 1995), Mallinckrodt plans to produce no more Mo-99 than will suffice for supply of their own customers in Europe and the US. It could however produce more – Vermeeren said that in the event of disruption of supply from Canada, "it would be possible for IRE and Mallinckrodt to crank up production to supply the world." Possibly the reason Mallinckrodt is not competing for Nordion's market share is to maintain good relations – Nordion will be a back-up supplier in the case of problems with HFR. (Anon., 1994).

In the early 1990s Mallinckrodt was involved in a project to produce Mo-99 in the US. This involved negotiations with the US Department of Energy (DOE), but Mallinckrodt pulled out because those negotiations were troubled and protracted and the possibility of using the HFR reactor emerged. As at 1994, involvement in bulk reactor radioisotope production in the US remained a possibility (Anon., 1994). That would seem to be even less likely now that the DOE has recently begun a project for Mo-99 production in the US without any direct involvement from Mallinckrodt or other radiopharmaceutical companies.
Despite its age, there is no sign that HFR will be shut down in the near term - major refurbishments have been carried out and more are in train (European Commission, 1996). One possible cloud over the future of the reactor is that it uses HEU fuel. In response to pressure from anti-nuclear groups, and enactment of a US law, further exports of HEU from the US to the Petten site have been blocked. This is potentially a problem but other suppliers of HEU can probably be found or the reactor could be converted to LEU fuel. (Nuclear Control Institute, 1996; Leventhal and Kuperman, 1995.) Another possible concern is that two slight earthquakes in the neighbourhood of HFR, induced by natural gas exploitation, have given rise to a review of earthquake safety (European Commission, 1996).

**AMERSHAM**

Amersham does not produce the same volume of radioisotopes as Nordion or Mallinckrodt, but it is worth discussing for several reasons: it has some direct involvement in reactor and cyclotron radioisotope production; it is one of the biggest global processing/retailing radiopharmaceutical companies; and it is one of a small number of foreign suppliers of the Australian market.

Amersham's involvement in the radioisotope industry dates from the 1940s. It was a wholly-owned subsidiary of the UK Atomic Energy Authority but was privatised in 1982. (Amersham, 1993.) When DIDO and PLUTO were permanently shut down in 1990, Amersham lost its domestic source of radioisotopes. Britain changed from being a modest net exporter of radioisotopes to an importer, but this did not have much effect and Amersham posted its first profit since privatisation in 1992. (Berkhout, 1993.)

Amersham's sales were over £270 million in 1991/92. (ANSTO, 1993F, Annex 7.1.3.) Medical products, such as radioisotopes and cold kits, comprise most of Amersham's sales.

Amersham has radioisotope production and processing sites in the UK, Germany, and North America. It now operates eight commercial cyclotrons dedicated to radioisotope production. (Amersham, 1993; 1996.) As for reactor radioisotopes, Amersham's main strategy after the shut down of DIDO and PLUTO was to diversify its supply sources. As at 1993 it was being supplied by eight or nine reactors around the world, including reactors in Canada, Sweden, Belgium, France, Russia, and possibly elsewhere. (Amersham, 1993; Diesendorf, 1993.) Despite selling its 14.9% stake in Nordion to MDS in 1995, Amersham still has a
long-term supply agreement and Nordion is no doubt one of Amersham's major suppliers. According to the Research Reactor Review (1993, p.92), Amersham was "in the process of seeking arrangements with .... Indonesian reactors." This must refer to the 30 MW RSG-GAS reactor in Indonesia.

Amersham is involved in a joint venture in Russia. After two years of negotiation, Reviss Services was formed in April 1992 as a joint venture between Amersham, the radioisotope producer Mayak Production Association, and AO Techsnabexport (the export trade organisation of the Russian Ministry of Atomic Industry). The purpose of Reviss Services is to produce radioisotopes in Russia and market them worldwide. The three organisations had collaborated for some years but it was only in 1990 that a formal partnership became possible. As at 1992, the major radioisotopes produced and marketed by Reviss were cobalt-60 for industrial and medical sterilisation, tritium for molecular labelling, caesium-137 for medical and industrial applications, carbon-14 for molecular labelling, americium-241 for smoke detectors and krypton-85 for gauging. Radioisotopes from Reviss are used by Amersham for radiopharmaceutical production, and Reviss also supplies bulk radioisotopes to other manufacturers and research organisations. As well as using common target irradiation techniques, some radioisotopes are produced as by-products from nuclear fuel reprocessing operations using chemical and ion exchange technology. (Latham, 1992.)

The Mayak complex is located at Chelyabinsk in the Ural mountains. It had previously been a top-secret military installation - the city serving the plant did not officially exist. One of the purposes of the plant was plutonium production, with five reactors and a legacy of radioactive waste (some of it dumped in the nearby Lake Karachai). The Deputy General Manager of Reviss claims that funds generated from the joint venture is available for investment in programs to ameliorate the radioactive waste legacy. (Latham, 1992.)

Amersham is a 20% shareholder of Nihon Medi-Physics, one of the two major radiopharmaceutical companies supplying the large Japanese market. (Nihon Medi-Physics, 1995, pers. comm.) Also in Japan, Amersham KK, a 65% owned subsidiary of Amersham, is involved in marketing and sales of a range of products including radiopharmaceuticals. Amersham also has a 51% stake in Medi-Physics, which has a network of more than 100 radiopharmacies across North America and is one of the three major radiopharmaceutical companies supplying the US market. Both Medi-Physics and Nihon Medi-Physics manufacture Mo-99/Tc-99m generators along with many other products, and both operate cyclotrons, but both are dependent on other organisations for supply of
bulk reactors radioisotopes (as is Amersham to a large extent). (Medi-Physics and Nihon Medi-Physics have no connection with each other apart from Amersham's part ownership of both companies.) Amersham's radioisotope processing facility in Germany is used to supply a number of Western and Eastern European countries. Thus Amersham has significant involvement in supply of the three major markets around the world - North America, Japan, and Europe. In total Amersham has 15 foreign subsidiary companies and 40 distributors' offices, delivering radioisotopes to over 150 countries. Historically Amersham's focus has been on the UK and European markets but it has clearly extended its reach right around the world. Amersham has, or at least claims to have, a very good record in the research and development of new products. (Amersham, 1993; 1996; ANSTO, 1993F, Annex 7.1.3.)

SOUTH AFRICAN ATOMIC ENERGY COMMISSION

The South African Atomic Energy Commission (SAAEC) operates the 20 MW multipurpose reactor, Safari I. It is one of the few reactors in the world used for commercial, export production of fission-product Mo-99, and it is also used for production of iodine-131 and a number of other radioisotopes. Processing facilities enable manufacture of Mo-99/Tc-99m generators and various pharmaceutical labelling kits. Production of fission Mo-99 began in 1993, and production levels have increased to service a growing export market. As at early 1997, the SAAEC had routine (continuous) export contracts for Mo-99 (and some other radioisotopes) with China, Israel, and India. In addition, the SAAEC has made many ad hoc shipments to Argentina (CNEA), the Netherlands (Mallinckrodt), Belgium (IRE), Australia (ARI) and Taiwan (INER). The SAAEC has submitted "Drug Master Files" to regulators in Europe, the US, and Australia, indicating a willingness to supply these markets. As at early 1997, there was a demonstrated fission Mo-99 production capacity of 1500 Ci/week (6 days precalibrated), roughly 10-15% of world demand, and there is a short-term objective of supplying 15-20% of the world market. (Anon., 1996E; SAAEC, 1996; Iturralde, 1996; SAAEC, 1997, pers. comm.)

Safari I first achieved criticality in 1965. Despite its age, it is likely to outlast many other reactors built in the 1960s. The reason for this is that the US put an embargo on supply of HEU fuel from 1976, in response to suspicions concerning the South African nuclear weapons program. As a result, reactor power and operating time were drastically reduced for a number of years to preserve fuel stocks. Thus the reactor is in better condition than many others built in the 1960s. Indicative of this is the reactor's high level of reliability: in the 10 years to 1996, unplanned loss of
operating time was just 0.4% of total operating time; and reactor production of fission Mo-99 has been 100% efficient since it began in 1993. (Iturralde, 1996; SAAEC, 1997, pers. comm.)

The SAAEC has facilities for uranium enrichment and fuel manufacture, developed primarily to support the weapons program. Consequently the SAAEC may be unique among fission Mo-99 producers in that it controls the entire Mo-99 production cycle – manufacture of targets and fuel assemblies, irradiation and processing of targets, and waste storage. (Iturralde, 1996.)

The only cloud over the radioisotope production operations of the SAAEC is the possibility of reactor conversion to LEU fuel. With domestic supplies of HEU fuel and HEU targets, there is no threat of supply blockage, a possibility which faces other producers. Nevertheless, pressure is being put on the SAAEC to convert the reactor in keeping with the Reduced Enrichment for Test and Training Reactors program (see chapter 7.7). A feasibility study indicated that constraints to conversion may be more financial than technological (Iturralde, 1996). Conversion to LEU fuel would not jeopardise the viability of the whole operation, but it might affect the economics of the operation and make the SAAEC less competitive vis a vis competitors.

The SAAEC has a mutual back-up agreement with the IRE to ensure continuity of supply during planned or unplanned reactor excursions. (SAAEC, 1997, pers. comm.)

The SAAEC is the sole supplier of Amersham's products in South Africa. However there is no reciprocal arrangement – Amersham does not market SAAEC products overseas. (SAAEC, 1997, pers. comm.)

6.3. RESEARCH REACTORS AND RADIOISOTOPE PRODUCTION

RESEARCH REACTOR INFRASTRUCTURE
CLOSURES
RESEARCH REACTORS IN OPERATION
RADIOISOTOPE PRODUCTION

The major producers described in section 6.2 account for the bulk of commercial radioisotope production around the world. There are many other producers however, some of them commercial producers and exporters of radioisotopes and
potential suppliers to Australia. The following discussion on research reactor infrastructure and radioisotope production will serve as an overview of the many reactor radioisotope production operations around the world.

**RESEARCH REACTOR INFRASTRUCTURE**

The history and trajectory of research reactors was discussed in general terms in chapter 2.4. Some more detail will be necessary for the purposes of this analysis of the radioisotope industry.

Research reactors have been built in over 60 countries since World War II. Some were built to study the fission process, some were experimental reactors, some were designed for testing materials, fuels, and components for power reactors, and some were prototypes of power reactors. (ANSTO, 1993D, p.1.11; Amersham, 1993.) It was those countries embarking on major nuclear power and/or weapons programs that took the lead in the development of research reactors. Gradually research reactors became more widespread, purchased for a variety of reasons but frequently as a first step in longer-term plans to develop nuclear power and in some cases nuclear weapons.

Research reactors are diverse in form and function. Moreover the term is something of a misnomer. Historically research reactors were used primarily for research, but many have been used for a variety of other purposes including radioisotope production, (other) commercial uses, and plutonium production in support of covert weapons programs in some cases. In fact not all research reactors are used even in part for research, while some are not even nuclear reactors in the sense that they do not support a self-sustained fission reaction. The term encompasses a host of facilities from subcritical assemblies to 500+ MW prototype fast breeder reactors. (ANSTO, 1993L, p.3.1.) Definitions vary, but research reactors are generally considered to include all reactors except commercial (and sometimes prototype) power reactors and dedicated weapons (plutonium) production reactors.

About 600 research reactors have been built around the world in the past 50 years. The number in operation peaked in 1975 at 373 reactors. Construction peaked in the 1960s, with 274 units commissioned during that decade compared to 84 in the 1970s and 35 during the 1980s. Shut-downs began to exceed commissions during the 1970s. About half of the 600 or so research reactors ever built have since been permanently shut down. Many reactors now in operation are ageing: as at 1993,
over two thirds of research reactors throughout the world were more than 20 years old. (ANSTO, 1993L, pp.3.1-3.5.)

CLOSURES

Most research reactor closures (i.e. permanent shut downs) have been the result of program changes and other such logistical factors relating to nuclear programs: in particular, many reactors used in support of nuclear power or weapons programs were closed once they had served their purpose. Reflecting this pattern, 70% of the reactors listed as permanently shut down in 1993 were in the US (137 shut-downs from a total of 231 reactors) or the UK (27 of 36). A similar pattern is in evidence in France (12 of 31) and Germany (19 of 40). There are exceptions to this general pattern: in Japan, for example, where the emphasis was on importation of power systems, only two out of 23 research reactors had closed as at 1991, and one of them has since restarted. (ANSTO, 1993L, pp.3.14-3.16; IAEA, 1994.)

Other than program-related closures of research reactors, according to ANSTO (1993D, p.1.12), closure has "occasionally" been because of defects giving rise to safety concerns, "infrequently" a result of local community pressures, and "very rarely" a consequence of accidents. Funding restraints have certainly played a role in the closure of many reactors.

Relatively fewer multipurpose reactors have been permanently shut down in comparison with single-purpose reactors. This is a consequence of their functional versatility and also their amenability to engineering modification to suit changing requirements. (ANSTO, 1993L, p.3.16.) Nevertheless a number of multipurpose reactors have been permanently shut down and this has had significant consequences for radioisotope production (e.g. Cintichem, DIDO, PLUTO, NRX).

RESEARCH REACTORS IN OPERATION

The IAEA (1994) listed 297 research reactors in operation as at December 1994, in 58 countries. The IAEA (1994) data distinguishes "research" reactors (primarily multipurpose research reactors) from a number of other categories (test, training, prototype, critical assemblies, non-commercial electricity producing). Most radioisotope-producing reactors are listed in the "research" category, but some are listed in the test or training categories. There were 186 "research" reactors

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64 The number had fallen to 288 by March 1996, and to 273 by December 1996. (IAEA, 1996; ANSTO, 1997). However I will use the more comprehensive 1994 data.
operating in late 1994, with 111 reactors in the other categories – test (24), training (49), critical assemblies (32), prototype (3), or electricity-producing reactors (3).

Advanced capitalist countries predominate in the operation of research reactors, but not completely as the following table shows (drawn from IAEA (1994) data):

<table>
<thead>
<tr>
<th>Region</th>
<th>Operating reactors (%)</th>
<th>Planned/Under construction</th>
<th>Number of countries operating research reactors</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America, Western Europe,</td>
<td>183 (62%)</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>Industrialised Pacific (Australia and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Former Soviet countries, Eastern</td>
<td>47 (16%)</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Europe:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asia:</td>
<td>37 (12%)</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Latin America, Africa, Middle East</td>
<td>30 (10%)</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>TOTALS:</td>
<td>297 (100%)</td>
<td>22*</td>
<td>58</td>
</tr>
</tbody>
</table>

* Twelve under construction, 10 planned. This assumes that one of AECL/Nordion's Maples is under construction and the other planned. It takes account of the decision to abandon a project to build an Advanced Neutron Source reactor in the US. And it takes account of recent plans to build a new reactor in both France and Germany.

In addition, seven countries without operating research reactors have reactors under construction or planned, five of these being African countries. Another seven countries once operated research reactors but no longer do so and have no research reactors under construction or planned.

RADIOISOTOPE PRODUCTION

Of the 297 research reactors in use in 1994, about 130 were used for radioisotope production. Research reactors are used for radioisotope production in about 50 of the 58 countries operating research reactors.65

Leaving aside the IAEA's categories, all of the research reactors used for radioisotope production are multipurpose reactors – in other words, there are no

65 Calculated from INSC (n.d.) data.
dedicated radioisotope production reactors. Multipurpose reactors are diverse in form, function, and power levels (ANSTO, 1993L, p.3.2). Very few if any were built primarily for radioisotope production, but because of their flexibility many multipurpose reactors have been modified for greater radioisotope production. Modified reactors which were originally designed primarily for materials testing play a particularly prominent role in radioisotope production, mainly because they have high neutron flux levels (e.g. NRU/Canada, HFR/Netherlands, BR-2/Belgium).

There have been fewer closures of multipurpose reactors than of single-purpose reactors, and consequently multipurpose reactors are generally among the older research reactors. As at 1992, 85% multipurpose reactors were over 20 years of age and nearly two thirds were over thirty years of age. (ANSTO, 1993L, pp.3.4-3.7.)

Of the 130 or so reactors used for radioisotope production, a large majority produce only low volumes of a limited variety of radioisotopes. A major reason for this is the low power and neutron flux levels of most research reactors, as indicated by figures on the power levels (MW) of research reactors operating in 1991 (ANSTO, 1993L, pp.3.11-3.13):

<table>
<thead>
<tr>
<th>MW</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td>63.6</td>
</tr>
<tr>
<td>1.1-5</td>
<td>15.4</td>
</tr>
<tr>
<td>6-20</td>
<td>10.5</td>
</tr>
<tr>
<td>23-70</td>
<td>6.5</td>
</tr>
<tr>
<td>&gt;100</td>
<td>4</td>
</tr>
<tr>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

Even the smallest reactors can be and often are used for radioisotope production. Indeed about 50 reactors between 0.001-1 MW power are used for radioisotope production (INSC, n.d.). However the volumes are so small that these reactors are rarely if ever used to produce radioisotopes for export. Despite these limitations, the numerous low-power reactors around the world are of some significance. They are often used to supply a reasonable proportion of the (modest) demand for medical radioisotopes in developing countries. Moreover in a number of cases, particularly in Asia, very low-power reactors have been upgraded, in part to meet growing demand for radioisotopes. In other countries, the operation of low-power research reactors has facilitated the later development of more powerful reactors and associated infrastructure (e.g. radioisotope processing facilities, transport regimes). One last point to be made in relation to the many low-power reactors operating around the world is that technologies are being developed - particularly in relation to Mo-99/Tc-99m - which may encourage the more widespread
production of Mo-99/Tc-99m using reactors with low to medium power and neutron flux; this will be discussed in more detail later.

Now to consider medium and high-power multipurpose reactors. As at late 1992 there were 52 multipurpose reactors around the world of at least 5 MW power (ANSTO, 1993L, pp.3.4-3.7). Their geographical distribution follows familiar patterns:

**Distribution of multipurpose reactors, >5 MW, 1992 (ANSTO, 1993L, pp.3.4-3.7):**

<table>
<thead>
<tr>
<th>Region</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrialised Western countries</td>
<td>27</td>
</tr>
<tr>
<td>Former Soviet countries, Eastern Europe</td>
<td>14</td>
</tr>
<tr>
<td>Developing countries</td>
<td>11</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>52</strong></td>
</tr>
</tbody>
</table>

Almost all of these 52 reactors are used for radioisotope production (among other functions): INSC (n.d.) data indicates that about 48 reactors of ≥5 MW power are used for radioisotope production. However in many cases, volumes and variety are limited, and in some cases the potential for increased production is minimal for reasons such as competing demands, technical limitations, or reactor age and other factors discouraging refurbishment. Overall Amersham (1993, p.4) is probably right in saying that only 20-30 research reactors around the world could be considered suitable for routine, large-scale production of radioisotopes.

Tied in with the issue of reactor power is neutron flux levels. Generally, low-power reactors do not have sufficient flux for production of some important medical radioisotopes. So too many of the more powerful reactors do not have sufficient neutron flux levels for production of radioisotopes of high specific activity. For some radioisotopes this is not much of a problem: a number of medical applications do not require radioisotopes with high specific activity, such as therapeutic bone agents (e.g. rhenium-186, samarium-153, holmium-166, yttrium-90). However the small number of high-flux reactors is important in that it limits the production of certain radioisotopes such as those required in the emerging field of radioimmunotherapy using labelled monoclonal antibodies. (Vera-Ruiz, 1993.) A longer-standing and more important problem has been production of high specific activity Mo-99. The method used for commercial production of Mo-99 is irradiation of HEU targets in high-flux reactors, but suitable reactors are not common and HEU targets are not freely available.
6.4. REGIONAL SUMMARIES OF RADIOISOTOPE PRODUCTION

INTRODUCTION

NORTH AMERICA

WESTERN EUROPE AND SCANDINAVIA

ASIA

FORMER SOVIET COUNTRIES AND EASTERN EUROPE

AFRICA, THE MIDDLE EAST, AND LATIN AMERICA

INTRODUCTION

This section presents regional summaries of research reactor infrastructure and radioisotope production. I begin each section with data on research reactors and radioisotope production, followed by commentary on current and future production. The emphasis is on reactors which are, or could be, used for production of significant volumes of radioisotopes for export (and might therefore be able to supply the Australian market). Little or nothing will be said about the dozens of small reactors used for limited or occasional radioisotope production.

Some assumptions made in this section need brief comment.

Firstly, the best indicator of radioisotope production potential is useable neutron flux – although in practice neutron beams are used for purposes other than radioisotope production, in particular research. However data on useable neutron flux is hard to come by. Figures on steady thermal power levels (MW) are more accessible. The link between useable neutron flux and power level is not direct since it depends on other factors such as the size of the reactor core, the type of fuel, the nature of the moderator, and the number and nature of irradiation rigs. Nevertheless power level is a reasonable indicator of radioisotope production capacity.

Secondly, reactors with greater power levels generally have a greater radioisotope production capacity than less powerful reactors, but this correlation is complicated by several factors. Powerful reactors may have a limited radioisotope production capacity for technical reasons (e.g. flux, fuel type, limited or inappropriate irradiation rigs) or for other reasons such as competing demands. Conversely some medium-power reactors have a high radioisotope production capacity – for example Nordion plans to maintain its hold on the world Mo-99 market using a
single 10 MW Maple (with another for back-up), and the US DOE once planned to supply 40% of the large US Mo-99 market using an 8 MW reactor.

Thirdly, the longevity of research reactors cannot be predicted with any certainty. The assumption made here is that most of the reactors built in the 1950s and 1960s will be permanently shut down in the next 20 years, though some will last longer. I return to the question of reactor longevity in chapter seven.

In sum, the reactors of greatest interest are the newer reactors with high power and neutron flux levels, and those with a track record of use for commercial radioisotope production. However other reactors cannot be discounted as potential sources of export radioisotopes.

The following summaries are skewed in the sense that little mention is made of particle accelerators (in particular cyclotrons), which are becoming increasingly important for radioisotope production. Accelerators are discussed in chapters 7-8.

Lastly, brief comment needs to be made on the two main methods of reactor Mo-99/Tc-99m production. The common commercial method involves fission of HEU targets. This produces high specific activity Mo-99 (hereafter fission Mo-99), the preferred product. Production of fission Mo-99 requires high-flux reactors, expensive processing facilities for handling uranium fission products, and it produces large volumes of fission waste products. Another method is neutron bombardment of natural molybdenum or enriched Mo-98 targets. This method produces low specific activity Mo-99 (hereafter l.s.a. Mo-99). It does not require HEU targets, it does not require the complex facilities for dealing with fission products, and it produces less waste. However yields are low, and when used in nuclear medicine scans, Tc-99 derived from l.s.a. Mo-99 generally produces inferior images and imparts a higher radiation dose to the patient. Low specific activity Mo-99 is produced in many countries, but in limited volumes and little if any is exported. I assume in the following summaries that there will continue to be a strong demand for reactor-produced fission Mo-99, but this is a worst-case scenario. Technical innovations may enable more widespread reactor production of Mo-99/Tc-99m using LEU or molybdenum targets, and non-reactor methods of producing Mo-99/Tc-99m may become more common. These innovations may enable ample production of Mo-99/Tc-99m of acceptable quality and with benefits in terms of waste, complexity, cost, proliferation concerns, security of supply, and other factors.
## NORTH AMERICA

**RESEARCH REACTORS AS AT DECEMBER 1994 (IAEA, 1994):**

<table>
<thead>
<tr>
<th>Country</th>
<th>Total Research Reactors</th>
<th>&quot;Research&quot;/multipurpose reactors*</th>
<th>Under construction, + [planned]</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNITED STATES</td>
<td>75</td>
<td>44</td>
<td>1+[1]</td>
</tr>
<tr>
<td>CANADA</td>
<td>9</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>84</strong></td>
<td><strong>52</strong></td>
<td><strong>3+[1]</strong></td>
</tr>
</tbody>
</table>

* The figures in this column give a reasonable idea of the number of reactors suitable for radioisotope production. However not all these reactors are used for radioisotope production, and a few reactors which are used for radioisotope production are not included in the IAEA's "research" category (instead being listed in the IAEA's "test" or "training" categories).

### RESEARCH REACTORS OF 5+ MW (IAEA, 1994):

<table>
<thead>
<tr>
<th>Country</th>
<th>Number</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNITED STATES</td>
<td>10</td>
<td>5, 5, 8, 10, 20, 60, 60, 62, 85, 250 MW*</td>
</tr>
<tr>
<td>CANADA</td>
<td>2</td>
<td>5, 135 MW</td>
</tr>
</tbody>
</table>

* Most, but not all, of these reactors are multipurpose research reactors. The same applies for equivalent data in other countries.
### REACTORS USED FOR RADIOISOTOPE PRODUCTION:

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>NAME</th>
<th>MW</th>
<th>AGE</th>
<th>RADIOISOTOPE PRODUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>McMaster</td>
<td></td>
<td>5</td>
<td>1959</td>
</tr>
<tr>
<td>USA</td>
<td>ACRR</td>
<td>30</td>
<td>1967</td>
<td>From 1997, fission Mo-99, possibly I-125, I-131 and xenon-133.</td>
</tr>
<tr>
<td></td>
<td>HFBR</td>
<td>60</td>
<td>1965</td>
<td>Yes.</td>
</tr>
<tr>
<td>ORR</td>
<td>30</td>
<td>1958</td>
<td>Various. Shut down in 1987 but could be restarted.</td>
<td></td>
</tr>
<tr>
<td>(Oak Ridge)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MURR</td>
<td>10</td>
<td>1966</td>
<td>Ir-192 (70 KCi/year), P-32 (2.4), Au-198 (1), Cr-51 (0.1), many neutron rich isotopes.</td>
<td></td>
</tr>
<tr>
<td>(Missouri)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NBSR</td>
<td>20</td>
<td>1967</td>
<td>Varied, occasional. About 24 other reactors, mostly &lt;1 MW, are used to produce radioisotopes. About half of these are located on universities.</td>
<td></td>
</tr>
<tr>
<td>Others:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The main source for the above table, and equivalent tables in following sections, is the International Nuclear Safety Centre (INSC) database, which was last updated in 1993 (INSC, n.d.). A number of changes have been made where more comprehensive, current, or accurate information is available from other sources. Apart from the INSC database, the only other publicly-accessible database on reactor radioisotope production, as far as I am aware, is the IAEA’s (1995C) *Directory of Nuclear Research Reactors*, which was last updated in 1994. The IAEA database is as short on detail as the INSC data; both rely on scanty information supplied by reactor operators.
The AECL/Nordion facilities have been discussed in section 6.2.

A 5 MW reactor at McMaster University is used for medical radioisotope production. It was to be shut down but the University has recently secured commercial contracts for sales of medical radioisotopes. (ANSTO, 1996.) This facility is of little significance given the small production volumes and the age of the reactor – 40 years in 1997.

Ontario Hydro, one of the major nuclear power companies in Canada, has formed an isotope sales division to expand its radioisotope business. It uses its CANDU power reactors for radioisotope production. Ontario Hydro produces a number of radioisotopes, and is planning to increase its range, but the only medical radioisotope currently produced is cobalt-60. (Anon., 1985.) The activities of Ontario Hydro are something of an unknown but the company is unlikely to have an important impact on the medical radioisotope industry since power reactors are not well suited for radioisotope production. Power reactors are generally not well equipped (if equipped at all) for insertion and removal of irradiation rigs. In addition, research reactors usually generate higher neutron flux levels – especially materials testing reactors, which are designed to test power reactor components in much less time than the proposed use.

Apart from the AECL/Nordion's NRU reactor, and the McMaster University reactor, the only other research reactors in Canada are six very low power (20 kW) Slowpoke reactors, and one other reactor at Chalk River Laboratories (ZED-2, almost 40 years old). At least three of the Slowpokes are used for radioisotope production, but volumes are very small.

**UNITED STATES**

In the post-war generation the US was at the forefront of development of research reactors and their use for radioisotope production. However the research reactor infrastructure has been in steady decline – over 130 research reactors have been permanently shut down. About 75 research reactors are still in operation, including six reactors of 10 MW power or more and several others in the 5-10 MW range. (IAEA, 1994.) However these reactors are mostly used for other purposes (military, neutron beam research, nuclear power development), and many of the existing reactors are ageing and are likely to be permanently shut down in the next 10-20 years. Some of the reactors which are used for radioisotope production are
operated intermittently, and some are totally dependent upon physics funding (DOE, 1992, p.46).

There are about 30 reactors producing radioisotopes in the US, but mostly in very small volumes (INSC, n.d.). Thus radioisotope users have been largely dependent on imported radioisotopes. Since the Cintichem reactor was permanently shut down in 1990, all of the Mo-99, and about 90% of all medical radioisotopes, have been supplied by Nordion (with some supply from Mallinckrodt more recently) (Anon., 1994E).

The situation of total reliance on Nordion for fission Mo-99, after the Cintichem shut down, led to efforts to increase security of supply one way or another. These efforts have involved the Department of Energy (DOE), radiopharmaceutical companies, reactor operators, and nuclear medicine professional societies. Most of the effort has been to modify an existing reactor for Mo-99 production. There have also been efforts to increase security of Mo-99 supply through negotiations with operators of Russian and Canadian reactor facilities. (Carretta, 1994.)

The DOE succeeded in gaining an $US 8 million line of credit from Congress for the Mo-99 project. In the early 1990s the plan was to use the Omega West reactor at the Los Alamos National Laboratory. The DOE attempted to enlist the support of the major radiopharmaceutical companies - Du Pont Merck (linked to Syncor), Medi-Physics (51% owned by Amersham), and Mallinckrodt. However the radiopharmaceutical companies pulled out of negotiations with the DOE after making initial financial contributions of $US 40 000 each. They objected to some of the terms being offered by the DOE, such as a five-year plan for the companies to buy a certain percentage of Mo-99 from the DOE at a price in the upper bounds of the commercial price range. They turned their attention elsewhere - Mallinckrodt began its venture in the Netherlands, Du Pont signed a long-term contract to purchase Mo-99 from Nordion, and Amersham continued to diversify its sources. (Rojas-Burke, 1992B; 1993C; ORNL, 1995.)

A power surge accident at the Omega West reactor, and the later discovery of a leaking coolant line, were partly responsible for the waning interest of the radiopharmaceutical companies. They were also sceptical about the capacity of the DOE to bring the project to fruition, claiming that the DOE did not have a good track record in the radioisotope business and that there was a history of the DOE giving priority to military programs over commercial customers' radioisotope needs. Sometimes there were "unbusinesslike" price increases from the DOE, according to Vermeeren from Mallinckrodt (quoted in Rojas-Burke, 1992B). Later
the DOE abandoned the Omega West project altogether, despite having invested several million dollars in the project. (Rojas-Burke, 1992B; Anon., 1993C.)

After several more years of negotiation and planning, a Mo-99 plan was settled upon in 1996, using existing facilities in New Mexico. The DOE will fabricate Mo-99 targets at the Los Alamos Chemistry and Metallurgy Research Facility. The targets will then be transported to the Sandia Laboratories, for irradiation in the 30 MW Annular Core Research Reactor (ACRR) and target processing using an existing hot cell facility. The reactor may also be used to produce other medical radioisotopes including iodine-125, iodine-131 and xenon-133. The cost for the Sandia project is estimated at between $US 10-20 million – initial DOE estimates were $US 11.4 million. (DOE, 1996; German, 1996; Rojas-Burke, 1995B.)

The Sandia project seems likely to reach fruition. The requirements of the National Environmental Policy Act have been fulfilled. Work has already begun on the project. By late 1997 it is expected that the new facilities will be able to supply 10% of the US market and eventually they will be able to supply the entire US market "if needed". Modifications to reach full production capacity could be completed by 1998. (DOE, 1996.)

The lack of interest of the radiopharmaceutical companies, and some nuclear medicine professionals and professional associations, in the Sandia project is ironical given that these were the groups that had initially been the main advocates of another Mo-99 source. Their view is that there are now sufficient overseas producers to guarantee security of supply. The radiopharmaceutical companies have outwardly supported the DOE's Mo-99 project, but they are still unsure about how reliable shipments will be and what prices will be charged. None of the three major radiopharmaceutical companies in the US has given the DOE firm commitments to buy Mo-99 from Sandia. (Kotz, 1996.) An alternative suggestion has been to use the Sandia money to ensure supply of radioisotopes other than Mo-99. (Rojas-Burke, 1995B.)

The long term future of the New Mexico project is unclear. One variable is the age of the reactor, which was built in 1969. Another variable is the DOE's long-term commitment to the project. The DOE says that federal support of the project will terminate when US, Canadian, or other suppliers establish new, reliable sources of Mo-99. A DOE representative (quoted in Kotz, 1996) says that there is a need to have a reliable back-up supply at least until Nordion's Maples are operating.
The DOE might decide to continue to operate the facilities - major, reliable alternative suppliers notwithstanding - if the project begins to turn a profit. In the initial stages the capital costs (e.g. reactor modification) will be borne by the DOE and the Mo-99 will be sold at something similar to market prices. A more likely scenario than continued DOE operation of the Mo-99 production facilities is that the venture will be privatised. The DOE (1996) says that it will "actively encourage the early privatization of this production capability". The eagerness to privatise the venture seems to be a result of a government policy of no public-sector competition with private producers. In any case, with the facilities operating, and the DOE keen to privatise the venture, there must be a reasonable likelihood that privatisation will go ahead. Several radiopharmaceutical companies might be interested. Mallinckrodt, for example, was still considering a Mo-99 production plant in the USA in 1994, even though its venture in the Netherlands was already operational (Anon., 1994C). Amersham/Medi-Physics and Du Pont/Syncor could be other contenders, given that they have less direct involvement in (and thus control over) Mo-99 production than both Mallinckrodt and Nordion.

If the New Mexico venture is privatised, production volumes might be increased. For the time-being, the DOE (1996) insists that the reactor will be used solely as a back-up source. It is intended that maximum production will be sufficient to supply the entire US Mo-99 market. In fact maximum production capacity may be sufficient to supply much more than the US market. As many as 37 targets (steel tubes coated with uranium-235) can be irradiated at any one time. Each target will be irradiated for a "few days" and each will generate up to 800 Ci of Mo-99. (German, 1996.) Assuming irradiation for a "few days" equates to 100 irradiations per year, then overall production could reach 37 x 100 x 800 = 2.96 million Ci/year. This is roughly four times current annual global demand. Inevitably there will be inefficiencies - even during irradiation there is considerable decay of Mo-99 (which has a half life of 66 hours), and decay between production and use can also account for a significant percentage of initial radioactivity. Nevertheless it is possible that this reactor could be used to supply significant volumes for both domestic and export markets.

To date the DOE has emphasised that the Sandia facility will only be used for back-up supply of the domestic market. However when the plan was to develop the Omega West reactor, the DOE was interested in the possibility of foreign orders. (Rojas-Burke, 1992D.) There is no obvious reason why the DOE would not be prepared to supply other countries. Export would be even more likely in the case of privatisation.
The DOE currently produces isotopes at six locations using reactors, accelerators, and calutrons. These sites include the Los Alamos, Oak Ridge, Idaho, Brookhaven, and Sandia National Laboratories. (Kotz, 1996.) Oak Ridge National Laboratories (ORNL) uses the 85 MW HFIR reactor for radioisotope production. In late 1996 the US federal government announced that $US 10 million would be provided to upgrade the HFIR reactor (ANSTO, 1996). It will not produce Mo-99 but it is likely that it will produce other medical radioisotopes. There are some other powerful reactors operated by the Laboratories with some potential for development to increase radioisotope production. These include the ORNL’s 30 MW Oak Ridge Research Reactor, and the 60 MW HFBR reactor at Brookhaven National Laboratories. (ORNL, 1995.)

The DOE has a long history of involvement in radioisotope production. Government agencies were at the forefront of radioisotope production in the post-war period. Then as commercial producers emerged, the government largely withdrew from radioisotope production. Government facilities were prohibited from competing with private producers, and the DOE was further limited by a law which made the DOE fund its radioisotope program through sales. Then a number of commercial producers pulled out of radioisotope production. Consequently, there has been pressure for the DOE to assume more responsibility for radioisotope production in the past 10 years or so, one example of which is the Sandia project. (ORNL, 1995; Anon, 1996D; Rojas-Burke, 1992C; DOE, 1996B; O'Leary, 1995.)

The cycle of public then private-sector production seems set to repeat itself. The DOE (n.d.) has been pursuing efforts to privatise its radioisotope programs in the past few years. In response, it received 30 responses and proposals, ranging from proposals to take over the Department’s entire isotope production program, to specific proposals concerning specific facilities or isotopes. The only deal which has been struck to date is that a company has bought exclusive rights for isotope production (especially iridium-192) using a reactor (and possibly another test reactor) at the Idaho National Laboratory. (Kotz, 1996.) The company, MAC Isotopes, claims to be the only commercial (private-sector) producer of radioisotopes in the US, and this may be true except for the commercial cyclotrons operated by radiopharmaceutical companies.

The major radiopharmaceutical companies are adopting a wait-and-see position, to see how privatisation works. One issue is regulation. For example the DOE has
insisted that MAC Isotopes hire labour represented by the Oil, Coal and Atomic Workers Union and pay workers union rates and benefits. (Kotz, 1996.)

The Sandia venture goes against the grain of the DOE's current push to privatise radioisotope production. Part of the motivation of the DOE would seem to be a desire to be involved in the production and sale of a radioisotope for which there is a substantial market, and potentially profits. That could facilitate - in effect subsidise - the production of other, unprofitable radioisotopes, including many low-volume radioisotopes used for research. (Rojas-Burke, 1992C.) However it must be doubtful whether Sandia will be profitable. Another complication for the DOE has been the policy of no public-sector competition with the private sector - there has always been the possibility that after spending millions of dollars on a project, it would be moth-balled in the event of a private producer emerging.

As a result of the cost recovery and no-competition policies, there was no incentive, and very little funding available, for the DOE to produce radioisotopes which were unprofitable. Recently the cost recovery policy has been relaxed. This has improved the situation somewhat, but if the DOE's radioisotope programs are largely privatised, the same problem is likely to emerge again. One option discussed for the DOE's isotope program is an internal program partially funded by government and partially from sales. Another option is a non-profit joint venture involving government agencies, industry, researchers, and professional societies. This would decide which unprofitable radioisotopes are important enough to produce. A common view is that isotope production cannot be left to government or private enterprise alone. Another line of thought is that radioisotope production should largely be a public-sector responsibility, with no more "fantasies" about profitability (Atcher, quoted in Rojas-Burke, 1993C).

Apart from the DOE's radioisotope program, and radioisotope production by MAC Isotopes, very few reactors produce significant quantities of radioisotopes. The University of Missouri reactor (MURR) produces substantial quantities of radioisotopes for research and medicine; it is the only university research reactor which produces radioisotopes in large volumes. (Rojas-Burke, 1995B.) The MURR reactor has been used to produce large volumes of iridium-192 but that may stop given the no-competition policy and the MAC Isotopes venture in Idaho.

Running in parallel with projects to increase radioisotope supply have been plans and negotiations to build a new reactor, or a very large accelerator, primarily to accommodate the 1000 or so neutron science researchers in the US. One of the most fully-developed proposals was for a 350 MW reactor, known as the
Advanced Neutron Source, at the ORNL. However this proposal has recently been abandoned. Reasons given were the estimated cost ($A 3-4 billion), and the proposed use of HEU fuel which contradicts the US policy to limit the use of HEU fuels. (ANSTO, 1993L, p.3.22; Nuclear Control Institute, 1995.)

Accelerator production of radioisotopes is taken up in greater detail in chapter 7.9, but a little should be said here about the use of accelerators for radioisotope production in the US. The overall picture with respect to the high-power accelerators appears to be much the same as for research reactors: infrastructure is declining, the future of some existing facilities is in doubt, and supply of some accelerator-produced radioisotopes, including some used in nuclear medicine procedures and research, is in jeopardy. There is no dedicated accelerator for radioisotope production in the US apart from the commercial cyclotrons of the radiopharmaceutical companies. One proposal under development for several years was for a high-power (100 MeV) particle accelerator (either a cyclotron or a linear accelerator) to be known as the National Biomedical Tracer Facility. However that project was dropped. One project still in train is upgrading of the large "BLIP" accelerator at the Brookhaven National Laboratory (Rojas-Burke, 1992B, 1993, 1994; DOE, 1992.)

Now to sum up radioisotope production in the US. There is at least some chance that the Sandia venture will produce Mo-99 for export markets. A few other reactors are producing reasonable volumes of a limited range of radioisotopes. There is some potential for the development of existing large reactors, including those that have shut down, but in all these cases the reactors are ageing. There is a small possibility of the construction of a large reactor which would be primarily be for research but may be of some consequence in relation to radioisotope production.
**WESTERN EUROPE AND SCANDINAVIA**

**RESEARCH REACTORS AS AT DECEMBER 1994 (IAEA, 1994):**

<table>
<thead>
<tr>
<th>Country</th>
<th>Total Research Reactors</th>
<th>&quot;Research&quot;/ multipurpose reactors</th>
<th>Under construction, + [planned]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUSTRIA</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>BELGIUM</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>DENMARK</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>FINLAND</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>FRANCE</td>
<td>19</td>
<td>8</td>
<td>[1]</td>
</tr>
<tr>
<td>GERMANY*</td>
<td>20</td>
<td>8</td>
<td>[1]</td>
</tr>
<tr>
<td>GREECE</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ITALY</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>NETHERLANDS</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>NORWAY</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>PORTUGAL</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SWEDEN</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SWITZERLAND</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>TURKEY</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>9</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

**TOTALS:** 76 39 [2]

* Adjusted to account for closure of the 15 MW FRG-2 reactor.

**RESEARCH REACTORS OF 5+ MW (IAEA, 1994):**

<table>
<thead>
<tr>
<th>Country</th>
<th>Number</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUSTRIA</td>
<td>1</td>
<td>10 MW</td>
</tr>
<tr>
<td>BELGIUM</td>
<td>1</td>
<td>100 MW</td>
</tr>
<tr>
<td>DENMARK</td>
<td>1</td>
<td>10 MW</td>
</tr>
<tr>
<td>FRANCE</td>
<td>9</td>
<td>14, 25, 35, 40, 57, 70, 100, 120, 563 MW*</td>
</tr>
<tr>
<td>GERMANY</td>
<td>3</td>
<td>5, 10, 23 MW</td>
</tr>
<tr>
<td>GREECE</td>
<td>1</td>
<td>5 MW</td>
</tr>
<tr>
<td>NORWAY</td>
<td>1</td>
<td>25 MW</td>
</tr>
<tr>
<td>SWEDEN</td>
<td>1</td>
<td>50 MW</td>
</tr>
<tr>
<td>TURKEY</td>
<td>1</td>
<td>5 MW</td>
</tr>
</tbody>
</table>

* This list includes the 120 MW BWR prototype reactor and a 563 MW Phenix Fast Breeder. Most or all of the other reactors are multipurpose reactors.
**REACTORS USED FOR RADIOISOTOPE PRODUCTION:**

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>NAME</th>
<th>MW</th>
<th>AGE</th>
<th>RADIOISOTOPE PRODUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUSTRIA</td>
<td>ASTRA</td>
<td>10</td>
<td>1960</td>
<td>Some radioisotope production, future uncertain.</td>
</tr>
<tr>
<td></td>
<td>Others:</td>
<td></td>
<td></td>
<td>Two small reactors used for radioisotope production.</td>
</tr>
<tr>
<td>DENMARK</td>
<td>DR-3</td>
<td>10</td>
<td>1960</td>
<td>Na-24 (2 GBq), Cu-64 (6 GBq), Br-82 (1300 GBq)</td>
</tr>
<tr>
<td>FRANCE</td>
<td>Orphee</td>
<td>14</td>
<td>1980</td>
<td>Yes.</td>
</tr>
<tr>
<td></td>
<td>Osiris</td>
<td>70</td>
<td>1966</td>
<td>Yes, probable shut down 2000-2010</td>
</tr>
<tr>
<td></td>
<td>Siloe</td>
<td>35</td>
<td>1963</td>
<td>Yes, probable shut down 2000-2010</td>
</tr>
<tr>
<td></td>
<td>Phenix Fast Breeder</td>
<td>(563)</td>
<td></td>
<td>Co-60</td>
</tr>
<tr>
<td></td>
<td>Other:</td>
<td></td>
<td></td>
<td>One small reactor used for radioisotope production.</td>
</tr>
<tr>
<td>GERMANY</td>
<td>FRG-1</td>
<td>5</td>
<td>1958</td>
<td>Various.</td>
</tr>
<tr>
<td></td>
<td>FRJ-2</td>
<td>23</td>
<td>1962</td>
<td>Co-60 (10 K Ci), Zr-95, Ir-192/194.</td>
</tr>
<tr>
<td></td>
<td>Others:</td>
<td></td>
<td></td>
<td>At least five other small reactors used for radioisotope production.</td>
</tr>
<tr>
<td></td>
<td>BER-II</td>
<td>10</td>
<td>1973</td>
<td>Mostly for scientific research, possibly for limited isotope production.</td>
</tr>
<tr>
<td>GREECE</td>
<td>GRR-1</td>
<td>5</td>
<td>1961</td>
<td>I-131, Au-198, Tc-99m (l.s.a. Mo-99)</td>
</tr>
<tr>
<td>ITALY</td>
<td></td>
<td></td>
<td></td>
<td>Three small reactors used for radioisotope production.</td>
</tr>
<tr>
<td></td>
<td>Others:</td>
<td></td>
<td></td>
<td>Two small reactors used for radioisotope production.</td>
</tr>
<tr>
<td>NORWAY</td>
<td>HBWR</td>
<td>25</td>
<td>1959</td>
<td>Some production, mostly research.</td>
</tr>
<tr>
<td></td>
<td>Others:</td>
<td></td>
<td></td>
<td>One &lt;5 MW reactor used for radioisotope production.</td>
</tr>
<tr>
<td>SWEDEN</td>
<td>R2-MTR</td>
<td>50</td>
<td>1960</td>
<td>Iridium-192 (250 000 Ci/year), Sr-89, Na-24, P-32, S-35, others.</td>
</tr>
<tr>
<td>TURKEY</td>
<td>TR-2</td>
<td>5</td>
<td>1981</td>
<td>Tc-99m, Ir-192.</td>
</tr>
<tr>
<td>UNITED KINGDOM</td>
<td></td>
<td></td>
<td></td>
<td>Three small reactors used for radioisotope production.</td>
</tr>
<tr>
<td>PORTUGAL, FINLAND, SWITZERLAND</td>
<td>5</td>
<td>1981</td>
<td>One &lt;5 MW reactor used for radioisotope production in each country.</td>
<td></td>
</tr>
</tbody>
</table>

Age D.O.C.: date of first criticality, given only for 5+ MW reactors.
MW: Steady thermal power level.
GENERAL COMMENTS

The significant radioisotope production facilities in Belgium (IRE/Nordion, SCK-CEN) and the Netherlands (Mallinckrodt) were discussed in section 6.2.

