Nuclear Science and Technology in Australia

1985
My dear Prime Minister

We have the honour to present to you a report by ASTEC on nuclear science and technology in Australia. The report presents a review of current Australian activity in this field. ASTEC concludes that Australia should continue to participate in nuclear science and technology because there are economic, scientific, social and foreign policy advantages to be gained by so doing. A number of recommendations for government action are made which we believe will ensure an optimal, yet economically feasible, future course for nuclear science and technology in this country.

Yours sincerely

(R.O. Slatyer)
Chairman

4 November 1985

For and on behalf of:

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1 SUMMARY AND RECOMMENDATIONS

1.1 Introduction

1.1.1 In this report ASTEC describes current activities in nuclear science and technology in Australia and advises on future directions for this sector and the resources and facilities which will be required. Chapters 2 to 6 of the report review basic research in nuclear science, the broad range of applied research programs in diverse scientific disciplines which rely on nuclear technology, the applications of nuclear technology in industry and medicine, and the organisations which are involved in nuclear science and technology. Chapter 7 presents an overview of earlier chapters, discussion of issues and the recommendations.

1.1.2 The most important tools of the nuclear scientist are the particle accelerator and nuclear reactor. Particle accelerators range from relatively simple machines which produce low energy particle beams to extremely sophisticated high energy accelerators which are operated at a small number of overseas centres and used to investigate the smallest sub-particles of matter. A number of low energy accelerators are located in Australian institutions of higher education and government laboratories but there are no accelerators which operate at intermediate or high energies in this country. Australia has two nuclear reactors situated at the Australian Atomic Energy Commission (AAEC) Research Establishment at Lucas Heights. One of these, HIFAR, is used for research and isotope production and the other, MOATA, is a very small research reactor.

1.1.3 The expenditure of the Commonwealth Government on nuclear science and technology is relatively small compared to other developed countries, especially with respect to basic research. We have estimated that Australia's current annual expenditure in basic nuclear research is about $2.5 million and in applied research using nuclear technology, about $31 million.

1.1.4 A number of important themes are presented in this report. ASTEC believes that Australia should maintain a balanced effort in both basic nuclear research and applied research using nuclear technology. The Australian research effort must be linked into the international forefront of nuclear research. Applied research programs using nuclear technology should be relevant to the needs of Australian industry and other user groups, and there should be increased transfer of nuclear technology into industry. Provision must also be made for continued training of nuclear scientists. ASTEC's recommendations on how these objectives might be achieved within the limits of economic feasibility are outlined in the remainder of this chapter.
1.2 Australian Participation in Basic Research in High Energy Physics

1.2.1 Some of the most exciting basic research in science, probing the fundamental laws of nature, is conducted at a small number of high energy physics centres overseas. This research relies on sophisticated high energy accelerator facilities which, because of their considerable expense, generally are operated only by international co-operation. Australia has at present almost no involvement in this important area of nuclear science. ASTEC believes that Australian basic research in nuclear science should not develop in isolation from radical new developments in this field which are taking place overseas. The minimum effort required to keep Australia in touch with this area of research is to fund one group of Australian scientists to work collaboratively in a significant experiment in Europe or in the USA. The University of Melbourne and Flinders University have expressed interest in the joint establishment of a high energy physics research centre for such a group.

**Recommendation 1**

(i) That the Minister for Education undertake to fund a special research centre for high energy physics.

(ii) That funding for the centre be provided at the rate of approximately $0.5 million per annum for five years in the first instance.

(iii) That the progress of the centre be reviewed after three years and continued funding be dependent on the satisfactory establishment of collaborative basic research projects of a world standard and evidence of the diffusion of the knowledge so acquired through the Australian scientific community.