Over a quarter of the world's research reactors are in Western Europe, with about half of these in France and Germany. In many respects the situation in Western Europe is much the same as in the US. The research reactor infrastructure has declined markedly over the years - more reactors have been shut down than are currently operating. There are no research reactors under construction and just two in the planning stages. However there have been some significant refurbishments allowing increased radioisotope production, including BR-2 (Belgium) and HFR (Netherlands).

The radioisotope production operations in Belgium and the Netherlands will be significant sources of Mo-99, and some other radioisotopes, for the next 10-20 years at least. Outside of those countries it is difficult to predict if there will be any major producers and exporters in the coming decades. Planned reactors in Germany and France may be the next most likely candidates.

GERMANY

The reactor infrastructure has declined in Germany and more shut downs are expected in the coming 10-20 years. Generally, what impetus there exists for the construction of new research reactors in Western Europe stems from the scientific research community. For example in Germany, about 600 scientists work in the field of neutron research. Moreover while there are some facilities elsewhere in the region, in particular the 57 MW Institut Laue-Langevin reactor in France, these are said to be inadequate for the estimated 3500 neutron researchers in Europe. Under pressure from the research community, the German government has formalised $US 500+ million plans to build a 20 MW research reactor, FRM-II, at the Technical University of Munich. This project is being pushed through despite considerable public opposition - evidently some funding will come at the expense of the Bavarian state budget for education, and some will come from a special federal budget originally intended to support poor students (Anon., 1996). The reactor will use HEU fuel; this is one of the objections of public opponents and has also drawn criticism from the US government. The proponents of the new reactor have said much about the medical applications of the reactor - in particular neutron beam cancer therapy - to encourage acceptance of the project. However the reactor design is to be maximised for thermal and cold neutron...
research, not for medical applications. The reactor will probably only be a modest radioisotope producer although that could conceivably change, if for example there are radioisotope shortages. (FRM-II Project Group, 1995; ANSTO, 1995F; 1996; 1996B; Nuclear Control Institute, 1995B, Leventhal and Kuperman, 1995.)

FRANCE

Radioisotope production in France is modest, although it is one of the few countries producing fission Mo-99 (or at least irradiating targets for fission Mo-99 production). The 35 MW Osiris and 70 MW Siloe reactors, and possibly also the 57 MW HFR reactor, are used to irradiate targets for processing by IRE in Belgium (Iturralde, 1996.)

In 1996 the French Atomic Energy Agency (CEA) announced plans for a new research reactor, Reacteur Jules Horowitz (RJH), at Cadarache. Operation is expected to begin in 2005. It will be used for testing in support of French and European nuclear power programs, medical radioisotope production, silicon irradiation and neutron research. The feasibility studies are considering a 100 MW reactor with initial cost estimates of $US 192-384 million. This reactor will replace Siloe and Osiris, both of which are ageing and will be permanently shut down in the next decade. (ANSTO, 1996B.)

The loss of the Siloe and Osiris reactors is unlikely to have an impact on fission Mo-99 supply around the world as their role was modest and other producers will easily cover the loss of these reactors. It is certainly possible that the high-power RJH reactor could be an important source of export radioisotopes, even if radioisotope production is not the primary function, but that cannot be assumed at this early stage and in the absence of more information.

The 14 MW Orphee reactor, which went critical in 1980, is used for radioisotope production and may be of some significance. Other large reactors are ill-equipped for radioisotope production, are committed to other purposes, or are ageing and thus of little interest. These reactors include the 40 MW Phebus (1978), the 100 MW Scarabee reactor (1982), the 25 MW Cabri reactor (1963), a 120 MW boiling-water power prototype, and the 563 MW Phenix Fast Breeder (which does however produce some cobalt-60).
SWEDEN

Studsvik Nuclear operates a 50 MW, high-flux reactor, R2-MTR. It is used primarily for neutron beam research and fuels and materials testing. In addition there is some radioisotope production, including strontium-89, sodium-24, phosphorus-32, sulphur-35, and iridium-192. Bulk production of iridium-192, in the range of 250 000 Ci/year, was expected to begin in early 1997. Cobalt-60 has been produced but not now because there is an excess of it on the market. Similarly gadolinium-153 is no longer produced because of a lack of buyers. (Lundström, Studsvik Nuclear, 1996, pers. comm.)

As for Mo-99 production, l.s.a. Mo-99 was produced when Sweden had its own radiopharmaceutical production facilities. Fission Mo-99 can be produced - the reactor has sufficient neutron flux and there are suitable reactor irradiation facilities. However there are no processing facilities for separation of Mo-99 from other fission products. Separation could conceivably be carried out overseas, but Sweden is too remote for that sort of production regime - international transport of bulk Mo-99 is common enough, but to transport unprocessed, highly-radioactive fission products over long distances would be excessively difficult and expensive. According to the Products and Production Manager of the Irradiation Services division of Studsvik Nuclear, fission Mo-99 could be produced in commercial quantities if a radiopharmaceutical company built a separation plant in Studsvik. (Lundström, 1996, pers. comm.)

Most of medical radioisotopes used in Sweden, including fission Mo-99, are supplied from abroad - mainly from Amersham, Nordion, and Mallinckrodt. (Lundström, 1996, pers. comm.) There is also some export: according to Diesendorf (1993), Sweden is one of Amersham's suppliers.

The R2-MTR reactor first went critical in 1960. The reactor vessel was changed in 1986 and Studsvik Nuclear plans to operate the reactor for another 20 years or more. (Lundström, 1996, pers. comm.)

DENMARK

Denmark has a nuclear research program based on a 10 MW research reactor, a sister reactor to HIFAR. (ANSTO, 1993L, p.3.23.) It is operated by the Riso National Laboratory and one of its uses is production of large volumes of a few radioisotopes - sodium-24, copper-64, and bromine-82. The reactor first went
critical in 1960 and for that reason it is unlikely to be an important source of export radioisotopes in the future.

**NORWAY**

The Institute for Energy Technology (IFE) operates a 2 MW reactor and a 25 MW reactor (HBWR). These reactors are used for a number of functions including radioisotope production. HBWR is owned and operated by IFE but it is funded as a co-operative research project between ten OECD countries. (ANSTO, 1993L, p.3.23; IAEA, 1994.) The HBWR is unlikely to be of significance for commercial radioisotope production in future because it is primarily used for research (especially fuels testing) and it first went critical in 1959.

**AUSTRIA**

As at 1995 there were two small research reactors, one of them a training reactor, as well as an ageing 10 MW multipurpose reactor (ASTRA, first criticality in 1963). These reactors are located at a Research Centre which is required to earn half its revenue from contract work. The ASTRA reactor produces medical radioisotopes among its other purposes. As at 1993 funding problems had limited operation to one week per month, and the reluctance of the US to accept spent reactor fuel had also cast a shadow over future operation of ASTRA. (ANSTO, 1993L, p.3.23; IAEA, 1994.)

**BELGIUM**

Apart from the SCK-CEN's BR-2 reactor, the processing of bulk radioisotopes from other European reactors (by IRE and Nordion), and Nordion's two cyclotrons, there are just two small (<5 MW) reactors used for radioisotope production in Belgium.
### RESEARCH REACTORS AS AT DECEMBER 1994 (IAEA, 1994):

<table>
<thead>
<tr>
<th>Country</th>
<th>Total Research Reactors</th>
<th>&quot;Research&quot;/Multipurpose Reactors</th>
<th>Under construction + [planned]</th>
</tr>
</thead>
<tbody>
<tr>
<td>BANGLADESH</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>CHINA</td>
<td>13</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>INDONESIA</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>INDIA</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>NORTH KOREA</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SOUTH KOREA</td>
<td>2*</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>MALAYSIA</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>PHILIPPINES</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>PAKISTAN</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>THAILAND</td>
<td>1</td>
<td>1</td>
<td>[1]</td>
</tr>
<tr>
<td>VIETNAM</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**INDUSTRIALISED PACIFIC:**

<table>
<thead>
<tr>
<th>Country</th>
<th>Number</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>JAPAN</td>
<td>19</td>
<td>11</td>
</tr>
</tbody>
</table>

**TOTAL:** 51 38 3 [+2]

* Adjusted to account for the permanent shut down of two small reactors in 1995.

### RESEARCH REACTORS OF 5+ MW (IAEA, 1994):

<table>
<thead>
<tr>
<th>Country</th>
<th>Number</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHINA</td>
<td>4</td>
<td>5, 5, 15, 125 MW</td>
</tr>
<tr>
<td>INDONESIA</td>
<td>1</td>
<td>30 MW</td>
</tr>
<tr>
<td>INDIA</td>
<td>2</td>
<td>40, 100 MW</td>
</tr>
<tr>
<td>NORTH KOREA</td>
<td>1</td>
<td>5 MW</td>
</tr>
<tr>
<td>SOUTH KOREA</td>
<td>1</td>
<td>30 MW</td>
</tr>
<tr>
<td>PAKISTAN</td>
<td>1</td>
<td>9 MW</td>
</tr>
<tr>
<td>AUSTRALIA</td>
<td>1</td>
<td>10 MW</td>
</tr>
<tr>
<td>JAPAN</td>
<td>5</td>
<td>5, 10, 20, 50, 100 MW</td>
</tr>
</tbody>
</table>
# REACTORS USED FOR RADIOISOTOPE PRODUCTION:

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>REACTOR NAME</th>
<th>MW</th>
<th>AGE D.O.C.</th>
<th>RADIOISOTOPE PRODUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AUSTRALIA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CHINA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MJTR</td>
<td>5</td>
<td>1991</td>
<td>Mo-99, 1000 Ci. p.a.</td>
</tr>
<tr>
<td></td>
<td>HWRR-II</td>
<td>15</td>
<td>1958</td>
<td>Low volumes of Tc-99m, Co-60, I-131, I-125, Au-198.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Others:</strong> Four &lt;5 MW reactors used to produce radioisotopes.</td>
</tr>
<tr>
<td><strong>INDIA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50 000 Ci p.a. total production.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Other:</strong> One &lt;5 MW reactor used to produce radioisotopes.</td>
</tr>
<tr>
<td><strong>INDONESIA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Other:</strong> One &lt;5 MW reactor used to produce radioisotopes.</td>
</tr>
<tr>
<td><strong>JAPAN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>JMTR</td>
<td>50</td>
<td>1968</td>
<td>Co-60, Ir-192, C-14, Au-198, Cr-51, C-14, several others.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Others:</strong> Three &lt;5 MW reactors used to produce radioisotopes.</td>
</tr>
<tr>
<td><strong>NORTH KOREA</strong></td>
<td>IRT-DPRK</td>
<td>5</td>
<td>1965</td>
<td>11 000 Ci p.a. I, P, CR, S, Au, Te, Ca, Co, Fe, Se, Ir, Sb.</td>
</tr>
<tr>
<td><strong>PAKISTAN</strong></td>
<td>PARR-1</td>
<td>9</td>
<td>1965</td>
<td>Au-198 (10 Ci), I-131 (10 Ci), Tc-99m (2 Ci), Hg (1.5 Ci), Cr-51 (0.5 Ci).</td>
</tr>
<tr>
<td><strong>TAIWAN</strong></td>
<td>THOR</td>
<td>10</td>
<td>1961</td>
<td>Yes.</td>
</tr>
<tr>
<td></td>
<td>TRR-II</td>
<td>30</td>
<td>1973</td>
<td>Shut down in 1987, restart planned.</td>
</tr>
<tr>
<td><strong>THAILAND</strong></td>
<td></td>
<td></td>
<td></td>
<td>One &lt;5 MW reactor used to produce radioisotopes, one 5 MW reactor planned.</td>
</tr>
<tr>
<td><strong>BANGLADESH, VIETNAM</strong></td>
<td></td>
<td></td>
<td></td>
<td>One &lt;5 MW reactor used to produce radioisotopes in each country.</td>
</tr>
<tr>
<td><strong>PHILIPPINES, MALAYSIA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MW: Steady thermal power levels. Age: Date of first criticality.
Fourteen countries in the region produce reactor radioisotopes. Mostly these operations involve low-power reactors, which have in a number of cases been upgraded (usually to between 2-5 MW), in part to enable increased radioisotope production. (McDonald, 1992.)

There are some medium to high-power reactors in the region, though considerably fewer than in North America, Western or Eastern Europe. Of the larger producers, China produces large volumes of a limited range of radioisotopes using a 125 MW reactor but only modest volumes of Mo-99; Indonesia began operation of a 30 MW reactor in 1987 and this produces modest volumes of export radioisotopes (possibly larger volumes in future); India has an ageing 40 MW reactor, a 100 MW reactor in operation since 1985, and ambitions to establish export markets; Japan produces modest volumes of radioisotopes but no Mo-99; Taiwan is planning to restart a 30 MW reactor; South Korea's new 30 MW reactor may be a source of significant volumes of export radioisotopes; and ANSTO's future as a radioisotope producer and supplier is of course dependent on whether a replacement reactor is built.

Overall the research reactor infrastructure in Asia is younger than other regions in the world. Fifteen research reactors were under 10 years old as at 1992. All of the older research reactors in the Asia Pacific have undergone refurbishment. (McDonald, 1992.) For these reasons Asia may become a more important source of export radioisotopes in the future.

The Japanese market accounts for 80-90% of total Asian demand for radioisotopes, and about 25% of world demand (ANSTO, 1993F, p.7.5). Radioisotope markets are growing at a considerable rate in other countries in the region, but from low starting points. According to Berkhout (1993), Nordion predicts that it will be a decade before the Asian market (outside Japan) becomes significant.

China, India, South Korea, and Japan all have plans to significantly increase nuclear power generation, and plans have been in train for many years to introduce nuclear power into Indonesia. To the extent that this involves further development of nuclear infrastructure (e.g. research reactors, fuel supplies, regulatory regimes) this might encourage increased radioisotope production. However the links between nuclear power programs and radioisotope production are ambiguous - for example existing research reactors might be put to greater use...
in support of nuclear power programs to the detriment of radioisotope production. These links are taken up in chapter seven.

Of the five research reactors under construction or planned in the region - four in Japan, one in Thailand - some will produce radioisotopes but it is unlikely that any will be used to supply export markets to any significant extent.

In sum, there is no radioisotope producer in the region which will certainly be producing significant volumes of radioisotopes for export markets, but there are some possibilities of large export producers emerging such as South Korea. There is little likelihood of a major production venture in Japan, but it is possible that a major export venture could be developed using imported bulk radioisotopes. Other production and export ventures of some significance might emerge - Indonesia, India, and China are candidates. Lastly, Amersham (1993) claims that it will be sourcing fission Mo-99 from one or two reactors in the region by the time HIFAR is shut down and this could have a significant impact on supply of the Asian market.

**SOUTH KOREA**

As at 1994 South Korea had four research reactors including a zero power training reactor at Suwon, and two low-power Triga reactors at the Korea Atomic Energy Research Institute (KAERI) in Seoul. The two Trigas were permanently shut down in 1995. One of them was a 2 MW reactor which had been used for radioisotope production, including l.s.a. Mo-99/Tc-99m.

The fourth reactor is HANARO, which first went critical in early 1995. It has a high power level (30 MW) and high neutron flux (maximum core thermal flux of $4.5 \times 10^{14} \text{n/cm}^2/\text{sec}$). It uses 19.75% enriched LEU fuel. HANARO was built to replace the two small reactors in Seoul. It is the first reactor to have been completed based on the Canadian Maple design. The functions of the reactor are fuels and materials testing in support of the nuclear power program (30%), neutron physics experiments (28%), radioisotope production (22%), neutron activation analysis (16%), and silicon doping and neutron radiography (4%).


HANARO has substantial beam facilities and radioisotope processing facilities and will be used for production of a range of medical radioisotopes. In KAERI's (n.d.) words, the facilities for radioisotope production are "ample". As at late 1996 a
feasibility study was underway for commercial production of fission Mo-99 using HEU or LEU targets. The expectation is that production of Mo-99 will begin in the year 2000 and some of it will be exported to Asia-Pacific countries. KAERI is already producing a range of other radioisotopes – including iodine-131, phosphorus-32, samarium-153, holmium-166 – and can export these radioisotopes. (KAERI, 1996, pers. comm.)

The HANARO facility is not likely to nearly as significant as major ventures such as those of Nordion or Mallinckrodt, given the numerous other functions of the HANARO reactor and its use in support of the nuclear power program. However it is possible that a high-flux, high-power reactor such as HANARO could be used as a major radioisotope producer along with its other functions. Moreover the Vice President of KAERI says that much basic research will have already been carried out within a few years, and thus radioisotope production (and medical radioisotope research) will become a "major application" for HANARO towards the end of the 1990s and into the next century. (Kim, 1995.)

KAERI hopes to use HANARO as the basis of an international research centre. Co-operation agreements already exist between KAERI and JAERI (Japan) and AECL. (Kim, 1995.) Both of these connections could be important in relation to radioisotope production. It could be to the advantage of Japanese companies and agencies to have another supplier of Mo-99 and other radioisotopes given their heavy reliance on Nordion. The proximity of South Korea and Japan would be an added advantage. AECL was involved in the construction of HANARO and there is ongoing collaboration of some sort or another between KAERI and AECL. This could be of consequence given AECL's connections to Nordion. Nordion might see HANARO as a useful back-up supplier. Amersham could also be interested in collaboration with KAERI and may have HANARO in mind when saying that it expects to have one or two sources of fission Mo-99 in the Asia Pacific within a decade or so (Amersham, 1993).

The construction of experimental and production facilities for HANARO had been slowed by lack of finances from the government, but this work was proceeding steadily, facilitated by "discussions and communications with user groups." (Kim, 1995.) This is a further reason for thinking that collaboration between KAERI and radiopharmaceutical companies may eventuate, or might already be in train.
BATAN, the National Atomic Energy Agency of Indonesia, operates a 30 MW, high-flux, multipurpose reactor (RSG-GAS) at Serpong. It is used for a range of functions including radioisotope production. The reactor has been in operation since 1987. There is also a cyclotron at the Serpong site and radiopharmaceutical processing facilities. (ANSTO, 1993L, p.3.29.)

There was some debate during the Research Reactor Review as to whether the RSG-GAS reactor could be used to supply the Australian market for a number of radioisotopes including fission Mo-99. It is possible that this reactor may be used for production and export of large quantities of fission Mo-99 and other radioisotopes in the future. However this would require modification of the reactor facilities and further development of processing facilities. Conceivably this could occur in collaboration with – and with a capital injection from – one of the major radiopharmaceutical companies. According to the Research Reactor Review (1993, p.92), Amersham has negotiated with BATAN in relation to bulk radioisotope supply. One submission to the Review, from an Australian nuclear medicine professional, flagged the possibility that Amersham, Nordion, the US DOE, or ANSTO, might collaborate with BATAN to use RSG-GAS for commercial radioisotope production and export (Morris, 1993).

ANSTO disagreed with suggestions that it might collaborate with BATAN to use RSG-GAS for radioisotope production and other purposes such as neutron research. ANSTO claimed that the Serpong facilities are inadequate for ANSTO's radioisotope production and research purposes. ANSTO also claimed that the potential of the reactor to be developed as a major radioisotope producer is limited as it will become increasingly important for nuclear power related applications as Indonesia's nuclear power program gains momentum. (ANSTO, 1993G, pp.2.1-2.4; 1993F, Annex 7.2.3.) Perhaps so, but this is not certain – the Indonesian regime might opt, for example, for turn-key power reactors with minimal local input, or it might abandon plans for nuclear power and choose instead to develop its large reserves of fossil fuels. In early 1997 a Nuclear Energy Bill was approved by the Indonesian parliament and signed by the President, establishing a legislative framework for the introduction of nuclear power, but the Research and Technology Minister has since said the first power reactor could be delayed, citing discoveries of natural gas (ANSTO, 1997).

Whether or not RSG-GAS is used for a major commercial export venture, it will certainly be used to produce sufficient fission Mo-99, and other radioisotopes, to
satisfy local demand and for modest exports in the region. In fact this is already the case. BATAN’s production of fission Mo-99 was 12 000 Ci in 1996 (roughly equivalent to ANSTO). That capacity can still be increased somewhat without major upgrading of the reactor. There was some export of Mo-99 to Malaysia and China in 1996. BATAN also produces a range of other reactor and cyclotron radioisotopes - iodine-131, iridium-192, phosphorus-32, xenon-133, gallium-67, thallium-201, l.s.a. Mo-99/Tc-99m, iodine-123, sulfur-35, chromium-51, and others on request. (BATAN, Radioisotope Production Division, 1997, pers. comm.)

As at late 1997, a consortium between BATAN and a private Indonesian company was investigating the feasibility of building a 10 MW dedicated radioisotope-production reactor. This proposal was subject to a market survey. (Hastowo, 1997.)

CHINA

Currently, reactor radioisotope production is dominated by a 125 MW, high-flux reactor (HFETR). It is considerably younger than comparable reactors around the world, having been in operation since 1979. A 5 MW reactor has been in operation since 1991, and produces some Mo-99, and four smaller reactors are used for limited radioisotope production.

In the early 1990s, production of l.s.a. Mo-99 was 2000 Ci/year with plans to increase this to 10 000 Ci/year by the turn of the century. In addition, 1000 Ci/year of fission Mo-99 was produced in 1993, with plans to increase this to about 3000 Ci/year by 1995. (ANSTO, 1993D, pp.1.13-1.14; 1993F, Annex 7.2.2.) These volumes amount to no more than 1-2% of world production. The remainder of the demand for Mo-99 has been supplied by Nordion and, more recently, by Indonesia.

As with so many other countries, the future of radioisotope production in China is difficult to predict. The HFETR reactor could be operating well until the next century, and it has the power and flux levels for major radioisotope production, but from what little is known there seems to be no intention to develop a radioisotope export business. Perhaps this is because of the other uses of the reactor - the familiar range of neutron beam physics research, fuel and materials testing, and so on.

The nuclear medicine market in China is growing at about 20% p.a., though from a very low starting point (ANSTO, 1993F, Annex 7.2.2). This could conceivably spur greater domestic radioisotope production. Another development which
might encourage greater radioisotope production is the shifting focus of China’s nuclear programs. The China National Nuclear Corporation was formed in 1987 to co-ordinate a shift from a defence role to economic/industrial functions. The Corporation has over 200 enterprises, a staff of 300 000, and responsibility for every aspect of the nuclear industry including radioisotope production. (ANSTO, 1990, p.4.) Certainly such a shift would be compatible with increased radioisotope production and export. However the research reactor infrastructure is modest apart from the HFETR reactor, no new research reactors are under construction or planned, and the existing infrastructure (including the HFETR reactor) may be used increasingly in support of the nuclear power program.

JAPAN

As at 1995 there were 20 research reactors operating in Japan. The Japan Atomic Energy Research Institute (JAERI) uses a number of reactors to produce a considerable variety of radioisotopes, but only in modest volumes. All of Japan's demand for Mo-99 is met by Nordion. Two Japanese companies - Nihon Medi-Physics and Daichii - import bulk Mo-99 from Nordion and use it to produce generators as well as instant Tc-99 radiopharmaceuticals. Nihon Medi-Physics operates cyclotrons dedicated to medical radioisotope production. The Japanese Radioisotope Association - which combines the roles of a professional peak body and a science R&D institution - also operates cyclotrons. (ANSTO, 1993L, p.3.22; 1995C; Japanese Society of Nuclear Medicine, 1995, pers. comm; Nihon Medi-Physics, 1995, pers. comm.)

Some projects to upgrade research reactors or to build new reactors have been completed in recent years or are in progress. A 10 MW reactor, JRR-3, was rebuilt as a 20 MW reactor (JRR-3M) at a cost of over $A 400 million. The upgraded reactor is equipped with facilities for radioisotope production but only limited volumes are produced. A 30 MW engineering test reactor is under construction but will not be used for radioisotope production. One other research reactor is under construction but there is no indication that it will be a major radioisotope producer. (ANSTO, 1995C; McMillan and Silver, 1993; Japanese Society of Nuclear Medicine, 1995, pers. comm.)

In the past 10-20 years there has been sporadic production of both fission Mo-99 and l.s.a. Mo-99. However the volumes were modest and production ceased some years ago. The main difficulty is that the reactors have low operational efficiencies - for example the JRR-3M and JMTR reactors operate for just 182 days each year. There is also considerable competition for reactor space and time between
radioisotope production and other functions (in particular R&D in support of nuclear power). It is because of these limitations that the radiopharmaceutical companies import all Mo-99. Another consideration is the large volume demand. In 1994 the market value for in vivo radiopharmaceuticals was $A 425 million, with about 1800 gamma cameras and growth at 10%. The Mo-99/Tc-99m market is about $A 50 million p.a., representing 50 000 Mo-99/Tc-99m generators (Japanese Society of Nuclear Medicine, 1995, pers. comm.) Maximising domestic production using existing facilities would still satisfy only a small part of demand unless major refurbishments and upgrading of reactors and processing facilities took place, or unless other research reactor programs were scaled down.

The Director of the Department of Radioisotopes at JAERI's Tokai Research Establishment says that in the case of Nordion's supply of Mo-99 looking doubtful, Japanese radiopharmaceutical manufacturers would probably look to alternative overseas sources in preference to establishing domestic facilities. Discussions with IRE in Belgium, for supply of fission Mo-99, have not progressed because of IRE's limited production volume. (Yamabayashi, 1996, pers. comm.)

As in the US, public-sector research reactor operators are not allowed to compete with the private sector in Japan (Cook, 1993, p.83). Government policy is to privatise JAERI's radioisotope production, but to maintain existing facilities and to maintain production of radioisotopes for research purposes. (Japan Radioisotope Association, 1997, pers. comm.)

In sum, there is little if any concern about the reliance on imported radioisotopes in Japan, and little if any momentum to increase domestic reactor radioisotope production. Despite this, Japan may indeed become a radioisotope exporter. As at early 1997, Nihon Medi-Physics (pers. comm.) had established an International Sales Department and was investigating the Asia/Oceania market. If an export venture were to be established based in Japan, it would presumably be importing bulk radioisotopes, carrying out processing functions such as Mo-99/Tc-99m generator manufacture, and then exporting to regional countries. This sort of supply regime has parallels in Europe and North America, such as with Amersham's diverse chain of radioisotope supply and export. In fact Amersham, as a part-owner of Nihon Medi-Physics, would almost certainly be involved in the establishment and operation of an export venture in Japan.

INDIA

As at 1995 India had five research reactors. Of these only two are of interest. The
40 MW Cirus reactor, based on the Canadian NRX design, has a range of functions including radioisotope production although it is better known as a source of plutonium for India’s weapons program. The 100 MW Dhruva reactor is used for large-scale production of high specific activity radioisotopes along with neutron physics research, materials testing, and so on. Despite the operation of these two powerful reactors, Mo-99 production in India is very modest, about 1500 Ci/year, and this is probably l.s.a. Mo-99. (McMillan and Silver, 1993, p.12; Anon., 1994E; ANSTO, 1990, p.10; 1993L, p.3.28; IAEA, 1994.)

The Cirus reactor is unlikely to be of significance in the future given its age - it began operating in 1960. The Dhruva reactor on the other hand is very powerful and young by research reactor standards (operating since 1985). Perhaps the major limitation in relation to radioisotope production is that both Cirus and Dhruva are used extensively in support of the nuclear power program.

The Board of Radiation and Isotope Technology (BRIT), a division of the Indian Department of Atomic Energy, is the sole manufacturer and supplier of radiopharmaceuticals and radioimmunoassay kits in India, supplying 300 nuclear medicine centres. BRIT markets about 40 diagnostic products. It has recently been looking to expand and diversify its product range and to secure export contracts. (BRIT, 1995.)

TAIWAN

Taiwan operates three small research reactors, none of which produce radioisotopes. The 40 MW TRR reactor, which had functions including radioisotope production, was shut down in 1987. However there are plans to rebuild this reactor (TRR-II) with a power level of about 30 MW. (ANSTO, 1990, p.22; 1993L, p.3.32; McMillan and Silver, 1993, pp.31-32.) This reactor could conceivably be used for commercial radioisotope production and export, but it is more likely to be used primarily in support of the nuclear power program.

OTHER ASIAN COUNTRIES

Some Asian countries operate low to medium-power reactors which are used for radioisotope production. It is unlikely they will be used for commercial radioisotope production and export, but they are worth passing mention.

As at 1994 Thailand had one 2 MW research reactor. One of its functions is medical radioisotope production, including l.s.a Mo-99. ANSTO supplies a further
3-4 Mo-99/Tc-99m generators per week. In 1989 the government decided to close the existing research centre and research reactor and to build new nuclear facilities at a new site. A new reactor of about 5 MW power is to be built. $US 100 million had been allocated to the project, which will include facilities for radioisotope production. Once that project is complete, the 2 MW reactor will be permanently shut down. (McMillan and Silver, 1993, p.33; ANSTO, 1990, p.23; 1993L, p.3.32; 1993F, Annex 7.2.3; Rees, 1997.)

As at 1994 Pakistan had two research reactors – a 9 MW reactor and a very low-power reactor. The 9 MW reactor (PARR), located at the Pakistan Institute of Nuclear Science and Technology, is used for various functions including the production of small volumes of radioisotopes for medicine, industry and agriculture. (ANSTO, 1993L, p.3.31; McMillan and Silver, 1993.) The PARR reactor is 30 years old and it is unlikely that a reactor of this power, built using 1960s technology, will be of much significance to radioisotope users outside Pakistan.

In North Korea, there was one research reactor as at 1994, with 5 MW power. (IAEA, 1994.) Its functions include medical radioisotope production. A cyclotron has been constructed to broaden the range of radioisotopes available. (ANSTO, 1990, p.4; 1993L, p.3.27-3.28.)
FORMER SOVIET COUNTRIES
AND
EASTERN EUROPE

RESEARCH REACTORS AS AT DECEMBER 1994 (IAEA, 1994):

<table>
<thead>
<tr>
<th>Country</th>
<th>Total Research Reactors</th>
<th>&quot;Research&quot;/multipurpose reactors</th>
<th>Under construction + [planned]</th>
</tr>
</thead>
<tbody>
<tr>
<td>BULGARIA</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>CZECH REPUBLIC</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>HUNGARY</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>KAZAKHSTAN</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>LATVIA</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ROMANIA</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>RUSSIAN FED.</td>
<td>27</td>
<td>21</td>
<td>1 [+1]</td>
</tr>
<tr>
<td>SLOVAK REPUBLIC</td>
<td>1</td>
<td>1</td>
<td>1 [+]</td>
</tr>
<tr>
<td>UKRAINE</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>UZBEKISTAN</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>YUGOSLAVIA</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>44</strong></td>
<td><strong>33</strong></td>
<td><strong>3 [+2]</strong></td>
</tr>
</tbody>
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RESEARCH REACTORS OF 5+ MW (IAEA, 1994):

<table>
<thead>
<tr>
<th>Country</th>
<th>Number</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>CZECHOSLOVAKIA</td>
<td>1</td>
<td>10 MW</td>
</tr>
<tr>
<td>HUNGARY</td>
<td>1</td>
<td>10 MW</td>
</tr>
<tr>
<td>KAZAKHSTAN</td>
<td>3</td>
<td>10, 10, 60 MW</td>
</tr>
<tr>
<td>LATVIA</td>
<td>1</td>
<td>5 MW</td>
</tr>
<tr>
<td>ROMANIA</td>
<td>1</td>
<td>14 MW</td>
</tr>
<tr>
<td>RUSSIAN FED.</td>
<td>14</td>
<td>6, 8, 8, 10, 10, 10, 12, 15, 18, 40, 40, 60, 100, 100 MW</td>
</tr>
<tr>
<td>UKRAINE</td>
<td>1</td>
<td>10 MW</td>
</tr>
<tr>
<td>UZBEKISTAN</td>
<td>1</td>
<td>10 MW</td>
</tr>
<tr>
<td>YUGOSLAVIA</td>
<td>1</td>
<td>6.5 MW</td>
</tr>
</tbody>
</table>
### Reactors Used for Radioisotope Production:

<table>
<thead>
<tr>
<th>Country</th>
<th>Reactor Name</th>
<th>MW</th>
<th>Age</th>
<th>Radioisotope Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Czech Republic</td>
<td>LWR-15</td>
<td>10</td>
<td>1957</td>
<td>Radiopharmaceuticals, IR, SI, UENR.</td>
</tr>
<tr>
<td>Poland</td>
<td>EWA</td>
<td>10</td>
<td>1958</td>
<td>Yes.</td>
</tr>
<tr>
<td>Romania</td>
<td>BR-10</td>
<td>8</td>
<td>1958</td>
<td>IR-10 + AM: Fission Mo-99, Sr-89, S-35,</td>
</tr>
<tr>
<td></td>
<td>AM</td>
<td>10</td>
<td>1954</td>
<td>Cs-137, ruthenium-106, zirconium-95, barium-140, I-125, I-131, C-14, Y-90, In-113m</td>
</tr>
<tr>
<td></td>
<td>IR-8</td>
<td>8</td>
<td>1957</td>
<td>Hg-197, Au-198, Tc-99m, others.</td>
</tr>
<tr>
<td></td>
<td>MR</td>
<td>40</td>
<td>1963</td>
<td>Medical radioisotopes.</td>
</tr>
<tr>
<td></td>
<td>SM-2</td>
<td>100</td>
<td>1961</td>
<td>Fission Mo-99 from 1998.**</td>
</tr>
<tr>
<td></td>
<td>WWR-M Gatchina</td>
<td>18</td>
<td>1959</td>
<td>Yes.</td>
</tr>
<tr>
<td></td>
<td>WWR-TS Other:</td>
<td>12</td>
<td>1964</td>
<td>Mo-99, Xe-133. One &lt;5 MW reactor used to produce radioisotopes.</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>WWR-M</td>
<td>10</td>
<td>1960</td>
<td>Radioisotopes for technology.</td>
</tr>
<tr>
<td>Yugoslavia</td>
<td>R-A</td>
<td>6.5</td>
<td>1959</td>
<td>Eu-152, 154, Co-60, I-131, etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>One &lt;5 MW reactor used to produce radioisotopes in each country.</td>
</tr>
</tbody>
</table>

*These are the radioisotopes produced by the Institute of Physics and Power Engineering (IPPE) using the BR-10 and AM reactors.

**These are the radioisotopes produced by the Institute of Atomic Reactors, Dimitrovgrad.
GENERAL COMMENTS

About 15% of the world’s research reactors are in the former Soviet states and Eastern Europe. There are a considerable number of multipurpose research reactors of 5 MW power or more. However of the 5+ MW reactors used for radioisotope production, 13 of 15 were built in the 1950s and 1960s, and none achieved first criticality later than 1979. (IAEA, 1994; INSC, n.d.)

The situation with radioisotope production is complex and contradictory. On the one hand, there is a large nuclear infrastructure, an interest in foreign currency, some production facilities producing significant volumes of radioisotopes and exporting some of this product, and some potential for the development of new projects using existing reactors. On the other hand the research reactors are ageing and in some cases in disrepair. In addition funding is scarce for the up-keep of existing facilities, and in most cases foreign investment would probably be required for refurbishments, upgraded radioisotope processing facilities, or other such ventures.

Five research reactors are under construction or being planned in these regions. (IAEA, 1994). These include a 200 MW reactor under construction in Kazakhstan, a 100 MW reactor under construction and another 100 MW planned in the Russian Federation, a very low power reactor under construction in the Slovak Republic and a training reactor planned for the Slovak Technical University.

Other than in Russia, it seems that there is little if any production of radioisotopes on a commercial, export scale in the region. According to one report, there may be fission Mo-99 production in Poland, Hungary, and the Czech Republic (Iturralde, 1996). The 30 MW Maria reactor in Poland, and the 14 MW Triga II reactor in Romania, are the only radioisotope-producing reactors in the region which began operation after the 1960s. The Hungarian reactor (Budapest Research Reactor) is notable in that it was upgraded from 2 MW to 5 MW in 1967, then to 10 MW in 1986, and there were plans at that time for a future upgrade to 20 MW (INSC, n.d.). It is used for many purposes including radioisotope production. It is not an important source of export radioisotopes, but it illustrates the general point that even ageing, low-power reactors could potentially have some impact on the radioisotope industry if the necessary investments are made.

There are some high-power reactors in the region which are not currently used for radioisotope production, but could possibly be developed, for example the 60 MW reactor in Kazakhstan (1972) and some of the Russian reactors discussed below.
RUSSIA

There are seven reactors in the 8-100 MW range used for radioisotope production in Russia. A number of other large reactors are in operation and could conceivably produce radioisotopes on a commercial basis in the future. However nearly all of the reactors date from the 1950s or 1960s.

Revis Services, the joint venture between Amersham, the Mayak Production Association, and AO Techsnabexport, is possibly the major source of export radioisotopes from Russia (see section 6.2).

The Soviet Union had a long history of commercial export of stable isotopes (some of which are used as targets for radioisotope production). Some facilities for production of stable isotopes in the US were closed in part because of cheaper Soviet supply to the US market. This supply seems to have continued in the post-Soviet era - in the early 1990s the DOE's share of the world market for stable isotopes fell from about 90% to 50% because of competition from Russian suppliers. (Rojas-Burke, 1993C; Amersham, 1993; Anon., 1996D.)

In the early 1990s, the US DOE considered some sort of joint venture using Russian facilities for fission Mo-99 production. Nothing eventuated from this however. (Carretta, 1994.) Given Amersham's venture and the DOE's passing interest, perhaps there are further possibilities for collaborative ventures. Berkhout (1993) mentions reports of potential new fission Mo-99 suppliers in Russia but gives little detail, saying only that there are enough suitable reactors and enough interest in foreign currency for Russia to supply a substantial proportion of European and Asian markets.

The nuclear infrastructure in Russia is geared around a number of large state-owned institutes involved in various facets of nuclear programs; this arrangement is similar to the DOE's national laboratories. Brief summaries follow of the institutes of most significance in relation to radioisotope production. The institutes liaise with each other to co-ordinate radioisotope production.66

The State Scientific Centre of the Russian Federation Institute of Physics and Power Engineering (IPPE) is the major producer of medical radioisotopes among the various institutes. It produces a wide range of medical radioisotopes using the 8 MW high-flux reactor called BR-10, which first went critical in 1958, and also a 10

66 Data on research reactors at the various institutes is drawn from Anon., 1996B.
MW reactor called AM (1954). It also produces several dozen types of stable isotopes. The IPPE already exports some of its product, could supply the Australian market with a number of radioisotopes, and is planning to increase production. (IPPE, 1996, pers. comm.)

The Institute of Atomic Reactors, Dimitrovgrad, operates at least five research reactors with medium to high power levels: MIR (100 MW) and SM-2 (100 MW), both used for radioisotope production, and also RBT-10/1 (10 MW), RBT-10/2 (10 MW), and RBT-6 (6 MW). The Institute produces and sells about eight radioisotope products. Production of fission Mo-99 is planned to begin from 1998, with the intention of supplying Russian and overseas customers. The fission Mo-99 will meet "Drug Master File" quality standards being developed by the European Community. (Institute of Atomic Reactors, 1996, pers. comm.)

The Kurchatov Institute operates about eight research reactors, including a 40 MW reactor (MR) and an 8 MW reactor (IR-8), both of which are used for radioisotope production.

The St. Petersburg Institute of Nuclear Physics operates two or more research reactors including WWR-M (18 MW, used for radioisotope production) and PIK (100 MW).

The Ural Nuclear Centre, Ekaterinburg (a branch of the Research and Construction Institute for Energy Technique, Moscow) operates a 15 MW reactor, IVV-2M. (This Centre may be the site of the reactor(s) used by Reviss Services.)
AFRICA, THE MIDDLE EAST, AND LATIN AMERICA

RESEARCH REACTORS AS AT DECEMBER 1994 (IAEA, 1994):

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>Total Research Reactors</th>
<th>&quot;Research&quot;/ multipurpose reactors</th>
<th>Under construction + [planned]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LATIN AMERICA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Argentina</td>
<td>5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Chile</td>
<td>2</td>
<td>2</td>
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</tr>
<tr>
<td>Colombia</td>
<td>1</td>
<td>1</td>
<td>[1]</td>
</tr>
<tr>
<td>Ecuador</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Jamaica</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
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<td></td>
</tr>
<tr>
<td>Peru</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>AFRICA AND THE MIDDLE EAST:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algeria</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Egypt</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Ghana</td>
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<td>1</td>
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<tr>
<td>Iran</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
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<td>Israel</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Libya</td>
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<td>Madagascar</td>
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<tr>
<td>Nigeria</td>
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<tr>
<td>South Africa</td>
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</tr>
<tr>
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<td>1</td>
</tr>
<tr>
<td>Tunisia</td>
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<td>Zaire</td>
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<td>1</td>
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</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td>31</td>
<td>21</td>
<td>4 + [4]</td>
</tr>
</tbody>
</table>

RESEARCH REACTORS OF 5+ MW (IAEA, 1994):

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>NUMBER</th>
<th>POWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chile</td>
<td>1</td>
<td>5 MW</td>
</tr>
<tr>
<td>Peru</td>
<td>1</td>
<td>10 MW</td>
</tr>
<tr>
<td>Algeria</td>
<td>1</td>
<td>15 MW</td>
</tr>
<tr>
<td>Iran</td>
<td>1</td>
<td>5 MW</td>
</tr>
<tr>
<td>Israel</td>
<td>2</td>
<td>5, 26 MW</td>
</tr>
<tr>
<td>Libya</td>
<td>1</td>
<td>10 MW</td>
</tr>
<tr>
<td>South Africa</td>
<td>1</td>
<td>20 MW</td>
</tr>
</tbody>
</table>
REACTORS USED FOR RADIOISOTOPE PRODUCTION:

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>REACTOR NAME</th>
<th>MW</th>
<th>AGE</th>
<th>RADIOISOTOPE PRODUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>PERU</td>
<td>RP-10</td>
<td>10</td>
<td>1988</td>
<td>Iodine-131, samarium-153 (both exported); iridium-192 (from 1997); l.s.a. Mo-99</td>
</tr>
<tr>
<td>CHILE</td>
<td>La Reina Rech-1</td>
<td>5</td>
<td>1974</td>
<td>Tc-99m, I-131, Ir-192, P-32.</td>
</tr>
<tr>
<td>BRAZIL</td>
<td></td>
<td></td>
<td></td>
<td>Two &lt;5 MW reactors used for radioisotope production.</td>
</tr>
<tr>
<td>ARGENTINA, IRAN COLOMBIA, EGYPT, MEXICO, ZAIRE</td>
<td></td>
<td></td>
<td></td>
<td>One &lt;5 MW reactor used to produce radioisotopes in each country.</td>
</tr>
</tbody>
</table>

GENERAL COMMENTS

Despite the number of countries in these regions operating research reactors, the overall research reactor infrastructure is small. There are eight research reactors of 5 MW power or more, and some of these reactors (and some smaller reactors) are used for limited radioisotope production.

It is notable that seven research reactors are under construction or being planned in these regions. These include reactors of 2 MW or less under construction in Iran, Morocco and Syria. The reactors planned for Madagascar, Nigeria and Tunisia will be the first reactors for these countries and are unlikely to be of consequence to radioisotope users outside these countries. A 22 MW reactor under construction in Egypt, to be operated by the Egyptian Atomic Energy Authority, could conceivably be of significance in relation to future radioisotope production and export. Egypt has recently begun producing Mo-99/Tc-99m generators, presumably using Mo-99 produced in the one operating reactor, which has a power level of just 2 MW.

According to one report, the Argentinian nuclear agency (CNEA) is a fission Mo-99 producer (Iturralde, 1996), though almost certainly only a modest producer since there are no high-power research reactors operating in Argentina. Two more important producers are the nuclear agencies operating in South Africa (discussed in section 6.2) and Peru.
A high-flux 10 MW reactor, known as RP-10, has been in operation in Peru since 1988. The reactor, situated 40 kms from Lima, is operated by the Nuclear Research Centre, RASCO, which is an organisation within the Peruvian Institute of Nuclear Energy, IPEN. A radioisotope processing plant is located alongside the reactor. The RP-10 reactor has attracted attention from time to time because it has sufficient power and flux (core maximum flux of $2 \times 10^{14}$ n/cm$^2$/sec) for production of fission Mo-99, it is relatively young, and the reactor operators are interested in using the reactor for commercial radioisotope production. It was seen as a potential back-up facility in the early 1990s when there were questions over Nordion's supply. Nordion sent a team to visit the Peruvian facilities but evidently is no longer interested in a joint venture. There are a number of obstacles to fission Mo-99 production in Peru: the project would need foreign investment; competition with the major global suppliers; and political instability. The President of Peru was pushing a large-scale privatisation of government-run industries in the early 1990s and this has probably encouraged RASCO to pursue commercial radioisotope production. (Anon., 1992.)

As at late 1996, the RP-10 reactor was producing iodine-131 and samarium-153, both of which were being exported. There was also some production of l.s.a. Mo-99/Tc-99m for domestic use. There were short-term plans to produce iridium-192 for domestic use and for export. As for commercial production of fission Mo-99, the situation had not changed. RASCO is interested, but a joint venture would be necessary to provide additional investment. The radioisotope processing plant is capable of processing much greater volumes of radioisotopes than it is currently handling. RASCO plans to upgrade the reactor to 15 MW. (RASCO, 1996, pers. comm.)
CHAPTER SEVEN: 
ANALYSIS OF THE RADIOISOTOPE INDUSTRY

7.1. FUTURE RADIOISOTOPE DEMAND
7.2. FUTURE PRODUCTION LEVELS
7.3. CONCENTRATION OF RADIOISOTOPE PRODUCTION
7.4. PUBLIC AND PRIVATE ENTERPRISE
7.5. VERTICAL INTEGRATION
7.6. DEDICATED PRODUCTION FACILITIES
7.7. LINKS BETWEEN RADIOISOTOPE PRODUCTION AND NUCLEAR POWER, WEAPONS, AND RESEARCH PROGRAMS
7.8. TECHNICAL INNOVATIONS
7.9. CYCLOTRONS AND LINEAR ACCELERATORS

The analysis in this chapter pulls together a number of issues which were introduced in the preceding two chapters, and takes up some other issues which need consideration before considering options for the future supply of the Australian radioisotope market in chapter eight.

7.1. FUTURE RADIOISOTOPE DEMAND

In the preceding two chapters I have said far more about radioisotope production than about the demand side of the market (i.e. health-care systems and the clinical practice of nuclear medicine). That emphasis will continue through the following two chapters but some general comments should be made on growth trends and future demand for medical radioisotopes.