1.3 A National Accelerator Facility for Basic and Applied Research

1.3.1 Scientists working in both basic and applied research have identified a need for a domestic accelerator which operates at higher energies than accelerators which are presently available to them in Australia. ASTEC believes it is necessary to have in Australia an accelerator facility where nuclear scientists can be trained in basic research and where they can gain sufficient experience and recognition to enable them to gain access to overseas accelerator facilities. ASTEC also recognises that scientists who utilise nuclear technology in applied research require access to a domestic accelerator which operates in the 8 to 10 MV range. Some of the more important uses of such an accelerator in applied research would be in addressing the problems of soil salinity and erosion and the management of ground water resources using accelerator mass spectrometry and in the field of materials science for surface modification using ion beam implantation. These fields of research are already established at the AAEC and the Royal Melbourne Institute of Technology respectively. ASTEC believes that most of the further needs of scientists in both basic and applied research for a domestic accelerator facility can be met by one accelerator which is suitable for research at appropriate energies and is operated as a national research facility.
Recommendation 2

(i) That the Government provide funds for the establishment of a national accelerator research facility to support basic and applied research of a world standard.

(ii) That the facility be operated as a national research facility, with an independent steering committee and serving the needs of researchers from a broad range of scientific disciplines.

1.3.2 Two proposals for new or upgraded accelerator facilities are before government at present. The Department of Nuclear Physics at the Australian National University (ANU) proposes to upgrade its 14 UD accelerator facility to double existing beam energy at a cost of $6.6 million. This would enable the basic research program in heavy ion physics at ANU to continue at the forefront of this field. The AAEC proposes that a new 8 MV tandem accelerator be installed at Lucas Heights at an estimated cost of $7 million. This would replace the existing 3 MV accelerator and be used for applied research in a broad range of collaborative programs with users from outside the AAEC.

1.3.3 ASTEC concludes that neither the ANU nor the AAEC accelerator proposal meets Australia's need for a national accelerator facility. Neither proposal seeks to serve the broad future requirements of scientists engaged in both basic and applied research in Australia, to actively link into international research programs or to encourage the rationalisation of existing accelerator facilities in this country.

Recommendation 3

That establishments which have the desire and competence to operate a national accelerator facility be invited to prepare proposals to this effect which take account of the broad requirements of Australian scientists as outlined in this report.

1.4 An Australian Nuclear Reactor

1.4.1 Australia's nuclear reactor, HIFAR, at Lucas Heights is now 25 years old and its future must be considered. ASTEC believes it is essential to maintain a nuclear reactor in Australia for research and the production of radioisotopes.

1.4.2 Neutron scattering techniques using a neutron beam from a nuclear reactor or other neutron source, play a central role in advanced research in materials science. Australia has already a small group of internationally recognised experts in this field. This core of expertise should be nurtured, not only because of the scientific excellence of the research, but also because of the potential economic advantages arising from industrial applications of neutron scattering technology.
1.4.3 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.

1.4.4 Three options for providing a neutron beam source in Australia in the medium term future have been proposed:

- replacement of HIFAR with a reactor which produces at least equal neutron fluxes at an estimated capital cost of about $80 million;
- replacement of HIFAR with a smaller 5 MW reactor at a capital cost of about $25 million together with a guarantee of access of overseas high flux continuous and pulsed neutron sources; and
- further refurbishment of HIFAR to upgrade the instrumentation and to ensure continuing safe operation, at an estimated cost in the vicinity of $10 million over the next ten years.

1.4.5 ASTEC believes that the preferred option for providing an adequate neutron beam source in Australia in the medium term future is to retain HIFAR and provide a regular budget for the continuation of upgrading and maintenance. Upgrading should include modification to improve the neutron beam instrumentation on HIFAR as well as to ensure continuing safe operation. ASTEC considers that replacement of HIFAR with a reactor which produces an equivalent neutron flux is not feasible in the present Australian economic climate, while replacement of HIFAR with a 5 MW reactor would mean that very few of the international standard research programs carried out at HIFAR could continue.