There are no reliable figures on the world market for radioisotopes, or for processed radiopharmaceuticals, in the publicly-accessible literature. Much data on sales is kept confidential by private companies. This problem is compounded by the concentration of the industry with a small number of organisations holding the lion's share of the market.
Using a variety of sources, ANSTO (1993F) arrived at the following figures for the total radiopharmaceutical imaging market in 1992:

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>Market ($A million)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>530</td>
<td>40</td>
</tr>
<tr>
<td>Europe</td>
<td>360</td>
<td>27</td>
</tr>
<tr>
<td>Japan</td>
<td>360</td>
<td>27</td>
</tr>
<tr>
<td>Other Asia</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>45</td>
<td>4</td>
</tr>
<tr>
<td><strong>Totals:</strong></td>
<td><strong>$A 1315m.</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

In addition, the total market for therapeutic radiopharmaceuticals is estimated to be about $US 50-60 ($A 70-90) million p.a. (ANSTO, 1993F, Annex 7.2.1).

The above figures are the retail markets for processed radiopharmaceuticals; the market for bulk radioisotopes is far smaller, roughly 10-20% of the radiopharmaceutical market.

The practice of nuclear medicine is highly uneven around the world. Advanced capitalist countries account for over 95% of the world market. (ANSTO, 1993F, Annex 7.1.4, 7.2.1.) Some efforts have been made by the advanced capitalist states to stimulate the growth of nuclear medicine in developing countries. However the practice of nuclear medicine in developing countries is minimal, uneven, and plagued by problems such as a lack of trained personnel and obsolete and rundown equipment. The practice of nuclear medicine, and thus the demand for radioisotopes, is growing in many developing countries, but from such low starting points that the growth is of little consequence for overall global radioisotope demand. (Nofal, 1985; 1987; Cuarón, 1994; Wang and Chou, 1988; Touya, 1987.)

Even considering only the advanced capitalist countries, and using figures which take account of population differences between countries, there are variations of an order of magnitude or more in the practice of nuclear medicine, as indicated by figures on the number of gamma cameras per thousand hospital beds in various countries (Ell, 1992) and the density of gamma cameras per million inhabitants in various Western European countries (Askienazy, 1993). Historically there were correlations between the scale of nuclear medicine and the existence of domestic research reactors (which in turn correlated with nuclear power and weapons programs), but those correlations have weakened over the years with the growth of the international trade in radioisotopes. The main reasons for the differences in
the scale of nuclear medicine practice between capitalist countries are mostly to be found at the level of economic arrangements for the funding of medical care. Variations in government licensing and regulation requirements are also important.

The picture generally presented by practitioners and advocates of nuclear medicine is one of substantial growth of nuclear medicine around the world. ANSTO (1993F, Annex 7.1.4) says that an overall growth rate of 8% is expected for the total global radioisotope market, but without substantiating the figure. There is clear, substantiated evidence of substantial and steady growth of nuclear medicine in many countries around the world. This includes Western Europe and Japan, two of the major markets. In Western Europe, figures on sales of nuclear medicine equipment indicate substantial growth of nuclear medicine in the late 1980s and early 1990s - as much as 10-20% p.a. in some countries (Askienazy, 1993). Accurate data on the radiopharmaceuticals market in Japan is compiled, and the figures show an annual growth rate of about 10% in recent years (Japanese Society of Nuclear Medicine, 1995, pers. comm.).

Some underlying reasons contribute to the growth of nuclear medicine. Patients subjected to nuclear medicine procedures are heavily skewed to those over 45 years of age. The ageing of populations in capitalist countries (numbers of elderly people as a proportion of the overall population) is likely to stimulate further growth of nuclear medicine (ANSTO, 1993, pp.4.12-13). Technical progress is continuing on several fronts; developments in fields such as molecular and immunological nuclear medicine may provide a boost to the overall practice of nuclear medicine. According to one commentator, products based on radiolabelled monoclonal antibodies are expected to account for the second largest growth among medical radioisotopes, after cardiac imaging (Anon., 1993). Further progress can also be expected in areas such as computer imaging equipment and this may promote greater usage. Another spur to the further growth of nuclear medicine, and various other diagnostic technologies, has been the threat of litigation (Patton, 1993; Roebuck, 1996; Nelkin and Tancredi, 1989).

From what has been said it would appear that the future of nuclear medicine is likely to be one of sustained growth. However there are a range of forces operating to curtail the growth of nuclear medicine. Particularly important are restraints stemming from economic stagnation (in particular the efforts of governments around the world to reduce medical spending), and also increased competition from alternative technologies. To date these pressures appear to have been felt
most keenly in the US, though they are evident in many other countries including Australia.

According to Shanahan, a nuclear medicine professional writing in *The Journal of Nuclear Medicine* in 1995, fewer and fewer nuclear medicine physicians, technologists, and scientists are entering the field in the US; the profession is ageing at a rapid rate; and the number of nuclear medicine procedures is declining every year with nuclear medicine under fire from competing technologies. (Shanahan, 1995;, see also Carretta, 1993; O'Leary, 1995.)

Actually the claim that the number of nuclear medicine procedures is in decline in the US is not shared by other commentators. Khafagi (1992) says the overall annual growth of nuclear medicine in the US is 3%. Data on sales of nuclear imaging equipment from 1987-1991 indicated considerable growth (Anon, 1993F). Kasses (1995) says the growth rate for radiopharmaceutical sales in the early 1990s was about 10% p.a., with the growth rate of nuclear medicine procedures about 5% p.a. (Presumably the difference was because of stronger growth of *in vitro* diagnostic studies.) Kasses (1995) goes on to say that only nuclear cardiology is growing; virtually all other fields are flat or in decline. Even in cardiology, echocardiology was performed seven times as frequently as nuclear perfusion imaging, and had a growth rate of 25% compared to 12% for nuclear cardiology.

Another notable article in *The Journal of Nuclear Medicine* is Vermeeren's (1995) contribution to a series of articles on "Strategies for Survival" for nuclear medicine in the US. That such a debate is taking place at all is significant. Vermeeren - Chairperson of the Corporate Committee of the American College of Nuclear Physicians and the Senior Vice President of Mallinckrodt Medical - says there is a growing trend to using imaging modalities less expensive than nuclear medicine in the US. Nuclear medicine will be forced to compete with other modalities with both medical value and cost being taken into consideration and this could emerge as a "critical" variable in nuclear medicine's future. Vermeeren goes on to say that future growth of nuclear medicine is not certain despite growth in the past generation, and that radiopharmaceutical suppliers report a flat market despite the introduction of new products.

Vermeeren (1995) notes that the underlying market fundamentals are not very attractive in the radioisotope industry: a relatively small market; flat growth rates; a history of low profit margins; enormous competitive intensity, especially in distribution channels; and the negative environmental impact due to radioactive
waste. In these circumstances companies are cutting costs by eliminating unprofitable activities and by staff reduction. (Vermeeren, 1995.)

Ell (1992), writing in the journal *Nuclear Medicine Communications*, notes that the market for radiopharmaceuticals is far smaller than the market for many (other) pharmaceuticals - the annual turnover of a pharmaceutical company can be about 50 times that of a radiopharmaceutical company. This has considerable consequences for nuclear medicine. The cost of registration of new products is independent of the projected market size. This is a substantial impediment to the development and clinical use of new products for nuclear medicine. There are many low-volume specialist products used in nuclear medicine, "perhaps too many" according to Ell (1992, p.70).

Bringing new radiopharmaceuticals to market has always been limited by the market size, and development costs have escalated making new product development still more difficult. Products introduced since 1988 accounted for only 8% of nuclear medicine procedures in 1993 in the US. Regulatory standards for the demonstration of efficacy of radiopharmaceutical products now require either more or more extensive pre-approval studies or significantly limit the proposed uses of such agents. The cycles for developing new products are becoming longer and more costly. These factors increase development costs and reduce the return on investment. (Kasses, 1995; Kotz, 1995B.)

Miller (1994), a nuclear medicine professional writing in *The Journal of Nuclear Medicine*, backs up many of the points already made and also points to the push from health-care reformers towards generalist medicine and away from specialist medicine, and the increasing importance of debates over cost-effectiveness in the new managerial environment. (Miller, 1994.)

Overall it would appear that there is substantial growth in medical radioisotope markets around the world, but the growth is very uneven, and whether it will be sustained cannot be predicted with confidence.
7.2. FUTURE PRODUCTION LEVELS

OVERVIEW

PRODUCTION OF Mo-99

PRODUCTION OF OTHER RADIOISOTOPES

NEW REACTORS AND REFURBISHMENTS

CONCLUSION

OVERVIEW

A commonly expressed view is that the research reactor infrastructure is in decline around the world, there are many obstacles to the development of new radioisotope production ventures, and that future supply of medical radioisotopes is therefore insecure. The survey of radioisotope production in chapter six supports some aspects of this general argument, but not others; most importantly, the overall security of supply of medical radioisotopes is not likely to be nearly so precarious as is commonly argued, especially for the small number of radioisotopes that account for over 95% of all nuclear medicine procedures.

It is certainly the case that the worldwide research reactor infrastructure is in decline, particularly when the overall number of reactors is taken as the criterion. This trend is certain to continue. Many of the reactors built in the 1950s and 1960s face closure in the coming 10-20 years. In a number of cases reactors are still operating despite shut-down schedules having been exceeded (Lagunas-Solar, 1993; Egan et al., 1994). Of the reactors of 5 MW or more used for radioisotope production, the dates of first criticality (D.O.C.) are as follows (drawn from INSC (n.d.) data):

<table>
<thead>
<tr>
<th>D.O.C.</th>
<th>Number of Reactors</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950-1969:</td>
<td>39</td>
<td>74</td>
</tr>
<tr>
<td>1970-1979:</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>1980-1989:</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>1990-1994:</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Totals</td>
<td>53</td>
<td>100%</td>
</tr>
</tbody>
</table>

It is also true that there are considerable obstacles to the construction of new reactors or the refurbishment of existing reactors. There are three important, interlinked obstacles: financial costs, waste storage and disposal costs and problems, and (in some cases) public opposition.
The potential for shortages of supply cannot be dismissed in light of the overall decline of reactor infrastructure and the obstacles to new reactors and refurbishments. However the future of reactor radioisotope production is not nearly so bleak, for the following reasons.

Firstly, the decline in reactor infrastructure is not so rapid as to be of immediate concern. The decline has proceeded from a starting point of a very large number of reactors. Amersham (1993) noted in its submission to the Research Reactor Review that "world capacity for reactor space directly available for isotope generation is actually at a high level and this capacity is under utilised." Contrary to the common view, reactor space and time is no great obstacle to radioisotope production, nor is it likely to be a crucial limitation in the coming decades. A more important factor is the commitment, of radiopharmaceutical companies and nuclear agencies in particular, to use existing facilities for radioisotope production. This can require some investment, for example reactor modification to facilitate target irradiation, or construction or upgrading of radioisotope processing facilities.

In the future a likely scenario is more efficient usage of a more modest overall reactor infrastructure. The US illustrates the broader trend, with numerous projects in train to maximise usage of existing infrastructure for radioisotope production, neutron beam research, commercial activities such as silicon doping, and so on. The situation that existed in the US during the first half of the 1990s - with dozens of research reactors but little radioisotope production - will probably become less common in the US and elsewhere.

Secondly, the obstacles to the construction of new radioisotope production facilities, including research reactors, or the refurbishment of existing facilities, are substantial, but some new reactor projects are underway and certainly refurbishments are common enough. It is likely, though not certain, that the decline in the number of operating research reactors may reach a point of equilibrium, with the impact of shut downs being matched by refurbishments, the odd new reactor, more efficient use of existing facilities, and further development of non-reactor methods for radioisotope production - and all this without any major problems with respect to radioisotope production and supply.

Thirdly, a number of technical innovations could ameliorate concerns over future production and supply. These include innovations enabling more efficient and widespread reactor production of radioisotopes; new types of reactors which may
be less expensive and generate less waste; further development of non-reactor methods of radioisotope production (esp. cyclotrons, linear accelerators, spallation sources); research into radioisotopes which may replace Mo-99/Tc-99 as the workhorse of nuclear medicine; and further development of alternative imaging modalities and other diagnostic and therapeutic technologies which do not require radioisotopes. These innovations are discussed in more detail in section 7.8.

It needs to be taken into account when assessing claims of imminent shortage of radioisotope supply that these claims sometimes have an element of self interest and fear mongering. Such arguments can be overstated to persuade governments to fund new reactors or refurbishments, not least in Australia. In other cases similar arguments are deployed to support increased research into cyclotron radioisotope production (e.g. Lagunas-Solar, 1993; Egan et al., 1994). Once again some overstatement may be at work – though a good case can certainly be made for greater emphasis on non-reactor methods of radioisotope production.

PRODUCTION OF Mo-99

Concerns over future radioisotope production and supply often reflect the problems encountered with Mo-99 supply in the early 1990s. Those concerns were well-founded at the time. However since then a number of major projects have reached fruition, and in hindsight the tenuous Mo-99 supply situation in the early 1990s was less an indicator of future supply problems than a result of a conjunction of specific factors: unforeseen closure of several important reactors; a higher level of concentration of fission Mo-99 production than had previously been in evidence or is likely to be repeated; and rapid increase in demand through the 1970s and 1980s.

Another factor leading to the tenuous state of Mo-99 supply in the early 1990s was a lack of consciousness among radioisotope users and radiopharmaceutical companies that a potential supply problem was looming. This complacency was, as Lagunas-Solar (1993, p.2) says, a result of the "excellent" record of availability of fission Mo-99 in most regions of the world and the reasonable prices being charged for Mo-99/Tc-99m generators. The problems of the early 1990s have underpinned, or at least hastened and given momentum to, a number of new ventures for reactor production of fission Mo-99 and also a number of innovative research projects which may resolve some of the fundamental difficulties with fission Mo-99 production such as the need for high-flux reactors and HEU targets.
Worldwide supply of Mo-99 will be secure for some decades to come. Indeed there will be a glut, or at least the capacity to produce Mo-99 considerably in excess of demand. The reactors in Canada (Maples), Belgium (BR-2), the Netherlands (HFR), the US (ACRR), and South Africa (Safari I) will by themselves guarantee worldwide security of supply for the next 20 years and possibly longer.

There will soon be fission Mo-99 production in about 12 countries, perhaps a few more. Information on production levels is limited for a number of reasons but the following estimates give at least some idea. (The figures are at-delivery volumes, which are lower than production volumes because of decay.)

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>PRODUCTION OF FISSION Mo-99 (Ci/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>600 000+, up to 100% of world demand</td>
</tr>
<tr>
<td>Netherlands</td>
<td>150 000++++, most or all of world demand if required</td>
</tr>
<tr>
<td>Belgium</td>
<td>50-150 000</td>
</tr>
<tr>
<td>South Africa</td>
<td>50-150 000</td>
</tr>
<tr>
<td>USA</td>
<td>Eventual capacity 200-300 000+</td>
</tr>
<tr>
<td>South Korea</td>
<td>Production from the year 2000; some export planned</td>
</tr>
<tr>
<td>Australia</td>
<td>13 000</td>
</tr>
<tr>
<td>Indonesia</td>
<td>12 000</td>
</tr>
<tr>
<td>China</td>
<td>3 000</td>
</tr>
<tr>
<td>Russia</td>
<td>? (Probably modest, growing)</td>
</tr>
<tr>
<td>France</td>
<td>? (Probably modest)</td>
</tr>
<tr>
<td>Argentina</td>
<td>? (Probably modest)</td>
</tr>
<tr>
<td>Poland, Hungary, Egypt, &amp; Czech Republic</td>
<td>? (Possible production)</td>
</tr>
<tr>
<td>Peru, Sweden, several others</td>
<td>None, but potential for development</td>
</tr>
</tbody>
</table>

According to ANSTO's (1993F, p.7.5) calculations, world demand for Mo-99 in the early 1990s was 560-730 000 Ci/year. Even allowing for sustained, substantial growth in demand, it is highly unlikely that there will be shortages of fission Mo-99 for the next 20 years or so.

If the major existing suppliers of fission Mo-99 are unable to meet demand, which is highly unlikely, then a string of other modest producers will probably increase production and other producers are likely to emerge. There has been considerable interest from a number of countries in producing and exporting fission Mo-99, including Argentina, Peru, and Indonesia. (Rojas-Burke, 1993D.) In some cases

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67 According to Russ Knapp (1996, pers. comm.), a researcher at the Oak Ridge National Laboratory, Mallinckrodt's Mo-99 production capacity is 20 000 Ci/week, well in excess of world demand.

68 I will use the ANSTO figures though other estimates differ. Iturralde (1996) gives a figure of 5 700 Ci/week as the world demand for Mo-99, equivalent to 285 000 Ci/year or roughly half of ANSTO's estimate.
this interest is highly ambitious. In Argentina, for example, the most powerful research reactor has a power level of just 2.8 MW and an equally modest flux level.

There is no question about security of supply of Mo-99 in the coming decades. Indeed a more revealing question is why there is likely to be such an over-capacity for fission Mo-99 production. The short answer is that fission Mo-99 is one of the few radioisotopes for which there exists a sizeable world market, and thus the potential for profitable production. Another issue which follows from the over-capacity of fission Mo-99 production is whether all the production facilities will maintain financial viability, or whether there will be some consolidation with the less competitive (and less well subsidised) producers being forced out of the market.

PRODUCTION OF OTHER RADIOISOTOPES

There is little discussion in the publicly-accessible literature on radioisotopes other than Mo-99/Tc-99m. Nevertheless two conclusions can be drawn from the available information in relation to other radioisotopes. Firstly, there is very little likelihood of shortages of the most commonly used medical radioisotopes in the foreseeable future. Secondly, availability of some radioisotopes, for which there is little demand and thus little profit to be made from production and supply, has always been precarious and this is not likely to change.

Dozens of different radioisotopes are used for both diagnostic and therapeutic nuclear medicine procedures; new applications are being developed all the time with new radioisotopes coming into use (or new applications of existing radioisotopes being developed), while others go out of fashion. There is no need here to elaborate on the wide range of radioisotopes used in nuclear medicine - suffice it to make a few comments on the most frequently used radioisotopes. A few radioisotopes – Mo-99/Tc-99m, thallium-201 (Tl-201), and gallium-67 (Ga-67) – account for well over 95% of all nuclear medicine procedures. Another significant radioisotope is iodine-131, which accounts for 90% or more of all therapeutic nuclear medicine procedures (although therapeutic procedures account for just 1-2% of all nuclear medicine). Iodine-131 is also used for some functional imaging procedures. It accounts for only a small percentage of all nuclear medicine procedures, but it is far more expensive than most other radioisotopes.
Radiopharmaceutical markets (data drawn from Morris, 1993; Egan et al., 1994):

<table>
<thead>
<tr>
<th>Radioisotope</th>
<th>Mo-99</th>
<th>Tl-201</th>
<th>Ga-67</th>
<th>I-131</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated world market ($US million)*</td>
<td>300</td>
<td>350</td>
<td>50</td>
<td>300</td>
</tr>
<tr>
<td>Percentage of nuclear medicine procedures</td>
<td>80-90</td>
<td>10-15</td>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Percentage of world market by cost</td>
<td>30%</td>
<td>35%</td>
<td>5%</td>
<td>30%</td>
</tr>
<tr>
<td>Production method</td>
<td>Reactor</td>
<td>Cyclotron</td>
<td>Cyclotron</td>
<td>Reactor</td>
</tr>
</tbody>
</table>

* These are retail figures for processed radiopharmaceuticals (including Mo-99/Tc-99m generators). The markets for bulk radioisotopes are far smaller. For example the worldwide bulk Mo-99 market is estimated at about $US 50 million p.a. (Anon., 1995E).

Summing the markets for these four radioisotopes gives a total of $US 1 billion. This is roughly equivalent to ANSTO's (1993F, Annex 7.2.1) figure of $US 910 million ($A 1315 million) for the total radiopharmaceutical imaging market. All these figures should be treated as rough estimates because of factors such as commercial confidentiality and the fragmented and fluid nature of radioisotope production and markets.

There is no likelihood – at least for the next 20-30 years or so – of a shortage of any of these four radioisotopes. Mo-99 has been discussed. Thallium-201 and gallium-67 are widely produced using cyclotrons. High specific activity iodine-131, along with some other radioisotopes including xenon-133 and iodine-125, can be produced as by-products of fission Mo-99 production. All fission-product radioisotopes will benefit from the various projects to increase production of fission Mo-99. Indeed given the over-capacity of Mo-99 production, some producers may put more effort into sales of other fission-product radioisotopes. Iodine-131 is the second most important fission-product radioisotope after Mo-99, and both fission-product iodine-131 and l.s.a. iodine-131 will, according to Amersham (1993), be freely available worldwide for the foreseeable future.

Apart from these four major radioisotopes, other radioisotopes used for clinical nuclear medicine or medical research can be considered in two broad categories. Firstly there are radioisotopes which are reasonably easy to produce, whether using particle accelerators (especially commercial cyclotrons) or reactors. In some
cases there is substantial demand for particular radioisotopes for industrial uses, and additional production for medical markets can be achieved easily and profitably, e.g. iridium-192. Overall, the subsidisation of reactor radioisotope production, and the modest marginal costs of producing radioisotopes using existing facilities, has facilitated the production and supply of the wide range of radioisotopes that are currently in use.

The second category comprises those radioisotopes which are less freely available, for various reasons: they are difficult to produce (e.g. requiring high-flux reactors, limited availability or high cost of target material); they are too short-lived for widespread transport and use; and/or the market is small and there is little or no opportunity for profitable production. Radioisotopes used for research are particularly prominent in this second category. Inevitably, availability of these radioisotopes tends to be limited and precarious, even in countries such as the US with a large reactor and accelerator infrastructure and a high level of clinical nuclear medicine and research. Government funding is almost always necessary for these radioisotopes to be available. Sometimes private companies produce these radioisotopes in the hope of stimulating the development of a profitable market, but predicting demand for many radioisotopes is difficult and this deters investment (O'Leary, 1995).

NEW REACTORS AND REFURBISHMENTS

There are several obstacles to the construction of research reactors and the refurbishment of existing reactors, in particular cost, radioactive waste problems, and sometimes public opposition. For new reactors the question of cost is particularly salient. To satisfy neutron beam researchers, reactors of ever-higher neutron flux, equipped with all sorts of gadgetry (e.g. cold sources to change the wavelength of neutron beams) are in demand. Thus the price tags for new reactors are often extremely high: over $A 500 million for the German FRM-II, and $A 3-4 billion or more for the (abandoned) Advanced Neutron Source project in the US. Despite the obstacles, a number of research reactors are under construction or planned.
RESEARCH REACTORS UNDER CONSTRUCTION OR PLANNED
(IAEA, 1994; 1995):

<table>
<thead>
<tr>
<th>Under construction</th>
<th>Planned</th>
<th>Power (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russian Fed.</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Slovak Republic</td>
<td>1</td>
<td>&lt;1, no data</td>
</tr>
<tr>
<td>Canada</td>
<td>1*</td>
<td>10, 10</td>
</tr>
<tr>
<td>United States</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Japan</td>
<td>3</td>
<td>&lt;1, &lt;1</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>Egypt</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>Iran</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Morocco</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Syria</td>
<td>1**</td>
<td>100</td>
</tr>
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<td>France</td>
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<td>Madagascar</td>
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Totals: 12 10

* This is the back-up Maple, not included in the IAEA data.
** The RJH and FRM-II reactors, not listed in IAEA data.

Of these 22 reactors, the two Canadian Maples are of great significance in relation to future radioisotope production. The French and German reactors will be high-power, high-flux reactors but probably only modest radioisotope producers. The 5 MW reactor in Thailand will produce modest volumes of radioisotopes. The three reactors under construction in Japan are primarily for research and testing in support of the nuclear power program, and will thus have little impact on the radioisotope industry. The two high-power reactors in the Russian Federation might be used for commercial radioisotope production but I have little information. Both are to be operated by the Russian Federation Atomic Energy Ministry. One has been under construction since 1976, which suggests the project may have stalled, and perhaps the planned reactor will be a long time coming or it will be abandoned. The 200 MW reactor under construction in Kazakhstan is listed in the IAEA's "test" category, which makes it less likely to be of significance in relation to radioisotope production (most radioisotope-producing reactors are listed in the "research" category). There is at least some possibility that the Egyptian 22 MW reactor will be used for commercial radioisotope production and export. Most of the other reactors under construction or planned are <1 MW.
reactors and are therefore of no interest. One reactor not listed above is the 50 MW research reactor under construction at Khusab in Pakistan (see chapter 2). This reactor is not listed in IAEA data – perhaps it is not classified as a research reactor. In any case the reactor is unlikely to be of importance in relation to radioisotope production and export.

In the nuclear power industry, emphasis is being placed on more efficient and longer-term usage of existing facilities as an alternative to the construction of new reactors. A similar trend is in evidence with research reactors, a recent expression of which was the 1996 IAEA seminar on enhancement of research reactor utilisation, which dealt with radioisotope production among other things. Refurbishments are undertaken for the following reasons: repair or replacement of failed, worn or obsolescent parts; accommodation of new user facilities; upgrading or modernising systems; and/or responses to evolving safety and regulatory requirements. In many cases, a number of these factors have led to a number of reactor refurbishments over the years. (McDonald, 1992.)

The trend to refurbish research reactors, as an alternative to building new reactors or simply going without, has implications for future radioisotope production. One consequence is that reactor refurbishments have enabled the development of a number of radioisotope production ventures around the world and thus increased security of supply. Fission Mo-99 illustrates the trend. The five biggest fission Mo-99 producers over the next 10-20 years will probably be Nordion, SCK-CEN, Mallinckrodt, the US DOE, and the SAAEC. Four of these five ventures involve refurbished reactors, with only Nordion using new reactors.

A related issue is the longevity of refurbished reactors. Since the first research reactors were built just over 50 years ago, predicting the longevity of refurbished reactors is a dubious science. As with power reactors, research reactors inevitably suffer the effects of ageing, such as radiation-induced alloy embrittlement, temperature and pressure effects, fatigue and wear, corrosion, and erosion (Krull, 1994B). In other words research reactors cannot be operated indefinitely. On the other hand the cost of refurbishment for research reactors is not nearly as high as for power reactors. In many cases, design limitations, tied in with program-related redundancies, are more important life-span determinants for research reactors than costs associated with operation or refurbishment. (Krull, 1995.)

Considerable resources have been invested in the refurbishment of a number of reactors around the world. These refurbishments would not have occurred if there was not some expectation of continued operation for, say, 10-20 years or
more. However what little empirical evidence there is suggests that refurbished reactors are not expected to last much longer than 10-20 years. The Belgian BR-2 reactor will operate for just another 15 years despite a major, recent refurbishment involving a shut down of the reactor for 12-18 months. In Sweden, Studsvik Nuclear plans to operate the R2-MTR reactor, which first went critical in 1960, for another 20 years; in other words it may have a life span of 60 years or possibly more. It is expected that the German FRG-I reactor will be used until the year 2010, by which time it will have operated for over 50 years (Krull, 1995).

Another consideration is that longevity depends in part on the commitment of reactor operators to refurbish reactors and the willingness of governments to fund such projects: sometimes extremely costly and time-consuming refurbishments have been carried out to allow for continued operation. In a review of research reactors in the Asia / West Pacific region, McDonald (1992), an ANSTO employee, concludes that with careful maintenance, operation, and refurbishment, even the oldest research reactors might be used for many more years.

Almost three quarters of the 5+ MW reactors currently used for radioisotope production were built in the 1950s or 1960s. Many of these are certain to be permanently shut down in the next 10-20 years. However on the strength of what has been said it can be predicted that the closure of this cohort of reactors will be spread out over a longer period; some, particularly those built in the mid to late 1960s, are likely to be in operation for another 30+ years.

Returning to the specific case of fission Mo-99, reactors in a number of countries will probably face closure before, say, 2020. These include some reactors which are or promise to be major producers of fission Mo-99 – BR-2, HFR (Belgium), ACRR, and Safari 1. Some reactors used for modest production levels will also face closure, including reactors in Australia, Russia, and perhaps elsewhere. However a number of high-power, high-flux reactors will remain in operation beyond 2020. Nordion should be able to continue to meet a large part of world demand using the two dedicated Maples. In addition, reactors in the following countries will or could be producing fission Mo-99 beyond 2020, though production levels are in doubt: Indonesia (30 MW, first criticality in 1987), South Korea (30 MW, 1994), Peru (10 MW, 1988), China (125 MW, 1979), and possibly the reactors planned in Germany and France. In addition there may be some "dark horses" among recently-built reactors, and some new reactors may be built and have an impact.
CONCLUSION

In sum, it is highly unlikely that declining research reactor infrastructure will cause serious shortages of radioisotopes over the next 20 years. In the longer term, declining research reactor infrastructure may be felt more keenly but this is by no means certain. At least some of the technical innovations discussed in section 7.8 will balance the impact of declining reactor infrastructure. Another important factor is that if the declining reactor infrastructure is the Achilles heel of radioisotope production, this is balanced by the nature of reactor radioisotope production, with the potential for a very small number of reactors (just one in the case of the Canadian NRU reactor) to produce the entire world demand for radioisotopes.

7.3. CONCENTRATION OF RADIOISOTOPE PRODUCTION

OVERVIEW
MOLYBDENUM PRODUCTION: A MONOPOLY TO A CARTEL?

OVERVIEW

A number of radioisotope producers have pulled out of the industry over the years. Ice (1995) offers the following reasons: market forces; an "inordinate" array of regulations; difficulties in locating and establishing production facilities; and radioactive waste problems and costs. Despite the loss of a number of producers, commercial radioisotope production for export markets is not as concentrated now as it was in the early 1990s; there have been increases in both the number of producers and the number of facilities.

The first argument to be developed here is that a reasonably high level of concentration in the industry is not entirely problematic; indeed it may be the most conducive situation for sustained radioisotope production and security of supply for radioisotope users. Another issue to be considered here concerns the relations between Mo-99 producers; in simple terms it could be argued that the near-monopoly of the early 1990s has given way to something resembling a cartel.

The level of reliance on Nordion in the early 1990s was problematic, but a substantial degree of concentration is not entirely problematic in terms of overall production levels and security of supply. This issue has some parallels in broader debates about the relationship between industry concentration and technological
innovation. A reasonably high degree of concentration can encourage technol-
ogical innovation because of the high costs and risks that are often involved: large
firm size, and a high degree of control over a market, can insure against loss. On
the other hand complete monopolisation can have a negative impact: firms may
sit on an existing product if they have captured the market and are secure and
satisfied with the situation, and conversely the existence of threats or even
potential threats from smaller companies can encourage innovation throughout
an industry. There is no clear evidence of a generally valid relationship between
concentration and levels of innovative activity, but much of the research supports
the generalisation that innovation is usually highest when industry structure is
somewhere between complete monopolisation and even competition between a
number of companies. (Baldwin and Scott, 1987; Hård, 1993, pp.422-423.)

The issue of reactor radioisotope production levels and security of supply is in
some respects different from the issue of technological innovation in that the
former may depend primarily on the use of existing technologies rather than
innovation. Nevertheless the issues are similar, and the evidence from the
radioisotope industry suggests that a reasonably concentrated though not totally
monopolised industry is the situation most conducive to continuity of production
and security of supply. Recent history suggests that only the companies with a
major share of the world market - Nordion, Mallinckrodt, and Amersham - are
in a position to be undertaking substantial upgrading of radioisotope production
facilities including (in Nordion's case) the construction of new reactors. In this
sense concentration facilitates increased production and greater security of supply
around the world. (The US DOE (Sandia) and the SAAEC go against this trend, but
those ventures were crucially dependent on the existence of suitable facilities and
also public-sector funding.) In the absence of investments from the major private
companies, there would either be greater problems with availability of
radioisotopes or a greater level of public-sector production and subsidisation than
currently exists.

Concentration in the radioisotope industry is in some respects an impediment for
would-be producers or small producers to invest in new production facilities or to
upgrade existing facilities: the major producers enjoy economies of scale which
make it difficult for smaller competitors to enter the market or to increase their
market share. Nevertheless more modest production ventures are proceeding,
most of them publicly-funded and using existing research reactor facilities.

To sum up, it might be the case that further marginal shifts in the level of
concentration in the radioisotope industry would improve future security of
supply, but it is unlikely that a substantial swing in one direction or the other would do so.

MOLYBDENUM PRODUCTION: A MONOPOLY TO A CARTEL?

Firstly, I will discuss the issue of Nordion's near-monopoly position as supplier of 80-90+% of the world demand for fission Mo-99 from the early to mid 1990s. Has Nordion used its strong position in the market to its advantage and to the disadvantage of competitors, would-be competitors, hospitals, patients, and other interested parties? The two most obvious ways it could do this would be to discourage the establishment of other fission Mo-99 production ventures, or secondly to use its strong position to charge unduly high prices.

It is possible that Nordion may have used its position to curtail the development of new fission Mo-99 projects. Du Pont's agreement in the early 1990s to buy Mo-99 exclusively from Nordion for a period of 10 years may be an example. If not for that agreement, Du Pont may have put more effort into negotiations with the US DOE towards the conversion of the Omega West reactor. Several other radiopharmaceutical companies have long-term supply agreements with Nordion, but they are not exclusive supply agreements. Overall, there is no evidence of Nordion attempting to limit the development of new fission Mo-99 production facilities beyond the one, ambiguous case of the Du Pont agreement.

As for prices, it does not seem that Nordion was charging unduly high prices in the early 1990s. It is true that Mallinckrodt's venture in the Netherlands was motivated partly by a desire to protect itself against price increases, but it seems that those concerns were hypothetical in nature. In the abundant literature on efforts to re-establish domestic fission Mo-99 production in the US (or to increase security of supply some other way), there is no mention of Nordion charging excessive costs nor that the DOE-led Mo-99 project would act as a check on price increases. It is also notable that Nordion's first substantial price increase for some years came in 1996, when there was already greater competition, and this increase was specifically linked to the Maple project.

Nor is there much evidence that Nordion's strong position in the bulk Mo-99 industry had any important effect on the retail arm of the industry. Amersham might have had hopes of preferential treatment given its 14.9% stake in Nordion, but ANSTO (1993F, Annex 7.1.3) says that Amersham did not receive preferential treatment in relation to pricing. Many of the major radiopharmaceutical
companies had (and still have) long-term contracts with Nordion and there is no indication that any were given preferential treatment.

Anything that might be said about Nordion's near-monopoly position in the early 1990s is largely redundant now given the new production ventures. Of more pressing concern is the cartel-like manoeuvrings between Nordion and other bulk Mo-99 producers. The issue is basically that there seems to be only limited interest among the new producers in competing with Nordion for established markets, particularly in the US. Thus a DOE representative (quoted in Kotz, 1996) says that the DOE will be competing "in a small way" with Nordion (and Mallinckrodt) in the US market, but "small" is certainly the operative word given that the DOE will only provide a back-up service, it will not be under-cutting private suppliers in relation to prices, and it is keen to privatisate the venture or it may moth-ball the Mo-99 production facilities when the Canadian Maples are operating. Similarly Mallinckrodt has made a large investment in the Petten project but claims that it will only use Petten-produced Mo-99 to supply existing customers, not to compete for Nordion's customers. Why this is so is a matter of speculation: possibly Mallinckrodt's reliance on Nordion as a back-up supplier is the key factor.

Another example is the radioisotope operations in Belgium. The complicated arrangements between Nordion, IRE, and the reactor operator SCK-CEN are difficult to piece together, but it seems that SCK-CEN's BR-2 reactor will be used mainly as a back-up facility, and IRE's major role is as a back-up supplier. Perhaps the modest role of SCK-CEN and IRE has more to do with limited market opportunities and modest production capacity than with cartel-like manoeuvring in the industry. In addition, the limited use of the production and processing facilities in Belgium to compete for export markets may reflect Nordion's involvement - evidently Nordion has an exclusive supply agreement in relation to the SCK-CEN, which would limit the latter's capacity to compete for markets, and IRE has a back-up agreement with Nordion and may even be part-owned by Nordion.

The South African Atomic Energy Commission (SAAEC) seems to have maintained some distance from the collusion between the producers just mentioned. It has a mutual back-up supply arrangement with IRE, but that is unremarkable. The SAAEC has plans to increase its export sales and presumably expects to do this at the expense of other bulk producers. It has yet to break into the large markets of Western Europe or North America: it is unclear whether this is because of limited opportunities or for some other reason. The SAAEC does not appear to be interested in competing with ANSTO for the Australian market,
although it supplies ANSTO during routine HIFAR shut downs. The SAAEC (1997, pers. comm.) says that "We view ANSTO/ARI as a much valued customer and have no intention to compete with them in the Australian radioisotope market." One could speculate that the SAAEC does not like its chances of breaking ANSTO's stranglehold on the Australian market, and considers it preferable to maintain good relations to secure its position as a back-up supplier.

Indicative of the level of cooperation between the major Mo-99 producers (and some other radiopharmaceutical companies), was the establishment in the mid 1990s of a body called the Council on Radionuclides and Radiopharmaceuticals, Inc. (CORAR). The members of CORAR are the major radiopharmaceutical manufacturers in the US - Du Pont, Mallinckrodt, Medi-Physics, Amersham, and Nordion. (Seidel, 1995.) One of the objectives of CORAR is to ensure continuity of supply through back-up agreements between the member organisations. No doubt it pursues the collective interests of the industry in other ways, such as lobbying government.

Clearly there is a good deal of cooperation between the major producers of fission Mo-99. Whether this is problematic, and whether the arrangements qualify as a cartel, is another matter. It is possible that Nordion's recent price increase, of 40% or less, was facilitated by the unwillingness of other producers to compete for its markets. However as discussed (in chapter 6.2) the price increase seems to be less an opportunistic manoeuvre than a legitimate means of funding the new Maples, and it will have only a minor impact on hospital radiopharmaceutical budgets.

Certainly there is nothing objectionable in the major producers establishing back-up agreements; indeed that is essential given that all reactors are subject to routine shut downs. Nor is it unusual or inherently sinister for competitors in any particular industry to establish a peak body such as CORAR.

The collusion/cooperation exists alongside a degree of competition. It appears that it is the US market where there is the least competition, with both the DOE and Mallinckrodt showing little inclination to compete with the third supplier, Nordion. Supply of the European market may be more competitive, notwithstanding the complicated web of back-up agreements, supply agreements (sometimes exclusive), and cross-ownership between Nordion, Mallinckrodt, IRE, and SCK-CEN. There is no indication in the publicly-accessible literature of cartel-like collusion in relation to markets in the Asian region, although it is notable that the SAAEC says it will not compete with ANSTO for the Australian market.
To the extent that the intermediate, processing/retailing segment of the radioisotope industry can still be distinguished from bulk production, it seems that there is still considerable competition at this level. Indicative of this was the 1994 decision of Amersham/Medi-Physics that it would no longer distribute products in the US through Syncor/Du Pont. Syncor's response was to look for alternative suppliers, and the most likely outcome of this was intense competition between Syncor and Amersham for supply of customers previously supplied by Amersham-via-Syncor. (Funari, 1995.)

The falling out between Amersham/Medi-Physics and Syncor/Du Pont could be indicative of things to come, and there must also be a reasonable likelihood that the intense competitiveness in the intermediate segment of the industry will become more common in relation to bulk production. Given the substantial over-capacity of radioisotope production which has emerged in the past few years, and the modest size of the international radioisotope export market, there is a good chance that some producers will struggle to make a profit and to maintain viability in the coming years. This could easily result in fiercer competition.

7.4. PUBLIC AND PRIVATE ENTERPRISE

In the 10-20 years after World War II, radioisotope production was dominated by state-controlled institutions - in particular science research organisations and the newly-developing nuclear agencies. Radioisotope production was closely tied to military programs, under tight regulation, and shrouded in secrecy. One illustration of this is that in the US, shortly after the war, shipments of medical radioisotopes from the reactor at Oak Ridge National Laboratories were diverted to the Berkeley cyclotron facility, then shipped to hospitals from Berkeley and advertised as having being produced using the cyclotron. The reason for this was that reactor flux could be calculated from the specific activity of the radioisotopes, and for plutonium production that was a secret parameter. (Smathers and Myers, 1985; Smathers, 1996, pers. comm.)

Since then the links between radioisotope production and nuclear weapons and power programs have weakened and private companies have assumed a more important role in radioisotope production. A range of public, private, and hybrid structures now exist in relation to bulk radioisotope production, and private companies dominate in the downstream segments of the industry. Here I will discuss the extent to which private companies have become involved in radioisotope production. Then I will briefly canvass debates over the politics of ongoing state support for reactor radioisotope production.
There are two main pressures leading to the privatisation and commercialisation of radioisotope production. One is economic stagnation, with governments around the world less willing to fund nuclear programs and radioisotope production. A second driving force is that private radiopharmaceutical companies have shown at least some willingness to invest in research reactor facilities (and a greater willingness to invest in cyclotrons dedicated to radioisotope production).

As a response to economic problems, a common response from governments has been to privatise public assets as a short-term financial fix. Governments are particularly keen to privatise public institutions and programs that are non-profitable, but these are of course the very institutions and programs that the private sector is least interested in. In lieu of privatisation, governments have pursued such strategies as corporatisation – reshaping public institutions to run on a more commercial basis, either as an end in itself or as a first step to privatisation – or partial privatisation of profitable components of public-sector programs.

There has been limited potential for governments to privatise civil nuclear programs based on research reactors. There is tight regulation of such programs because of issues such as reactor safety, the potential for covert weapons development, the possibility of terrorist actions directed at research reactors, and so on. Moreover the private sector has been reluctant to invest in research reactor facilities.

According to ANSTO (1993L, p.3.13), about ten research reactors around the world are owned and operated by private companies and are used for commercial purposes. These reactors go against the grain. In all probability they are low-power reactors with specific functions related to nuclear power or weapons programs. As for multipurpose reactors, there has been much less private-sector interest. The Research Reactor Review (1993, p.119) found only one overseas example of a company contributing to the costs of a research reactor, and that was only for the costs of a specific instrument to improve the quality of silicon doping. At most other research reactor facilities, the Review went on to say, industry has been given free access initially and charged only subsequently, and then usually at subsidised prices. Actually there are some examples of radiopharmaceutical companies contributing to the costs of research reactor projects – new reactors in Nordion’s case and refurbishments in other cases (e.g. Mallinckrodt, Amersham).
Given the extremely limited potential for full-scale privatisation of research reactor programs, governments have pursued a number of alternative strategies to lessen the financial burden of these programs. Funding reductions, resulting in rationalisation of research reactor programs, have been common. Many shut downs of research reactors have been partly or largely a result of funding cuts. Another option is partial privatisation of aspects of research reactor programs. There are some notable examples of this in relation to radioisotope production. Nordion and Amersham were originally attached to AECL and the UK Atomic Energy Authority, respectively, and both were privatised.

A weaker form of privatisation is corporatisation, with the commercial operations of nuclear agencies being refashioned as commercial entities though still connected to the nuclear agency. Typically this is associated with a reduction or withdrawal of state funding; the corporatised entity is expected to support itself through radioisotope sales or other commercial activities. An example of corporatisation is Australian Radioisotopes, established in 1987 as a commercial subsidiary of ANSTO though still supported and subsidised by ANSTO (and indirectly by the government). A similar process has been carried out in the US on occasions: companies are paid to run government nuclear facilities but must keep government price controls and turn over any profit to the DOE (Kotz, 1996). As the examples of Amersham and Nordion demonstrate, corporatisation can be a step along the road to privatisation.

Forms of commercialisation, weaker than both privatisation and corporatisation, can take place without any significant structural change to the agencies involved. This is when nuclear agencies, usually under direction from government, place greater emphasis on cost reductions and cost recovery through sales. This has taken place in dozens of countries including Australia, Austria, China, South Africa, Russia, the UK, and the US.

Another solution to the financial burden of research reactor programs has been cost-sharing collaborations. For research reactors used primarily for neutron beam research (often in support of nuclear power programs), the tendency has been for governments of different countries to pool resources. One example is the Institute Laue-Langevin in France, a collaboration between six European countries which operates the 57 MW HFR reactor (ANSTO, 1993L, pp.3.25-3.26). Another example is the 25 MW HBWR reactor in Norway, which is funded as a co-operative research project between ten OECD countries (ANSTO, 1993L, p.3.23; IAEA, 1994). A third example is the Petten HFR reactor in the Netherlands, which is used for neutron beam research as well as radioisotope production. The research is under
the direction of the Joint Research Centre of the European Commission, and also involves the Energy Research Foundation. (Mallinckrodt, 1996.) A fourth example is the South Korean HANARO reactor, which KAERI hopes to operate as an international research centre. There are also a number of examples of collaborative ventures involving high-power accelerators.

With respect to radioisotope production, there is a similar trend towards collaborative ventures, but the collaborations are different in nature. Rather than being collaborations between governments (and state institutions such as civil nuclear agencies), radioisotope-production collaborations generally involve major radiopharmaceutical companies and nuclear agencies. The most significant examples here are Nordion's collaboration with AECL, Mallinckrodt's collaboration with the operators of the Petten reactor, and Amersham's venture in Russia. There are a number of other reactors around the world which have some potential for collaborative development of this nature, such as those in South Korea, Peru, Sweden, the US (Sandia), and Indonesia.

It is possible to argue that public subsidisation of radiopharmaceutical companies has been excessive, that the radioisotope industry is another example of government industry policies "opening the coffers of the state to plunder by industrialists who could claim large subsidies for doing what they had fully intended to do anyway." (Holmes and Sharp, 1989, pp.1-2.). Private companies have become used to supply from government-owned reactors and have been unwilling to invest resources themselves. That reluctance has been amply illustrated with the fission Mo-99 saga in the US over the past five years, and it was evident in Nordion's dispute with AECL. In the absence of publicly-funded alternatives, the radiopharmaceutical companies have shown some willingness to invest resources themselves.

Another form of strong and arguably excessive support of private radioisotope producers has been the restrictions operating in the US and Japan on public-sector competition with private producers. To give an example of problems arising from this policy, in 1989 the DOE pulled out of production of enriched oxygen-18 water (which is used to produce radioactive fluorine-18, one of the most important radioisotopes for positron emission tomography). This left a single company, Isotec, producing the product. Prices rose markedly and Isotec was unable to meet demand. (Anon., 1993D.)

Whatever might be said about public-sector subsidisation of corporate interests in the radioisotope industry, it is clear that radioisotope markets are not sufficiently
large, when weighed against the capital and operating costs of production facilities, for radioisotope production to be satisfactorily left to the private sector alone. Supply of low-volume, unprofitable radioisotopes in particular requires public-sector support. Although radiopharmaceutical companies have shown some willingness to invest in reactor facilities, the overall picture is that some degree of state support is essential for research reactor programs and for reactor radioisotope production. Nordion's investment in the new Maple reactors is the closest example of a reactor radioisotope production venture which has been largely funded privately. However even in that example, there is some capital investment from the government and AECL, an interest-free loan to Nordion, and Nordion will undoubtedly make use of the publicly-funded nuclear infrastructure, especially for waste storage/disposal. Mallinckrodt and Amersham have made even more extensive use of publicly-funded nuclear infrastructure, including the use of existing reactors.

While it is true that ongoing state support is necessary for radioisotope production (some radioisotopes more than others), this need not be taken as an argument for domestic production. Rather, there is a need for state support whether this involves domestic production or importation or a mixture of both.

7.5. VERTICAL INTEGRATION

Vertical integration is a typical method by which companies secure their place in a market and maximise profits by reducing uncertainties and increasing efficiencies. It has affected the development of a number of diagnostic imaging modalities (Blume, 1992, p.45). Vertical integration in the radioisotope industry has involved several overlapping processes. One has been movement "downstream", with radiopharmaceutical companies assuming more of the functions previously carried out in hospitals. An associated aspect of downstream integration has been closer integration between the radioisotope and pharmaceutical industries. Another aspect of the vertical integration of the radioisotope industry has been for radiopharmaceutical companies to extend their activities "upstream" into bulk radioisotope production.

I will focus most of these comments on the fission Mo-99 industry, but most of the companies discussed are also major suppliers of other radioisotopes, and most of the changes in the industry have had similar effects for other radioisotopes.

Before considering the radioisotope industry, some brief comments on imaging equipment and reactor construction. The radioisotope industry is neatly separated
from the industries producing imaging equipment (esp. cameras and computer systems). Companies such as Siemens and Toshiba are involved in both the imaging equipment industry and research reactor construction, but they are not involved in radioisotope production. Some other organisations are involved in both research reactor construction and radioisotope production, including General Atomics (USA), the US DOE, Techsnabexport (Russia), and AECL would qualify here given its close association with Nordion. These links are of no great significance however. They involve very large, multifaceted organisations, and in most cases research reactor construction and radioisotope production are largely separate aspects of their operations. Moreover there is no sign of a trend for research reactor constructors to move into the field of radioisotope production, and conversely it would of course be an enormous leap for companies focused on radioisotope production to move into reactor construction. The most important link between reactor construction and radioisotope production is that some constructors of power reactors have put more emphasis on construction and sales of research reactors in response to the decline in the nuclear power industry (see section 7.7).

No more needs to be said about the reactor construction and imaging equipment industries. As for the radioisotope industry, it has historically been split between three levels:

i) bulk radioisotope production;

ii) intermediate functions (e.g. generator manufacture, supply of cold kits, retailing, marketing, etc.), generally carried out by the radiopharmaceutical companies and some nuclear agencies (e.g. ANSTO, SAAEC); and

iii) final processing functions, producing ready-to-use radiopharmaceuticals, historically carried out in hospitals but increasingly carried out by regional radiopharmacies owned and operated by radiopharmaceutical companies.

The radioisotope industry is undergoing major and fairly rapid change. The industry is no longer neatly split between these three levels. One of the most important processes has been for radiopharmaceutical companies to move "upstream" into radioisotope production. Given the costs and other restrictions associated with reactors, the most common method for radiopharmaceutical companies to move into bulk radioisotope production has been to purchase cyclotrons which are used for commercial radioisotope production, and sometimes also research. Most or all of the major radiopharmaceutical companies operate cyclotrons: Amersham, Nordion, Mallinckrodt, and the Japanese company Nihon Medi-Physics each operate between one and eight. The capital costs of
cyclotrons run into the tens of millions of dollars, but capital and operating costs are far less than for reactors, they generate far less radioactive waste, and they are cheaper and less problematic than reactors in relation to liability in the case of accident.

As for reactors, there are several examples of upstream integration into bulk radioisotope production. One is Mallinckrodt's venture in the Netherlands. Another is Nordion, the first radiopharmaceutical company to have invested funds towards the construction of a new reactor. Amersham has pursued a number of strategies to increase its involvement in radioisotope production or to increase security of supply by other means: it owned a 14.9% stake in Nordion for some time; it has secured a long-term contract with Nordion; it is involved in the joint venture in Russia; and it has agreements of some sort with other reactor radioisotope producers. Other companies seem to be satisfied to maintain nothing more than an arms-length involvement in reactor radioisotope production. Du Pont has a 10-year contract for Mo-99 supply with Nordion, and it has strengthened its role in the processing/retailing arm of the industry through its agreement to take on Nordion's sales and marketing operations in Europe. It should be noted that Du Pont does not seem to be totally uninterested in more direct involvement in reactor radioisotope production; its involvement with the DOE project to develop the Omega West reactor facility in the early 1990s indicates a willingness to tread the same path as its competitors. More recently, the decision of Amersham/Medi-Physics not to supply Syncor (linked to Du Pont) with proprietary products might encourage Syncor/Du Pont to move upstream into reactor radioisotope production.

More direct involvement in radioisotope production has potential advantages in terms of radioisotope costs and security of supply. The costs of research reactor construction, refurbishment, and operation set limits on the extent to which upstream integration can be pursued. Nevertheless there is a clear trend in this direction, with collaborations between radiopharmaceutical companies and operators of existing reactors being more likely than new reactors. Radiopharmaceutical companies are also likely to continue to purchase cyclotrons.

One consequence of upstream integration is that there is now greater competition in the business of bulk radioisotope production, with a number of producers challenging Nordion’s position. Against this, there is the curious lack of competitive spirit in the industry discussed previously, but the point holds to some extent. A second consequence of upstream integration is that there is greater overall production – it is unlikely that a number of important ventures would
have gone ahead without the direct involvement of radiopharmaceutical companies (e.g. Mallinckrodt, Nordion, Amersham).

Now to consider the processing/retailing (intermediate) arm of the industry, in particular Mo-99/Tc-99m generator manufacture. Six companies compete in the business of building and supplying Mo-99/Tc-99m generators in Europe – Amersham, Mallinckrodt, CIS, Sorin, Hoechst, and Du Pont. The three major suppliers of the US market are Medi-Physics/Amersham, Mallinckrodt, and Syncor/Du Pont. (Berkhout, 1993.) The biggest radiopharmaceutical companies – in particular Mallinckrodt and Amersham – supply most other countries around the world with generators. The most important exception is Japan, where Nihon Medi-Physics and Daichii manufacture generators using bulk Mo-99 from Nordion. Other exceptions are countries such as Australia and South Africa where there is domestic production of fission Mo-99 and also domestic generator manufacture.

Historically there has been fierce competition in the manufacture and retailing of Mo-99/Tc-99m generators. It is no surprise that some manufacturers have been pushed out of the industry. One example is E.R. Squibb and Son, which was once a large supplier of Mo-99/Tc-99m generators. There has also been a tendency for companies to focus on particular market segments. For example, Amersham/Medi-Physics focuses on supply of large generators for central radiopharmacies, while Du Pont and Mallinckrodt focus on the supply of hospital/clinic size generators. (Carretta, 1994.)

The fierce competition in the generator industry is on the wane because of the changing nature of the radioisotope industry. The emphasis is shifting in a number of directions: upstream integration into bulk radioisotope production; (horizontal) integration with the pharmaceutical industry; and downstream integration into final processing functions. One consequence of this is that there does not seem to be much movement of bulk producers into the intermediate segment of the radioisotope industry including generator manufacture. Indeed Nordion has lessened its involvement in this segment of the industry through its arrangement with Du Pont.

Apart from the manoeuvring between the levels of bulk production and processing/retailing, there has been further integration downstream with bulk radioisotope producers and radiopharmaceutical companies assuming more of the final processing functions which were previously carried out in hospitals. Historically mixtures of radioisotopes and reagents were produced close to the
point of use, in hospitals. Hospitals required the facilities and the trained personnel for complex radiochemistry. Increasingly cold kits containing pre-processed chemicals for subsequent labelling with radioisotopes were made available. This most recent phase of integration extends that process - hospitals (and private clinics) are often now supplied with ready-to-use unit doses of radiopharmaceuticals.

Mallinckrodt is the clearest example of the various, interconnected trends, focusing less effort on generator manufacture and sale, and moving both upstream into radioisotope production and downstream into unit-dose radiopharmaceutical production. It moved downstream by establishing Diagnostic Imaging Services, a network of "nuclear pharmacies" in the US that supplies ready-to-use radiopharmaceuticals (Mallinckrodt, 1996). It is very likely that Mallinckrodt's supply to the European market is also organised in this manner. Nordion also illustrates these processes. It plans to continue to be a major producer of bulk radioisotopes, its has sold its processing/retailing operations in Europe to Du Pont, and Nordion recently claimed that it now produces a "growing line of finished radiopharmaceuticals". (Nordion, 1994.) The same general points apply to Amersham. It has moved upstream into radioisotope production through a number of manoeuvres, though not so directly as Mallinckrodt and Nordion. It has also moved downstream into unit-dose radiopharmaceutical manufacture and supply, particularly through its part-ownership of Medi-Physics and Nihon-Medi-Physics.

The downstream integration into unit-dose radiopharmaceutical production has changed the structure of the radioisotope industry. Hospital radiopharmacies are smaller where they exist at all, with regional radiopharmacies, such as Mallinckrodt's Diagnostic Imaging Services, and a network of radiopharmacies in 60 US cities operated by Syncor/Du Pont, increasingly common. Physicians place orders with the regional radiopharmacies which generally arrive on the same day or the following day. (Carretta, 1994.) Former Mo-99/Tc-99m generator producers - such as Mallinckrodt, Syncor and Medi-Physics - have been transformed to some extent into radiopharmacy companies though they have not pulled out of generator manufacture altogether (Berkhout, 1993).

One impetus for this trend to regional radiopharmacies is shortages of skilled personnel in hospitals and also increased hospital labour costs. The cost for hospitals of buying pre-mixed radiopharmaceuticals is only slightly greater than buying radioisotopes and chemicals/pharmaceuticals direct from manufacturers. Overall it is cheaper given that hospital radiopharmacies can be further scaled
down or done away with. (Anon., 1993.) Centralised, regional radiopharmacies are better able to manage the regulatory and waste disposal expenses than hospital radiopharmacies (Knapp and Mirzadeh, 1994).

In the US, regional radiopharmacies were preparing about 64% of all doses by 1991. (Anon., 1993.) According to Lagunas-Solar (1993C), radiopharmacies are also commonplace in Western Europe. Over half the supply of Mo-99/Tc-99m in Japan is in the form of Tc-99 solutions - the radiopharmaceutical companies operate big generators into which bulk Mo-99 is loaded, with daily elution and supply to users (Yamabayashi, 1996, pers. comm.). These three markets account for about 90% of world radioisotope usage, suggesting that market size is important to the economics of establishing regional radiopharmacies. In other countries regional radiopharmacies have generally not been established and supply of hospital-size generators remains the norm.

Another reason for downstream integration, and the establishment of radiopharmacies, is that the greatest profits are being realised in this part of the industry. Increasingly the chemicals and pharmaceuticals which are attached to radioisotopes - e.g. for organ localisation or therapeutic effect - are becoming more profitable than the radioisotopes per se. These products can be up to 50 times as expensive as the Tc-99m according to Berkhout (1993) although the difference is usually less. This has led to closer integration between the radioisotope and pharmaceutical industries. Many of the radiopharmaceutical companies - including Du Pont, Mallinckrodt, Hoechst, Nordion, and Amersham - have long-standing involvement in pharmaceuticals and these links are becoming increasingly important. A number of processes have increased the integration between the radioisotope and pharmaceutical industries - radioisotope producers moving into pharmaceutical production, pharmaceutical companies moving into the radiopharmaceutical industry and looking to secure supply of radioisotopes through contracts, mergers, take-overs, and so on.

The major consequence of vertical integration is that a small number of very large, integrated operations dominate the global radiopharmaceuticals industry. Smaller ventures, such as those of ANSTO and the SAAEC, are integrated themselves to a considerable extent, but may find it increasingly difficult to compete with the larger operators. Other consequences of vertical integration include the establishment of regional radiopharmacies and the impact of this on technical innovation, such as the development of very large generators for supply of regional radiopharmacies.
7.6. DEDICATED PRODUCTION FACILITIES

Multipurpose reactors are not ideal for radioisotope production for several reasons. Conflicting demands can limit radioisotope production. A number of logistical and technical factors affect radioisotope production, such as low neutron flux levels, or limited or inappropriate irradiation facilities. These limitations are all the more common because reactors have almost always been designed primarily for functions other than radioisotope production. Refurbishments can overcome some of these problems, but limitations generally remain. Conversely, maximising reactor usage and facilities for radioisotope production impedes research and other reactor functions. Another difficulty with multipurpose reactors is that, because of the array of reactor facilities required to satisfy various projects, they have relatively high maintenance requirements in comparison with simpler, single-purpose facilities. Consequently, there is a need for frequent routine shut downs. Multipurpose reactors are also prone to a greater number of unplanned shut downs than single-purpose reactors, and this further limits continuity of radioisotope production and supply. The age of so many of the reactors used for radioisotope production further reduces efficiency and increases costs.

Because of the limitations of multipurpose reactors, particularly the ageing reactors currently in operation, there has been some momentum towards the development of dedicated radioisotope production reactors in recent years. Berkhout (1993) argued in his contribution to the Research Reactor Review that intensified competition in the radioisotope industry is forcing Mo-99 suppliers to develop dedicated production reactors. Certainly Nordion's new Maples will be dedicated to radioisotope production, and possibly dedicated to Mo-99 production depending on factors such as demand and prices. At the time that Berkhout made his analysis there was also a possibility that the US DOE would convert the Omega West reactor into a dedicated radioisotope-production reactor, although it was a lack of producers rather than intensified competition driving that project. Berkhout also alluded to Russian reactors, but it is highly unlikely that there are dedicated radioisotope production reactors in Russia. The most likely candidates would be the reactor(s) which have been converted to supply the Amersham/Mayak joint venture – but Amersham (1993) said that there was no reactor in the world totally dedicated to radioisotope production some time after the Mayak project was underway.

In short, Nordion's Maple reactors will be the first research reactors in the world to be dedicated to radioisotope production. It cannot be said from this one case that
there is a trend towards dedicated production reactors. Certainly cyclotrons
dedicated to radioisotope production have become more important in the past 10-
20 years, but that is a different issue.

In the US, efforts to re-establish domestic Mo-99 production, and to build a new
neutron source for research, have been separated to some extent. This could be
seen to be indicative of a trend towards the development of dedicated radioisotope
production facilities, but it is more likely that the separation of the two projects
has been due to logistical factors. Specifically, there was greater urgency to re­
establish domestic Mo-99 production, and a widespread view that existing facilities
would suffice for the job. Bringing to fruition plans for a powerful neutron source
for research, such as the Advanced Neutron Source, was always likely to take far
more time, negotiation, and funding, than the Mo-99 project. Furthermore, there
was some speculation that the Advanced Neutron Source could be a long-term
solution to Mo-99 supply problems, in which case the two projects would not
have been separated. For Mo-99, the concern was simply to increase security of
supply. Whether this involved a dedicated or multipurpose reactor, domestic or
foreign facilities, or reactors or particle accelerators, were all secondary issues.

A similar separation between radioisotope production and other research and
commercial reactor functions is taking place in Canada. Along with the dedicated
radioisotope-producing Maples, there are ongoing efforts to develop an
"Irradiation Research Facility" (IRF), also based on Maple design. The IRF will be
used for research and testing in support of the nuclear power program, and for
other research projects. (AECL, 1996.) Both projects are replacements for the
multipurpose NRU reactor. Why the two projects have been separated is unclear,
but the Canadian situation is a special case in that there is a large, multifaceted
nuclear program, and a large, established market for commercial radioisotopes.

Undoubtedly there is a desire among radiopharmaceutical companies and nuclear
medicine professionals for dedicated radioisotope-production reactors. The major
problem is funding. It is difficult for dedicated radioisotope-production reactors to
be "piggy-backed" on better-funded nuclear power and weapons programs, as so
much radioisotope production has been and continues to be. The only scope for
cross-program subsidisation of that sort is conversion of existing reactors to enable
dedicated radioisotope production, and possibly some subsidisation in areas such
as waste storage and disposal. Movement towards dedicated radioisotope-
production reactors not only reduces the potential for radioisotope production to
be piggy-backed on nuclear programs, but also for cost-sharing collaborations.
(Rojas-Burke, 1993B.)
Radiopharmaceutical companies are generally not in a position to be funding dedicated reactors given the extremely high costs and the modest size of the radiopharmaceutical market. There is a small possibility of other dedicated reactors in the future, if radioisotope markets grow and industry concentration puts one or another major supplier in a position to be pursuing such a project. As for government funding of reactor projects, it will almost certainly continue to make more economic sense to build or refurbish multipurpose reactors than to fund the construction of dedicated reactors. Against that, the cost of dedicated radioisotope production reactors may be considerably lower than multipurpose reactors, as Nordion’s Maples would seem to indicate – $C 140 million for two reactors plus processing facilities. This is because neutron research tools such as cold sources comprise a significant proportion of the cost of multipurpose reactors. Nevertheless the cost of funding multipurpose reactors will, as a rule, be less than separate funding of facilities for radioisotope production, neutron beam research, and other functions.

While the prospects for new, dedicated radioisotope-production reactors are slim, other than the Maples, there are better prospects for the conversion of existing reactors for dedicated radioisotope production. The literature on the Sandia Mo-99 project does not make it clear whether the ACRR will be dedicated to radioisotope production, but it may be, and there may be similar conversions in future.

7.7. LINKS BETWEEN RADIOISOTOPE PRODUCTION AND NUCLEAR POWER, WEAPONS, AND RESEARCH PROGRAMS

THE IMPACT OF NUCLEAR POWER, WEAPONS, AND RESEARCH PROGRAMS ON RADIOISOTOPE PRODUCTION LEVELS
PUBLIC OPPOSITION
THE REDUCED ENRICHMENT FOR RESEARCH AND TEST REACTORS PROGRAM
 RADIOACTIVE WASTE

Some of the links between nuclear medicine and the broader nuclear industry have been discussed, such as the development of radioisotope production as a spin-off from nuclear power and weapons programs, and the symbiosis between medical and nuclear institutions. Here I will discuss several more links: firstly, a fuller discussion on the relationships between nuclear power, weapons, and research programs and radioisotope production levels; secondly, the impact of
public opposition to research reactors on radioisotope production; thirdly, the impact of the Reduced Enrichment for Research and Test Reactors program; and fourthly, the impact of radioactive waste problems on radioisotope production.

THE IMPACT OF NUCLEAR POWER, WEAPONS, AND RESEARCH PROGRAMS ON RADIOISOTOPE PRODUCTION LEVELS

It is commonly argued that the decline in nuclear power and weapons programs is responsible for the declining research reactor infrastructure, with dire consequences for radioisotope production. However the links between nuclear programs and radioisotope production levels are complex and contradictory and do not allow for simple generalisations. It is worth bearing in mind that global medical radioisotope production has increased several fold over the past 20 years to meet increasing demand, despite (and in some cases because of) the decline of many nuclear power programs around the world. Similarly a number of important radioisotope production ventures have been brought to fruition despite the end of the Cold War and the down-scaling of some nuclear weapons programs. To a large extent the increases in radioisotope production have occurred despite, not because of, the down-scaling of power and weapons programs, but they have occurred nonetheless.

A closer analysis of the relationships between nuclear programs and radioisotope production will serve two purposes. Firstly, it is of some value in the development of a better overall understanding of the radioisotope industry. Secondly, it can be of use in debunking the fear-mongering arguments sometimes put forward by proponents of various reactor projects about imminent shortages of radioisotopes.

In the post-war generation it was those countries with major nuclear power and weapons programs that took the lead with radioisotope production, in particular the US, the UK, and the Soviet Union. These countries had the research reactors and the scientific and engineering expertise for substantial radioisotope production. Funding for nuclear power and weapons programs was orders of magnitude ahead of that specifically set aside for civil radioisotope production. Radioisotope production was "piggy-backed" on power and weapons programs without much additional expense and with some clear gains in terms of public relations.

The historical process of radioisotope production being piggy-backed on power and weapons programs was clear enough. The patterns in the past generation have
been more complex. I will consider nuclear power first. Apart from the US, the UK, and the Soviet Union, other countries have piggy-backed commercial radioisotope production on nuclear power programs in the past generation, including Canada, Belgium, the Netherlands, South Africa, and South Korea. Thus there is still some correlation between nuclear power development and radioisotope production, simply because these countries have the appropriate nuclear infrastructure. The historical patterns are not all the same. In Japan the research reactor infrastructure was closely matched to the needs of the power program and there was less scope for subsidiary radioisotope production. In Sweden, a large nuclear power program was pursued but only three research reactors were built and Sweden is a net importer of radioisotopes. A substantial nuclear power program was pursued in Spain, with nine power reactors operating in 1995, but only two research reactors were built and both have been closed.

Piggy-backing radioisotope production on nuclear power programs has proved a mixed blessing in that downturns in power programs have had a negative impact on radioisotope production. Thus for example the UK and the US are no longer major producers and exporters of radioisotopes. With the downturn in their nuclear power (and to some extent weapons) programs, there is less incentive for the continued operation of research reactors or the construction of new reactors. The pattern is much the same in France and Germany.

On the other hand downturns in power programs have facilitated some radioisotope production ventures. In some cases this occurs because reactor time and space, and other resources such as trained personnel, are freed up. There are several examples of this process, including the increased production of radioisotopes by the AAEC once the Jervis Bay project was abandoned. A different example is the nuclear power company Ontario Hydro, which has increased its isotope sales business, partly as a result of the downturn in the nuclear power industry.

Another mechanism by which radioisotope production has increased as a result of downturns in power programs concerns reactor constructors. The striking example is Canada, where research reactor construction, including the new Maple design, as well as radioisotope production, have all been boosted in part because of the decline in the nuclear power industry (Lewis, 1996). Another example is the UK, where reactor constructors were unable to break into the power reactor export market but sales of research reactors compensated for this to some extent (Camilleri, 1984, p.230). A third example is Babcock and Wilcox, a heavy engineering firm whose prospects in the nuclear power industry plummeted
because of its involvement in the construction and operation of the Three Mile Island reactor. A recent initiative of Babcock and Wilcox has been research into a dedicated radioisotope-production reactor (see section 7.8). More generally, the historical process of nuclear supplier states seeking to stimulate and supply new markets for nuclear power often involved the supply of research reactors, on generous terms in many cases, and this strategy became all the more important as the nuclear power industry went into decline.

The down-scaling of nuclear power programs has been gradual and uneven. Moreover there has been some modest, regional growth in nuclear power, especially in Asia. In some cases these plans have encouraged the construction of research reactors, with a positive impact on radioisotope production. The notable examples are the 30 MW reactors in South Korea and Indonesia. The proposal to rebuild a shut-down reactor in Taiwan, with a power level of 30 MW, probably also fits this pattern. On the other hand plans to further develop nuclear power programs can absorb research reactor time and beam space to the detriment of radioisotope production; this has happened in Japan to some extent.

Now to consider the links between nuclear weapons and radioisotope production. The historical pattern of radioisotope production being piggy-backed on weapons programs took place in a number of the countries. The process was clearest in the US, where most of the isotope production facilities, in particular the numerous National Laboratories, were developed for military programs. (Kotz, 1995.) Spill-over funding for civil radioisotope production was readily available, though the military program took precedence and there was a tendency for supply of commercial customers to be interrupted because of this (Rojas-Burke, 1992B).

The overall impact of the scaling back of weapons programs in recent years has probably been a reduction in radioisotope production. However the evidence is ambiguous, not least because the down-scaling of weapons programs has been ambiguous and uneven. There are not too many swords-to-ploughshares projects to report. South Africa is the most important case of swords-to-ploughshares. Whether or not the Safari I reactor was used directly in support of the weapons program, HEU fuel supply was cut off thus limiting opportunities for radioisotope production and research reactor projects more generally. Now, with a stock-pile of HEU from the weapons program to use for research reactor fuel and HEU targets, the SAAEC is an important supplier of fission Mo-99 and other radioisotopes.

There are some other, less striking examples of swords-to-ploughshares. The modest radioisotope production in Argentina - and the ambitions to increase
production - might owe something to the abandonment of the covert weapons program.

In the US, there are probably one or two examples of military cut-backs freeing up reactors and other resources for radioisotope production - the Sandia Mo-99 project might be one. However the overall effect has been decline in infrastructure and decline in spill-over funding for radioisotope production (Kotz, 1995). Moreover the overall decline in funding and infrastructure has meant greater competition for existing facilities and consequently the pattern of radioisotope production being disrupted by military programs continues - for example the Los Alamos Meson Physics Facility, a high-power accelerator used for radioisotope production among other functions, was recently given over to a military project concerning tritium production (Rojas-Burke, 1994). Nuclear power projects are also caught in the squeeze, and probably take priority over radioisotope production as a rule. The 40 MW Fast Flux Test Facility illustrates the priorities – this reactor, which first operated in 1980, was built to support the US fast breeder power program, then it was used for production of a number of medical research radioisotopes, then radioisotope production was stopped in 1992 and the reactor was put on standby to produce plutonium-238 for power generators in space probes, and most recently the reactor has been put on "hot standby" to produce tritium for weapons purposes. (Rojas-Burke, 1992C; ANSTO, 1997.)

The pattern in the UK (and possibly also France) has been similar to the US, with some decline in nuclear weapons spending, an overall decline in nuclear infrastructure, and less radioisotope production. The situation in Russia is probably similar but not quite as negative for radioisotope production, in part because of some swords-to-ploughshares projects such as Reviss Services. In China, civil nuclear applications have historically been dwarfed by the weapons program; what little radioisotope production has occurred has been piggy-backed on the weapons program. This probably remains the case. For example military-affiliated institutions play a leading role in nuclear medicine research (Yeh, 1993), and it is unlikely that this is a case of swords-to-ploughshares. The situation in China is complicated by the substantial nuclear power program and the commercialisation of parts of the overall nuclear program. The pattern in India is not dissimilar to that in China.

The correlation between nuclear weapons programs and civil radioisotope production has generally been weaker than for nuclear power. In some cases this has been because of efforts to separate civil from military programs. More generally the correlations are weaker because far fewer countries have pursued
nuclear weapons programs in comparison with nuclear power. Thus a number of the major radioisotope-producing countries have nuclear power programs but have never developed nuclear weapons, including Canada, Belgium, and the Netherlands.

International non-proliferation initiatives designed to stop production of weapons-grade fissile materials could have an impact on radioisotope production. In particular, some dedicated plutonium-production reactors would be suitable for radioisotope production including production of fission-product radioisotopes. Indeed the reactor(s) used by Revisis Services in Russia were probably dedicated to plutonium production.

In sum, the correlations between nuclear power and weapons programs and radioisotope production are ambiguous. Overall there is probably still a positive correlation between power programs and radioisotope production - countries with nuclear power programs are more likely to produce and export commercial radioisotopes, and conversely down-scaling of power programs has an overall negative impact on radioisotope production - but this correlation is weakening with time. The connections between nuclear weapons and radioisotope production are both weaker and weakening.

More generally, there is no neat correlation between numbers of research reactors, even numbers of high-flux multipurpose reactors, and radioisotope production as the example of the US shows. Perhaps the main reason that general patterns and trends do not have a predictable effect on radioisotope production is the capacity for a small number of reactors to supply the entire world demand; the radioisotope production industry is inherently idiosyncratic and unpredictable because of this. Substantial radioisotope production and export depends primarily on two variables. The first is the state of development of nuclear infrastructure - primarily research reactors but also radiochemical processing facilities, facilities for waste storage, and so on. The second variable - more subjective and arguably more important - is the determination of key institutions, such as nuclear agencies and radiopharmaceutical companies, to produce and export radioisotopes and the ability of these institutions to secure government support and subsidisation.

As for the future, there is little prospect of a significant upturn in the nuclear power industry. Similarly it is likely that weapons development has reached a plateau, perhaps a modest decline, and there is no indication of a major shift in this situation though it is unpredictable. If either of these situations should
change, the impact on radioisotope production is difficult to predict but it may not be so great. Partly this is because of the varied, contradictory nature of the links. Partly it is because there has been a modest trend towards disentangling radioisotope production from power and weapons programs, either with reactors or cyclotrons dedicated to radioisotope production. A third consideration is that the huge wave of research reactor construction from the 1950s to the 1970s was a phenomenon specific to the first generation of the nuclear age. A wave of construction of anything like that magnitude is unlikely to be repeated.

Putting aside the links between nuclear power and weapons programs and radioisotope production, there are also a host of complex relationships between radioisotope production and neutron beam research and commercial applications such as silicon doping. Within the scope of revenue-generating functions, there is generally no great preference for radioisotope production. The major money spinners are contracts for testing of fuels and materials for the nuclear power industry, silicon doping, and some others such as colour enhancement of gemstones. Revenue from radioisotope production can be significant but is generally much less. (ANSTO, 1993D, pp.1.14-15; 1993L, pp.3.33-3.34.)

It might be expected that revenue-generating functions including radioisotope production would take precedence over non-commercial research, especially in the cost-cutting environment of the past 20 years. There is some evidence of this, not least in Australia with the cost-recovery targets set for ANSTO. Predictably enough, there are also claims from the non-commercial research community that commercial programs have been given precedence; one such researcher in the US (quoted in Rojas-Burke, 1992D) claims that radiopharmaceutical companies have more "clout" when it comes to using DOE facilities. However this does not seem to apply as a rule. Certainly weapons and power-related research generally takes priority, but it is also the case that much of the impetus for research reactor construction and refurbishment stems from the (non-commercial) neutron beam research community whose work is only loosely connected to power and weapons programs if connected at all. This is particularly clear in Western Europe, with neutron beam research the main reason for plans for new reactors in France and Germany, but it also applies elsewhere.

The overall decline in research reactor infrastructure in many countries has exacerbated competition for reactor time and space, and this competition promises to sharpen in the future. However the relationship between radioisotope production and (other) commercial and research functions is not all competitive, at least in relation to refurbishments and new reactor projects. The different
functions can be complementary. In the case of the German FRM-II, there would be no plans for a new reactor, and thus no radioisotope production (however modest), if not for the momentum developed by the neutron science research community: radioisotope production will essentially be piggy-backed on neutron science. In other cases the relationship is more than complementary, it is synergistic – refurbishments or new reactor projects would not proceed if only to satisfy one function and constituency, but in combination sufficient momentum can be developed to bring projects to fruition. The proposed new French reactor might be an example of this synergy, and several refurbishments could be given as examples.

PUBLIC OPPOSITION

There are a sufficient examples of significant public opposition to research reactors to claim with some confidence that they have become more contentious over the decades. The issues taken up include cost, weapons proliferation concerns, and public and environmental safety (Lagunas-Solar, 1993; Egan et al., 1994). Some examples are the growing concern over the operation of research reactors in Australia, opposition to the German FRM-II reactor, and a major dispute in Mexico, in the early 1980s, over a proposed nuclear research centre which was abandoned in response to public opposition (de la Court et al., 1982, pp.43-44).

There has also been some opposition to research reactors in Canada – for example residual bitterness over the impact of the NRU and NRX accidents in the 1950s, and a controversy generated by AECL's plan to "donate" (at taxpayers' expense) a Slowpoke research reactor to a hospital (CCNR, 1991). No doubt there are other examples of public opposition to research reactors.

In addition to public opposition, there are examples of state opposition to research reactors, usually relating to the potential or actual uses of research reactors in nuclear weapons programs. For example the US government objects to the use of HEU fuel in the planned German FRM-II reactor, and Iraq's research reactors have been bombed several times.

While it is very likely that research reactors have become more contentious over the past generation, it is difficult to make any confident claims in relation to the overall level of public opposition to research reactors. There is little discussion on opposition to research reactors in literature such as the newsletters and journals published by anti-nuclear groups, the more academic social movement literature, or in the more technical nuclear literature such as the Bulletin of the Atomic Scientists. It seems clear enough that research reactors are considerably less
contentious than the big-ticket items of nuclear weapons and power and other nuclear fuel cycle industries such as uranium mining and reprocessing.

Nor can it confidently be predicted to what extent public opposition will affect research reactor programs in the future and what affect this will have on radioisotope production.

Direct public opposition to research reactors may not be as important an obstacle as other factors affecting research reactor programs, such as financial restraints. On the other hand, the indirect impact of public opposition is important. Public opposition has forced improved public and environmental safety regulation, which in turn increases capital and operating costs. Similarly, public concerns and campaigns concerning weapons proliferation or radioactive waste management are likely to have an important indirect effect on research reactor programs.

THE REDUCED ENRICHMENT FOR RESEARCH AND TEST REACTORS PROGRAM

The Reduced Enrichment for Research and Test Reactors (RERTR) program dates from the 1978 US Nuclear Non-Proliferation Act. As discussed in chapter 2.4, it is an initiative designed to reduce production of and trade in HEU because of weapons proliferation concerns.

The main aim of the RERTR program is to develop the technologies for conversion of HEU-fuelled reactors to LEU fuel without significant penalties in terms of performance, economics, or safety. A related aspect of the program has been for the US to take back spent research reactor fuel. A third aspect of the program involves the development of LEU targets for radioisotope production to replace HEU target technology. (Travelli, 1995; Leventhal and Kuperman, 1995; Nuclear Control Institute, 1996; Krull, 1994.)

REACTOR CONVERSION AND ADVANCED FUEL DEVELOPMENT

Conversion of research reactors to LEU fuels is the most important aspect of the RERTR program. The program has had some success in relation to reactor conversion. A large majority of research reactors, both in the US and elsewhere, of at least 1 MW power and having previously used HEU fuel supplied by the US, have been converted or are in the process of being converted. This amounts to 37 reactors converted or in the process of conversion. Since the US has historically been the major supplier of HEU for civilian use, the RERTR program has reduced
HEU trade. The US government has entered into agreements with Russia and China to work on conversion of reactors operating in, or supplied by, these countries. The Russian program is in a developmental phase. A Statement of Intent has been signed between Chinese and US officials. (Travelli, 1995.)

Whether conversion to existing LEU fuel types affects reactor performance is a contested issue. Those closely involved in the RERTR program argue that performance losses are modest, and a small price to pay for the non-proliferation gains (e.g. Travelli, 1995). Some reactor operators are not convinced – an operator of a German research reactor claims that performance losses of less than 10% have rarely been achieved and that most operators have experienced a "severe" decrease in overall performance (Krull, 1994).

Whatever problems exist with LEU fuels may be resolved with further research. The development of advanced fuels has been a stop-start affair in the US – in fact the entire RERTR program was scaled back considerably during the Bush administration. Nevertheless some research is proceeding in the US, and also in South Korea (KAERI) and France (CERCA) (Il-Hiun, 1996; Tissier, 1991; Travelli, 1995.)

Thus far it seems that the reactor conversion program has had only a limited impact on radioisotope production – certainly the issue is not a major talking point in the nuclear medicine professional literature. Partly this is because some important radioisotope-producing reactors – including BR-2 (Belgium), Safari I (South Africa) and HFR (Netherlands) – are still using HEU fuel. (The expectation at ANSTO is that HIFAR will be shut down in the next decade, but conversion to LEU fuel will be necessary if HIFAR is refurbished.) The preference of some reactor operators for HEU fuel, and their unwillingness to convert to LEU fuel, seems to relate mainly to research projects, but it may be the case that radioisotope production is a concern. The production of some radioisotopes requires a high neutron flux, and while fuel enrichment is not the only variable impacting on flux levels it is certainly an important one. Moreover radioisotope production was one of the reasons that the use of HEU fuels in research reactors became commonplace historically (Muranaka, 1983). Radioisotope production operations may partly explain the reluctance to convert reactors such as Safari I, the Petten HFR, and the Belgian BR-2 reactor, despite the pressure that is being applied to operators of these reactors to convert to LEU fuel. On the other hand the fact that AECL/Nordion's NRU reactor uses 20% enriched LEU fuel and plays such an important role as a radioisotope supplier suggests that fuel type is not a particularly important variable for radioisotope production. That fuel type may
not be a very important variable in relation to radioisotope production is further indicated by ANSTO's (fading) hopes of becoming a major radioisotope producer using a new LEU-fuelled reactor.

LOW ENRICHED URANIUM TARGETS

Another aspect of the RERTR program is to develop LEU targets to replace HEU targets for production of fission-product radioisotopes – such as Mo-99, iodine-131 and xenon-133 – without significant losses in terms of yield or specific activity, and without greatly increased costs.

According to Rojas-Burke (1993D), HEU targets, which are 90% enriched, are available only from the US. However there are probably some other countries producing HEU targets, if only for domestic reactors – South Africa, possibly Russia, and possibly China. Certainly there are enrichment facilities operating in several countries outside the US (Hardy, 1996, ch.9).

While HEU targets have generally been made available by the US to the major radioisotope producers, there is no guarantee of secure supply in the future. As with reactor conversion, the US can encourage use of LEU targets through the use of both carrot (LEU target technology development, spent fuel take back) and stick (refusal to supply HEU targets). In 1988, the US DOE stopped supply of HEU targets to Cinticchem and to AECL. Clearly this was of concern, but no disruption in supply of Mo-99 occurred, and HEU target supply was re-started after several weeks. There was speculation that the embargo was initiated because of allegations that HEU had been diverted from Germany to Libya and Pakistan. (Harby, 1988; Anon., 1988B.) More recently, the US Congress made a three-year agreement to supply Nordion with HEU targets conditional on continued development of LEU fuel and target technology in the US; this gave some new momentum to the RERTR program after some years of decline. (Rojas-Burke, 1993D.)

Whereas the use of LEU fuel may not to be a major limitation for radioisotope production, there is definitely a strong preference for HEU targets. Research into LEU targets has been a secondary concern of the RERTR program, with priority given to reactor conversion and the development of advanced LEU fuels. Funding for target technology research was scaled down in the US, and stopped altogether in 1992, but some funding has been provided since then. (Rojas-Burke, 1993D.)

Production of fission-product radioisotopes using LEU targets is feasible, but the general view is that it increases production costs. The radiopharmaceutical
companies claim – perhaps for self-interested reasons – that the cost is prohibitive. For example when Cintichem was producing Mo-99, it claimed that it would be forced to terminate Mo-99 production if HEU targets became unavailable. (Rojas-Burke, 1993D.) However it is not certain that the increased costs associated with the use of LEU targets would be significant, and further research could certainly change this situation. Nor is it clear that the profit margins of Mo-99 producers are so low that the use of LEU targets would threaten the viability of any but the most marginal production operations. Travelli (quoted in Rojas-Burke, 1993D), who is closely involved with the RERTR program, says that although the Mo-99 business is cut-throat, profit margins are not as narrow as producers claim. Certainly it is unlikely that the major producers would stop production if forced to use LEU targets. Another consideration is that all Mo-99 producers are subsidised, and producers could make a good case to governments or government agencies to subsidise conversion to LEU target technology given that it is a non-proliferation initiative.

Radiopharmaceutical companies have also questioned whether the marginal reduction in HEU circulation brought about by conversion to LEU targets would have any significant effect in relation to weapons proliferation. However the amounts of HEU involved are not insignificant. Nordion uses about 20-25 kg of HEU for targets each year. (Rojas-Burke, 1993D.) This is sufficient for at least one nuclear weapon or for several cruder devices.

Ongoing research may reduce or negate the performance gap between HEU and LEU targets. Several possible processes are under investigation at a number of facilities including BATAN in Indonesia, the University of Illinois, and the US Argonne National Laboratory. The 30 MW reactor in Indonesia has been used for prototypical irradiation of a LEU metal foil target for Mo-99 production. Another line of research is for dissolution and processing of LEU silicide targets; in 1995 this method was ready for demonstration on a full-size target. (Travelli, 1995.) In South Korea, KAERI is testing the possibility of commercial production of fission Mo-99 using HEU or LEU targets.

The research effort is to make new processes compatible with existing facilities and know-how. According to Aliludin et al. (1995), research carried out to date suggests that LEU targets (either natural or depleted uranium spiked with irradiated HEU) can be used with little or no modification of production facilities. However a number of different technical solutions may need to be found since different producers use different technologies to produce Mo-99 from HEU targets (Rojas-Burke, 1993D).
The IAEA has given some support to the development of LEU target technology, partly because it might facilitate radioisotope production in developing countries which have difficulty securing HEU targets from the US. (Rojas-Burke, 1993D.) If the technologies are successfully developed, it is possible that LEU target technology could have an important effect on the fission Mo-99 industry, with new producers entering an industry which is already promising to be over-supplied for the next generation. However this depends entirely on the development of efficient and economical LEU targets. It is likely that despite mounting political pressure, conversion to LEU targets may drag on for years, and it still remains a secondary concern to converting reactors to LEU fuels. (Rojas-Burke, 1993D.)

**RADIOACTIVE WASTE**

The generation of radioactive waste by research reactors is minimal in comparison with waste generation associated with nuclear power and weapons programs. However it is not a trivial issue, and it certainly has implications for radioisotope production.

According to an article in the *IAEA Bulletin*, accurate figures are not available on the amount of spent fuel from research reactors in storage, but many operators of research reactors find themselves in a "crisis situation" because of waste management problems. The crisis has been precipitated by the cessation of practices to take back spent research reactor fuel by the countries where they were originally enriched (mainly the US and Russia). Waste problems have slowed, stopped, or put in jeopardy the operations of many research reactors in many countries. These problems have been exacerbated by the RERTR reactor conversion program, primarily because of the greater throughput of LEU fuels. (Takats et al., 1993.) The RERTR program involves a trade-off: conversion to LEU fuel lessens the possibilities for weapons proliferation but it exacerbates the problems associated with radioactive waste.

There are fleeting signs of partial resolution of some of these problems - for example the resumption of US take back of spent fuel. Acceptance of spent fuel by the US has been used as an inducement to cooperate with the RERTR program. (As a further inducement, agreements have been struck to take back LEU spent fuel from converted reactors.) The program of spent fuel return to the US has been on and off for many years, but is now proceeding. A number of countries have already returned some spent fuel, and the plan is that a total of 41 countries...
will be able to do so. The volume involved is about 20 metric tons of fuel containing about 5 metric tons of HEU. This is a tiny fraction of the 30 000 metric tons of commercial spent fuel managed in the US, but a much larger percentage of HEU waste. (Takats et al., 1993.)

Take back of spent research reactor fuel by the US is a minor development in the context of worldwide radioactive waste problems: all that can be said is that it will facilitate research reactor operations in those countries able to rid themselves of waste stockpiles. In addition the resumption of spent fuel return to the US is not certain to proceed - decisions to proceed with the program have been made before, only to be blocked by legal challenges and other tactics employed by anti-nuclear activists in the US. Recently, anti-nuclear groups in the US have threatened to sue the government if it attempts to defray the cost of this initiative by reprocessing the spent fuel. (Uranium Information Centre, 1996.) According to Takats et al. (1993), a protracted delay could lead to the closure of important research facilities, particularly in several Western European countries where operating license extensions are tied to successful resolution of spent fuel problems.

Apart from US take back of spent fuel, there is also some potential for the establishment of waste repositories in some countries after decades of stockpiling. However it can be safely predicted that waste disposal problems will continue to affect research reactor operations and thus radioisotope production for many years to come.

Apart from spent fuel generated as a result of reactor operations, the irradiation of targets and the processing of radioisotopes generates significant volumes of radioactive wastes. Mostly this is low and intermediate-level waste, but some high-level waste is generated through irradiation and processing of HEU targets (see chapter 4.4).

As with reactor conversion to LEU fuels, increased waste is also a burden that comes with the use of LEU targets for radioisotope production instead of HEU targets. LEU targets require a greater volume of uranium to make up for decreased enrichment levels. Processing more uranium means handling more radioactive by-products - 3-6 times the volume of dissolver solution, about six times more dissolver salts, six times more fission-product salts, and up to 30% more waste at the end of all processing steps. (Rojas-Burke, 1993D.) As yet this is not an issue because few if any producers of fission-product radioisotopes are using LEU targets.
Another issue worth brief mention is radioactive waste from hospitals. In some cases this is returned to reactor operators – for example used Mo-99/Tc-99m generators are returned to ANSTO. Other wastes from the use of radioisotopes in hospitals or universities are stockpiled at numerous sites (Senate Legal and Constitutional Legislation Committee, 1994). This is a contentious issue in Australia, although it does not seem to have affected the practice of nuclear medicine. In the US the issue is more pressing. Landfill owners in the US are screening incoming trash for radioactivity. Hospital operators have borne increased costs for setting up screening procedures and for dealing with rejected loads. In a number of cases hospitals have been able to negotiate agreements with landfill owners to allow for disposal of low-level waste, but in other cases the problems and added costs have threatened the viability of nuclear medicine practice. (Culver et al., 1993.)

In chapter 4.4, I noted ANSTO's tactic of "playing up" the connection between radioactive waste and nuclear medicine in order to pacify public concern and opposition. In the US, the links are more tangible, with nuclear medicine professional associations actively involving themselves in the establishment of low-level waste repositories. Often this involves conflict between the professional associations on the one hand, and public campaigns and government regulatory agencies on the other. (Shanahan, 1993.)

In the US, and possibly elsewhere, the lack of availability of low-level waste repositories, and the expense of storage and disposal, has prompted the search for alternatives to radioisotope techniques, for research purposes in particular. A number of chemical and biological alternatives to radioisotopes are not only better in terms of waste disposal, but can also offer better sensitivity, increased safety, and reduced costs. In general, each of the alternatives for any particular purpose will have some advantages and some disadvantages. There is also some effort to replace longer-lived radioisotopes with shorter-lived radioisotopes because that reduces storage time before transport to waste disposal sites. (Party and Gershey, 1995.)

A number of research projects are underway to reduce the substantial waste problems associated with reactor production of fission Mo-99, mostly involving new production methods; this research is taken up in the following section. Another issue is that nuclear medicine is operating in an increasingly competitive environment vis a vis alternative imaging modalities, and the radioactive waste
problems associated with nuclear medicine do nothing to secure its place (see chapter 8.3).

7.8. TECHNICAL INNOVATIONS

REACTOR IRRADIATION OF MOLYBDENUM TARGETS
SPALLATION SOURCES
LIQUID FUEL REACTORS
CYCLOTRON PRODUCTION OF Mo-99/Tc-99m

Here I will discuss several research projects, which are largely though not exclusively concerned with Mo-99/Tc-99m production. Research into new methods of producing Mo-99/Tc-99m reflect the problems with current methods of production of fission Mo-99 – the need for high-flux reactors, the weapons proliferation implications of HEU, the complexity and cost of facilities for irradiating and processing HEU targets, and waste generation. The waste issue is particularly salient and the four alternative methods of Mo-99/Tc-99m discussed below all hold the promise of marked reductions in waste generation.