**Recommendation 4**

*That the Minister for Resources and Energy make funds available to maintain and upgrade HIFAR so that its continued safe operation can be guaranteed and improvements made to the neutron beam instrumentation; this will ensure a continued Australian capability in neutron beam research and application and radioisotope production.*

1.5 The Use of Overseas Nuclear Facilities by Australian Scientists

1.5.1 Many of the facilities required for basic research in nuclear science and for applied research using nuclear technology are very expensive. It is not economically feasible to provide these facilities in Australia, nor is it possible to maintain an effective Australian nuclear science research effort without providing scientists with access to such facilities.
1.5.2 In Recommendation 1, ASTEC proposed a mechanism whereby some
Australian scientists could participate in high energy physics research at overseas
centres. Important advances in basic research in nuclear science are also being
made at foreign intermediate energy accelerators in Europe, North America and
Japan and Australian scientists need to remain in contact with this work. Neutron
sources in other countries provide neutron fluxes which are not available at HIFAR
but which are required for some applied research using neutron scattering
techniques.

1.5.3 ASTEC considers it important to maintain in Australia a nuclear research
effort in both basic and applied research which is in contact with forefront research
at overseas centres. The government should, therefore, provide funds for Australian
scientists who need to travel overseas to use nuclear facilities which are not
available in this country but which are necessary to support excellent research
projects.

1.5.4 ASTEC considers that the best mechanism for delivering funds to
scientists who need to travel overseas to use nuclear facilities other than high
energy particle accelerators is by the appropriation of new dedicated funds to the
Australian Research Grants Scheme. The Australian Research Grants Committee
already has broad experience in the assessment and evaluation of research proposals
in many scientific disciplines including nuclear science.

Recommendation 5

(i) That an additional amount of $250,000 per annum be appropriated to the
Australian Research Grants Scheme (ARGS) for the establishment of a
dedicated nuclear science and technology travel fund.

(ii) That this fund be used to support the travel of Australian scientists
whose projects have been determined to be of the highest international
standard and require accelerator or neutron beam facilities which are not
available in Australia.

1.5.5 In addition to supporting the travel of Australian scientists using overseas
nuclear facilities it is necessary to consider the provision of funds or alternative
mechanisms to meet charges which will in future be levied by overseas accelerator
and nuclear reactor facilities. Payment could be negotiated in terms of a financial
commitment, the provision of ancillary equipment or possibly by offering the
reciprocal use of advanced Australian facilities to foreign scientists without
payment.

Recommendation 6

(i) That the Minister for Science endeavour wherever possible to secure
access for Australian scientists to overseas neutron beam and
accelerator facilities by the negotiation of reciprocal arrangements
between foreign nuclear facilities and Australian scientific facilities.
That where such reciprocal arrangements are not possible, and charging by foreign accelerator or neutron beam facilities is instigated, the dedicated nuclear science and technology fund of the ARGS should extend its funding to include such charges in addition to travel expenses.

That should these circumstances arise, the appropriation to the ARGS for the nuclear science and technology fund should be increased by an appropriate amount.

1.6 The Australian Atomic Energy Commission

1.6.1 The AAEC Research Laboratories at Lucas Heights constitute the largest centre of nuclear science and technology in Australia. In the present study, ASTEC has examined the broad field of nuclear science and technology in Australia rather than conduct a detailed investigation of the AAEC or any other individual organisation. For this reason we have made no specific recommendations about the structure and function of the AAEC in this report.

1.6.2 The Minister for Resources and Energy has proposed that part of the Atomic Energy Act 1953 be repealed and replaced by legislation establishing an Australian Nuclear Science and Technology Organisation (ANSTO) in place of the AAEC. ASTEC supports proposed changes in the legislation which will direct the organisation towards the needs of Australian industry and the further development of the varied, peaceful applications of nuclear science and technology.
2.1 Nuclear science and technology have a central position in scientific research in Australia as well as many economically and socially important applications in medicine, industry and environmental studies. These important applications are less well known to the Australian public than uses of nuclear science and technology in power generation or weapons production, which do not occur in Australia but are often the subject of public debate.