REACTOR IRRADIATION OF MOLYBDENUM TARGETS

Here I return to the relative advantages of high specific activity fission Mo-99 versus low specific activity (l.s.a.) Mo-99. Fission Mo-99, produced by the U-235(n, fission)->Mo-99 reaction, is the preferred product because of its high specific activity - the high proportion of Mo-99 in relation to contaminants. Production yields using the fission method are far higher than for the Mo-98(n,µ)->Mo-99 method. The Tc-99m generated from fission Mo-99 provides better images and imparts a lower radiation dose to the patient and medical staff. Another reason that fission Mo-99 is preferred is that generator technology developed hand-in-hand with fission Mo-99 production, such that the common commercial generator types cannot use l.s.a. Mo-99. In fact l.s.a. Mo-99 has usually been used for production of "instant" Tc-99m, without the use of generators. Because of the relative half lives of Mo-99 (66 hours) and Tc-99m (6 hours), instant Tc-99m must be delivered and used quickly and thus cannot be transported over long distances because of decay.

The Mo-98(n,µ)->l.s.a. Mo-99 method, which uses molybdenum targets, requires less complex and expensive facilities; generates less waste; is suitable for low to medium-flux reactors; and results in lower radiation exposure for reactor and
processing staff. According to Egan et al. (1994, pp.4-5), waste generation is only 5% that of the fission method.

Low specific activity Mo-99/Tc-99m is produced in many countries. It is produced in at least some, and probably most, of the dozen or so countries which also produce fission Mo-99, because some users prefer instant Tc-99m. It is also produced in another dozen or so countries: Bangladesh, Chile, Greece, Hungary, Malaysia, Pakistan, Slovenia, Taiwan, Thailand, Turkey, Vietnam, Zaire, and probably a few other countries besides (INSC (n.d.) data). Low specific activity Mo-99/Tc-99m is generally produced in small quantities, because of the limitations of the process and because demand is low in many of the countries where it is produced.

The following table summarises the two processes:

<table>
<thead>
<tr>
<th>Fission Mo-99</th>
<th>Mo-98(n,µ)-&gt;Mo-99</th>
</tr>
</thead>
<tbody>
<tr>
<td>Targets</td>
<td>HEU</td>
</tr>
<tr>
<td>Product</td>
<td>Mo-99 -&gt; generators</td>
</tr>
<tr>
<td>Generators</td>
<td>Chromatographic, several other types</td>
</tr>
<tr>
<td>Yield</td>
<td>High</td>
</tr>
<tr>
<td>Waste</td>
<td>High</td>
</tr>
<tr>
<td>Reactor flux</td>
<td>High</td>
</tr>
<tr>
<td>Specific activity</td>
<td>High</td>
</tr>
<tr>
<td>No. countries</td>
<td>About 12</td>
</tr>
</tbody>
</table>

Research has been taking place for some years, in a number of countries, to facilitate Mo-99/Tc-99m production using molybdenum targets and to improve the supply logistics (especially generator technology). In fact the relatively widespread production of l.s.a. Mo-99 probably reflects the early fruits of this research. Research has focused on three, interconnected areas. One is increasing the yield, for example by using enriched Mo-99 targets instead of natural molybdenum. The enriched targets are more expensive but the increased yield may make it worthwhile. A second research area is increasing specific activity, or alternatively devising methods for the extraction of useable, carrier-free Tc-99 from l.s.a. Mo-99. The third research area is generator technology.

The IAEA has funded and co-ordinated research into Mo-99/Tc-99m generators which can use l.s.a. Mo-99 produced by low to medium-flux reactors. Scientists from India, Argentina, the Czech Republic, Vietnam, Belarus, Germany, Peru, Hungary, and Thailand have been involved in the IAEA program. A number of generator types have been explored - two or three show promise, with the most
promising being gel generators - polymolibdate gels with extraction of Tc-99m by a low-temperature sublimation process. (IAEA, 1995D; Knapp and Mirzadeh, 1994).

In China, gel generators have already been used in over 100 hospitals. According to the IAEA (1995B), "Clinical results have been as good as those when the technetium is obtained from fission process generators." The expectation is that when gel-generator technology is further improved, there will be still less demand for fission Mo-99 generators. An IAEA technical cooperation project is working to overcome some of the current limitations, which include standardising gel production, reducing contamination with natural molybdenum, and streamlining the process. (IAEA, 1995B.)

The gel generator is not the only possibility under investigation. In Japan research is underway into a highly absorbent polymer which may enable generator construction using l.s.a Mo-99. (Yamabayashi, 1996, pers. comm.)

Another line of research, to overcome the low specific concentration of Tc-99m derived from l.s.a. Mo-99, concerns solvent extraction of carrier-free Tc-99m from l.s.a. Mo-99. This approach requires central processing facilities having the necessary hot cells and processing facilities. (Knapp and Mirzadeh, 1994.) Development of this technology could dove-tail with the spread of regional radiopharmacies, already commonplace in the US, Europe, and Japan.

In addition, new, improved methods of Tc-99m extraction, yielding higher specific activity Tc-99m than current methods, might be developed to the point that less complex hospital radiopharmacies could be supplied with l.s.a. Mo-99/Tc-99m generators and carry out the final processing. The Health Sciences Research Division of the Oak Ridge National Laboratory (ORNL) has developed two simple, efficient methods for the concentration of Tc-99m solutions obtained from elution of generators prepared with l.s.a. Mo-99 from irradiation of molybdenum targets. The ORNL has recently licensed these technologies, which are still proprietary. (Knapp, ORNL, 1997, pers. comm.) If the process is simple enough, it might not require complex and therefore centralised processing facilities. This would facilitate deployment of the new technology in countries, particularly developing countries, where sophisticated radiopharmacies are rare.

The development of gel-generator technology and improved methods of Tc-99m extraction have improved the potential for producing generator-grade Mo-99 using reactors of low to medium neutron flux. Reactors with a relatively low
thermal neutron flux - of the order of $10^{13}$ neutrons/cm$^2$/second - can be used for this production route (Knapp and Mirzadeh, 1994, p.1152). Reactors with this flux are commonplace. IAEA (1994) data indicates that about 130 reactors of at least this flux level were in operation in 1994. No doubt dozens of those reactors would be unsuitable for l.s.a. Mo-99 production for one reason or another, but the general point holds: development of this method could enable far more widespread reactor production of Mo-99/Tc-99m.

Since the research effort has recently been focused on production of generators using l.s.a. Mo-99, rather than instant Tc-99m, there is the potential for international trade of new generator types based on l.s.a. Mo-99. The new generator types could be imported into Australia. Alternatively the greater use of l.s.a. Mo-99 in some countries could free up fission Mo-99 and make importation of the latter all the more viable an option for Australian users. Another advantage with gel generators is the potential for reduced transport costs, as gel generators may not require the bulky lead shielding used for conventional generators (IAEA, 1995B).

There is considerable research in a number of countries into the use of l.s.a. Mo-99. This research has already borne fruit, for example in China. It seems likely that the technologies will be further improved and more widely applied. The biggest obstacle will probably be loss of momentum and lack of opportunity given the likelihood of ample fission Mo-99 production to meet world demand for the next 20 years at least. Either way, reliance on imported Mo-99 will be a viable option for Australian users.

**SPALLATION SOURCES**

Spallation sources comprise a particle accelerator (usually a cyclotron) which is used to direct a proton beam onto a heavy element target (e.g. uranium, lead, bismuth). Proton bombardment of this target (the primary spallation target) generates neutrons. The primary spallation target is surrounded by a moderator (e.g. water) and a neutron reflector. The moderator-reflector systems vary greatly depending on the primary application of the facility and the method of operation. (Boldeman, 1995.) Essentially, spallation sources generate a neutron flux without the need for a self-sustained fission reaction as in a reactor.

Spallation sources have been competitive with research reactors for neutron beam research for 15 years or so. About five are operating around the world, mostly used for condensed matter research. Other potential applications of spallation sources
have been discussed in the literature for many years, but further development was impeded by limitations in the performance of accelerators. These limitations have been overcome to a considerable extent with advances in accelerator technology. Consequently, a number of projects are being proposed and developed to build new varieties of spallation sources, and these proposals have a much higher probability of being realised given the improvements in accelerator technology. (Boldeman, 1995.)

Several possible applications of spallation sources are being explored, including research, transmutation of radioactive waste, power generation, and radioisotope production. As for radioisotope production, there has been very little use of spallation sources for radioisotope production. The Los Alamos Meson Physics Facility is a medium energy nuclear physics facility which, among its other functions, provides proton beams for a spallation neutron target and has been used for radioisotope production. There has also been parallel development of "superconducting" cyclotron facilities, essentially the same as spallation sources, for neutron beam cancer treatment (Anon., 1989).

As for future radioisotope production using spallation sources, one project in particular warrants mention. This is the "Adonis" project - Accelerator-Driven Operated Nuclear Isotope System. This project is a collaboration between the Belgium Nuclear Research Centre SCK-CEN, and Ion Beam Applications (IBA), a company which manufactures cyclotrons (SCK-CEN, 1995; Egan, 1995; Yongen, 1995).

The Adonis system shares the same general features of other spallation sources. It comprises two main parts. It is envisaged that radioisotope production would be one of the major applications of Adonis. Indeed the second phase of the research project has involved Mo-99 production.

Without providing any substantiating evidence, SCK-CEN (1995) asserts that one Adonis system could produce 40% of world demand for Mo-99. Egan (1995) arrives at similar figures, and provides supporting calculations and assumptions. Those figures assume 93% HEU secondary targets. If 12% enriched LEU secondary targets are used, production could drop by a factor of 30-40 according to Egan's calculations, but the output of one system using 12% LEU would still comfortably satisfy Australian demand for Mo-99.

Effort has been made to make the system match current fission Mo-99 reactor production regimes as closely as possible, for example by using identical HEU
targets as those used in (some) reactors for Mo-99 production. Thus there would be no need to develop new target technologies, and existing downstream processing technologies and facilities could be used. This has obvious advantages in terms of logistics and costs.

An important advantage of this system over reactor radioisotope production is accident safety. Adonis does not require a self-sustained uranium fission reaction; in fact design features exclude the possibility of uranium fission criticality. Unless uranium is used in the primary spallation target, the only uranium required is for the secondary targets. Since the initial power source is an accelerator rather than the uranium fission reaction of a research reactor, the Adonis system offers major advantages over reactors in relation to radioactive waste and weapons proliferation concerns, notwithstanding the use of small amounts of HEU for the secondary targets. Waste generation would probably be increased if LEU secondary targets were used as a non-proliferation measure or because of lack of availability of HEU targets.

Theoretical calculations indicate that one Adonis system could produce most or all of world demand for Mo-99. Capital costs are expected to be considerably less than a commercial 10 megawatt (thermal) reactor. (For comparison, ANSTO expects the proposed new 14-20 MW reactor will cost $300 million.) Decommissioning costs would be considerably cheaper, as would waste management and disposal costs. (Yongen 1995.)

The production of Mo-99 using Adonis, permitting widespread distribution including supply of overseas markets, gives it a major advantage over the Tc-99m production techniques under development by Lagunas-Solar and colleagues (discussed later).

While the Adonis system is extremely promising, no pilot plant has been built as yet. The third phase of the Adonis research program is underway and is expected to yield detailed engineering and economic information. IBA's involvement is significant; presumably the company sees some commercial potential in the project. It is also notable that there is considerable development of accelerator and spallation source technology taking place for purposes other than radioisotope production. It is likely that radioisotope production applications will be facilitated as spin-offs from this research.

During the Research Reactor Review (1993, ch.5), there was some debate as to whether a spallation source might be a more appropriate investment than a new
research reactor. One argument against a spallation source was that it was unsuitable for radioisotope production, and difficult to combine radioisotope production with other functions. Research in the past few years suggests that spallation sources are becoming increasingly attractive as neutron beam research tools, and that they may also be suitable for commercial radioisotope production. Spallation sources are varied in design, and they are more flexible technologies than research reactors – parameters such as neutron flux can be varied through adjustments to the accelerator or the primary and secondary targets. This increases the potential for development of multipurpose spallation sources.

The flexibility of spallation sources also increases the potential for production of a wider range of radioisotopes. With the potential to generate a range of charged particle beams from the accelerator, and neutron beams from the primary spallation target, spallation sources have the potential to be all-in-one radioisotope production machines, capable of producing a wider range of radioisotopes than reactors or cyclotrons alone.

**LIQUID FUEL REACTORS**

The heavy engineering and reactor construction company Babcock and Wilcox are working on the design of a Medical Isotope Production Reactor (MIPR), which may be used for dedicated production of Mo-99 and other fission-product radioisotopes. Essentially the system involves a low-power reactor with a liquid fuel. It eliminates the need to prepare a target and secondly to dissolve it; instead of target irradiation, fission products are derived from the fissioned fuel itself. The system comprises a Zircaloy cylinder for the reactor, which is immersed in a large pool of water. The fuel is a 19% LEU uranyl nitrate solution. At this concentration, and with the correct geometry, fission takes place within the solution. The water acts as a heat removal medium and as a reflector and radiation shield. (Ball, 1995.)

Overall the system has the potential to produce large quantities of high specific activity fission Mo-99 using a very low power reactor and without the need for HEU fuel or HEU targets. In the usual system for reactor production of fission Mo-99, fission products (including Mo-99) created in the "driver" reactor are wasted – only the fission products in the target are retrieved, and over half of this material is lost because of decay in the time that the target is in the reactor. Recovering fission products from the fuel, as occurs with the MIPR, is far more efficient and, according to Ball (1995), it offers the potential for a hundred-fold reduction in uranium consumption and radioactive waste generation. Another potential advantage is safety, because the MIPR has an extremely large negative power
coefficient of energy, a common characteristic of aqueous homogenous reactors. (Ball, 1995.)

Babcock and Wilcox’s “reference” MIPR operates at 200 kW(t) and produces 2000 Ci of Mo-99 per day within the solution, with daily extraction of Mo-99. Using these figures, output could be 2000 x 365 = 730 000 Ci/year of Mo-99, roughly equivalent to current world demand. Downstream processing is much the same as for the usual method of reactor production of fission Mo-99. (Ball, 1995.)

The MIPR test and demonstration phase was set to begin in 1996. This phase was to demonstrate heat removal capability in the bulk water; ability to extract Mo-99 as the solution ages; capability for gas recombination and storage; and corrosion resistance of components. (Ball, 1995.)

Babcock and Wilcox is not the only organisation involved in research along these lines. In the US, the Oak Ridge National Laboratory (ORNL) has a long history of work on liquid fuel reactors for diverse uses, and some of this work has been carried out in conjunction with Babcock and Wilcox and also Russian organisations. Some of the ORNL’s research work on liquid fuels reactors has concerned the production of Mo-99 and other fission-product radioisotopes with a uranyl sulfate liquid fuelled, low-power (50-100 kW) reactor. However there is no effort being expended on this research at present, in part because of the ORNL’s commercial venture concerning concentration of Tc-99m solutions obtained from l.s.a. Mo-99. (ORNL, 1995; Kerr, ORNL, 1997, pers. comm.)

**CYCLOTRON PRODUCTION OF Mo-99/Tc-99m**

It is technically feasible to produce instant Tc-99m and Mo-99 using proton bombardment of Mo-98, Mo-100, or uranium-238. According to Lagunas-Solar (1993), several accelerators (including cyclotrons) have produced small amounts of Mo-99 and Tc-99m for research purposes. However cyclotron Mo-99/Tc-99m production has not been developed on a large-scale, commercial basis. There is considerable debate as to whether this could be achieved, and some ongoing research into the issue.

The debate over cyclotron production of Mo-99/Tc-99m was prominent during the Research Reactor Review.69 ANSTO and a few doctors argued that technical

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limitations made the process unviable at present and there were at best slim prospects that further research would resolve the problems. One of the major limitations is that it is agreed by all that the prospects for large-scale cyclotron production of Mo-99 are slim; the more promising line of research is direct production of Tc-99m with minimal co-production of Mo-99. This raises questions about supply logistics given the six-hour half life of Tc-99m. Various groups and individuals opposing a new reactor argued in favour of cyclotron production of Mo-99/Tc-99m, as did some scientists involved in research projects concerning cyclotron Mo-99/Tc-99 production. The most prominent of these scientists were Manuel Lagunas-Solar, from the Crocker Nuclear Laboratory at the University of California, and Gary Egan from the cyclotron and positron emission tomography (PET) centre at the Austin Hospital, Melbourne.

The Review (1993, pp.46-48) sat on the fence:

...... the Review was presented with claim and counter-claim about the possibilities for Tc-99m production via cyclotrons. It explored the issues to the extent possible and can do no more than conclude that only time and further research will illuminate this question further.

Debates over cyclotron Mo-99/Tc-99m production revolve around a number of interconnected technical, logistical, and economic factors. These debates concern production yields and rates, target cooling, target purity, specific activity and purity of cyclotron-produced Mo-99/Tc-99m, the logistics of supplying remote areas, and last but not least, cost. Suffice it here to say that the overall debate, and each of the component debates, was highly polarised during the Research Reactor Review. One sub-debate which was not contested was radioactive waste generation – there is no doubt that cyclotron Mo-99/Tc-99m production generates far less waste. This applies both to target irradiation and processing, and also fuel since cyclotrons are powered with electricity.

There have been small pockets of research into cyclotron production of Mo-99/Tc-99m over the years. Probably the most significant research in recent years has been a collaborative project involving the two Australian cyclotron centres (in Sydney and Melbourne), and the Crocker Nuclear Laboratory at the University of California. Lagunas-Solar is heavily involved in this work, as was Egan for some time. Amersham has provided funding and other assistance for some of the research into cyclotron production of Mo-99/Tc-99m at the Crocker Nuclear Laboratory. (Egan et al., 1994; Lagunas-Solar et al., 1996B.) Through its involvement in the National Medical Cyclotron in Sydney, ANSTO has some
involvement in the research project. This is surprising given that ANSTO was such a strong opponent of cyclotron Mo-99/Tc-99 production during the Research Reactor Review, and since its deeply pessimistic attitude seems not to have changed since then (ANSTO, 1996D). Public controversy over the issue appears to be one reason for ANSTO's involvement (Lambrecht et al., 1994). The research project has the following specific objectives (Egan et al., 1994):

- to determine the low energy region (<20 MeV) for optimum cyclotron production of Tc-99m from enriched Mo-98;
- to determine the medium energy region (<40 MeV) for optimum cyclotron production of Tc-99m from enriched Mo-100; and
- to determine the acceptable levels of specific activity and impurities in cyclotron produced Tc-99m which does not increase patient dosimetry or degrade image quality, compared to reactor produced Tc-99m.

As at late 1995, studies at the Crocker Nuclear Laboratory revealed a lower than expected Tc-99m yield using a 99.45% enriched Mo-98 target. However good production yields of 15 Ci/mAh were achieved using a 97.4% enriched Mo-100 target with low to medium energy (<25 MeV) proton beams, with low levels of impurities. (Egan, 1995; Lagunas-Solar et al., 1996B.)

A related line of research involves high energy proton induced fission of natural uranium targets, with proton induced fission of uranium-238 yielding Mo-99 among other fission products. This cyclotron technique is being studied at the Crocker Nuclear Laboratory in collaboration with the Canadian TRIUMF laboratory. The proton-induced fission method has some advantages over neutron-induced fission in reactors - reduced costs of installation, operation, maintenance, and decommissioning. It is also preferable to Tc-99m production using Mo-98 or Mo-100 targets given the short half life of Tc-99m and the logistical difficulties that entails. Downstream processing would be much the same as for Mo-99 produced by neutron-induced fission in reactors. Research results at the Crocker Nuclear Laboratory have been promising with respect to yield and purity; a full technical and economic comparison with reactor methods is now underway. (Egan, 1995; Egan et al., 1994; Lagunas-Solar, 1993; 1993B; Lagunas-Solar et al., 1996.)

The IAEA may provide funding or other forms of assistance for research into cyclotron production of Mo-99/Tc-99m. An IAEA Consultants' Meeting on the topic was held in South Africa in April 1997. (Lagunas-Solar, 1997, pers. comm.)
INTRODUCTION

The most important accelerators for radioisotope production are cyclotrons. Cyclotrons have a number of advantages over reactors for radioisotope production, such as safety, cheaper capital, operating and decommissioning costs, and generation of far less radioactive waste than reactors. For these and other reasons, cyclotrons have assumed an increasing important role for radioisotope production.

Cyclotrons belong to a class of machines called particle accelerators. There are two basic types of particle accelerators – linear accelerators (linacs) and cyclotrons. Both types accelerate charged particles to high velocities, and the particle beams can then be directed at targets for research, radioisotope production, and other purposes.

THE HISTORY OF PARTICLE ACCELERATORS

As discussed in chapter five, particle accelerators were developed from the early 1930s and one of their early uses was medical radioisotope production. However accelerators were marginalised during and after World War II, with far more effort expended on reactor technology. The marginalisation of accelerators for radioisotope production became self-perpetuating. Thus Boyd (1977), an AAEC employee, wrote in 1977 that

Cyclotron production of radionuclides is usually avoided because of the expense and the relatively lower yield when compared to that of a nuclear reactor. However if a cyclotron-produced radionuclide can be shown to have an ideal combination of physical and biochemical properties which lend themselves to a diagnostic task not otherwise satisfied by a reactor-produced radionuclide then considerable justification exists for its manufacture.
The important role of reactor radioisotopes was firmly entrenched with the establishment of Tc-99m as the workhorse of nuclear medicine.

Accelerators were marginalised, but not entirely. There was an ongoing thread of development and innovation. As with research reactors, this was often connected to nuclear power or weapons programs and involved radioisotope production as a subsidiary function.

At one end of the spectrum of accelerator technology is the development of ever-more powerful accelerators for physics research. This frontier research is having a dramatic impact on the more traditional applications of accelerators, including medical cyclotrons. (Boldeman, 1995.)

Very high energy linacs are sometimes used for production of medical radioisotopes. For example the Los Alamos Meson Physics Facility produces Sr-82 (via a spallation reaction, used in Sr-82/Rb-82 generators), xenon-127, Ge-68, and copper-67. The Brookhaven Linac Isotope Producer has produced medical radioisotopes including xenon-127, iodine-123, Sr-82 and Ge-68. (Saha et al., 1992; Ice, 1995.) However the developmental work of integrating radioisotope processing technology with a commercial linac has not been carried out. (Egan et al., 1994.) Since linacs are generally used for physics research, including military R&D, medical radioisotope production is a subsidiary function and has been given low priority. Less powerful linacs are widely used to produce photon beams for radiation cancer therapy (Blosser, 1993).

Some small cyclotrons were built and used for radioisotope production and cancer treatment from the 1940s and 1950s. There have been several arms of R&D with medical cyclotrons. One is proton and alpha particle radiotherapy. Another is the use of cyclotrons (and reactors) to generate neutron beams for cancer treatment. A third is diagnostic proton radiography. (Smathers and Myers, 1985.) These three cyclotron applications have limited and in some cases precarious niches in medicine. A more important field has been cyclotron production of radioisotopes for use in diagnostic nuclear medicine, and to a lesser extent radioisotope therapy.

Cyclotron production of medical radioisotopes has undergone a resurgence in the past 20-30 years. This has been led by cyclotron manufacturers and radiopharmaceutical companies. In the mid 1960s Amersham was the first radiopharmaceutical company in the world to install a cyclotron dedicated to the routine commercial production of radioisotopes (Bindon, 1988). Other companies have followed suit, including Nordion, CIS, Mallinckrodt, Nihon Medi-Physics, and probably others.
Medium energy (usually 30-45 MeV) cyclotrons are favoured by the radiopharmaceutical companies and produce the majority of commercial cyclotron radioisotopes (Egan et al., 1994).

There are several reasons for the resurgence of cyclotron radioisotopes. One is the advantages of cyclotrons over reactors in relation to safety, cost, and radioactive waste generation. Advances in cyclotron technology have also been important, including the development of cyclotrons with several beams, allowing simultaneous bombardment of several targets, and with high flux levels. These innovations have improved radioisotope yields, historically an important limitation. (Egan et al., 1994.)

Recently there has been a trend to develop more compact and less expensive cyclotrons, with power levels of 3-10 MeV, for hospital-based PET radioisotope production (Sajjadd and Lambrecht, 1993.) At lower energies, many of the radiation hazards associated with high-energy cyclotrons are avoided and less shielding is required. To supplement short-lived PET radioisotopes produced on site, radioisotopes with a longer half life or those that can be milked from a longer-lived parent can be purchased commercially from reactors or larger cyclotrons. (Smathers and Myers, 1985; Vera-Ruiz, 1985.)

For both small hospital cyclotrons and larger cyclotrons operated by radiopharmaceutical companies, technical improvements have occurred in areas such as target design and chemical synthesis allowing alternative reactions. These innovations have expanded the range of radioisotopes that can be produced with cyclotrons, and enabled more efficient, reliable production. (Smathers and Myers, 1985; Egan et al., 1994.)

Another field of innovation has been the use of cyclotrons to indirectly generate neutron beams, as in spallation sources.

**CURRENT USE OF CYCLOTRONS**

About 150-200 cyclotrons are operating worldwide. About 35 of these are operated by radiopharmaceutical companies and are used solely for production of medical radioisotopes. Another 25 are used in part for radioisotope production. (CERN, 1995; Amersham, 1993.)

Reflecting the worldwide trend, two medical cyclotrons were built in Australia in the early 1990s. The National Medical Cyclotron (NMC) is located at the Royal
Prince Alfred Hospital (RPAH) in Sydney. The 30 MeV NMC was purchased from the Belgian company Ion Beam Applications. It began operation in 1992, with capital costs of $20 million. It is used in connection with adjacent PET facilities at the RPAH. ANSTO operates the NMC and the associated radioisotope production laboratories, while the RPAH operates the PET centre. In addition to supply of short-lived PET radioisotopes for use at the RPAH, the NMC produces radioisotopes for commercial supply (through ANSTO/ARI) to nuclear medicine departments around Australia, with some radioisotopes also being exported. The NMC produces a range of radioisotopes. It produces enough thallium-201 (160 GBq, 2 days precalibration) to supply the entire Australian market (although some is still imported by radiopharmaceutical companies). It produces a high proportion of domestic demand for gallium-67 (60 GBq, 4 days precal.). Iodine-123 (25 GBq, 24 hours precal.) and fluorine-18 are produced. Some other PET radioisotopes are produced, such as nitrogen-13. Indium-111 production is under development. Sales of NMC radioisotopes have been expanding steadily. In 1995, sales were over $2.7 million, a 14% increase over the previous year. (Anon., 1994G; ANSTO, 1989; 1996E; 1995-96; Egan et al., 1994; Boyd, 1992; ARI, 1997, pers. comm.)

A smaller, 10 MeV cyclotron has been in operation in Melbourne since 1992, adjacent to PET facilities at the Austin Hospital. It is used primarily for production of PET radioisotopes such as fluorine-18, nitrogen-13, and oxygen-15. (Egan, 1993B.)

The trend towards using cyclotron radioisotopes is shown in the following table:

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Technetium-99 (reactor):</td>
<td>53.3</td>
<td>89.0</td>
<td>83.5</td>
</tr>
<tr>
<td>Thallium-201 (cyclotron):</td>
<td>0</td>
<td>1.6</td>
<td>11.9</td>
</tr>
<tr>
<td>Gallium-67 (cyclotron):</td>
<td>0</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Iodine-131 (reactor):</td>
<td>31.1</td>
<td>0.9</td>
<td>0.2</td>
</tr>
<tr>
<td>Others:</td>
<td>15.6</td>
<td>6.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Total reactor produced:</td>
<td>100</td>
<td>96.4</td>
<td>84.6</td>
</tr>
<tr>
<td>Total cyclotron produced:</td>
<td>0</td>
<td>3.6</td>
<td>15.4</td>
</tr>
</tbody>
</table>

Clearly there has been a trend towards greater usage of cyclotron radioisotopes. However the percentage figures do not reveal another important pattern: there has been growth in the use of both reactor and cyclotron radioisotopes. Cyclotron radioisotopes have replaced reactor radioisotopes only to a limited degree. The rest of the growth of cyclotron radioisotope procedures has resulted from the development of new tests, or at the expense of alternative (non-radioisotope)
clinical technologies, and it is not uncommon for two or more different diagnostic tests to be performed on the same patient.

The following list gives summary details of the most important cyclotron radioisotopes:

**Thallium-201** - half life 72 hours - myocardial studies and tumour localisation - still some importation but most Australian demand is now met by the NMC.

**Gallium-67** - half life 78 hours - soft tissue cancer diagnosis and staging, diagnosis of infection, other uses - currently imported by increasingly demand is met by domestic cyclotrons.

**Iodine-123** - half life 13 hours - various diagnostic studies - one of the most commonly used cyclotron radioisotopes - potential to replace iodine-131 for various studies (reduces radiation exposure by a factor of 100 in comparison to I-131) - also potential for growth in usage as production methods have recently been improved to rid it of impurities - also some potential to replace Tc-99m for some studies but the short half life of I-123 limits transport.

**Indium-111** - half life 67 hours - various in vivo and in vitro studies - labelling, CNS studies, other uses - one of the most commonly used cyclotron radioisotopes - potential to replace iodine radioisotopes for antibody radiolabelling for diagnosis and therapy of cancer - potential to replace Tc-99m for some antibody-labelling studies - reactor or cyclotron produced - already imported into Australia, and domestic cyclotron production of indium-111 for use in SPECT is in train at the NMC.

**Fluorine-18** - half life 110 minutes - brain studies, cancer diagnosis and prognosis - the most important diagnostic radioisotope for PET studies - can be used at a site up to six hours travelling time from the cyclotron - produced in compact cyclotrons including the NMC.

**Rubidium-81** - lung ventilation studies - half life 78 hours.

**Krypton-81m** - vascular studies, lung studies - half life 13 seconds, extracted from rubidium-81 (half life 4.6 hours) generators.

**Oxygen-15** - oxygen metabolism and blood flow studies - produced in compact cyclotrons and used for metabolism and blood flow with PET - half life two minutes.

**Nitrogen-13** - heart studies - produced in compact cyclotrons and used for PET radiopharmaceuticals - half life 10 minutes.

**Carbon-11** - brain imaging, clinical PET - produced in compact cyclotrons - half life 20 minutes.

**Copper-67** - produced in large (say, 30 MeV) cyclotrons and used for molecular genetics research.

**Potassium-38** - produced by compact cyclotrons, cardiovascular studies.

**Titanium-45** - produced in compact cyclotrons, new class of radiopharmaceuticals.

**Iodine-124** - radioimmunospecific therapeutic radioisotopes - produced in compact cyclotrons, used for PET dosimetry for iodine-131 cancer therapy.

**Rubidium-81** - half life 78 hours - diagnostic studies.

**Potassium-43** - half life 22 hours - potassium metabolic studies.

**Iron-52** - half life 8.2 hours - iron uptake studies.

**Yttrium-87** - half life 80 hours - decays to Sr-87m for bone scans.

**Gallium-68** - half life 68 minutes - scanning and localisation of tumours - from Ge-68 parent generator system.
COMPARING CYCLOTRONS AND REACTORS

SAFETY, WASTE, AND WEAPONS

In terms of accident safety, waste generation, and weapons proliferation, cyclotrons have important advantages over reactors.

Since cyclotrons are powered by electricity, and reactors by uranium fission, there is far less scope for serious accidents with cyclotrons, and the worst case accident is far more serious for a reactor. Another advantage with cyclotrons is that their emergency shut-down systems are much simpler than those of reactors. (Mukerjee and Cochrane, 1992; Boyd, 1991, p.15.)

Cyclotrons do not generate any high level radioactive waste, and far less low and intermediate-level waste than research reactors. There are no fission fuel wastes from cyclotrons. In addition, cyclotron production methods enable flexible control of beam energy, beam optics, and targetry, enabling maximum relative production of the desired radioisotope and thus minimising waste production; research reactors are less flexible. (Egan et al., 1994).

Historically, linacs and cyclotrons played an important role in the development of nuclear weapons, no more so than during the Manhattan project. Linacs are still used for weapons research and production, for example by the DOE. However there is little or no use of cyclotrons for weapons research or production. Certainly the cyclotrons operated by radiopharmaceutical companies or in hospitals are of no concern in relation to weapons proliferation because of their design and relatively low power levels.

PATIENT SAFETY

Some cyclotron radioisotopes, in particular the very short-lived radioisotopes, impart lower radiation doses to patients than reactor radioisotopes, and thus reduce the risks of iatrogenic effects such as cancer. The use of very short-lived radioisotopes has other advantages: clinical procedures can be repeated over short periods to obtain multiple views or to measure rapid responses to physiological or pharmacological intervention; there is no interference to subsequent radioisotope procedures in the same patient; and the radioactivity administered to the patient can be increased thereby improving the accuracy of the measurement and the fidelity of the visual information. (ANSTO, 1992B, p.11.)
While some cyclotron radioisotopes are advantageous in terms of patient safety, others are not. For example, commonly-used thallium-201 and gallium-67 scans impart a radiation dose of about 18 millisieverts (mSv), whereas common Tc-99m scans impart a dose of about 3-4 mSv. (Perkins, 1995.)

**COSTS**

Capital, operating, and decommissioning costs are generally considerably cheaper for cyclotrons than for research reactors (Egan et al., 1994, p.10). There are large variations in the costs of both cyclotrons and reactors, but the point holds as a generalisation. The cost benefits of cyclotrons do not translate into comparably cheaper prices for cyclotron radioisotopes when compared to reactor radioisotopes. This is because of lower yields in cyclotrons, lower demand, and other factors such as greater state subsidisation of reactors than cyclotrons. ANSTO (1993, p.4.12) claims that cyclotron radioisotopes cost "1 or 2 orders of magnitude" more than reactor-produced radioisotopes. That may or may not be overstating the difference. The gap is likely to narrow as cyclotron technology advances.

**COMPLEMENTARY OR COMPETING TECHNOLOGIES?**

During the Research Reactor Review the general debate was whether cyclotrons and research reactors are complementary or competing/alternative technologies for radioisotope production. The implications of this are clear enough: to the extent that cyclotrons can replace reactors, the case for a new reactor is diminished.

To support its case for a new reactor, ANSTO repeatedly argues that cyclotrons and reactors are complementary – that cyclotrons produce neutron-poor radioisotopes, reactors produce neutron-rich radioisotopes, and there is little scope for cross-over (e.g. ANSTO, 1993, pp.4.9-10). However there is some overlap in the radioisotopes that can be produced using either cyclotrons or reactors, and the degree of overlap is increasing with advances in cyclotron technology. Fluorine-18 is a good example of the variety of methods that can be used to produce radioisotopes. In a reactor, neutron bombardment of lithium carbonate gives rise to tritium which, in turn, bombards the oxygen in the carbonate producing carrier-free fluorine-18. Cyclotron production of fluorine-18 can be achieved by several methods including alpha, proton, or helium particles on oxygen, or deuterons on neon. (Ice, 1995.)

Most cyclotron radioisotopes are produced using protons to bombard targets, but other particles such as deuterons or alpha particles are also used, thus extending the range of radioisotopes that can be produced. (Perkins, 1995.) In fact because of
the variety of particle types that can be used, cyclotrons can produce a wider range of radioisotopes than reactors, which are limited to neutron bombardment. The coupling of cyclotrons to spallation sources to generate neutron beams is the technology which offers the greatest potential for cyclotron technology to replace reactors for radioisotope production. Since cyclotrons can thus be used to generate neutron beams, they are theoretically capable of being used to produce all reactor radioisotopes. However there is some distance between theoretical feasibility and practical application. For example some therapeutic radioisotopes can be produced (for the time being at least) either in reactors, or in high-power accelerators which are few in number. Overall the picture is that some radioisotopes traditionally produced in reactors can now be produced in cyclotrons (e.g. fluorine-18), and commercial-scale cyclotron production of others may be possible in future (e.g. Tc-99m, iodine-131).

REPLACING Tc-99m WITH CYCLOTRON RADIOISOTOPES

One line of R&D to overcome the problems associated with fission production of Mo-99 concerns new methods of producing Mo-99/Tc-99m, whether using cyclotrons, spallation sources, conventional reactors with LEU or molybdenum targets, or liquid-fuel reactors. Another set of solutions, discussed here, is to replace Tc-99m with radioisotopes that are less problematic to produce.

There are several reasons why Tc-99m is used for 80-90% of nuclear medicine procedures: its gamma energy, which is suitable for imaging with devices such as gamma cameras; the lack of particulate radiation, which minimises radiation dose and improves image quality; the relatively short half life of Tc-99m, which minimises radiation dose; the convenience and affordability of Mo-99/Tc-99m generators; and the chemical versatility of Tc-99m which enables it to be synthesised into a range of radiopharmaceuticals which can be targeted to specific body organs. (ANSTO, 1993E, p. 2.57; Research Reactor Review, 1993, p.83.)

Diagnostic agents for all major organs have been developed with Tc-99m chemistry. Technetium imaging techniques are being improved in existing fields (e.g. heart and brain studies), and are expanding into new fields such as Tc-99m-labelled peptides and monoclonal antibodies. (Carretta, 1994; Knapp and Mirzadeh, 1994.)

The dominant role of Tc-99m has become self-perpetuating. The thrust of research into new radiopharmaceuticals, even when initial research involves radioisotopes other than Mo-99/Tc-99m, is towards a situation where doctors can simply
"shake and bake" pharmaceuticals with Tc-99m (Khafagi, 1993, pp.449-450). Often this involves a transfer from initial research with cyclotron radioisotopes to the development of agents which can be labelled with Tc-99m.

Despite its advantages, there are two sets of limitations with Mo-99/Tc-99. First are the various problems associated with reactor production of fission Mo-99 - waste, HEU targets, and so on. A second set of problems concerns the clinical limitations of Tc-99m. Given the wide range of radioisotopes which can be used in nuclear medicine studies, and the range of potential clinical applications, there are inevitably some clinical procedures for which radioisotopes other than Tc-99m are better suited. One such area is therapeutic nuclear medicine; the criteria for selection of therapeutic radioisotopes are very different to the criteria for diagnostic radioisotopes, and Tc-99m has no uses in therapeutic nuclear medicine. Another area is functional diagnostic studies. Although Tc-99m is widely used for functional studies, there is some momentum towards the use of other radioisotopes.

Under the impact of competition from alternative diagnostic technologies (e.g. CT, MRI), nuclear medicine has moved away from anatomy to focusing on functional studies. On this topic, Boyd (1992, p.4), an ANSTO employee, says that:

As this evolution occurred it became obvious that the dynamics of human physiology and metabolism place additional requirements on the choice of tracer substance. This, coupled with the fact that technetium is not a biologic element, led to the realisation that the goals of nuclear medicine would be achieved only with the help of other radioisotopes besides technetium-99m.

The cutting edge of functional imaging involves PET radioisotopes which mimic biological molecules, in particular carbon-11, oxygen-15, nitrogen-13, and fluorine-18. All of these can be produced in cyclotrons, and some can only be produced in cyclotrons (or linacs).

PET provides a series of cross-sectional image slices (tomographs) which can be used to generate a three-dimensional image using computers. To date the development of PET has been limited by the expense of PET cameras and computing equipment, and the need for an on-site cyclotron for production of very short-lived radioisotopes. A range of innovations are making PET more affordable and accessible, including the development of increasingly compact and inexpensive cyclotrons, automated radiopharmaceutical production facilities, and generator radioisotope systems enabling the use of PET radioisotopes without an
Radiopharmaceutical companies are involved in the supply of longer-lived PET radioisotopes; for example Syncor/Du Pont announced in 1996 that it was investing $US 14 million in a radioisotope supply network for PET in the US (Anon., 1996).

The growth of PET has been gradual at best. The number of PET facilities worldwide rose from 29 in 1984 to 134 in 1995 (NHTAP, 1984; Cafarella, 1995). There is no certainty that the growth will be sustained, much less that it will seriously challenge conventional nuclear medicine systems using Tc-99m and various other reactor and cyclotron radioisotopes. The main impediment is the cost of existing PET systems and the scarcity of R&D funding. Another limiting factor has been medical turf battles, with some nuclear medicine professionals viewing PET as a threat to their established positions and technologies (Cafarella, 1995). Because of the high financial costs, PET has to date been "science fiction" as Cuaron (1994) puts it - science in industrial countries and fiction in developing countries.

Of the cyclotron-produced PET radioisotopes, a fluorine-18 labelled compound, fluorodeoxyglucose (FDG), shows the most promise as an alternative to Tc-99m for some studies. Until recently the use of FDG has required PET facilities. While it is possible that PET facilities may become more common and challenge conventional nuclear medicine systems to a greater extent, a more promising development is modification of single photon emission computed tomography (SPECT) gamma cameras to enable FDG imaging.

SPECT gamma cameras have become fairly common in hospitals in advanced capitalist countries including Australia, gradually replacing conventional gamma cameras. Like PET, SPECT can produce three-dimensional images, showing the planar distribution of a radiopharmaceutical within the body slice-by-slice; conventional gamma cameras cannot do this. SPECT has some disadvantages in relation to PET. It cannot use biological tracers, i.e. radiopharmaceuticals equivalent to, or closely matching, substances involved in physiological processes. SPECT also has lower sensitivity than PET, and is less suitable for quantitative studies. The main advantage of SPECT over PET is that SPECT facilities are cheaper, more versatile, and more widely available. SPECT uses more readily available, longer-lived radioisotopes such as Tc-99, thallium-201, gallium-67, xenon-133, and iodine-123. Because these radioisotopes have longer half lives

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20 The NHTAP (1990) said there were 200 PET facilities worldwide in 1990 - this probably includes facilities used entirely for research rather than clinical applications.
than most of the PET radioisotopes, and because some of them are reactor produced anyway, SPECT does not require an on-site cyclotron as is generally necessary for PET. In short, SPECT was developed in part as a superior alternative to conventional gamma cameras, in part as an inferior but more practical alternative to PET.

A number of research projects have been underway in recent years to enable the use of FDG with SPECT cameras. The modified camera can still be used for routine nuclear medicine studies, an important advantage. (Drane et al., 1994.) FDG SPECT is an attractive alternative to dedicated PET facilities, and it is doubly attractive given its potential to replace some Tc-99m studies.

FDG can be used for heart studies, many of which use cyclotron-produced thallium-201. Thallium-201 imparts a considerably higher radiation dose to patients than most other diagnostic nuclear medicine procedures (Roebuck, 1996). In part because of the radiation dose of thallium-201, there has been momentum towards the use of Tc-99m instead of thallium-201. FDG has advantages over both Tc-99m and thallium-201 in that it is both cyclotron produced and imparts a low radiation dose.

Overall, heart studies using thallium-201 and Tc-99m account for 20% of nuclear medicine procedures in Australia, although not all of these various heart studies may be vulnerable to replacement by FDG. In the US, nuclear cardiology is more prominent, accounting for almost two thirds of radiopharmaceutical sales in the US in 1991 (Anon., 1993). Apart from its use in heart studies, FDG has been used extensively in diagnosis and prognosis of primary brain tumours. In other areas of oncology, the usefulness of FDG imaging is being explored. (Drane et al., 1994.)

The use of FDG SPECT has already taken hold to a limited extent in clinical practice. It is also the subject of a number of research projects around the world and there has been interest and financial support from manufacturers of imaging equipment such as Siemens, Philips, and Du Pont (Noelpp et al., 1994). Modifying existing SPECT equipment to enable and improve FDG SPECT studies is the crux of the research and thus the involvement of these companies is important. There is also some research into the possible uses of FDG with modified conventional gamma cameras (Noelpp et al., 1994), which are more widespread than SPECT cameras and far more widespread than PET facilities.

Fluorine-18 has a half life of 110 minutes, and thus FDG can only be used within a certain radius (about 6 hours travelling time) from the point of production. It can
be produced using reactors or cyclotrons; either way the replacement of Tc-99m with FDG is advantageous given the problems with reactor production of fission Mo-99, and cyclotron production is particularly advantageous given the more general problems with reactors.

Iodine-123 is another radioisotope which has some potential to replace Tc-99m for some studies. It has numerous uses - thyroid, kidney, and brain studies, measurement of blood flow in stroke patients and possibly epilepsy patients, and localising tumours of the adrenal glands. The full potential of iodine-123 has yet to be realised, in part because methods to produce high-purity iodine-123 have only been available for the past 5-10 years. ANSTO (1992E) says that iodine-123 should eventually replace iodine-131 for many diagnostic applications. ANSTO (1992B) also say that iodine-123 is superior to Tc-99m in its overall diagnostic accuracy. Iodine-123-labelled molecules have numerous targets that cannot be reached with Tc-99m (Anon., 1994). Iodine-123 can be used with PET equipment and is also ideal for transfer to SPECT (Lambrecht et al., 1994).

Historically the use of iodine-123 was limited because of its production with cyclotrons. This created problems such as high cost and limited availability. Thus there was some momentum towards replacement of iodine-123 with Tc-99m for some studies (e.g. brain studies). Given the increasing availability of cyclotrons, and also the technical improvements enabling production of high-purity iodine-123, the momentum could swing the other way, towards replacement of Tc-99m with iodine-123 for some studies.

There is a long history of various imaging/diagnostic technologies finding clinical niches, sometimes pushing other technologies out in the process, sometimes being overtaken themselves. Within the field of nuclear medicine there is a highly fluid process of radioisotopes finding niches, being replaced, and so on. As mentioned the momentum within nuclear medicine has been towards ever-greater reliance on Tc-99m. If a sustained trend away from Tc-99m does occur, it is unlikely to happen quickly. It is conceivable but unlikely that any particular radioisotope (or system such as PET) will emerge to rapidly and fundamentally alter the practice of nuclear medicine, overtaking Tc-99m along the way. If a trend away from Tc-99m does develop, it is more likely to be gradual and uneven. As with research into new production methods, the likelihood of ample supplies of fission Mo-99, for the next generation at least, may act as a brake on efforts to replace Tc-99m with other radioisotopes.
CHAPTER EIGHT:
FUTURE SUPPLY OF RADIOISOTOPES
IN AUSTRALIA

8.1. HISTORY AND CURRENT SUPPLY OF THE AUSTRALIAN RADIOISOTOPE MARKET
8.2. FUTURE SUPPLY IN THE ABSENCE OF A DOMESTIC REACTOR
8.3. FUTURE RESEARCH INTO NUCLEAR MEDICINE AND THE RADIOISOTOPE INDUSTRY

On the basis of the information and analysis presented in chapters 5-7, the issue of future radioisotope supply in Australia can now be addressed. I begin this chapter with a brief discussion on the history and current supply of the Australian market, focusing on the reasons for the current dominance of ANSTO and Australian Radioisotopes (ARI). Then I evaluate the scenario of radioisotope production and supply in Australia in the absence of a domestic reactor, drawing on the material presented in the preceding chapters and also taking up issues such as costs and reliability of supply. Then I discuss potential roles for various organisations in the absence of a domestic reactor, including ANSTO/ARI and private companies.

Nuclear medicine and the radioisotope industry have been the subject of very little sustained analysis and this thesis is by no means exhaustive in its analysis of these topics. Thus I conclude this chapter with some suggestions for future research and summarise some of these issues, in particular iatrogenesis, overuse of nuclear medicine, and alternative medical technologies.

8.1. HISTORY AND CURRENT SUPPLY OF THE AUSTRALIAN RADIOISOTOPE MARKET

HISTORY OF SUPPLY
CURRENT SUPPLY

HISTORY OF SUPPLY

There have been four phases in the supply of the Australian radioisotope market. Until HIFAR began operation in 1960, most radioisotopes used in Australia were imported. Importation of medical radioisotopes was funded by the federal government, and it was not substantial in quantity. (ANSTO, 1993, p.4.7.) In addition to imported radioisotopes, there was some sporadic mining of radium which was used in cancer therapy, and in medical and beauty treatments.
purporting to cure all things from rheumatism to "double chin". (Cawte, 1992, ch.1.)

The second phase began with the construction and routine operation of HIFAR from 1960. However radioisotope production was minimal and *ad hoc*. Radioisotopes were imported unless that was a problem because of short half lives or excessive transport costs or unavailability: nothing was to interfere with the power-reactor research. A turning-point was 1967 when the Commission decided that its operations should include the regular production and processing of radioisotopes, and radiopharmaceutical production laboratories were commissioned. With the abandonment of the Jervis Bay nuclear power project, radioisotope production was further expanded. In 1973 the AAEC's Radioisotope Production Laboratories were upgraded. In fact radioisotope production, processing, and research facilities have been improved a number of times over the years, most recently with the completion of a $3.3 million radiopharmaceuticals laboratory in 1995. (Boyd, 1968; Moyal, 1975, p.380; ANSTO, 1995G.)

This second phase was a period of considerable growth. In 1975 sales of radiopharmaceuticals exceeded $1 million for the first time; in 1980 sales exceeded $2 million. From the late 1960s, when the AAEC systematised radioisotope production and processing, radioisotopes were imported only if they could not be manufactured by the AAEC. There were a number of disincentives facing foreign suppliers, not least the AAEC's provision of medical radioisotopes at no cost to users. By 1976/77, 95% of medical radioisotopes used in Australia originated from the AAEC, with total subsidisation from the National Welfare Fund. (ANSTO, 1993E, p.2.58; 1993D, p.2.14; 1993, p.4.7.)

The federal government decided that from 1 January 1978, the Commonwealth Department of Health would no longer be involved in radioisotope procurement, the government would no longer distribute radioisotopes free of charge, and market forces should be allowed to determine prices. These decisions had the effect of ending the AAEC's "virtual monopoly" for its radioisotope products and opened the door to increased competition from foreign suppliers (ANSTO, 1993, p.4.7). Thus began the third phase of supply of the Australian radioisotope market. The AAEC's share of the Australian market dropped considerably. In 1984 the National Health Technology Advisory Panel (1984, p.14) said:

*Overseas competition has been very significant in the case of reactor-produced radioisotopes. The AAEC has had difficulty in maintaining a*
satisfactory market share for these radioisotopes, and imported products account for a high proportion of the Australian market.

The AAEC's share of the Mo-99/Tc-99m market also dropped markedly (National Health Technology Advisory Panel, 1984, p.14):

Molybdenum generators used for technetium-99m production may be purchased from the AAEC. Overseas products are however highly competitive and a high proportion of the generators used in Australia are imported.

The AAEC's share of the Mo-99/Tc-99m market, and of the overall market for radiopharmaceuticals, slipped to about 35% in the early 1980s (AAEC, 1982-83, p.15; ANSTO, 1993E, p.317).

In the fourth phase of supply of the Australian radioisotope market, from the mid 1980s, the AAEC regained its prominent position. A technical improvement strengthened the AAEC's position: in the mid 1980s the Commission developed the capacity to produce Mo-99/Tc-99m generators of sufficient quality (sterility) to enable it to compete more successfully with foreign suppliers. These generators were marketed at a cheaper price than the imported products, and the AAEC's share of the generator market increased to 85% within a few years. (Turner, 1993, p.780; ANSTO, 1993, p.317.)

Apart from this specific technical improvement, the AAEC reorganised its radioisotope operations through the 1980s to improve its competitive position. The 1979 review of the AAEC by the National Energy Research Development and Demonstration Council (NERDDC) said that the AAEC's radioisotope program was not as cost-effective as it might be, and that radioisotope production, distribution, and marketing should be separated from the rest of the Lucas Heights research establishment and made part of an organisation such as the Commonwealth Serum Laboratories. Radioisotope production was not removed from the AAEC's responsibilities, but in response to the criticism by the NERDDC, and also in response to increasing competition from foreign suppliers, the AAEC reorganised its resources to produce a more commercial structure. This eventually culminated in the establishment of Australian Radioisotopes (ARI) as a commercial subsidiary of ANSTO in 1987. (ANSTO, 1993, p.4.8.)

ANSTO (1993, pp.4.17-4.18) offer a string of reasons for their dominance of the market over the past decade: ARI's products are considered comparable in quality
to imported products; there is an "overall cost advantage"; the local market supports an indigenous industry; ARI provides a comprehensive and personal service to users; ARI has the flexibility to move with the changing demands of the market; there is continued liaison with major hospitals through research and development programs; ANSTO supports ARI with research and licensing; the relatively small size of the Australian market deters and delays foreign companies from making the necessary investments to satisfy Australian licensing regulations for new and improved products; and finally, HIFAR's irradiation facilities enable not only routine production but also specialist products for research.

A number of these claims need comment. As for ANSTO/ARI's comprehensive and personal service, its flexibility to move with changing demands, and its continued liaison with hospitals, these may be fair generalisations - the tone of the numerous medical submissions to the Research Reactor Review suggests so, even though many of the submissions were solicited. However there is some evidence to the contrary. The 1994 Bain report argued that ARI, along with ANSTO's Biomedicine and Health research program, should be removed from ANSTO's control, because of problems stemming from the physical separation and cultural isolation of ANSTO/ARI from the health and medical community (Bain et al., 1994, p.44). This separation and isolation, the Bain report went on to say, was a "strong barrier" to more effective collaboration. It seems that nuclear medicine professionals said one thing to the Research Reactor Review panel and another to the organisations which produced the Bain report.

The manner in which "the local market supports an indigenous industry" is a euphemism for national chauvinism, fuelled by fear-mongering from ANSTO. As much was acknowledged by a nuclear medicine professional in a verbal submission to the Research Reactor Review (Turner, 1993, p.780). Professor Turner noted that in Western Australia, there was competition between ANSTO/ARI and foreign suppliers for supply of a number of radioisotopes. The Australian products were of inferior quality, and Amersham and Mallinckrodt brought their prices down to a level comparable with the domestic product. Turner (1993, p.780) goes on to say that:

Western Australia, for purely chauvinistic reasons, elected to go with the ANSTO product, because there was a threat that, if they did not have a market, they would close down their production facility for radioisotopes in Australia. ......... In fact, the multi-national companies were considering legal action under the Trade Practices Act, because they considered that what we
were doing was not in the interest of freedom of trade and, indeed, I guess it was not, but it was in the national interest as we perceived it at that time.

ANSTO notes that the relatively small size of the Australian market deters and delays foreign companies from making the necessary investments to satisfy Australian licensing regulations. In the absence of domestic reactor production, the licensing costs in relation to the size of the market for imported products would be less of a burden. The growth of the Australian market would be a further incentive; according to ANSTO (1993, p.4.12), in the early 1990s annual growth in the number of nuclear medicine procedures was 10%.

**CURRENT SUPPLY**

All of the suppliers of the Australian market, including ANSTO/ARI, are coy about their activities to a greater or lesser extent, but a reasonably accurate picture can be pieced together.

According to ANSTO (1993, p.4.17, 4.20), ARI maintained (as at 1993) a market share of "around 80% overall" for radioisotope products and 95% of the Australian market for Mo-99/Tc-99m generators. In 1991-92, about 55% of ARI's sales were of HIFAR radioisotopes and the rest were sales of products imported by ARI or sales of non-radioisotope products. In the past few years, ARI has also played a role in the sale of radioisotopes produced by the National Medical Cyclotron.

Amersham is the only foreign licensed supplier of Mo-99/Tc-99 and thus ANSTO/ARI's only competitor in the Australian Mo-99/Tc-99m market. It supplies about 15 Mo-99/Tc-99m generators each week, manufactured in the UK. Amersham (1996, pers. comm.) also imports thallium-201, gallium-67, cobalt-60 sources, and perhaps a few other radioisotope products. According to Diesendorf (1993), Amersham supplies 10% of the Australian market. According to Amersham (1996, pers. comm.), they supply roughly 10-15% of the Australian market. It is notable that, according to Amersham (1996, pers. comm.), there is greater demand for the company's Mo-99/Tc-99m generators in Australia than it is willing to supply. This reluctance is because of the very low profit margins associated with generator sales. In particular, profits are low for large generators which must be returned to the UK because of non-proliferation regulations concerning the depleted uranium contained in the shields of these generators. Many hospitals require these larger generators, and most or all are supplied by ANSTO/ARI. It is not apparent why Amersham has not simply increased its
prices to satisfy demand; perhaps the situation is further complicated by
competition with and manoeuvring by ANSTO/ARI.

Mallinckrodt supplies Australia with some products manufactured in Europe and
North America. According to Mallinckrodt, its supply of the Australian market is
roughly equivalent to Amersham’s. However the product range is different. It
supplies a range of cold kits for labelling in hospitals with radioisotopes, but its
supply of radioisotopes is limited to thallium-201, gallium-67, an indium-111
labelled radiopharmaceutical, and perhaps one or two others. Mallinckrodt used
to have a license to supply Mo-99/Tc-99m generators, but let the license lapse.
(Mallinckrodt, 1996, pers. comm.)

Over the years, Nordion has supplied Mo-99 (and other radioisotopes) during
routine HIFAR shut downs, and during the extended shut downs which take
place every few years. More recently the South African Atomic Energy
Commission has become a significant back-up supplier when HIFAR is
temporarily shut down; for example in December/January 1996-97, four
shipments were made to ARI totalling 301 Ci of Mo-99. (SAAEC, 1997, pers.
comm.)

There may be one or two other smaller suppliers of radioisotope products to the
Australian market; for example the American company Manicrop was listed as a

8.2. FUTURE SUPPLY IN THE ABSENCE OF A
DOMESTIC REACTOR

OVERVIEW
RADIOISOTOPE COSTS
RELIABILITY OF SUPPLY
RADIOISOTOPE HALF LIVES & SPECIFIC RADIOISOTOPES
ORGANISATIONAL ARRANGEMENTS

OVERVIEW

From the analysis and information presented in chapters 5-7, it can be concluded
that the prospects for greater reliance on imported radioisotopes are good.
International trade in radioisotopes is well established, with supply networks
stretching all around the world. Bulk production of the most commonly used
reactor radioisotopes will be sufficient to meet world demand for at least the next

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Several large, vertically-integrated operations - in particular Nordion, Mallinckrodt, and Amersham - have made significant investments in recent years and will continue to dominate the global market. Other producers and suppliers, such as IRE and the SAAEC, will also play a significant role in the international market, and in some cases will also act as back-up suppliers in the case of disruption of supply from the major producers and suppliers. These smaller producers can be seen as a reservoir from which significant radioisotope production and export ventures might emerge in future.

There is sufficient research reactor capacity to supply world demand many times over, and the overall decline in research reactor infrastructure is unlikely to have a significant impact for several decades, if at all. Upswings or downturns in nuclear power and weapons may have some impact on research reactor infrastructure and thus radioisotope production, but the effects are variable and unlikely to be of much consequence overall.

Technical innovations are likely to reduce or negate any impact caused by declining reactor infrastructure. The use of LEU or molybdenum targets is likely to enable more widespread reactor production of Mo-99/Tc-99m generators, increasing the opportunities for reliable, affordable importation. Innovation continues in the field of cyclotron technology - there are good prospects for continued growth in the use of cyclotron radioisotopes, and some potential for the replacement of Tc-99m procedures with cyclotron radioisotopes such as FDG and iodine-123. The impact of other research areas - cyclotron production of Mo-99/Tc-99m, and production of Mo-99/Tc-99m and other radioisotopes using spallation sources and liquid fuel reactors - cannot be confidently predicted but they may be of consequence.

One issue which needs comment is the argument that importation is parasitic. In its submission to the Research Reactor Review, Kylwind Pty. Ltd. (1993) made the following blunt comment about importation:

This is a parasitic case of the NIMBY syndrome. If Australia decides that it needs to use radio-isotopes, then it is morally bound to accept the problems that the production of such isotopes incurs.

Greenpeace (1993) made a similar point, but connected to its advocacy of greater reliance on cyclotrons. There may be specific cases when it would be appropriate to refuse supply from particular countries or particular suppliers on moral/political grounds, but the overall argument is flawed. Taken to its logical extreme the
argument would be that every country with a demand for reactor radioisotopes is morally bound to build and operate research reactors. Given the manifold problems associated with research reactors - radioactive waste problems, weapons proliferation, and so on - it makes far more sense to operate no more reactors than is necessary. In the longer term the solution is to reduce reliance on research reactors for radioisotope production. ANSTO could assist in this long-term solution, for example by pursuing with greater vigour research into the production and use of cyclotron radioisotopes. Building a new reactor in Australia would only add to the problems associated with research reactors and perpetuate reliance on reactor applications.

Greater reliance on imported radioisotopes would bring with it some minor problems or potential problems, discussed below. Nonetheless, in relation to radioisotope production, a new reactor in Australia promises to be superfluous over the next generation and it may, in the face of changes in the global radioisotope industry and technical innovations, be an anachronistic white elephant beyond that.

**RADIOISOTOPE COSTS**

It was frequently claimed during the Research Reactor Review, by organisations such as ANSTO, hospitals, and nuclear medicine professional associations, that the cost of importing radioisotopes is significantly greater than domestic production. The implication was that the costs of importation are excessive, or even prohibitive, and that a new reactor should therefore be built.

The Review (1993, p.93) reproduced figures supplied by the Royal Brisbane Hospital indicating that imported products were roughly twice as expensive as ANSTO/ARI products. The Concord Hospital (1993) said that during periodical shut downs of HIFAR, the cost of raw materials doubled and most of this increase was absorbed by ANSTO/ARI, with user price increases of about 30%. A number of other hospitals, nuclear medicine professionals, and professional associations claimed that prices would increase significantly in the absence of a domestic reactor, as did ANSTO and ANSTO's consultants.71

Comments made to the Review on the costs of importation were not unanimous. Little data on relative costs of ANSTO versus imported products was (or is) available, largely because producers are reluctant to make this knowledge publicly

known, and thus many of the claims were unsubstantiated. Claims varied widely, from modest costs increases to five-fold increases for imported products. There were a few dissenters, not just from opponents of a new reactor but also from a small number of medical professionals (e.g. Silink, 1993). A hospital-based nuclear medicine department made the pertinent observation - which escaped most other medical and pro-reactor submissions - that the costs of building a reactor might be factored into the equation: "It could undoubtedly be argued that the cost to the community of purchasing radioactive materials from overseas suppliers would still be less than the cost of building a new reactor." (Flinders Medical Centre, 1993.) The Sutherland Shire Council (1993B, p.57) compared 1993 retail prices of Amersham and ANSTO. ANSTO's prices were significantly cheaper for some products, significantly more expensive for others.

One of the concerns of medical professionals and institutions was expressed by a nuclear medicine professional (Chatterton, 1993, pp.811-812):

One of the fears of the nuclear medicine doctors is that if radioisotopes were to become more expensive, Medicare schedule fees would not automatically reflect this, certainly not immediately. So increased costs would be absorbed by patients and/or practitioners.

The major problem with the numerous claims made in support of a new reactor on the basis of increased costs of imported radioisotopes was the failure to consider the subsidisation of ARI by ANSTO (which is in turn funded mostly by the federal government). This subsidisation was noted by critics of a new reactor (e.g. Sutherland Shire Council, 1993B, p.56; Friends of the Earth, 1993B; Berkhout, 1993; see also Egan et al., 1994, p.5.)

Before 1992-93, only the marginal cost of reactor fuel was charged to ARI. ANSTO (1993, p.4.4) claims that since then, the "full" marginal costs have been charged to ARI - the costs of extra fuel, labour and materials required to produce radioisotopes. ANSTO (1993, p.4.4) further claims that subsidisation of radioisotope production is a thing of the past: "ARI has emerged into an era that has allowed it to become self-sustaining and unsupported by subsidy ....."

Despite ANSTO's claims, ARI is still subsidised in a number of ways. The fee charged to ARI does not consider the capital costs of HIFAR, on which point the Research Reactor Review (1993, p.92) said: "Inasmuch as the capital invested in the HIFAR reactor is a sunk cost this is not unreasonable, but would not be appropriate for a new reactor." ANSTO's charges to ARI also do not consider
depreciation costs, decommissioning costs, site costs, waste management costs, or the costs of research (which are mostly subsumed under the ANSTO's Biomedicine and Health program).

Estimating the extent of the subsidisation of ARI is difficult. It is not immediately apparent how the various costs associated with a multipurpose reactor should be factored into pricing for one particular program. Some of these factors can be quantified by estimating the extent to which HIFAR (or a new reactor) is used for radioisotope production as opposed to other functions. But even this calculation is complex and contestable. It might include consideration of reactor time, reactor neutrons, and staff time and engineering effort devoted to radioisotope production. ANSTO bases its assessment of reactor usage devoted to radioisotope production on the claim that 10% of HIFAR's neutrons are devoted to radioisotope production. Friends of the Earth (1993B) took issue with this during the Research Reactor Review, saying that a greater percentage of HIFAR's irradiation rigs (25%), operating staff time and effort are devoted to radioisotope production. Debates over other aspects of ANSTO's subsidisation of ARI are equally complex - it would be particularly difficult to reduce the economic, social, and environmental costs associated with radioactive waste management and storage to an economic figure to be factored into costs charged to ARI.

To attempt to quantify the extent of subsidisation of ARI would be complex and contentious, given the numerous assumptions it would entail. Suffice it here to note that the costs associated with reactor construction, "back-end" costs such as reactor decommissioning and waste management, and other costs not factored into ARI's prices, are large. For example, if 10% of HIFAR's neutrons are used for radioisotope production, as ANSTO claims, then it would be appropriate for ARI to contribute $42.5 million (10%) to the capital costs of a new reactor. This is 4-5 times as much as ARI recovers in annual sales revenue, and this alone could add 5-10% to ARI's prices over the 40-50 year life-span of a new reactor.

It should also be noted that even with ARI being charged only for marginal fuel, labour, and materials costs, it has struggled to generate revenue in excess of costs and was further subsidised with an "Operational Subsidy" from ANSTO until recently. It is highly unlikely that ARI could operate on a commercial basis without the various subsidies it enjoys.

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22 The $425 million figure was put forward by the Bain report (1994). See chapter 4.4.
All overseas radioisotope producers are subsidised, but that is of no consequence when evaluating the relative costs of domestic production versus importation for supply of the Australian market.

Another issue is competitive manoeuvring in the radioisotope market. Sometimes foreign suppliers have discounted heavily to get a toe-hold in the Australian market (Chatterton, 1993, pp.799-800). Conversely, it may be the case that in the absence of domestic production and competition, prices charged to Australian radioisotope users would increase as a direct consequence of the lack of competition – for example a nuclear medicine professional told the Research Reactor Review that sometimes ANSTO begins to produce products once they are already on the market and the imported price can be reduced by a factor of two or more (Kelly, 1993, p.501). Against this, the weakening of Nordion's stranglehold on bulk radioisotope production, and the competitive nature of the radioisotope processing/retailing industry, would act as brakes on opportunistic price increases in the absence of a domestic reactor.

The cost of imported Mo-99/Tc-99m would be considerably less if, instead of importing generators, bulk Mo-99 was imported with domestic generator manufacture. ANSTO's comparison of its generator prices, in comparison with Amersham's prices, fails to acknowledge this. In the absence of a domestic reactor, ANSTO could use its facilities to manufacture generators from imported bulk Mo-99, and/or a radiopharmaceutical company such as Amersham might establish facilities for generator manufacture.

As discussed in chapter 6.2, Nordion has increased its price for bulk Mo-99, but this was expected to have only a small impact on hospital radiopharmaceutical budgets because bulk Mo-99 accounts for only 30-60% of the cost of manufacturing generators, because other radioisotopes are more expensive than Mo-99 per unit dose, and because non-radioactive components of radiopharmaceuticals comprise a considerable proportion of radiopharmaceutical costs. Overall, it was expected that a 40% price increase would increase radiopharmaceutical budgets by about 3% for large nuclear medicine departments and up to 7% for smaller departments. (Anon., 1995E.) Neither generator manufacture, nor non-radioactive components of radiopharmaceuticals, need be affected in the absence of a domestic reactor.

Another important factor is that radiopharmaceutical costs comprise only a small percentage of overall nuclear medicine costs which also include imaging equipment, salaries and fees, and sundry other costs. Some indication of the
relative costs in Australia was presented to the Research Reactor Review by a nuclear medicine professional (Chatterton, 1993, p.803):

Radioisotope costs: $7 million p.a.
Non-radioisotope component of radiopharmaceuticals: $5 million p.a.
Other costs (e.g. salaries) $48-60 million p.a.
Total nuclear medicine costs: $60-72 million p.a.

The situation is much the same overseas. For example radiopharmaceutical costs in the US are less than 10% of average procedure charges, and that percentage figure has declined since the mid 1980s. Moreover radiopharmaceutical prices are increasing at a rate less than the consumer price index in the US. (Kasses, 1995.)

If radioisotope costs in Australia were doubled in the case of greater reliance on imports, which would probably be a worst-case scenario, overall nuclear medicine costs would increase by just 10% or so. Moreover this does not even begin to take into account the substantial subsidisation of ARI, a particularly salient issue at a time when a new reactor is under consideration.

RELIABILITY OF SUPPLY

ANSTO, and a number of nuclear medicine professionals and institutions, argue against greater reliance on imported radioisotopes, and conversely in support of a new reactor, because of the alleged unreliability of importation (e.g. ANSTO, 1993D, p.2.29; Royal Brisbane Hospital, 1993).

Claims of unreliability can be unpacked into several different arguments. The major argument is that because of delays and misplacements, failure of timely delivery occurs too often with imported radioisotopes. These problems cause inconvenience to medical staff and patients, for example by prolonging hospital stays. Another component of these arguments is that ANSTO's delivery of its products is reliable and rapid.

Undoubtedly there are sometimes problems with international transport of radioisotopes, because of pressures imposed by the short half lives of some radioisotopes. There are other problems too. Radioisotope shipments require shielding and this has limited importation, especially for Amersham's large generators with depleted uranium shields (see section 8.1). Another possible problem concerns regulations which limit the volumes of radioactive materials that can be transported in any one aircraft.
Whether these problems are common and important enough to significantly sway the argument in favour of a new reactor is another matter. As for delayed or failed deliveries, the Royal Brisbane Hospital (1993) made the unsubstantiated assertion that between 5-20% of imported radioisotopes do not arrive "within an acceptable time window". The Australian and New Zealand Society of Nuclear Medicine (1993) claimed that nuclear medicine departments using imported Mo-99/Tc-99m generators experience delivery failures about two times each year - assuming weekly delivery, this is a modest failure rate of about 4%. It is just as easy to find claims that overseas delivery is very reliable. For example Bindon (1988), writing in *The Nuclear Engineer* about Amersham's export operations from the UK, claims that "All arrangements are so well organised as to guarantee practically 100% delivery to most parts of the world within 48 hours of dispatch of the consignment from Amersham." Delivery from the South African Atomic Energy Commission is remarkably reliable. With routine shipments to China, India, and Israel, the frequency of transport delays from the SAAEC to its customers is less than 0.5% of all shipments, and the delay is usually less than 30 hours (SAAEC, 1997, pers. comm.).

Most of the radioisotopes used throughout the world are imported from other countries. For example the US, Japan, and the UK all rely heavily on imported radioisotopes. Together these three countries account for over two thirds of world usage of medical radioisotopes. There is no indication that delayed or failed delivery is common in these countries. Such problems would be taken up in the nuclear medicine professional literature if they were of great concern. However these issues rarely if ever surface in the European or American professional literature; the contrast with the depth of concern expressed by a number of submissions to the Research Reactor Review is striking and suggests that the problems were overstated in Review submissions. There would also be much more pressure for domestic radioisotope production around the world if importation was problematic.

Proponents of a new research reactor in Australia have pointed to the Mo-99 project in the US as evidence of the importance of domestic radioisotope production. This was reflected in the Research Reactor Review's (1993, p.92) sweeping statement that "As might be expected, the lack of a domestic supply of technetium-99m worries Americans." However the emphasis in the US has been on increasing security of Mo-99 supply; whether this involved domestic production was a secondary consideration. One source from a radiopharmaceutical company in the US put it thus (quoted in Rojas-Burke, 1992B): "We'd like to have a domestic supplier of molybdenum, but we don't
have to have a domestic supplier." Given the existing research reactor infrastructure in the US, domestic production was the obvious option, but possibilities for developing overseas facilities were also explored. That the three major radiopharmaceutical companies supplying the US market have pursued ventures overseas or sought out foreign suppliers, and are now largely uninterested in the Sandia venture, is further evidence that security of supply was more of an issue than domestic production per se.

The supply chains, technologies (e.g. shielding), and regulatory apparatus for international radioisotope trade are in place. Several organisations around the world have experience and expertise in the establishment and routinisation of long supply lines; Nordion's radioisotopes, for example, are used in over 100 countries all around the world and Amersham supplies 150+ countries. The high level of competition in the processing/retailing segment of the industry is an incentive for these companies to ensure reliability of supply. Vertical integration of the industry is likely to further improve reliability of supply by streamlining regimes of production, processing, and transportation.

Another line of argument advanced by ANSTO (1993, p.4.41) was that supply might be efficient in Europe and North America, but supply to Australia and other Asia Pacific countries is likely to be less efficient because of the distances involved. However the supply from South Africa to China is remarkably reliable. Similarly, Japan has few problems importing all of its Mo-99, and most of its other radioisotopes, from Nordion's Canadian facilities. The Director of the Department of Radioisotopes at the Japanese Tokai Research Establishment says that (Yamabayashi, 1996, pers. comm.):

...... The import from Nordion is quite stable and regular. It has been working so for more than 10 years without serious problems apart from occasional delay of flight schedule in the season of heavy snow.

In addition, the long-term supply contracts between Nordion and the Japanese radiopharmaceutical companies are secure, and there is little demand from these companies or from nuclear medicine professionals for domestic production of fission Mo-99 in Japan. (Yamabayashi, 1996, pers. comm.)

Yet another argument put to the Review in a number of submissions was that because of the relatively small size of the Australian market, suppliers would be likely to interrupt Australian supply in the case of shortages rather than disrupt supply to the larger, more lucrative markets. This was speculation at best, and
perhaps just clutching at straws. The Review (1993, p.94) noted that there was no
evidence of this having happened. Moreover this argument assumes shortages of
supply which are unlikely to occur, at least for the most commonly used isotopes
and at least for the next generation.

Whatever problems are currently experienced during importation of radio-
isotopes would most probably be reduced in the case of ongoing reliance on
imports as an alternative to domestic reactor production. As supply chains to
Australia are routinised, and teething problems overcome, problems would
become increasingly infrequent. For example, radioisotope shipments to Australia
are sometimes unnecessarily unloaded when planes are delayed for one reason or
another; this further delays shipment and can also result in completely failed
delivery. Potential suppliers could probably be induced to sign long-term supply
contracts with penalties for failed deliveries. ANSTO (then the AAEC) was a
world pioneer in establishing regular radioisotope delivery across large areas: it
might put that expertise and initiative to good use in solving some of the
complications arising from greater reliance on imported products. Many other
strategies could be pursued to minimise problems - diversifying supply sources,
inter-institutional arrangements between hospitals/clinics to minimise problems
when failed or late deliveries do occur, and so on.

RADIOISOTOPE HALF LIVES & SPECIFIC RADIOISOTOPES

It is commonly claimed that a number of important radioisotopes would not be
available in the absence of a domestic reactor because their half lives are too short
for importation (e.g. ANSTO, 1993F, p.7.4). However exactly which radioisotopes
would be unavailable is rarely spelt out. Here I will make some general comments
on the availability of specific radioisotopes in the absence of a domestic reactor,
and then briefly discuss the potential for importation (or domestic cyclotron
production) of the most important medical radioisotopes.

There is widespread international trade of the four most commonly used medical
radioisotopes, Mo-99/Tc-99m, gallium-67, thallium-201, and iodine-131. In fact it is
in part because of their amenability to long-distance transport that they are so
commonly used. It is the plethora of less commonly used radioisotopes that might
be in jeopardy in the absence of a domestic reactor. Generally it is those
radioisotopes with short half lives that are most difficult to import, for obvious
reasons. Many of the important short-lived radioisotopes are cyclotron produced,
and are (or could be) produced in Australia using cyclotrons. In sum, it is short-
lived, infrequently-used reactor radioisotopes that are in question.
Many infrequently used radioisotopes can in fact be imported. Some already are imported because demand is too low for ANSTO/ARI to be interested in producing them. Moreover ANSTO/ARI has rationalised its product line "to its financial advantage" in recent years. (ANSTO, 1993, p.4.8.) At ANSTO/ARI, as elsewhere, there is much more interest in producing radioisotopes which can be sold at a profit. If ARI continues down the path of commercialisation, it may be the case that even with a new reactor, many infrequently used radioisotopes will either be imported or will not be available because ANSTO/ARI will not produce them at a loss.

Since complaints about unavailability of radioisotopes in the absence of a domestic reactor tend to be non-specific, some assessments of which radioisotopes are most important will be useful. Amersham (1993) says that the most important medical radioisotopes for present day usage are Mo-99/Tc-99m, iodine-125, iridium-192, iodine-131, chromium-51, and yttrium-90. Morris (1993), a nuclear medicine professional, says the five most important radioisotopes are Mo-99/Tc-99m, thallium-201, gallium-67, fluorine-18, and iodine-131, with the next most important being iodine-123 and indium-111. There should be no problems with supply of any of these radioisotopes in the absence of a domestic reactor – they can all be imported and/or produced in domestic cyclotrons:

**Mo-99/Tc-99m** - reactor produced - half life 66/6 hours - many applications - several producers could supply Australia with bulk Mo-99 or generators.

**Iodine-125** - reactor or cyclotron produced - half life 60 days (ample for importation) - research and clinical applications such as radioimmunoassay, kidney studies - some imported, also produced by the National Medical Cyclotron - Amersham (1993) says there would be no difficulty supplying I-125 in research and clinical grades from reactors in the Pacific Basin.

**Iridium-192** - reactor produced - half life 72 days (ample for importation) - radiographic cancer treatment - Amersham (1993) claims to be the largest consumer of bulk Ir-192 in the world and could supply high-quality Ir-192 sufficient to meet Australian demand - several bulk producers, e.g. in Russia, Sweden, the US (Isotec).

**Iodine-131** - reactor produced - half life 8 days (ample for importation) - numerous applications in imaging and treatment - at least one submission to the Research Reactor Review (Endocrine Society of Australia, 1993) questioned the reliability and timeliness of supply of imported iodine-131, however both fission-product and irradiation-generated iodine-131 will be available in large quantities around the world for the foreseeable future according to Amersham (1993).
Chromium-51 - reactor produced - imaging (e.g. kidney) - half life 28 days (ample for importation) - produced in about 9 reactors around the world (INSC (n.d.) data.) - already imported.

Yttrium-90 - reactor produced - treatment of cancer and arthritis - half life 64 hours (sufficient for importation) - already imported because of patent restrictions - generator system under development using the parent strontium-90 (half life 29 years).

Thallium-201, gallium-67, fluorine-18, iodine-123, indium-111 - all cyclotron produced - all can be produced using domestic cyclotrons and/or imported.

A number of other radioisotopes have secure, if small, niches in nuclear medicine. Once again it is difficult to find any radioisotopes that could not be imported or produced using domestic cyclotrons:

Xenon-133 - reactor produced - half life 53 days (ample for importation) - inhalation and blood flow studies - already imported - produced as a U-235 fission product and will become more readily available as a by-product of ventures to increase production of fission Mo-99.

Phosphorus-32 - reactor produced - half life 14 days (ample for importation) - treatment - already imported.

Iron-59 - reactor produced - half life 45 days (ample for importation) - iron metabolism - already imported.

Cobalt-60 - reactor produced - half life 5 years (ample for importation) - radiotherapy - produced in about 15 research reactors around the world and some power reactors.

Selenium-75 - reactor produced - half life 120 days (ample for importation) - pancreatic imaging - already imported.

Rhenium-186 and Samarium-153 - half lives 89 hours and 47 hours respectively - reactor produced - candidates for future use in treatment or palliation - Amersham (1993) says possible supply solutions could be found using Pacific Basin or European reactors despite the relatively short half lives.

Copper-64 - reactor produced - half life 5 years (ample for importation) - genetic diseases affecting copper metabolism.

Strontium-89 - reactor produced - treatment - half life 50 days (ample for importation).

Gold-198 - reactor produced, cancer treatment - half life 65 hours (sufficient for importation).
Many other radioisotopes could be imported in the absence of a domestic reactor. The following radioisotopes were imported into Australia as at 1993, whether by ANSTO/ARI or other organisations (Nuclear Waste Management, 1993):

- Americium-241
- Cadmium-109
- Caesium-137
- Calcium-45
- Californium-252
- Chromium-51
- Curium-244
- Gallium-67
- Hydrogen-3
- Indium-111
- Iodine-125
- Iron-59
- Phosphorus-32
- Plutonium-238
- Selenium-75
- Thallium-201
- Xenon-133
- Yttrium-90

Ongoing research into parent-daughter generator systems promises to further increase the international trade in radioisotopes and lessen the need for domestic reactors and accelerators. As with Mo-99/Tc-99m generators, the parent radioisotopes have half lives which allow for long-distance transport in most cases. A variety of diagnostic radioisotope generator systems are already available. Generators for therapeutic radioisotopes have not been commercially developed as yet, but this is likely to change since it is one of the most vibrant areas of generator research. This is particularly significant since most or all therapeutic radioisotopes are reactor produced. Another area which has attracted considerable research interest is PET radioisotope generators. Some PET radioisotopes still require an on-site cyclotron because of the short half-lives of the radioisotopes and the lack of availability of generator systems. However a number of PET radioisotopes are available from generators, and this can be a cheaper, convenient alternative to an on-site cyclotron. (Knapp and Mirzadeh, 1994.)

Generator systems are being developed - or are already available - for the following radioisotopes (Knapp and Mirzadeh, 1994):

<table>
<thead>
<tr>
<th>PARENT</th>
<th>HALF-LIFE</th>
<th>DAUGHTER</th>
<th>HALF-LIFE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Therapeutic radioisotopes:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead-212</td>
<td>10.6 hours</td>
<td>Bismuth-212</td>
<td>61 mins.</td>
</tr>
<tr>
<td>Osmium-194</td>
<td>6 years</td>
<td>Iridium-194</td>
<td>19 hours</td>
</tr>
<tr>
<td>Ruthenium-103</td>
<td>40 days</td>
<td>Rhodium-103m</td>
<td>65 mins.</td>
</tr>
<tr>
<td>Strontium-90</td>
<td>29 years</td>
<td>Yttrium-90</td>
<td>64 hours</td>
</tr>
<tr>
<td>Tungsten-188</td>
<td>69 days</td>
<td>Rhenium-188</td>
<td>16 hours</td>
</tr>
<tr>
<td><strong>PET radioisotopes:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germanium-68</td>
<td>271 days</td>
<td>Gallium-68</td>
<td>68 mins.</td>
</tr>
<tr>
<td>Selenium-72</td>
<td>8.4 days</td>
<td>Arsenic-72</td>
<td>26 hours</td>
</tr>
<tr>
<td>Strontium-82</td>
<td>25 days</td>
<td>Ribidium-82</td>
<td>1.3 mins.</td>
</tr>
<tr>
<td>Titanium-44</td>
<td>47 years</td>
<td>Scandium-44</td>
<td>3.93 hours</td>
</tr>
<tr>
<td>Zinc-62</td>
<td>9.1 hours</td>
<td>Copper-62</td>
<td>9.7 mins.</td>
</tr>
</tbody>
</table>

326
<table>
<thead>
<tr>
<th>Radioisotope</th>
<th>Half-Life</th>
<th>Daughter Radioisotope</th>
<th>Half-Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium-109</td>
<td>453 days</td>
<td>Silver-109m</td>
<td>39.8 secs.</td>
</tr>
<tr>
<td>Rubidium-81</td>
<td>4.58 hours</td>
<td>Krypton-81m</td>
<td>13.1 secs.</td>
</tr>
<tr>
<td>Mercury-195m</td>
<td>40 hours</td>
<td>Gold-195m</td>
<td>30.6 secs.</td>
</tr>
<tr>
<td>Osmium-191</td>
<td>15.4 days</td>
<td>Iridium-191m</td>
<td>4.96 secs.</td>
</tr>
<tr>
<td>Tungsten-178</td>
<td>21.6 days</td>
<td>Tantalum-178</td>
<td>9.3 mins</td>
</tr>
</tbody>
</table>

Most of these parent radioisotopes have half lives sufficient for international transport.

Overall, it is clear that a very wide range of radioisotopes would still be available in the absence of a domestic reactor, including all of the most commonly-used radioisotopes. Radioisotope half lives prohibit international transport in very few cases. It is more likely that difficulties would arise because of limited government funding for importation of radioisotopes which cannot be imported on a commercial basis.

As for radioisotopes which might be difficult to supply in the absence of a domestic reactor, one is dysprosium-165, which has a half life of 140 minutes. This radioisotope may find a use in the management of arthritis but this research is still in the experimental stages; there is no certainty that it will be significantly more useful than existing radioisotopes used for this purpose (esp. yttrium-90). Bromine-82 is a reactor radioisotope used for a small number of diagnostic procedures. Its half life of 35 hours may complicate or prohibit importation. It is produced in about 10 reactors around the world, but none of these reactors are located in the Asia Pacific. A third radioisotope which might not be available in the absence of a domestic reactor is gadolinium-159, which has limited use in cancer treatment and has a half life of 18 hours.

Almost certainly there would be some other radioisotopes that it would be difficult or impossible to obtain other than the three just listed. In Australia, and all around the world, nuclear medicine professionals have access to some radioisotopes but learn to deal without others, and so it will remain. The lack of a domestic reactor need not have anything more than a marginal negative impact. If, to compensate for the lack of a domestic reactor, there is further investment in cyclotron technology and research in Australia, the loss of a reactor could be more than compensated for. It is also worth noting that there are usually alternative radioisotope procedures that can be used when particular radioisotopes are not available. For example a string of radioisotopes have applications in bone cancer therapy or palliation - phosphorus-32, strontium-89, samarium-153, rhenium-
186, and to a lesser extent holmium-166 and dysprosium-165. Often there are alternative imaging technologies (e.g. CT, MRI) or diagnostic technologies which involve neither imaging nor radioisotopes (see chapter 8.3).

It is doubtful that there is a single radioisotope that would not be available in the absence of a reactor that has been shown to be markedly better than alternative radioisotopes or alternative imaging/diagnostic technologies; advocates of a new reactor have yet to identify any such radioisotope. Concerns expressed during the Research Reactor Review focused on radioisotopes that could in fact be reliably supplied (e.g. iodine-131), or have yet to find a secure clinical niche and in some cases could probably be supplied anyway (e.g. samarium-153).

A problem related to radioisotope half lives is that it would be more difficult to supply products at short notice without a domestic reactor. Again this is not a major problem. There is rarely such urgency for nuclear medicine procedures that a delay of a few days, or even a week or two, will impact on patient outcome. With time and effort, many of the logistical problems associated with importation can be resolved. ANSTO/ARI can draw on its long history of resolution of logistical difficulties in supplying the Australian market. Suppliers (and users) can also learn from the vast international experience of supply of countries where there is little or no domestic reactor radioisotope production.

**ORGANISATIONAL ARRANGEMENTS**

To sum up the issues thus far addressed. Reliability of supply of imported radioisotopes would probably be only a minor problem in the absence of a reactor. Problems relating to short half lives affect so few radioisotopes that this is of very little concern. The issue of costs of imported radioisotopes is an unknown, but even in a worst-case scenario of a doubling of radioisotope costs, this amounts to something like a 10% increase in overall nuclear medicine costs, and the comparison would be far less flattering for domestic production if not for the subsidisation of ARI.

There are numerous issues that would need to be resolved in making a transition to importation of reactor radioisotopes supplemented by domestic cyclotron radioisotopes. The issues which need consideration are the roles to be played by radiopharmaceutical companies, ANSTO/ARI, and other parties; supply of both profitable and unprofitable radioisotopes; nuclear medicine research; and research relating to radioisotope production.
COMMERCIAL SUPPLIERS

It is worth briefly reiterating the general situation with radioisotope production and supply in Asia. Radioisotope markets are growing at a considerable rate in the Asian region, though mostly from very low starting points. The major, global radiopharmaceutical companies supply a number of Asian countries and can be expected to increase supply as the markets grow. In addition, some commercial operations in the region (e.g. Indonesia) already supply export radioisotopes (including fission Mo-99) to other countries in the region or are likely to do so in the near future (e.g. South Korea). These developments will facilitate supply of the Australian market in the absence of a domestic reactor in Australia.

Nordion has a history of aggressive marketing, is looking to make a return on its investment in the two Maples, is continuing its role as a major bulk radioisotope producer and also moving into the downstream segments of the industry (if unevenly), has some familiarity with the Australian market through its supply during HIFAR shut downs, and for all these reasons could be expected to increase its supply of the Australian market.

Similarly Mallinckrodt is looking to make a return on its investment in the Petten facilities, already has a toe-hold in the Australian market, and would probably look to increase its supply of the Australian market.

Amersham in particular would certainly play a more prominent role in the absence of a domestic reactor. Amersham’s (1993) interest in increasing its involvement in Australia was made abundantly clear in its submission to the Research Reactor Review. Amersham said that it could supply a considerable variety of radioisotopes to Australia in the absence of domestic production, including deliveries 3-4 times per week of Mo-99/Tc-99m generators. Amersham would be in a particularly good position to increase its share of the Australian market, already supplying 10-15% of the Australian market including supply of Mo-99/Tc-99m generators, with eight or nine reactor sources worldwide, established supply chains stretching right around the world, and plans to produce or at least source fission Mo-99 from reactors in the Asia Pacific in the coming years. Moreover Amersham (1996, pers. comm.) would consider establishing radioisotope processing facilities in Australia in the absence of a domestic reactor, instead of supplying products produced in Europe and North America; indeed Amersham already operates a small processing pharmacy in Sydney.
Amersham (1993) says that an option would be for it to organise bulk supply arrangements to ANSTO/ARI based on its existing global network of radioisotope procurement. ANSTO/ARI operations could continue largely unperturbed. With Amersham's extensive global operations, and ANSTO/ARI's long history of supply of the Australian market, collaboration between these organisations could greatly facilitate the change-over to greater reliance on imported reactor radioisotopes.

Many other more modest commercial suppliers might compete for the Australian market in future, including those in South Africa, Indonesia, Russia, possibly South Korea, possibly India, possibly the US (Sandia), and so on. The South African Atomic Energy Commission does not intend to supply Australia except during HIFAR shut downs, but in the absence of a reactor in Australia it would be a likely supplier.

**MOLYBDENUM SUPPLY**

ANSTO/ARI could play several roles in ensuring continuity of supply of Mo-99/Tc-99m even without being a producer. Obviously its operations would need to take account of supply by the radiopharmaceutical companies. One option is that there may be some role for ANSTO/ARI to play in the importation and supply of generators manufactured overseas, either in competition or collaboration with other generator suppliers. However, given the expense of importing generators, a better solution would be importation of bulk Mo-99. ANSTO/ARI could import bulk Mo-99 from whichever bulk producer offers the best price as well as security and reliability of supply. This opens up two further options - generator manufacture in Australia, or supply of instant Tc-99m drawn from imported bulk Mo-99.

About 10% of hospitals/clinics currently prefer instant Tc-99m to generators. Almost all users of this service are located in Sydney and Melbourne. (ANSTO, 1993, figure 4.10.) The reason for this preference appears to be that their volume demands are too low to warrant purchase of generators. ANSTO (1993, p.4.34) argues that its instant Tc-99m service would be stopped in the absence of a new reactor. However it need not be stopped. Instant Tc-99m could be drawn from imported bulk Mo-99; over half of the supply in Japan occurs this way. ANSTO says this would be possible but prohibitively expensive because of the distance between ANSTO/ARI and interstate users. If current users place such a premium on availability of instant Tc-99m, they can pay the added costs. In the worst-case
scenario of non-availability of instant Tc-99m, current users of this service will make do with small generators. Since almost all of the current users of instant Tc-99m are in Sydney or Melbourne, another alternative is that Tc-99m procedures can be carried out at other institutions in those cities. Overall, the fuss made by ANSTO about its instant Tc-99m service is ridiculous given that it is at worst a very minor issue.

The geographical spread of the Australian radioisotope market, and possibly also the small size of the market, limits the potential for ANSTO/ARI to operate as a central radiopharmacy supplying various ready-to-use radiopharmaceuticals (including instant Tc-99m) to users around Australia. Probably the only way this could occur would be for ANSTO/ARI (or a private company) to set up facilities in several states for processing of bulk Mo-99 and other radioisotopes; this is the regional radiopharmacy arrangement which is becoming the norm in the US, Europe and Japan. This is a possibility, but it may not be an economical or efficient option given the geographical size of the market.

Probably the best option for Mo-99/Tc-99m supply would be importation of bulk Mo-99 and centralised generator manufacture. ANSTO/ARI has the necessary facilities for generator manufacture and would probably continue this operation in the absence of a domestic reactor, especially if no private company builds facilities for generator manufacture.

The Research Reactor Review (1993, p.xv) said that if five conditions were met, it would be appropriate to make a positive decision on a reactor in about five years time (see chapter 4.4). One of the five conditions was that a new reactor might be indicated if there has been no "practical initiation" of a cyclotron anywhere worldwide to produce Tc-99m. There has been no initiation of cyclotron Mo-99/Tc-99m production on a large-scale basis in the intervening years, and it is certain that ANSTO will use this fact as an argument in support of a new reactor in the coming years. However the Review's condition concerning cyclotron Mo-99/Tc-99m production was inappropriate. The Review (1993, p.224) noted that countries importing radioisotopes had either overcome logistical problems with importation, or found them not to be a problem in the first place. Then this possibility is ignored in the Review's overall conclusions including the five conditions. There is no need for a new reactor in Australia for Mo-99/Tc-99m production. A more appropriate strategy would be to import Mo-99 for the time being, and at a later date to assess the various lines of research currently underway - cyclotron Mo-99/Tc-99m production, spallation sources, liquid fuel reactors, replacement of Tc-99m with cyclotron radioisotopes, and so on. Moreover
ANSTO/ARI could and should pursue research areas which promise to reduce reliance in imported radioisotopes.

A good case can be made for Australian research organisations to involve themselves in innovative research projects concerning production of Mo-99/Tc-99. Of the various options being researched around the world, cyclotron production may not be the most promising but it has potential advantages over all other methods. Specifically, cyclotron irradiation of Mo-98 or Mo-100 targets uses neither uranium fuel nor uranium targets. It is far preferable to reactor production in terms of waste, and also probably better than spallation sources and liquid fuel reactors in terms of waste generation. Cyclotron production of Mo-99/Tc-99m is probably the best option in terms of minimising the potential for nuclear weapons proliferation, although enrichment of isotopes (such as molybdenum isotopes) requires enrichment facilities which can be of use in nuclear weapons programs (see chapter two).

Whether cyclotron Mo-99/Tc-99m production is developed to the point of being an attractive alternative to reactor production depends on the commitment of governments and various research agencies to fund and conduct research to improve the technology. Around the world, what little interest exists may wane given that fission Mo-99 is likely to continue to be freely available for some decades to come at least. That is no reason for current Australian research to be discontinued however. Even if fission Mo-99 is freely available, it would be preferable to develop alternative methods because of the various problems associated with reactor production of fission Mo-99. ANSTO and the two Australian cyclotron centres already have some involvement in this research, which could and should be continued. In addition, ANSTO has also been involved in gel generator research for l.s.a. Mo-99; this may enable generator manufacture using cyclotron-produced Mo-99 and possibly there is scope for further research in this area.

UNPROFITABLE RADIOISOTOPES

The most commonly used medical radioisotopes are produced in numerous reactors or accelerators around the world. On the other hand production and supply of low-volume, unprofitable radioisotopes, including research radioisotopes, tends to be erratic and precarious. This is most obvious in the US, where the subject is frequently debated in the professional literature, but it is certainly a more widespread problem. The existence or lack of domestic production facilities is one variable determining availability of unprofitable
radioisotopes. However as the US situation demonstrates, a more important variable is the willingness of governments (or nuclear agencies) to fund production of these radioisotopes. In the US and Australia, two options have been pursued. One is that production of these radioisotopes has been scaled down or in some cases stopped because of funding restraints. A second option has been cross subsidisation, with profits from commercial radioisotopes (e.g. Mo-99, iodine-131) being used to subsidise production of unprofitable radioisotopes. Thus ANSTO (1993D, p.2.29; 1993, p.4.40) claims that loss of profits from its Mo-99/Tc-99m generator business would impinge on the development of new products.

Cross-subsidisation is a precarious solution, depending as it does on continued profitability (or the illusion thereof) in other areas. A better solution is firstly to acknowledge that many radioisotopes simply cannot be produced at a profit, and to establish appropriate decision-making processes to decide which radioisotopes are important enough to warrant public-sector production or ear-marked subsidisation of private production. One option being floated in the US is a non-profit body, involving government, industry, researchers, and professional societies, which would decide which unprofitable radioisotopes are important enough to produce (Rojas-Burke, 1993C). A similar body could be established in Australia to decide which reactor radioisotopes are important enough to warrant publicly funded/subsidised importation. There should be no pretence of this being a commercial venture, though some cost recovery could occur through charges made to users. Rather, it would specifically be designed to address problems associated with limited production and supply of certain radioisotopes from commercial operations. Nor should this operation be jeopardised by cross-subsidy arrangements. As well as providing a mechanism for ongoing supply of unprofitable radioisotopes, such a collaborative body might go some small way to overcoming the cultural isolation that the Bain report (1994) claims exists at ANSTO and ARI and acts as a barrier to more effective collaboration with medical institutions.

RESEARCH

In terms of research into the clinical applications of radioisotopes, one issue follows directly from the issue of supply of unprofitable radioisotopes. Obviously radioisotopes which are in the experimental stages of their careers are unlikely to be money-spinners, though some find a niche in nuclear medicine and may then be produced on a commercial basis. ANSTO, particularly through its Biomedicine and Health Program, undertakes research into a range of radioisotopes and radioisotope applications. This could continue with a minimum of disruption in
the absence of a domestic reactor, so long as processes are in place for importation of unprofitable, research radioisotopes. As discussed previously, radioisotope half lives prohibit importation of very few radioisotopes.

As discussed in chapter 7.8, radioactive waste problems have given impetus to the search for chemical and biological alternatives to radioisotopes. This would be an appropriate line of research for ANSTO/ARI and other research organisations.

As for research into radioisotope production technologies, as discussed previously a good case can be made for ANSTO to pursue research into cyclotron production of Mo-99/Tc-99m. That could be coupled to a more general development of cyclotron technology and thus assist in shifting the balance away from reliance on reactors in Australia and elsewhere.

Similarly, a case can be made for ANSTO/ARI to pursue research into generator systems for which l.s.a. Mo-99 will suffice, whether the l.s.a. Mo-99 is produced in cyclotrons or reactors (including low to medium-flux reactors). That might be coupled to a more general pursuit of research into generator systems. ANSTO has undertaken some research into generator systems (e.g. Mo-99/Tc-99m generators, tungsten-188/rhenium-188, dysprosium-166/holmium-166). Generator systems enable the more widespread usage of short-lived radioisotopes, which is already important given the geographical spread of nuclear medicine around Australia and will be more important in the absence of a reactor. Regardless of Australian input into generator research, various types of generators could be imported, or manufactured in Australia from imported reactor radioisotopes or cyclotron radioisotopes. A further reason for involvement in generator research is that the generator systems attracting the most attention involve therapeutic and PET radioisotopes, two of the most promising fields of development within nuclear medicine.

OTHER ROLES FOR ANSTO/ARI

Berkhout (1993) suggests that ANSTO/ARI could look to Amersham as a model for its future in the absence of a reactor. There are some clear parallels, with Amersham having dealt with the closure of domestic reactors (in the UK), as ANSTO/ARI may do, and with Amersham having been privatised and ARI heading in that direction. On the strength of this, ANSTO/ARI can obviously learn from Amersham's experience. Moreover as mentioned there would be considerable potential for collaboration between Amersham and ANSTO/ARI in the absence of a domestic reactor. Beyond this, there would be limited potential for
ANSTO/ARI to become a major global radiopharmaceutical company, or even a major operator in the Asia Pacific, with or without a new reactor. Another limitation with the Amersham model is that Amersham is completely privatised. This may be of little consequence in some respects, such as supply of commercial radioisotopes. In other respects, such as procurement of low-demand research radioisotopes, privatisation of ARI will do nothing to address these issues.

Another model which ANSTO might pursue is the Japanese Radioisotope Association (JRIA). The JRIA is essentially a peak body, representing 6700 people involved in clinical nuclear medicine, research, radioisotope production and so on. Such organisations are commonplace but the JRIA is larger, better funded, and plays a more proactive and extensive role; it is as much a science agency as a peak body. It assists in the procurement and supply of radioisotopes and radiopharmaceuticals upon request from users. It operates hot cells and laboratories for radioisotope processing and research. And along with many other functions, it operates a cyclotron centre with PET facilities. (Japan Radioisotope Association, 1997, pers. comm.) An organisation similar to the JRIA would be appropriate for Australia. It could involve ANSTO/ARI and various medical institutions.

8.3. FUTURE RESEARCH INTO NUCLEAR MEDICINE AND THE RADIOISOTOPE INDUSTRY

INTRODUCTION
IATROGENESIS
OVERUSE
ALTERNATIVE MEDICAL TECHNOLOGIES

INTRODUCTION

There are a number of issues that have been overlooked or only briefly touched upon in the preceding chapters on nuclear medicine and the radioisotope industry, and some of these have received little if any attention in other literature on these topics. Nuclear medicine and the radioisotope industry can be considered as interorganisational structures operating in space cleared for and by the actors within the structures of political and economic systems. Within this framework, nuclear medicine and the radioisotope industry can usefully be considered at the intersection of two complex and multifaceted domains of social activity - nuclear programs and health-care systems. In this thesis I have emphasised the links with nuclear programs, because of the salience of the nuclear connections to the HIFAR
controversy. The place of nuclear medicine within health-care systems has received less attention.

Any number of issues might be explored concerning the place of nuclear medicine within health-care systems. One such issue is the class structuring of nuclear medicine. Mention was made in chapter five of the broad symbiosis between nuclear medicine and dominant class interests. At a practical level this has involved the sponsoring and support of nuclear medicine by a coalition of state, corporate, nuclear, media, and professional interests. At an ideological level nuclear medicine exemplifies the framing of health and medical issues under capitalism as individual problems amenable to technical fixes, thereby obscuring the social/political determinants of health and providing another market for commercial exploitation in the process. A class analysis might also take up the division of labour in nuclear medicine, drawing from analyses of the class dynamics of the division of medical labour (e.g. Willis, 1989), analyses which relate class, gender, and race/ethnicity to the practice of hospital medicine (e.g. Taussig, 1980), and class analyses of radiology (e.g. Brown, 1973; Larkin, 1983.)

Some useful research could be pursued in relation to the nuclear and military connections of nuclear medicine. As mentioned in chapter five a number of diagnostic imaging technologies, including nuclear medicine, developed as spin-offs from World War II military R&D. There were practical links, such as the refashioning of military technologies (e.g. radar) as medical technologies (e.g. ultrasound). In the case of nuclear medicine there was the practical link of patients being used as guinea-pigs for military-medical experiments in the US. There are also ideological connections, such as swords-to-ploughshares rhetoric. A more nebulous ideological link is the co-development in medicine and the military of the idea of propagating a signal to reveal characteristics of the system being analysed (Yoxen, 1987). More generally there is the issue of the use of military metaphors in medicine (Short, 1985; Sontag, 1977). All this might be related back to the class foundations of reductionist, mechanistic ideologies in medicine.

A number of the issues just mentioned could be developed in different directions. For example the work of Yoxen (1987) dove-tails with Foucault's analyses of the historical development of forms of control, surveillance, classification, normalisation, differentiation, exclusion and so on. In the medical domain, human subjectivity was subjugated as hospital medicine took shape, giving way to the "clinical gaze". Nuclear medicine is arguably at the cutting edge of this

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historical movement towards the objectification of the patient and the opening up of the human body to detailed scrutiny - it is for example the only imaging modality in which the radiation source is placed inside the body, and it is at the cutting edge of functional, molecular imaging.

The "clinical gaze" is but one aspect of a broader pattern of surveillance and control. In Foucault's (1980) terminology, "disciplines of the body" developed in tandem with "regulations of the population". Indeed medical diagnostic technologies have themselves become embroiled in broader patterns of control and regulation, increasingly being used by insurance companies, employers, courts, the military, and so on. The specific uses of diagnostic technologies in these settings vary, but often the aim is classification and, for some, exclusion. (Nelkin and Tancredi, 1989.) Nuclear medicine has largely remained confined within medical institutions, but there is a trend towards the greater use of nuclear medicine in other settings. The development of in vitro radioisotope tests is of particular importance in this regard – an example is the use of radioimmunoassay tests in drug use/abuse screening programs. (Nelkin and Tancredi, 1989.)

A good deal of useful research could be framed around a lower-level critical analysis of nuclear medicine, taking up issues such as iatrogenesis, overuse, and alternative medical technologies. Summaries of these issues follow.

IATROGENESIS

As with other issues relating to nuclear medicine, the question of iatrogenesis has been given little attention by nuclear critics or sociologists of medicine. There is however a considerable body of literature, and an ongoing public controversy, on the health effects of low-dose exposure (LDE) to ionising radiation. This relates to weapons tests, routine and accidental emissions from the nuclear fuel cycle, and sundry other sources of ionising radiation including medical radiation. In the critical literature on ionising medical radiation, the emphasis is on x-radiology (including CT), with little discussion on nuclear medicine. Nevertheless nuclear medicine iatrogenesis can easily be treated as a case study within the broader debates over ionising medical radiation and other sources of LDE.

Any effort to seriously analyse nuclear medicine iatrogenesis will immediately be confronted with a host of highly complex and contested technical debates.74 Given the complexity of the debates, it would be tempting to bracket the technical debates and use constructivist/symmetrical techniques focused on the politicking. Either

74 For overviews of the technical issues, see Puskin and Nelson, 1995; Gofman, 1990.
way, a serious attempt to tackle the most important questions, concerning the
nature and extent of nuclear medicine iatrogenesis, would necessitate a thorough
engagement with the technical debates.

The crucial technical debate concerns thresholds for iatrogenic radiation effects.
The argument commonly put by nuclear agencies, governments, radiation
protection bodies, radiologists and others, is that below a certain level, and/or
below a certain dose rate, LDE has zero health effects. ANSTO (n.d.), for example,
claims that the radiation dose received during diagnostic nuclear medicine
procedures is "medically insignificant". A milder argument is that low-level,
slow-dose radiation has negligible health effects which are far outweighed by the
positive benefits associated with nuclear power, the medical uses of radiation, etc.
(e.g. Perkins, 1995, p.82).

On the other side of this highly polarised debate are several dozen dissident
scientists. Some of these dissident scientists were once employed by nuclear
agencies, and some of them were ostracised, intimidated, sacked, and/or suffered
funding and staff cuts. Among the dissident scientists are some, such as Alice
Stewart and John Gofman, whose work has dealt partly or wholly with medical
radiation. The work of the dissident scientists is routinely picked up and used by
nuclear critics and opponents of modern, high-tech medicine. (Wasserman et al.,
1982; Gofman, 1990; Ratcliffe, 1996; Freeman, 1981, ch.4; Gould et al., 1991.)

Among the people and institutions whose work is focused on radiation research
and regulation, the most common view is that LDE can have negative health
effects; in other words there is no threshold below which tissue repair completely
ameliorates radiation damage. However in broader public debates, this view tends
to be given short thrift. For example ANSTO (1987) says that:

Radiation effects may appear following exposure to large amounts of
radiation ...... it would take a very large dose to kill sufficient numbers of
your cells to cause your death ...... typically several thousand times as large as
the radiation dose you receive normally each year from the environment.
Note also that to cause your death, you would need to be exposed more or
less in one hit, not spread out over a year. (Compare with sunlight: spread
out over a year it gives you a suntan, but in one day of sunbaking it could
cause your death by sunstroke.)

Those comments do not explicitly state that death cannot be caused by LDE, but
that is the implication.

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The figure given by organisations such as the International Commission on Radiological Protection is that the risk of fatal cancer is 0.05 per Sievert (joules/kilogram) of radiation exposure (González, 1994). Roebuck (1996), a radiologist writing in the *Medical Journal of Australia*, uses this 0.05 figure in compiling the following estimates of cancer deaths likely to result from some common imaging procedures in Australia:

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Estimated fatal cancers in Australia per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear bone scan</td>
<td>17</td>
</tr>
<tr>
<td>Nuclear thallium scan</td>
<td>26</td>
</tr>
<tr>
<td>Chest x-ray</td>
<td>6</td>
</tr>
<tr>
<td>Abdomen x-ray</td>
<td>16</td>
</tr>
<tr>
<td>Intravenous pyelogram</td>
<td>27</td>
</tr>
<tr>
<td>Lumbar spine x-ray</td>
<td>62</td>
</tr>
<tr>
<td>Barium enema</td>
<td>38</td>
</tr>
<tr>
<td>CT abdomen</td>
<td>36</td>
</tr>
<tr>
<td>CT pelvis</td>
<td>29</td>
</tr>
<tr>
<td>CT lumbar spine</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>272</strong></td>
</tr>
</tbody>
</table>

To put this in perspective, this is an estimated 272 deaths from 2.748 million procedures, a rate of about one death per 10,000 procedures (Roebuck, 1996).

A 1991 study on the use of diagnostic radiopharmaceuticals, carried out by researchers from the Australian Radiation Laboratory, arrived at a figure for annual collective dose of about 1110 person-Sieverts (Colmanet and Samuels, 1993). Using the figure of 0.05 cancer deaths per Sievert, Colmanet and Samuels arrive at the figure of 56 potential fatal cancers arising from diagnostic nuclear medicine in Australia in 1991. That was from a total of about 170,000 nuclear imaging procedures, giving a ratio of one cancer death per 3035 procedures. In 1995 the total was about 260,000 procedures (ANSTO, 1995H). Assuming the same average dose per procedure, and still using the figure of 0.05 cancer deaths per Sievert, this gives a total of 86 potential fatal cancers arising from diagnostic nuclear medicine in Australia in 1995.

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25 For follow-up Letters to the Editor critical of Roebuck's work, see Daunt (1996) and Surveyor (1996); see also the rejoinder by Roebuck (1996B). There is some consensus that the figure of 0.05 cancer deaths per Sievert is conservative: some (e.g. radiologists) think it is far too high; others (e.g. Gofman, 1990) think it grossly underestimates the risks of LDE.

26 Therapeutic nuclear medicine involves far higher radiation doses, with a total of 21,274 person-Sieverts from the estimated 2340 therapeutic procedures in Australia in 1991.
Colmanet and Samuels (1993) say that 56 cancer deaths represents about 0.1% of the estimated 60,000 cancer deaths in Australia each year, and conclude that diagnostic nuclear medicine contributes very little to the radiation burden of the Australian population. However as Roebuck (1996) argues, many patients are investigated without any evidence that the benefits outweigh the risks; some imaging tests carry a small risk and the potential benefits are great, but it is likely that many tests do not fall into that category and thus there are unnecessary cancer deaths (and other iatrogenic effects) from the practice of nuclear medicine. These debates tie in with the question of overuse of nuclear medicine, taken up below.

Variations in exposure to medical radiation arise from faulty or obsolete equipment, or inexperienced or incompetent operators. As a result of these problems with equipment and personnel, the radiation dose imparted by similar diagnostic procedures can vary by orders of magnitude (Dalton, 1991, pp. 9-10; Cuarón, 1994; Roebuck, 1996). In some cases the radiation dose is higher than necessary for simple economic reasons: increasing the administered dose of radioisotopes in nuclear medicine procedures can decrease examination time, thus increasing through-put of patients and increasing profits (International Commission on Radiological Protection, 1987, p.5).

Efforts to reduce exposure to medical radiation because of the iatrogenic effects have generally been sporadic and half-hearted. The Royal Australasian College of Radiologists (RACR), along with similar overseas organisations, has published some guidelines with discussion on the weaknesses of radiological tests, advice on when not to investigate at all, and some discussion of risks. However Roebuck (1996) says that such guidelines are probably widely ignored and that the current RACR guidelines for referring doctors do not adequately explain the magnitude of the risks of individual tests.

If the iatrogenic effects of ionising radiation become an important variable affecting the future of imaging modalities, this could act as a break on the growth of nuclear medicine, x-radiology, and CT, and possibly result in greater use of imaging modalities which do not use ionising radiation such as MRI and ultrasound.

OVERUSE

In many countries there are obvious economic incentives for overuse of nuclear medicine and other technologies. Generally the financial arrangements between third-party payers (insurance companies, government), hospitals (or private
clinics) and practitioners are important determinants of the frequency of use of medical technologies. These various groups may have conflicting interests - for example cutting down on tests may save money for third-party payers, but a hospital or private clinic with a fully equipped and staffed nuclear medicine unit profits from the performance of nuclear medicine procedures. Clearly there is an incentive for overservicing in these situations - as Patton (1993) notes in the journal *Seminars in Nuclear Medicine*, "The nuclear physician may be under tremendous pressure from his hospital or his partnership to do more procedures to make his service more cost-effective." Profit motivation for overuse of technologies is most striking in private practice where medical professionals or entrepreneurs purchase major pieces of equipment and have a financial stake in the use of that technology (Blume, 1992, p.8).

Alongside the economic incentives to overservice are various social or cultural incentives - the pressure on doctors to intervene in patient management regardless of the situation, a need to control the situation, a desire to discourage patients from seeking help elsewhere, scientific curiosity and research interests, and a desire among referring doctors and specialists to strengthen professional ties. (Patton, 1993.)

Over-estimation of the value of diagnostic technologies can also lead to overuse. According to Roebuck (1996), many alleged abnormalities reported by radiologists are of no clinical significance. These tests can be iatrogenic themselves, they may lead to further unnecessary investigation and treatment, and the high incidence of false positive reports gives referring doctors a false impression of the value of these tests and encourages more referrals.

Another factor at work is the rapid incremental innovation in medical imaging. As the state-of-the-art technology quickly changes, there is an incentive to overuse existing equipment before it becomes obsolete, thus recovering capital and operating costs which are generally very large for imaging modalities. (Wasserman et al., 1982, ch.6.)

Also leading to overuse or dubious use of diagnostic technologies are health insurance programs which sometimes require diagnostic imaging procedures to be carried out before reimbursing a patient for treatment. The threat of litigation also encourages the use of diagnostic technologies in excess of medical need. (Wasserman et al., 1982, ch.6.)
While many financial arrangements encourage overuse, this is not ubiquitous. In the UK for example, there is tighter regulation of medical technologies and a high proportion of salaried doctors and this minimises the economic incentives to overuse medical technologies. Efforts to cut health spending usually involve changes to the financial and organisational arrangements between patients, providers, and third-party payers, hence the development of diagnostic related groups (DRGs), health maintenance organisations (HMOs) and various other mechanisms. These systems have considerable potential to reduce overservicing; indeed some encourage underservicing.

ALTERNATIVE MEDICAL TECHNOLOGIES

Until the 1950s, x-radiology was the only medical imaging technology available. Then a number of other imaging technologies were developed from the 1960s - ultrasound, MRI, CT, and various others. The integration (or exclusion) of all these imaging modalities was tied in with a great deal of collusion and confrontation between radiologists, other branches of the medical profession, and other health occupations.

The various imaging modalities were not always in competition. In many cases new medical niches were carved which did not involve competition between alternative modalities. Another common occurrence has been the use of two or more procedures on the same patient. Ideally this can be a rational and efficient process - cheaper and safer modalities being used to screen patients, with some then undergoing further tests - though the ideal can be distorted by factors such as profiteering and inadequate technology evaluation. In short there was room enough in the house of medicine for a number of imaging technologies, and turf battles focused mostly on who would control the new modalities rather than whether they would be introduced at all. This situation has changed markedly over the past 10-20 years. Thus one commentator in The European Journal of Nuclear Medicine notes that "The future holds the potential for many unpleasant battles between competing imaging specialists as the need to obtain the maximum information in the minimum time and at the lowest cost intensifies." (Jacobson, 1994.) The main reason for the increasing competitiveness between the various modalities has been the attempts by governments and other third-party payers such as insurance companies to cut health spending.

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7 E.g. electron paramagnetic resonance, magnetic source imaging, infrared noninvasive scanning, electrical impedance tomography, microwave scanning, acoustothermometry, and magnetic resonance spectroscopy among others. Most of these have not been incorporated into routine medical practice.
A number of nuclear medicine procedures have been superseded by competing modalities over the years. The introduction of CT scanning in the 1980s adversely affected some areas of nuclear medicine such as brain and liver imaging, which comprised a significant proportion of all nuclear medicine studies. A number of less frequently used nuclear medicine procedures have also given way to alternative modalities, including studies of the haematologic, gastrointestinal, lymphatic, adrenal, and central nervous systems. Nuclear medicine has survived by finding different areas such as tests of the skeletal, urinary, and cardiovascular systems. (Carretta, 1993; Russell, 1979, p.83; ANSTO, 1993, p.4.14.)

Whether nuclear medicine holds its own in an increasingly competitive environment is very much an open question. Certainly there are imaging modalities with the potential to replace a number of nuclear medicine procedures. These include modalities with numerous clinical applications – ultrasound, CT, MRI, and x-radiology – and other modalities with more specific applications. Moreover the competition is not only between imaging modalities; for example there are many chemical and biological alternatives to radioisotopes for in vitro studies (Party and Gershey, 1995).

To secure a niche within medical practice, practitioners and proponents of nuclear medicine frequently claim that nuclear medicine is pre-eminent as a modality for functional imaging in the realms of physiology, biochemistry, and molecular biology. (ASTEC, 1985, p.1; Khafagi, 1993, pp.449-450; Cuarón, 1994.) The main reason for this pre-eminence is said to be that nuclear medicine, alone among imaging modalities, involves radiation sources (radioisotopes) within the body. By contrast, alternative imaging modalities are said to be of little or no use for studies of this nature. These arguments were accepted by the Research Reactor Review (1993, p.89):

> The evidence put to the Review on the future of diagnostic nuclear medicine was that it would not be supplanted by any other technology in the foreseeable future because of its unique ability to perform functional diagnosis.

There is some substance to the claims about nuclear medicine's superiority in functional imaging, but the claims are overstated. Nuclear medicine is not unique in terms of its ability to perform functional studies, nor is it immune to challenges in this field.
Function and anatomy cannot neatly be separated; that much is acknowledged in the medical literature (e.g. Kaufman et al., 1982). The distinction is particularly blurred at the micro level. Alternative modalities – including CT, ultrasound and MRI – provide superior fine anatomical detail in comparison with nuclear medicine images. (Perkins, 1995, p.78.) A 1993 report in The Journal of Nuclear Medicine said that nuclear imaging equipment companies were succeeding in portraying the advantages of functional nuclear imaging as a complement rather than an alternative to precise anatomical imaging (Anon., 1993F). Whether they continue to succeed in that endeavour is an open question.

It is conceivable that having been squeezed out of anatomical studies by alternative modalities, nuclear medicine may increasingly find its more recent niche as a functional imaging modality under threat as it already does to some extent.

The trajectory of MRI has been similar to that of PET, although it was introduced into clinical practice at a greater rate than PET through the 1970s and 1980s. In both cases, growth has been greatly limited by high costs, limited funds available for R&D, and the increasingly competitive environment surrounding imaging modalities. As with PET, a number of innovations have reduced costs and MRI may undergo a resurgence on the strength of these innovations. (Ogle, 1996.) During the developmental phase of MRI, there was considerable expectation that it would become the predominant functional imaging technology. That did not occur, largely because of technical limitations and limited funding, and MRI found a niche as an anatomical imaging modality. Nevertheless MRI has some applications in functional studies, such as in blood flow and metabolism studies and musculoskeletal pathology (Holman, 1994; AIH&W, 1993; Blume, 1992, p.219; Jacobson, 1994). In part the threat that MRI poses to nuclear medicine is because MRI generates "exquisitely detailed structural pictures" as Mallinckrodt (1996) puts it, and the structure/function dichotomy breaks down at that level.

Radiology is another modality encroaching into nuclear medicine's turf. According to a nuclear medicine professional, the axiom that radiology equals anatomy and nuclear medicine equals function is obsolete: radiology has historically been descriptive, non-quantitative, and structural, but that is changing "very fast" with functional radiology (Holman, 1994).

A host of other diagnostic technologies are or can be used for functional diagnostics. Ell (1992, p.68), a nuclear medicine professional, nominates the following technologies capable of providing localised biochemical information:
nuclear medicine (PET and SPECT), microwave technology, infrared imaging, electronic spin resonance imaging, and MRI spectroscopy. Other modalities provide functional information for specific organs or physiological systems, such as echocardiology and computerised electroencephalography (Nelkin and Tancredi, 1989, pp.31-32). Ultrasound poses no great threat to nuclear medicine but there are some areas of overlap where nuclear medicine is vulnerable (Jacobson, 1994).

Another important point in relation to functional diagnostics is that PET is the most advanced modality in this domain, and most PET radioisotopes are cyclotron produced (see ch.7.9).

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78 See also Godik and Gulyaev (1991) for discussion on a number of these techniques.
CHAPTER NINE: CONCLUSION

9.1. THE HIFAR CONTROVERSY AND BEYOND

9.2. RESEARCH REACTORS AND NUCLEAR MEDICINE: THE OTHER SIDE OF THE COIN?

9.3. IMPLICATIONS FOR SCIENCE AND TECHNOLOGY STUDIES

This concluding chapter begins with some comments on the HIFAR replacement controversy and the place of this thesis in the context of that controversy and similar disputes overseas. In section 9.2 I pull together a number of threads emerging from the thesis concerning the problems with research reactor programs and nuclear medicine, and I develop those arguments a little further. I finish, in section 9.3, with some comments on the implications of the thesis for STS scholarship.

9.1. THE HIFAR CONTROVERSY AND BEYOND

As discussed in chapter four, all indications are that the HIFAR replacement controversy will flare up in 1997, or 1998 at the latest. Furthermore it is likely that the government will make a decision one way or the other on the issue; the only alternative to a clear decision to proceed or not to proceed with a replacement reactor would be to approve an upgrading of HIFAR and to defer a decision on a new reactor. However that option has very little support from ANSTO or from anti-reactor campaigners, and it would still require a very large financial investment from the government.

At one level the HIFAR replacement controversy comprises a series of interwoven sub-debates – scientific and medical uses, financial costs and benefits, the "national interest", health effects of routine emissions, potential for serious accidents, siting, financial costs, and the list goes on. In light of this, a firm decision one way or the other by the federal government on the replacement of HIFAR would best be characterised as a nodal point in a controversy which promises to extend well beyond any such decision. A new reactor, if it is built, is likely to be the subject of public opposition for many or all of the same reasons that the continued operation of HIFAR attracts opposition. Conversely, a decision not to replace HIFAR would be unlikely to put an end to the efforts of ANSTO and others to secure government approval and funding for a new reactor.
Engelhardt and Caplan (1987, pp.11-12) offer a list of conditions which hinder closure of scientific controversies. The level of consensus or conflicting opinions among scientists is one variable. In the case of the replacement of HIFAR, a number of sub-debates have been contested by different scientists including cyclotron production of Mo-99/Tc-99m, the scientific performance of ANSTO, the safety of HIFAR, and so on. A second variable is the involvement of competing groups with different political philosophies and interests. Certainly the HIFAR replacement controversy has involved a plethora of groups with widely disparate interests and ideologies. A third variable is the level of public involvement, which can retard closure by increasing the range of competing interests and ideologies. Once again the HIFAR replacement controversy appears resistant to closure because of public concern and public involvement in the campaign against a new reactor. Another variable is that multifaceted controversies - such as the HIFAR replacement controversy - are resistant to closure.

It is worth briefly canvassing the five forms of controversy closure identified by Engelhardt and Caplan (1987, pp.8-16): sound argument closure; loss of interest; force/coercion; consensus; or negotiation.

The HIFAR replacement controversy appears to be resistant to most of these forms of closure. Sound argument closure is highly unlikely given the number and complexity of sub-debates and the range and polarity of competing interests and ideologies. (Notions of sound argument closure are problematic because they rest on positivist appeals to scientific method, but no more needs to be said on that point.) The contentiousness of the HIFAR replacement controversy precludes the possibility of closure through lack of interest. As for force/coercion, it is certainly possible and even likely that the federal government will make a decision on the issue, despite the opposition and antagonism that a decision either way is certain to bring with it; but as discussed such a decision would be more accurately described as a nodal point in an ongoing controversy rather than closure. As for closure by consensus, this is meant to describe shifts in controversies relating "nonepistemic influences that lead to a community of belief" such as religious conversion (Engelhardt and Caplan, 1987, p.14). More generally it can be considered as closure consequent upon the reframing of a debate or controversy by changes in external circumstances; thus it is different from sound argument closure or negotiated closure. It is difficult to imagine any such closure of the HIFAR replacement controversy. Developments beyond the immediate context of the HIFAR replacement controversy can easily reframe the debates. For example the pursuit of nuclear weapons programs in regional countries could strengthen the constituency for a new research reactor for purposes of national defence/
security, but even in that (unlikely) scenario the national defence/security sub-debate would remain contentious as would the HIFAR replacement controversy more generally. Another example is the emergence of several large radioisotope export ventures around the world in recent years: this significantly improves the prospects for radioisotope importation, but it falls a long way short of settling the sub-debate over future radioisotope production and supply let alone the HIFAR replacement controversy. The last form of closure is negotiation, or procedural closure, in which decision-making procedures are agreed upon and carried out to close a controversy even if opinions remain polarised. In some respects the federal government is bound by the 1974 Environmental Protection Act to put in place a decision-making process which at least has a facade of fairness, inclusiveness, and accountability. Whether the procedures are seen to be fair by all sides is another matter, and the outcome of such procedures may still only close the controversy partially and temporarily if at all.

Some comments should be made about the potential for my research to influence the outcome of the HIFAR replacement controversy. These comments are necessarily tentative and speculative since the controversy has been all but dormant throughout the period of research.

To the extent that my research into the radioisotope industry could influence the HIFAR replacement controversy, its dissemination is important in order to build a constituency for the sort of radioisotope supply scenario proposed. The research can be expected to be welcomed by anti-reactor campaigners (and assorted anti-nuclear groups) since it supports the case against a new reactor.

As for future public reviews into the HIFAR replacement controversy, the potential for intervention in that context will depend on the nature of such a review. On top of any contribution that I might make in that context, there is some scope to canvass for submissions in much the same way as ANSTO solicited a large number of submissions during the Research Reactor Review. Indeed I have pre-empted this by suggesting to a number of people and organisations that a government review is imminent and that a submission from their organisation might be useful and could possibly work to their advantage. Specifically, several overseas nuclear agencies involved in commercial radioisotope export could be solicited to provide submissions, thus strengthening the case for greater reliance on imports. Submissions could also be sought from the organisations involved in innovative research projects such as the Belgian Adonis project, liquid fuel reactors, and spallation sources. Submissions might also be sought to balance the overstated claims made about the value and uniqueness of nuclear medicine:
from proponents of alternative imaging modalities; from medical regulatory institutions concerned with overuse of medical technologies and imaging technologies in particular; and from people or institutions with a more critical perspective on the issue of the iatrogenic effects of medical radiation than can be expected from nuclear and medical institutions.

There is clearly some potential to mobilise networks to influence the resolution of a future public review. However it needs to be acknowledged that public reviews tend not to be even playing fields. They are biased in ways such as the terms of reference, the personnel appointed to conduct reviews, and so on. ANSTO and others supporting a new reactor have many advantages in terms of resources, established bodies of knowledge (e.g. the propaganda ANSTO circulates concerning the allegedly unique and highly important place of nuclear medicine), established constituencies (e.g. nuclear medicine professionals, neutron beam scientists), and so on.

As Blume (1992, p.256) notes, while there are typically conflicting interests within the interorganisational structure of medical imaging, these are secondary to the common aims, and strong defensive responses are typical when the common interests of the medical imaging community (or a sub-set of it) are challenged. A critique of the case for a new reactor for radioisotope production can be expected to meet with a more or less unified response from ANSTO and other key proponents of a new reactor including the nuclear medicine community. The splits within the nuclear medicine community might be played upon to some extent - for example by attempting to enrol the support of proponents of PET (which primarily uses cyclotron radioisotopes), and the same applies for broader splits between proponents of different imaging modalities. Nevertheless the response is likely to be overwhelmingly defensive of nuclear medicine.

These comments are speculative and perhaps a little hopeful: it may be that the advocacy of myself and others for radioisotope supply scenarios other than domestic reactor production is so overwhelmed by support for domestic reactor radioisotope production that alternative supply scenarios are largely ignored. Alternatively the HIFAR replacement controversy may be decided primarily on issues other than radioisotope production - ANSTO still promotes radioisotope production as one of the key benefits of reactor operation but there are other important sub-debates. Another possibility is that there is very little scope for public input into future decision-making processes. It is worth noting that the HIFAR replacement controversy is as much as battle of power as a battle of ideas: the 1992-93 campaign against a new reactor was as good a demonstration as any of
the need to mesh intellectual critique with a political campaign which aims to mobilise the broadest possible alliances and to put as much political pressure on decision-makers (e.g. review panels, governments) as possible.

The immediate aim of the thesis has been to produce work which will influence the HIFAR replacement controversy. In addition, I have been in contact with groups opposing a similar project in Germany - the HEU-fuelled FRM-II research reactor. Medical radioisotope production is one sub-debate within that controversy, though not as important as it is to the HIFAR controversy. One correspondent says that a similar debate is likely to develop over the replacement of the 10 MW Austrian research reactor at Siebersdorf in the near future. There will be other proposals to build new research reactors around the world in coming years. Indeed there may be a considerable number of such proposals as the numerous reactors built in the 1950s and 1960s reach the end of their working lives in the coming decades. Possibly my research may be of some small consequence in those debates overseas, though that is speculation; all I have been able to do is to establish some contacts overseas, to mutual advantage, and to send copies of my research when requested. It should be noted that a fair proportion of my research into the radioisotope industry will date quickly, for example the empirical information on reactor radioisotope production around the world and the information on innovative radioisotope production techniques.

Other aspects of the thesis will not date nearly so quickly, and have potential uses beyond controversies over research reactor operations. These include the unfolding history of nuclear development in Australia, and the interconnections between civil and military nuclear programs.
9.2 RESEARCH REACTORS & NUCLEAR MEDICINE: THE OTHER SIDE OF THE COIN?

Although radionuclides were used in medicine before World War II, a variety of them only became widely available for medical purposes later, when newly built reactors started producing radionuclides in adequate quantities. In a way, it can be said that the medical profession was introduced to the monstrosity of atomic energy first and then only gradually realized the mitigating medical benefits of the monster. The primal driving force in nuclear medicine development was not its impact on health care, but a desire to look for more and more that could be done with atomic energy - for as many tales of good deeds as possible, as if looking for that elusive other side of the coin.

Ganatra and Nofal (1986)
International Atomic Energy Agency

In this section I will tie together a set of arguments concerning the problematic aspects of research reactor programs and nuclear medicine, with emphasis on the interconnections between civil and military nuclear development. I begin by discussing the problematic aspects of research reactor programs and nuclear medicine. Then it is argued that public opinions towards aspects of research reactor programs, most notably radioisotope production and "research" (however conceived), are generally positive, and that nuclear critics and critics of modern medicine have also tended to spare these aspects of research reactor programs from critical analysis. I suggest some reasons for the generous estimations of research reactor programs. Lastly, I consider the implications that might follow from a more critical perspective.

To begin I will summarise a number of arguments in relation to research reactors and nuclear medicine.

The operation of research reactors entails the same range of problems as power reactors, though generally on a smaller scale. One such problem is the potential for serious accidents - and the reality of serious reactor accidents in roughly a dozen cases over the years.

Next are the unresolved debates over the health effects and environmental impact of routine radioactive emissions from research reactors. Whatever might be said about the technical debates, the management of these issues by nuclear and
political institutions has all too often amounted to an unsatisfactory politics of denial and public pacification. In its crudest form this amounts to a narrowing and reframing of the issue as one concerning the psychology of those concerned about radioactive reactor emissions (Wasserman et al., 1982, ch.14).

Next are the possibilities for sabotage or terrorist attacks, such as the various incidents involving the AAEC/ANSTO - the discovery of gelignite and detonators inside the boundary fence, the threat to fly an aircraft packed with explosives into HIFAR, and so on. A more serious example is the bombing of Iraqi research reactors by Iran, Israel, and the US.

Next are the manifold interconnections between research reactor programs and nuclear power and nuclear weapons. Research reactors are widely and openly used in support of nuclear power. While a very large majority of research reactors have not been used directly or indirectly in support of weapons programs, some have and all research reactors lower the technical barriers, to a greater or lesser extent, to weapons development. Nor can technical fixes (e.g. the RERTR program) or regulatory tightening (e.g. of the IAEA/NPT regime) guarantee that there will not be further instances of research reactors being used in support of weapons development.

The links between research reactors and power and weapons programs can be broadened to consider the place of research reactors within the scope of nuclear fuel cycle activities, including front-end technologies (esp. uranium mining and enrichment) and back-end technologies (reprocessing, waste storage and disposal). These technologies are contentious for a number of reasons, not least weapons proliferation, and research reactors provide some justification for developments across the nuclear fuel cycle. In particular the radioactive waste problems associated with research reactors raise a host of issues concerning public and occupational health and safety, environmental impact, weapons proliferation, and the vexed question of long-term waste disposal.

Underlying many of the specific problems with research reactor programs are questions about public accountability, the adequacy of regulatory regimes, the bureaucratisation and militarisation of science, the legitimacy of state authority, and so on.

Now to summarise the contentious aspects of nuclear medicine, with emphasis on the symbiosis between nuclear medicine, the radioisotope industry, and nuclear development more generally. Nuclear medicine and reactor radioisotope
production are held in high public regard (as discussed below). Thus nuclear medicine and radioisotope production play an important role as ideological props for research reactor programs. In that general sense nuclear medicine and the radioisotope industry are linked to the manifold problems associated with research reactors discussed above: medical radioisotope production is both an important component of and ideological justification for research reactor programs and, to a lesser extent, nuclear development more generally.

In addition, radioisotope production and processing generate significant radioactive emissions and wastes.

In addition, there are some more-or-less direct links between radioisotope production and weapons proliferation. The production of high specific activity radioisotopes is one reason for the (continued) use of HEU fuel, and HEU targets, with weapons proliferation implications. There are also some examples of radioisotope processing facilities - hot cells - being used for plutonium separation in support of weapons development. And there is overlap in the enrichment of uranium and the enrichment of isotopes used as feedstock for radioisotope production.

Apart from the link provided by the radioisotope industry, nuclear medicine is symbiotic with nuclear development in other ways. Thus nuclear agencies promote the idea that medical radiation is benign or at least trivial in comparison with the medical benefits. Medical personnel and institutions, for their part, share that opinion and often go further, supporting numerous other aspects of nuclear development. For obvious reasons nuclear medicine practitioners and institutions are habitual and strong supporters of research reactor projects involving radioisotope production. Often the support of nuclear development goes further - at the far end of the spectrum are medical personnel stridently attacking nuclear critics and voicing their support for everything from nuclear power to the bombing of Hiroshima and Nagasaki. Also at the far end of the spectrum, but indicative of a broader symbiosis, was the series of radioisotope experiments carried out in the US involving such things as injections of plutonium into patients on behalf of nuclear and military institutions. This was "Not Nuclear Medicine", as Miller (1994B) put it in The Journal of Nuclear Medicine, but nuclear medicine provided a fig-leaf of pseudo-medical justification for those experiments along with practical assistance.

In addition, nuclear medicine raises questions which have little or nothing to do with its connections to nuclear development, but reflect the contradictory
elements of medicine under capitalism. As with most other aspects of contemporary modern medicine, nuclear medicine sets health problems in an individualist framework amenable to technical fixes which both obscure the social/political determinants of health and provide another market for commercial exploitation in the process. Overuse and iatrogenesis are related debates.

Enough has been said on the objectionable or questionable aspects of research reactor programs and nuclear medicine. Here I take this issue further, first by considering the level of public opposition to, or concern about, research reactors programs (esp. radioisotope production and research) and nuclear medicine.

As discussed in chapter 7.7, opposition to research reactors appears to have become increasingly common over the years. The issues taken up include cost, weapons proliferation concerns, public and environmental safety, and the adequacy of regulatory regimes. However it is difficult to make any generalisations about the overall level of opposition to research reactors. Certainly nuclear weapons and power programs generate far more opposition.

As for public attitudes towards nuclear medicine, it is clear enough that nuclear medicine has a very positive public image, with only modest levels of concern which generally stem from broader debates about the iatrogenic effects of ionising radiation. Indicative of the level of public support was the study commissioned by the Research Reactor Review which found that medical radioisotope applications generated the most positive reactions from respondents when compared to other aspects of ANSTO's activities (Roy Morgan Research, 1993).

Nuclear critics rarely incorporate a critique of nuclear medicine into their propagandising and campaigning around nuclear issues. For example Adamson (1981, p.90), in the context of a critique of nuclear power, asserts, without substantiation, that the production of radioactive isotopes for medical purposes serves a "proven need". Another example is provided by Suter (1985), an advocate of nuclear free zones. Suter notes that many nuclear free zones have specific exclusions for medical radioisotopes, (non-military) research and the industrial usage of radioisotopes, and that hospitals and research institutions practising nuclear medicine are completely unaffected by the establishment of nuclear free zones. Another example comes from the Independent Committee of Inquiry into the Nuclear Weapons and Other Consequences of Australian Uranium (1984, pp.xii-xiii), which argued that the IAEA should be split in two; one arm would deal with safeguards, the other with promotion of the "truly beneficial uses of
nuclear energy in medicine and research". (As Froggatt (1991) notes, splitting nuclear agencies into separate promotional and regulatory agencies has had little positive effect in the countries where it has occurred, but that is beside the point here.) Many more examples could be provided to demonstrate that nuclear medicine is generally spared from critique by nuclear critics.

While it is common for nuclear critics to spare nuclear medicine from critique, there are exceptions. For example several submissions to the Research Reactor Review made some critical comments about nuclear medicine, though generally in the nature of assertion rather than sustained argument. These comments referred to iatrogenesis, overuse of nuclear medicine, arguments that more effort should be directed to illness prevention and health promotion, and making the link between medical radioisotope production and radioactive waste problems (e.g. Matson, 1993). Wallace (1993), who worked for the Sutherland Shire Council in the campaign against a new reactor, said that "Opponents of a reactor do not dispute the current importance of radioisotopes as a diagnostic tool in medicine, but they have questioned the extravagant claims and simplistic statements ANSTO have made on this issue." The Lucas Heights Study Group (1993) noted the propaganda value of ANSTO's involvement in medical radioisotope production:

\[\text{AAEC and ANSTO have always battled to maintain a reason for existence. They seized on medical isotopes production because of public acceptance and an improved image and their usefulness. Still today they promote it as their main activity.}\]

Many nuclear critics advocate cyclotron radioisotope production as an alternative to reactors, though again this generally assumes the value of nuclear medicine. The Australian Conservation Foundation (1993) went a little further in its submission to the Research Reactor Review, calling for alternatives to be developed to radioactive medical products, but had nothing more to say on the topic.

It is also notable that academics and activists opposed to aspects of modern medicine seem to have largely spared nuclear medicine from critical analysis. As noted in chapter five, there is hardly any sociological literature on nuclear medicine and the radioisotope industry, and the literature that exists is generally bland. Of particular interest is the issue of the health effects of radiation. That radiation associated with nuclear weapons and nuclear power has generated more
public controversy than medical radiation is generally true. Thus Wright (1988, p.18), a doctor writing in the (liberal) medical journal New Doctor, says that:

(Ionizing radiation) causes horror when it comes from atom-bomb testing and nuclear power stations and irrational indifference when it comes from diagnostic radiology, particularly because the vast bulk of ionizing radiation received by patients and populations comes from this source.

However there has in fact been considerable public debate about the health effects of medical radiation. The work of a number of dissident scientists is important in this regard (see chapter 8.3). Moreover there has been organised public opposition. In the UK for example, there is a campaigning group called RAGE, 800 strong, comprised primarily of people who have suffered ill-health as a result of medical radiation iatrogenesis. This group campaigns around a range of issues associated with what it calls the "radiation road-show". Its emphasis is on the effects of x-rays whether in the form of radiotherapy, diagnostic x-radiology, or CT scans.

Now to consider why it is that nuclear medicine - and to some extent other aspects of research reactor programs - are held in high public regard and have not been subjected to sustained critique even by nuclear or medical critics.

As a starting point, the high public opinion of nuclear medicine could be treated from a positivist perspective. Proponents of nuclear medicine would see positive public opinions as an unproblematic reflection of the value of nuclear medicine - "saves lives, saves money". Remaining in this positivist framework, a factual challenge to this perspective could be advanced, confronting the positive opinions of nuclear medicine with the more critical evidence presented in this thesis. Either way, the positive opinions associated with nuclear medicine require further consideration.

Leaving the technical issues to one side, the propagandising by nuclear and medical institutions is an important variable. Propagandising about the benefits of nuclear development became increasingly important as concerns and anti-nuclear campaigns grew from the 1960s and coalesced into mass movements in the following decades. This propagandising has been more or less successful depending on the issue. In relation to nuclear medicine it appears to have been particularly successful. In the process, public opinions towards nuclear development more generally are shored up, as is the ideological divide between military and peaceful nuclear programs.

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29 ABC Television, "Four Corners", 20 May 1996.
Clearly propagandising about nuclear medicine provides some ideological legitimacy for nuclear development. So too there is a dialectic between propagandising about the value of nuclear medicine, and the broader rhetorics of medical benevolence and medical-scientific progress.

Positive public opinions about nuclear medicine can be largely explained by the factors just mentioned, but the uncritical perspective of nuclear critics is more puzzling. The propagandising of nuclear and medical personnel and institutions, and the rhetorics of medical benevolence and medical-scientific progress, offer a partial explanation. In addition, anti-nuclear groups typically focus on the big-ticket items of nuclear development, in particular power and weapons; there is less critical analysis of nuclear medicine or of research reactor programs more generally. The emphasis on big-ticket nuclear items is understandable and justifiable given the relative scale of the problems. The lack of critical analysis of nuclear medicine, and research reactor programs more generally, can also be seen as a reflection of relative lack of resources of nuclear critics in comparison with nuclear proponents. Thus it is common enough for nuclear critics to raise doubts about nuclear medicine - such as those voiced during the Research Reactor Review - but sustained critiques are rare.

Nuclear medicine is bound up in debates over the iatrogenic effects of ionising radiation. However nuclear medicine seems to be in the background of such debates, with most concern focused on the medical uses of x-rays. Some mundane explanations might be given. Therapeutic uses of radiation have the potential to cause considerably greater, and more visible and immediate, iatrogenesis than the smaller radiation doses associated with diagnostic technologies including nuclear medicine. Thus the UK group RAGE is more concerned about radiotherapy than diagnostic uses of radiation. Diagnostic procedures generally involve far smaller radiation doses, and the iatrogenic effects, if any, can be delayed by years or decades thus making the question of causal attribution far more complicated and contestable. Yet nuclear medicine also seems to be in the background of debates over the iatrogenic effects of diagnostic imaging, with more attention given to modalities such as x-rays, CT, and (foetal) ultrasound. One reason for the focus on other modalities is that nuclear medicine accounts for only a small fraction - 5-10% - of diagnostic imaging procedures. By contrast x-ray procedures account for about 80-90% of all medical radiation procedures and thus it is no surprise that x-ray therapy and diagnosis predominates in debates over radiation iatrogenesis.
The reasons suggested above go some way to explaining positive opinions about nuclear medicine and other aspects of research reactor programs. Nevertheless these opinions remain somewhat contradictory given the growing ambivalence or opposition towards nuclear development and modern medicine over the past generation, particularly when considering active opponents. To the extent that there is organised opposition to nuclear development and modern medicine, and broader public ambivalence to both, it is likely that there is some fertile, receptive ground for critiques of nuclear medicine and research reactor programs.

Now to briefly consider nuclear research. It is not just medicine that is shrouded and mystified by ideologies of scientific/medical expertise and progress and seen to be largely immune from critique. "Research", however conceived, is also held to be largely beyond challenge. Indeed it is common enough for nuclear critics to consider research and nuclear medicine to be the two - and the only two - beneficial aspects of research reactor programs, hence the Independent Committee's (1984, pp.xii-xiii) support of the "truly beneficial uses of nuclear energy in medicine and research".

Now to open, though only very briefly, this black box of nuclear research. Some aspects of nuclear research - in particular research in direct support of nuclear weapons - are highly contentious. At the other end of the spectrum is research which is so benign, and potentially socially useful, that it can be supported with few if any qualifications - for example some nuclear medicine research. Much nuclear research falls in between these two extremes. For example a great deal of the research carried out at the AAEC/ANSTO has been in support of the uranium mining industry. Even research carried out to minimise the environmental or social impact of uranium mining is tainted by the fact that it is in support of an industry which brings with it major social problems - such as the overwhelmingly negative impact of the industry on Aborigines, and the proliferation implications - which could never be resolved with technical fixes. Another example is the research which has been carried out by the AAEC/ANSTO to improve the technologies associated with safeguards against weapons proliferation. Such technical fixes may make some improvements to the safeguards regime, but once again the research is in search of technical fixes to proliferation concerns which are as much political as technical. Another issue is environmental research. Much has been made by nuclear proponents of the potential for nuclear research to address environmental problems. For example in their submission to the Research Reactor Review, Blank and Kearley (1993) argued that:
several environmental ideals, such as the development of biodegradable and recyclable plastics, depend critically on knowledge that comes from neutron-scattering experiments. Similarly, the development of metal hydride high power batteries, and hydrogen storage materials, for powering pollution-free vehicles requires an understanding of hydrogen atom location and motion which it is difficult to obtain without neutron scattering.

Research into the development of such things as pollution-free vehicles is certainly to be supported but once again it raises issues about the search for technical fixes to problems which are as much political as technological.

To sum up the arguments so far. There are numerous examples of public campaigns against research reactors, more so than in the first decades of nuclear development, but it is difficult to say anything more than this about the amount of opposition. The situation is a little clearer in relation to nuclear medicine: it has a positive public image, indeed an unduly positive image given the manifold problems associated with the practice of nuclear medicine and its connections to more contentious aspects of nuclear development. Moreover nuclear critics, and academics and activists opposed to aspects of modern medicine, have largely spared nuclear medicine from critique. Similarly, the black box of nuclear research tends not to be opened to critical analysis, and seems to be held in positive regard despite the problems and ambiguities noted above.

Do the manifold links between research reactor programs and nuclear power and weapons, along with the various other problems associated with research reactor programs, warrant their cessation? I have several comments to make in response to this question, none of which provides an unequivocal answer.

Advocacy of a reduction or cessation of research reactor programs needs to take into account the realpolitik of public support for such programs and the capacity of nuclear, medical, and research institutions to cultivate such support and to mount a strong and united defence against critics. To give the most obvious example, anti-nuclear protest actions which interfered with any aspect of medical radioisotope production and the practice of nuclear medicine could be highly counter-productive in terms of building and broadening public support.

An overall assessment of research reactor programs, and particular aspects thereof, must be made: cataloguing the problems, as I have done in this section, will not suffice. In broad terms, it is clear enough that the outcomes of such assessments would be ambiguous: research reactor programs involve a mixture of socially-
useful projects along with more contentious projects and social and environ­
mental problems. At another level there are winners and losers, notwithstanding
efforts to obscure this with universalistic appeals such as those made to the
"national interest".

To argue on the basis of such assessments that all nuclear technologies should be
abandoned would amount to nuclear Luddism. Such arguments were not
advanced by nuclear critics during the Research Reactor Review. A number of
critical submissions to the Review, such as those from the Sutherland Shire
Council (1993) and Friends of the Earth (1993B), argued that a large majority of
ANSTO's research, medical, and commercial projects would not be greatly effected
by the absence of a research reactor, and could and should continue.

I would argue the same position but with some qualifications. There needs to be
much closer scrutiny of the various research and commercial activities including
medical radioisotope production. Nuclear programs have been mystified by their
association with medicine and "research" (in particular environmental and
medical research) and nuclear critics need to adopt a more critical approach, to
open these black boxes to critical scrutiny. This is easier said than done. There has
been little critical scrutiny of these issues and much remains to be done. Moreover
the issues are generally complex, and as always nuclear proponents have the
advantage in terms of expertise, resources and other forms of state support, and
the ability to manipulate and restrict the flow of information. I go some way to
subjecting medical radioisotope production and nuclear medicine to critical
scrutiny in this thesis, but much work remains to be done on those topics and I
have had little to say on other aspects of research reactor programs.

A crucial component of assessments of research reactor programs is assessment of
alternative technologies. Thus in this thesis I have considered various means of
producing radioisotopes (cyclotrons, spallation sources, liquid fuel reactors), all of
which offer at least some advantages over research reactors. I have considered the
potential for cyclotron radioisotopes (e.g. iodine-123, FDG) to replace reactor
radioisotopes (esp. Mo-99/Tc-99m). I have discussed alternative imaging
modalities - in particular CT, MRI, x-radiology, and ultrasound. I mentioned in
passing the efforts of some researchers, motivated by radioactive waste problems,
to find chemical and biological alternatives to research radioisotopes and to
replace longer-lived radioisotopes with shorter-lived radioisotopes. Overall I
proposed a scenario for future radioisotope supply for Australia which involves
importation of reactor radioisotopes for the next generation at least, but which

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also involves research projects which could potentially break the nexus between research reactors and nuclear medicine in the longer term.

Similar assessments could be made of other aspects of research reactor programs. For example there is scope for useful research into the relative merits of research reactors, spallation sources, and particle accelerators for various purposes such as research and commercial activities.

Of course it is one thing for nuclear critics to assess alternatives to research reactor programs, and to advocate such alternatives where appropriate, but to realise such alternatives is more difficult. The forces and interests shaping nuclear development embrace numerous branches of the state, corporate interests, medical and scientific professional interests, and so on. Despite the scale and militancy sometimes apparent in anti-nuclear movements, they have on the whole only modestly retarded or redirected nuclear development and have had even less success in reshaping the social structures which give rise to nuclear development. Suffice it here to note that critical analysis of research reactor programs *vis a vis* alternative technologies is a useful exercise but by no means a panacea; ultimately the future direction of nuclear development is as much a power struggle as a battle of ideas.

Another complex issue is that advocacy of alternative technologies where appropriate, combined with support for the continuation of research reactor projects where they are socially useful and relatively environmentally benign, and alternatives are under-developed or non-existent, inevitably faces the problem that nuclear programs, from weapons to medical radioisotopes to termite eradication, are bound up with each other in so many ways. As Phillip Baxter (1968) noted:

*Almost every action, every piece of research, technological development or industrial activity carried out in peaceful uses of atomic energy could also be looked upon as a step in the ‘manufacture’ of nuclear weapons. There is such a large overlap in the military and peaceful uses in these areas that they are virtually one.*

The overlap between uranium enrichment and isotope enrichment provides a good example. Should the AAEC have been allowed to pursue work into isotope enrichment, in particular molybdenum isotope separation, once the centrifuge uranium enrichment program was terminated in the mid 1980s? At best, that
research could have improved molybdenum isotope separation and molybdenum target technology, enabling far more widespread reactor production of Mo-99/Tc-99m without the need for high-flux reactors (which often use HEU fuels) or HEU targets. Better still, that research could have improved the prospects for commercial-scale cyclotron production of Mo-99/Tc-99 using enriched molybdenum targets. On the other hand, pursuit of non-uranium enrichment R&D would have entailed the maintenance and further development of enrichment facilities and expertise, which might very easily have been used to restart uranium enrichment R&D at a later date – indeed one reason molybdenum separation research was carried out at the AAEC in the 1970s was the expectation that it would throw further light on the uranium enrichment research (Hardy, 1996, p.84).

To advocate continuation of some but not all aspects of nuclear development is clearly problematic, as is the Luddite position of discontinuation of all nuclear development. There is no simple answer to this dilemma, but the issue can be advanced a little further by reframing it as a political issue rather than a narrowly technical issue concerning the merits of specific aspects of research reactor programs: clearly the interconnections between research reactor programs and other aspects of nuclear development are as much political and institutional as technical.

A useful parallel can be drawn with an analysis of the US bases in Australia. Noting that the arguments as to whether the bases encourage or discourage nuclear war and weapons proliferation are very complex at a technical level, Hayes et al. (1986, pp.409-421) reframe the question in political terms. One option – the "willing accomplice" – is to maintain the bases and the US alliance in general in the hope of being able to influence the US and thus reduce the possibility of nuclear war. However there is little evidence to suggest that minor allies such as Australia can influence the US in such a way. A second approach – the "honest broker" – is to use the bases as bargaining chips. For example an ultimatum could be given: the bases will be closed unless a commitment to complete nuclear disarmament is made and seriously pursued. A third approach – "going it alone" – would be to close the bases and terminate (at least some) other aspects of the alliance such as visits by US nuclear warships. In fact as Hayes et al. argue, this approach need not be isolationist – it could be linked to efforts to demilitarise relations with Pacific states, adjusting military posture to a strictly territorial defensive posture, and so on. Thus Australia's anti-nuclear and anti-war credibility would rise, presenting a more potent political challenge to the nuclear arms race.
Much of Australia's involvement in nuclear programs involves other countries, and as with the US bases the general philosophy is the "willing accomplice" approach - involvement in nuclear projects and industries is justified on the grounds that international nuclear development can be made safer and less likely to follow a military rather than a civil path through Australia's involvement. Australia's national interests can be advanced through the acquisition of information and intelligence, commercial gains can be made, and so on. Such arguments are deployed in support of a host of nuclear projects including uranium mining and export, the numerous bilateral and regional technical assistance projects in which the AAEC/ANSTO has been (and still is) involved, Australia's role in forums such as the IAEA, and hosting the US bases and visits by US warships. As discussed in chapter four, many of these arguments are overinflated, and sometimes circular and contradictory.

A case can be made for reframing Australia's general approach to nuclear development. The "honest broker" approach is not greatly relevant - perhaps only the US bases are bargaining chips of importance. Following Hayes et al. (1986), a stronger approach would be to scale back nuclear activities and redirect international relations along a non-nuclear path. Support of US nuclear militarism could be stopped. Uranium mining and export could be stopped. Technical assistance projects could be redirected - greater support for basic health care as opposed to nuclear medicine, greater support for renewable energy sources instead of nuclear power programs, greater support for cyclotrons and less for research reactor programs, and so on.

Reframing the issues in political rather than technical terms does not resolve the dilemma as to whether nuclear programs should be completely abandoned or whether the most socially beneficial and environmentally benign projects should continue even if they have something of a Trojan horse character about them. Nevertheless the reframing of the issue in political rather than technical terms lends support to the view that nuclear development should at least be scaled back. Moreover the case for operating a research reactor in support of Australia's manifold nuclear activities abroad - already a shaky argument - would be weaker still.
9.3. IMPLICATIONS FOR SCIENCE AND TECHNOLOGY STUDIES

This final section reflects on some theoretical and methodological issues which were introduced in chapter one and have framed the thesis - integrated models for STS analysis, fourth-generation STS/SSK, and social problem centred research.

In chapter one mention was made of a number of integrated models proposed and/or deployed by STS academics in recent years. The main advantage of integrated models is that they can encompass structural analysis of science and technology without losing what is of value in lower-level constructivist approaches such as actor network analysis. Thus Giere (1993) proposes analysis of technological artifacts in their scientific-technological context; an understanding of relevant psychological or cognitive features of various actors; an understanding of relevant microsocial interactions; and fourthly, an understanding of various macrosocial interactions, including cultural and economic interactions. Mercer's (1993) "eclectic" approach to controversy analysis draws from controversy-as-politics, technocratic politics, fact-value approaches, historico-narrative approaches, controversy closure studies, and SSK. And Martin and Richards (1995) bring together structural, group politics, SSK/constructivist, and technical analysis.

No effort was made to map out the different levels to be used in this thesis; to do so would have risked schematically prefiguring the analysis, and in any case the scope of the thesis was too broad to be neatly mapped out. Instead, it was proposed that the analyses of the various topics taken up throughout the thesis would take account of i) the specific features of the system/technology/debate under discussion, ii) the aims of the discussion and its place within the thesis as a whole, iii) the variety of approaches and levels of analysis that could be deployed, and iv) the approaches to generic STS/SSK issues (reflexivity, symmetry, partisanship/impartiality, and epistemology) most suitable for a fourth generation of (politically-relevant) STS/SSK.

Now to briefly reflect on the different levels of analysis used throughout the thesis. At the broadest level the analysis of nuclear power, weapons, and research programs in chapters 2-4 operated primarily at a structural level of analysis, whereas the analysis of the radioisotope industry and nuclear medicine in chapters 5-8 was more eclectic and more concerned with technical detail.
The analysis of global nuclear development in chapter two operated primarily at a structural level of analysis. The development of nuclear power in the capitalist countries was seen to be broadly commensurate with post World War II capitalist development, reflecting trends such as those towards centralised production and the fusion of state and private capital; nuclear power was expected to be an important industry in itself and it was expected to facilitate industrial development (and capital accumulation) through the generation of cheap electricity. The combined impact of factors such as economic stagnation, technical problems and inflexibility, and public opposition was seen to have precipitated the problems facing the nuclear power industry in the past 20 years or so.

Similarly the analysis of nuclear weapons emphasised broad social structural forces. It was beyond the scope of the thesis to systematically analyse the interconnections between nuclear weapons and post World War II international politicking, but some attention was paid to the formation and reformation of regional and global alliances and antagonisms, the connections between civil and military nuclear development, the implications for weapons proliferation of economic stagnation and competition for commercial export markets, and so on.

The case of nuclear weapons can be used to briefly canvass some lower-level STS approaches that might have been adopted. A constructivist, group politics analysis of nuclear weapons, focused for example on the influence of the armaments industry, could not adequately explain current trends in nuclear armament/disarmament or the potential for further nuclear weapons proliferation; it would suffer the familiar limitations of liberal pluralism, empiricism, and functionalism. MacKenzie’s (1990) analysis of the development of nuclear missile guidance systems, and the impact of this on the Cold War nuclear arms race, is a well-known illustration of the value of SSK/constructivist approaches as applied to nuclear weapons. Yet MacKenzie’s analysis works at many levels - it has elements of actor network and group politics approaches (addressing for example the role of weapons developers and the importance of inter-service rivalries), it is influenced by the themes of the strong program (e.g. social interests, social shaping), it draws from other STS/SSK perspectives such as the sociotechnical systems work of Hughes (e.g. Hughes, 1987), and it is alert to the broad historical structuring of the Cold War nuclear arms race. MacKenzie’s analysis is more an indication of the value of integrated, multi-level analyses than an advertisement for SSK/constructivism.

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80 See for example the analysis by E.P. Thompson (1982), in which the "inertial thrust" of the military-industrial complex is considered crucial, and the critique of this approach by the Midnight Notes Collective (1984).
The analysis of nuclear development in Australia in chapters 3-4 also paid some attention to the broad features of political development in Australia – the pursuit of nuclear power in the hope of stimulating industrial development, the industrial and technological weakness of Australia vis à vis the UK and the US, the recurring theme of defence/security concerns (especially relating to Australia's location in the Asian region), and so on. The analysis of Australia's nuclear history can be seen to have operated at a number of levels, combining structural analysis with ANA approaches (e.g. Phillip Baxter as a heterogenous engineer), SCOT (numerous conflicts over nuclear projects), the strong program (social shaping, social interests), and so on. The history of the AAEC/ANSTO was considered in some detail, and that history along with other threads of Australia's nuclear history were seen to come together in the Research Reactor Review. It was argued that technical/positivist or SSK/constructivist analyses of the Research Reactor Review potentially had much to offer, but that further insights could be derived from the more structural, historical approach adopted in this thesis.

Whereas the analysis of nuclear programs in chapters 2-4 operated primarily at the structural level, the analysis of nuclear medicine and the radioisotopes industry in chapters 5-8 was more eclectic. There was however some order in the eclecticism: the issue of future radioisotope production and supply in Australia underpinned the entire analysis.

As for the social structuring of nuclear medicine and the radioisotope industry, they were considered to lie at the intersection of the two broad sociotechnical systems of nuclear programs and health-care systems. In some respects this approach was similar to the structural functionalism of Blume (1992), and as in Blume's analysis considerable attention was paid to the economics of the radioisotope industry. However whereas Blume focuses on the economics of innovation in imaging equipment markets, and on the symbiosis of industrial and professional interests, the radioisotope industry was seen to be distinctive because of its connections to the nuclear industry. The analysis also went beyond Blume's functionalism in that some consideration was given to the symbiosis of nuclear medicine and the radioisotope industry and dominant class interests.

Also in relation to the broad social structuring of nuclear medicine and the radioisotope industry, a recurring topic in chapters 5-8 was the economic stagnation of the past generation. This was shown to have many implications, such as the growing reluctance of government to fund or subsidise radioisotope production (and research reactor programs more generally), commercialisation (and sometimes corporatisation or privatisation) of radioisotope production, the
increasingly competitive environment between alternative imaging modalities, and stricter regulation of medical technologies.

The analysis in chapters 5-8 was alert to the broad social shaping of debates over radioisotope production and supply in relation to the HIFAR replacement controversy. Public debates, as during the Research Reactor Review, generally assume the value of nuclear medicine and revolve around questions concerning alternative methods of production and supply. While much of my analysis followed that approach, I also reframed the issue by questioning the value and uniqueness of nuclear medicine; hence the discussions on iatrogenesis, overuse of nuclear medicine, and competition with alternative imaging modalities.

Other than the broad framing of the radioisotope debate, some recurring themes in SSK/constructivist technology studies, such as interpretative and technological flexibility, or contingency in technological development, were common enough in chapters 5-8, although development of those themes was not given emphasis. Arguments such as that nuclear medicine is unique as a functional imaging modality, or that cyclotrons and reactors are complementary rather than competing radioisotope-production instruments, were opened up for scrutiny. Teasing out the politics of those arguments, and their implications for the HIFAR replacement controversy, was typical of the SSK/constructivist tradition and was also relevant to the substantive issue of future radioisotope production and supply for Australia. In some cases - such as the discussions on iatrogenesis and cyclotron production of Mo-99/Tc-99m - judgement was suspended on technical issues. However that was done not through any commitment to relativist epistemologies, but because it was beyond the scope of the thesis to analyse these complex debates in detail.

Analysis of the radioisotope industry also required an extensive, positivist treatment of technical issues, such as the empirical survey of radioisotope production in chapter six. In this respect the analysis was not dissimilar to the detailed treatment of microlevel issues common in STS/SSK - except that my analysis was driven by the practical issue of whether or not a new reactor is justified for radioisotope production in Australia, rather than being driven by an exploration of internal debates within STS/SSK.

I will finish with some comments on how integrated models of science and technology analysis could be further developed. Integrated models enable critical engagement with scientific and technological debates and artifacts as well as engagement with the politics of competing interest groups and social structures. It
is, however, easy enough to imagine integrated models for STS analysis becoming as esoteric and disconnected from political concerns as much other contemporary STS/SSK. One can also imagine schematic models for STS analysis substituting for rigorous sociological analysis. Intellectually, the primary task is to recast the abstractions of schematic models of science and technology analysis - e.g. ANA, SCOT, integrated models - within broader sociological theory. There has been a thread of class analysis running through this thesis, but the dialectics between science, technology and capitalism have not been systematically explored, with more emphasis being paid to topics inviting lower-level treatment. There remains much scope for linking integrated models more closely to general sociological theories such as the three traditions pioneered by Marx, Weber and Durkheim - both applying sociological theory and testing it in the process.

An important task is to marry theories of science-in-society with social problem centred methodologies. This is no simple task as Martin (1993) argues:

(It) would be desirable to develop a critique that is both epistemologically sophisticated and socially relevant, and also self-critical about its own method and social location. I look forward to analyses that fill all these specifications. But for those of us who are not superhuman, I suspect it is more appropriate to set less exalted goals.

Problem-centred research may not be as intellectually dense or tight as more academically-orientated studies. The empirical scope may be too broad and disparate too allow for a neat application of theory or testing of theories. So be it: problem-centred research can help re-establish the critical milieu of activists and academics that was evident in the early days of STS, and more generally to re-establish STS as a socially-relevant discipline. These are the central problems facing STS.

Some suggestions have been advanced in this thesis as to how theory can be integrated with a social problem centred methodology. At a general level the emphasis needs to shift from trivial topics to important science-in-society issues and there needs to be a willingness to engage in the politicking of science-in-society issues (as opposed to the internal politicking between competing camps in STS/SSK).

The four SSK shibboleths - reflexivity, impartiality, epistemology, and symmetry - can usefully be reframed as practical problems confronting the socially-engaged scholar/citizen rather than as narrowly intellectual issues. That pursuit could
form the basis for a fourth generation of STS/SSK as discussed in chapter one. This would not only be an improvement on earlier generations of STS/SSK, but could also be seen as a useful extension of the "politics of symmetry" debate in which a number of the SSK shibboleths have been reconsidered but the issues of reflexivity and impartiality/partisanship, and the general question of political engagement, remain largely unexplored.

As for integrated models and social relevance, in this thesis topics and sub-topics were chosen or overlooked with reference to the public policy issues rather than with reference to the elaboration and development of an integrated model. Various levels of analysis were taken up - or left alone - inasmuch as they were considered helpful in the analysis of the substantive science-in-society issues and questions. Thus integrated models are useful because of their flexibility, and can be contrasted with approaches in which theoretical or methodological schemas prefigure the analysis and are deployed in a mechanistic, and sometimes a circular and self-congratulatory, manner.81

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81 See Hirschman (1979) for a neat analysis of the differences between the mechanistic application of theoretical schemas as opposed to the intelligent application and testing of theory. C. Wright Mills' (1959, ch.2) polemic against "grand theory" is also useful here.
CHAPTER 10: POSTSCRIPT:
NEW REACTOR TO BUILD ON AUSTRALIA'S "LIFE-SAVING" NUCLEAR MEDICINE CAPABILITIES, SAYS SCIENCE MINISTER

On September 3, 1997, science minister Peter McGauran announced the federal government's decision to replace HIFAR with a new reactor, to be built at ANSTO's Lucas Heights site.

McGauran said in a media release that the proposal to replace HIFAR will be subject to a "stringent" environmental assessment process under the Environmental Protection Act 1974. The decision attracted considerable opposition from the federal ALP Opposition and the minor parliamentary parties (Greens and Democrats). On the initiative of the Opposition and minor parties, a Senate Committee has been established to investigate the proposal to replace HIFAR, to evaluate options such as cyclotrons and spallation sources, and to investigate whether the conditions set out by the Research Reactor Review (1993, p.xv) have been satisfied.

While the government's decision was announced as a fait accompli, it is in effect the opening move in the next phase of the controversy rather than the closure of the controversy. As mentioned in chapter 9, "a firm decision one way or the other by the federal government on the replacement of HIFAR would best be characterised as a nodal point in a controversy which promises to extend well beyond any such decision."

As for the reasons put forward for a new reactor, nothing has been added to the arguments rehearsed during the RRR. Very little information has been released in support of the proposed new reactor. ANSTO (1997B) has however released a "background information" document. The document is problematic in many respects (Green, 1997; 1997B; 1997C). Here I will summarise the medical misinformation in ANSTO's document.

ANSTO (1997B) says "The most frequently used radiopharmaceutical, technetium-99m, has a half life of six hours. It would not be possible to satisfy demand based on imports ...." This is misleading. ANSTO is well aware of the widespread international trade in the parent radioisotope, molybdenum-99.

ANSTO (1997B) says that "It is possible to import many radioisotopes but, on average, every third shipment is delayed by at least 24 hours. The resultant loss in
radioactivity renders many shipments unusable and increases substantially the real prices of others."

No more detail is provided to substantiate this claim. In the Sydney Morning Herald (4 September), Peter McGauran is quoted as saying that the figure of every third shipment arriving late, often by 24 hours or more, refers to shipments to ANSTO during routine shut downs of HIFAR. The preferred supplier of bulk Mo-99 - the most important product - during routine HIFAR shut downs is the South African Atomic Energy Commission (SAAEC). The SAAEC (1997, pers. comm.) says that only one in two hundred of its overseas shipments arrives late. It is difficult to see how the claims of the SAAEC and ANSTO can be reconciled with one another. I have written to ANSTO/ARI three times between September and November 1997, seeking clarification, but no response has been received. Nor was any clarification forthcoming from Peter McGauran's office.

On the potential use of accelerators (including cyclotrons) to produce Tc-99m, ANSTO (1997B) quotes a paragraph from the internet site of the University of California Chemistry and Agriculture Program (UCCAP, n.d.). The quote, which ANSTO uses twice in the "background information" document, appears to suggest that accelerator production of technetium-99m is not a viable option. Yet on the UCCAP internet site, the second of two paragraphs on this topic reads as follows:

Particle accelerators have broad scientific applications and play an important role in providing a broad spectrum of isotopes for medicine and research. Accelerator technology has evolved rapidly over the last decade and produced a new generation of machines capable of operating with high reliability, multiple beams allowing for multiple targets, and high intensities. This new accelerator capability may allow for new methods to be developed for the large-scale production of radioisotopes.

Further investigation reveals that both of the above-mentioned paragraphs were originally published in a 1993 article by Dr. Manuel Lagunas-Solar (1993). That article concludes with the words that "The feasibility of producing technetium-99m in large Curie quantities .... seems firmly established."

ANSTO's selective quoting from the UCCAP internet site does not reflect the opinions expressed on the internet site, nor the opinions expressed in the Lagunas-Solar article, nor does it accurately reflect the well-known views of Lagunas-Solar himself. This incident (among others) prompted to a letter from...
Lagunas-Solar to the Australian Prime Minister, which includes the following comments:

It is my understanding that my work has been reviewed by ANSTO, without the benefit of my direct participation, and clearly using outdated and/or incomplete information. ANSTO also provided statements to Parliament based on information (also out of date) available through our internet site. Based upon a general analysis of ANSTO's review, I strongly feel that it does not provide an objective and balanced review of the actual status or the conclusions of our work. Furthermore, I have invited an on-site review of our completed work, and one such visit was being considered but is yet to materialise.

ANSTO (1997B) says that "A spallation source cannot provide for bulk radioisotope production ...... The RRR acknowledged in 1993 that, even if Australia acquired a spallation source, a reactor would still be needed for radioisotope production. Costs of spallation sources plus required accelerator range from $US 500 million to $1 billion."

As discussed in chapter 7.8, theoretical calculations indicate that one Adonis spallation system could produce most or all of world demand for Mo-99, and capital, decommissioning and waste disposal costs are expected to be considerably less than a commercial 10 MW reactor. In the event of a spallation source being built in Australia for radioisotope production (and perhaps other purposes), and in addition to supply from domestic cyclotrons and overseas reactors, there would be no need for a research reactor for radioisotope production.

A federal Parliamentary Research Report, released the week after the decision on a new reactor, concludes with these words (Panter, 1997):

It is clear that, in coming to a decision in principle to have a new reactor constructed in Australia, the Government has not made a thorough, balanced comparison of the merits of spallation sources versus the reactor method for technetium production.

Events of recent months have clarified the importance of medical radioisotope production and supply within the broader HIFAR replacement controversy. The production of medical radioisotopes has been by far the major public-relations push from ANSTO and other proponents of a new reactor. Peter McGauran's media release began with the words that "The construction of a replacement
research reactor at Lucas Heights will build on Australia's life-saving nuclear medicine capabilities." However it is likely that other concerns, such as the "national interest" considerations, have had a greater impact on the federal Cabinet's decision to replace HIFAR (see chapter 4). Certainly the government's interest in medicine and health care appears to be a new-found interest. Nobel Prize winner Professor Peter Doherty (quoted in Pockley, 1997) has attacked the "massive" cuts of 30% over two years for medical research (from $174 million to $128 million).

The place of medical radioisotope debates within the broader controversy was summed up thus by science journalist Peter Pockley (1997B) in the October 1997 edition of the science journal Search:

As Search went to press, the Democrats and the ALP were trying to establish a Senate inquiry. But even if an inquiry is approved and hears evidence from some of the main characters, it and the mandatory Environmental Impact Statement will probably amount to little more than delaying nuisances for the government and ANSTO. After all, the government can always label any hindrance to their timetable as "jeopardising the saving of lives", and who will argue with that?

The October 1997 edition of Search also carried an article by Professor Barry Allen (1997) from the Department of Pharmacy, University of Sydney. Given that Allen used to be the Chief Research Scientist at ANSTO, his critical comments on the medical and scientific debates are all the more noteworthy:

...... the reactor will be a step into the past ...... (it) will comprise mostly imported technology and it may well be the last of its kind ever built. More importantly, anticipated developments in functional magnetic resonance imaging may well reduce the future application of reactor-based nuclear medicine. Certainly the $300 million reactor will have little impact on cancer prognosis, the major killer of Australians today. In fact, the cost of replacing the reactor is comparable to the whole wish list that arguably could be written for research facilities by the Australian Science, Technology and Engineering Council (ASTEC). ...... Apart from the neutron-scattering element of the reactor, there will be little research and development yet it will make a large dent in the budget for Australian research, which at this point is so badly needed in order to take us into the next century. ...... The decision to proceed with a new reactor is not wrong, but it is a far cry from the optimal expenditure of funds that Australia badly needs in science and technology.
On September 3, 1997, the government announced that the stockpile of spent fuel rods stored at Lucas Heights will be shipped to the USA and to Scotland (Green, 1997D). The 600-700 fuel rods shipped to the US will be stored indefinitely, without reprocessing. The 1300 or so fuel rods shipped to Scotland will be reprocessed, with the reprocessing waste returned to Australia in 10-20 years.

Where the waste will be stored when returned to Australia has not been decided. The current plan is to "co-locate" the waste at a national low-level waste repository. This raises two problems. Firstly, the low-level waste repository will no longer be a low-level waste repository if intermediate and/or high-level wastes are stored there. Secondly, Australia does not have a low-level waste repository at which to co-locate other wastes; successive governments have been unable to establish such a repository over the past two decades, primarily because of political and public opposition.

There are no immediate plans to build a reprocessing plant in Australia, although this has not been ruled out as a future option.
---, 1969B, "We'll spend $5,000M on nuclear power 'by year 2000'", The Australian, 14 July, p.3
---, 1995C, "Reactor's closure is welcome news - but it's only the small one!", Sutherland Shire Environment Centre Newsletter, Issue 14, July.
---, 1987, Biomedical Products and Labelled Compounds.
Australian Conservation Foundation, 1993, Submission to the Research
Reactor Review.
Australian Institute of Health and Welfare, May, 1993, Nuclear Medicine in
Australia, unpublished document, Canberra.
Australian Nuclear Science and Technology Organisation (ANSTO), Annual
---, 1987, Ionising Radiation, pamphlet.
---, 1990, Nuclear Developments in the Asia and Pacific Region, Sydney: ANSTO.
---, 1992B, "Clinical Applications of Cyclotron Radioisotopes", ANSTO
Technology, No.15, pp.11-12.
---, 1992E, "Patient absorbed dose and radiation risk in nuclear medicine", ANSTO
Technology, No.15, p.18.
---, 1993, Submission to the Research Reactor Review, Attachment B: "The Need
Benefits of Reactor Operations".
---, 1993B, First Round Supplementary Public Submission to the Research Reactor
Review, Working Paper S7: "Radiopharmaceuticals".
---, 1993C, Submission to the Research Reactor Review, Supplementary
Information.
---, 1993D, Submission to the Research Reactor Review.
---, 1993E, Submission to the Research Reactor Review, Attachment B: "The Need
for a New Research Reactor in Australia".
---, 1993F, First Round Supplementary Public Submission to the Research Reactor
Review.
---, 1993G, Submission to the Research Reactor Review, Supplementary
Information - 2.
---, 1993L, Submission to the Research Reactor Review, Attachment F:
"Evaluation of the New Research Reactor".
---, 1993J, Submission to the Research Reactor Review, Attachment D:
"HIFAR: The High Flux Australian Reactor", Working Paper 5: "Waste
Management".
---, 1993L, Submission to the Research Reactor Review, Attachment A: "Research
Reactors: Local and International Experience", Working Paper 3:
"International Experience with Research Reactors".
---, 1993N, Submission to the Research Reactor Review, Attachment A: "Research
Reactors: Local and International Experience", Appendix E: "The MOATA
Reactor".
---, 1993P, First Round Supplementary Public Submission to the Research
document.
---, 1995D, Nuclear Power and the Nuclear Fuel Cycle in the Republic of Korea:
Recent Developments, unpublished document.
---, 1995E, Status Summary for Power Reactors > 30 MWe (Net), unpublished
document.
---, 1995F, Nuclear Power and the Nuclear Fuel Cycle, September,
---, 1995G, New $3.3 million lab helps search for new drugs,


----, 1972, Australia in the Nuclear age: National defence and national development, Sydney: Sydney University Press.


Bertini, H.W., et al., 1980, "Descriptions of selected accidents that have occurred at nuclear reactor facilities" Springfield: NTIS.


Black, J.L., (Sir Charles Gairdner Hospital), 1993, Submission to the Research Reactor Review.

Blank, Dr. H., and Kearley, Dr. G.J., 1993, Submission to Research Reactor Review, (Attachment to the submission of the Australian Nuclear Association).


Bonnyma, John, 1994, "Use of Radiation in Medicine and Medical Research in Australia", Journal of the Australian and New Zealand Society of Nuclear Medicine, June, pp.36-38.


----, 1993, "Cyclotron Production of Technetium-99m and Molybdenum-99", in ANSTO, First Round Supplementary Public Submission to the Research Reactor Review.


BRIT - see Board of Radiation and Isotope Technology


CCNR - see Canadian Coalition for Nuclear Responsibility.


Clarke, Renfrey, 1996, "Mexico City in Moscow", *Links*, No.6, pp.65-76.


Concord Hospital, 1993, Submission to the Research Reactor Review.
CSIRO - see Commonwealth Scientific and Industrial Research Organisation.
Department of Energy (United States), 1992, Critical Technologies Research: Opportunities for DOE, December.


Department of Foreign Affairs (Australia), 1993, Submission to the Research Reactor Review.


DOE - see Department of Energy (United States).


----, 1993B, "Cyclotron Technology at the Austin Hospital, Melbourne", unpublished document.


Endocrine Society of Australia, 1993, Submission to the Research Reactor Review.

Flinders Medical Centre (Nuclear Medicine Section), 1993, Submission to the Research Reactor Review.
FOE - see Friends of the Earth.
Fricker, Algy, 1988, "Non-violence can be lethal - why CANE died", Chain Reaction, Number 53, pp.23-25.
Friends of the Earth (Sydney), 1993B, Supplementary Submission to the Research Reactor Review.
----, 1993C, Newsletter, March.
German, John, 1996, "Its official: Sandia will produce moly-99 at ACRR", Sandia LabNews, September 27.


Goertzen, Donald, 1988, "Conferring peace", Chain Reaction, Number 53, pp.35-36.

Gofman, John W., 1990, Radiation-Induced Cancer from Low-Dose Exposure: An Independent Analysis, San Francisco: Committee for Nuclear Responsibility.


Greenless, Don, 1997, "Options stay open on nuclear arsenal", The Australian, 1 January.

Greenpeace, 1993, Submission to the Research Reactor Review.


Hallam, John, 1988, "Flagging Safeguards", Chain Reaction, Number 54.


----, 1996B, "Ain't Perfect, but better than nothing", The Third Opinion, Spring, p.5.


IAEA - see International Atomic Energy Agency


Independent Committee of Inquiry into the Nuclear Weapons and Other Consequences of Australian Uranium, 1984, Australia and the Nuclear Choice, Sydney: Total Environment Centre.

INSC - see International Nuclear Safety Centre.


[Accessed: June-December, 1996.]


KAERI - see Korea Atomic Energy Research Institute.

Kagarlitsky, Boris, 1995, "Russia's communist party and the radical left", Links, No.5, August-October, pp.78-85.


Australian and New Zealand Society of Nuclear Medicine, June, pp.16-19.
Khafagi, Dr., 1993, Transcript of Proceedings, Research Reactor Review Public
Hearing, Brisbane, 11 March.
Kim, Seong-Yun, 1995, "Hopes for HANARO", Nuclear Engineering
King, Bert, 1985, "The nuke next door", Chain Reaction, Nos.42/43, p.15.
Kling, Rob, 1992, "When Gunfire Shatters Bone: Reducing Sociotechnical Systems
to Social Relationships", Science, Technology, & Human Values, Vol.17(3),
pp.381-385.
Knapp Jr., F.F. (Russ), and Mirzadeh, S., 1994, "The continuing important role of
radionuclide generator systems for nuclear medicine", European Journal of
Nuclear Medicine, Vol.21(12), pp.1151-1165.
Knorr-Cetina, Karin D., and Mulkay, Michael, 1983, "Introduction, Emerging
Principles in Social Studies of Science", in Knorr-Cetina, Karin D., and
Mulkay, Michael, (eds.), Science Observed: Perspectives on the Social Study
Koch, Ellen B., 1993, "In the Image of Science? Negotiating the Development of
Diagnostic Ultrasound in the Cultures of Surgery and Radiology",
Technology and Culture, Vol.34, pp.858-893.
Kooken, E., 1995, "Refurbishing BR2", Nuclear Engineering International,
December, pp.37-38.
Korea Atomic Energy Research Institute, n.d., "HANARO",
<http://hpngp01.kaeri.re.kr/hanaro/ripf.html> [Accessed: December,
1996.]
Kothari, Manu L., and Mehta, Lopa A., 1988, "Violence in Modern Medicine", in
Nandy, Ashis, (ed.), Science, Hegemony and Violence: A Requiem for
Modernity, Delhi: Oxford University Press.
Kotz, Deborah, 1995, "The A-Bomb, 50 Years Later: The Evolution of Nuclear
Medicine", The Journal of Nuclear Medicine, Vol.36(8), pp.17N-21N.
Journal of Nuclear Medicine, Vol.36(10), pp.15N-30N.
----, 1996, "DOE Commercializes Idaho Hot-Cell Facility", The Journal of
Nuclear Medicine, Vol.37(11), pp.21N-24N.
Krull, W., 1994, "Operators beware", Nuclear Engineering International,
December, pp.33-36.
----, 1994B, "Overcoming the effects of ageing", Nuclear Engineering International,
December, p.36.
----, 1995, "Attempting immortality", Nuclear Engineering International,
December, pp.35-36.
Kylwind, 1993, Submission to the Research Reactor Review.
Lagunas-Solar, Manuel, 1993, "Production of Tc-99m and Mo-99 for Nuclear
Medicine Applications via Accelerators as an Option to Reactor Methods",
paper presented to the 18th Annual Conference of the Australian Radiation
Protection Society, Sydney, Australia, 6-8 October.
----, 1993B, "Response to ANSTO's comments on possibilities of Mo-99/Tc-99m
production by cyclotrons", 24 June, Submission to the Research Reactor
Review.


----, 1993, Submission to the Research Reactor Review.


Martin, Brian, 1980, Nuclear Knights, Canberra: Rupert Public Interest Movement.


Martin, Brian, and Richards, Evelleen, 1995, "Scientific Knowledge, Controversy, and Public Decision Making", in Jasanoff, Sheila, Markle, Gerald E.,


Morris, John, 1993, Submission to the Research Reactor Review.


NHTAP - see National Health Technology Advisory Panel.


Ogle, Peter L., 1996, "Many remain unconvinced, but MRI's reputation as a good value is economically defensible", (Editor's Comment), Diagnostic Imaging, December.

O'Leary, Hazel R., 1995, "The DOE's Role in Isotope Production", The Journal of Nuclear Medicine, Vol.36(6), pp.30N-33N.

ORNL - see Oak Ridge National Laboratories.


Panter, Rod, 1993, Submission to the Research Reactor Review.

----, 1997, "Cyclotrons: Can they be used to make technetium-99m?" Parliamentary Research Report, prepared for Senator Dee Margetts, Information and Research Services, Department of the Parliamentary Library.


Pearson, Ben, (Greenpeace Australia), 1994, 250 Reasons: Australia's involvement in the nuclear industry, Sydney: Greenpeace.


Rae, Pauline, 1994, "ANSTO mulls over bid for replacement reactor", St. George and Sutherland Shire Leader, 29 November, p.2.

Ralfs, Clare, and Miller, Penny, 1988, "CANE is Dead - Why?", Chain Reaction. Number 53, pp.21-22.


----, 1993B, "Energy Department Proposes Two Isotope Initiatives", The Journal of Nuclear Medicine, Vol.34(6), pp.47N-48N.
---, 1993C, "Report Hints at Restructuring of DOE Isotope Program", The Journal of Nuclear Medicine, Vol.34(6), pp.49N-54N.


---, 1994, "Uncertainties face medical accelerator proposal", The Journal of Nuclear Medicine, Vol.35(12), pp.16N-17N.


Royal Brisbane Hospital, 1993, Submission to the Research Reactor Review.


SAAEC - see South African Atomic Energy Commission.


----, 1995, "Winter Summit to Discuss Current Crisis in Nuclear Medicine", The Journal of Nuclear Medicine, Vol.36(1), pp.18N-23N.


Sharp, Nonie, 1985, "In a Nuclear Cage", Arena, No. 70, pp.3-8.


Silink, Martin, (The Children's Hospital, Sydney), 1993, Submission to the Research Reactor Review.


Spigelman, Jim, 1972, Secrecy: Political Censorship in Australia, Sydney: Angus and Robertson.


Styles, Colin, (Geelong Hospital), 1993, Submission to the Research Reactor Review.


Sutherland Shire Council, 1993B, *Supplementary Submission to the Research Reactor Review*.

----, 1993C, "No Reactor Campaign Update", pamphlet, Spring.


----, 1996, Newsletter #3, May-June.


Watford, Gareth, 1993, Submission to the Research Reactor Review.  
Wright, James, 1988, "X-rays - a Mixed Blessing", New Doctor, Issue 49, pp.18-21.  