2.2 The equipment needed for nuclear science and technology is sophisticated and very expensive and is located at centralised facilities. Nuclear facilities generally are shared by different organisations and, in the case of larger facilities, by different nations.

2.3 Scientists in Australia have recognised that, in order to keep abreast of world progress in nuclear science and technology, they require access to more advanced nuclear facilities than are at present available in this country. Accordingly, proposals have been placed before the Commonwealth Government for funding for new nuclear facilities and for upgrading existing ones. ASTEC decided to undertake the present study so that it would be prepared to provide advice to the Government on the future development and funding requirements of nuclear science and technology in Australia. The aims of the study were:

(i) To review present activities in the field of nuclear science and technology in Australia.

(ii) To consider and make recommendations on:
   a. future options for an Australian participation in nuclear science and technology; and
   b. resources and facilities which will be necessary for an optimum future participation in nuclear science and technology by Australia.

2.4 The boundaries of nuclear science and technology are ill-defined. Basic research in nuclear science encompasses nuclear physics but this field is rapidly converging with particle physics. Traditionally, nuclear physics was concerned with the behaviour of the nucleus as a whole, while particle physics emphasised the study of sub-atomic particles. Applied research using nuclear technology is carried out in many scientific disciplines including, for example, geology, microelectronics, biology and chemistry, as well as in the discipline of nuclear science itself.

2.5 In this study ASTEC has reviewed basic research in nuclear and particle physics, applied research using nuclear technology in many areas of science, and applications of nuclear technology in industry and medicine. Theoretical research in nuclear and particle physics is considered only briefly because this work is not directly dependent on access to nuclear facilities. Research in plasma physics, astrophysics, fusion physics and solid state physics, which have strong links with nuclear physics, is not included in the present study. Australia's participation in the
mining and milling of uranium ores has already been considered by ASTEC in a previous report ('Australia's Role in the Nuclear Fuel Cycle', May 1984) and is not addressed again in this study.

2.6 Much of the information about the present allocation of resources for nuclear science and technology in Australia, which is presented in this report, was collected by ASTEC from the organisations involved. Often this data has not been presented elsewhere and consequently references for such data are not provided.

2.7 Specific proposals for nuclear facilities which were evaluated by ASTEC include proposals for new and upgraded accelerator facilities and for a new or refurbished nuclear reactor. In conjunction with these proposals, ASTEC also addressed the need for the allocation of resources to allow Australian scientists to use overseas nuclear research facilities which are not available in this country.

2.8 Expenditure by the Commonwealth Government on nuclear science and technology is relatively small, especially with respect to basic research. We have estimated that Australia's current annual expenditure in basic nuclear research is about $2.5 million and in applied research using nuclear technology, about $31 million. By comparison, Canada, for example, spends Can$11.5 million on basic nuclear research at Canadian and foreign nuclear facilities and provides an operating budget of Can$26 million for basic research at its national nuclear facility, TRIUMF. Applied nuclear research in Canada is centred at Chalk River which has an annual budget of Can$250 million, a proportion of which supports a nuclear power industry[1].

2.9 Australia's recent expenditure on nuclear facilities has been likewise modest. The Australian Atomic Energy Commission, for example, has not purchased a major item of new equipment costing in excess of $250,000 for the last 12 years. Proposals for new or upgraded nuclear facilities reviewed in this study cost, with one exception which is not supported by ASTEC, less than $10 million. This is two orders of magnitude less than new or proposed international nuclear facilities such as the new CERN (European Organisation for Nuclear Research) accelerator, which cost in the vicinity of $500 million.

2.10 ASTEC concludes that it is important for economic, social, scientific and foreign policy reasons that Australia maintains a domestic competence in nuclear science and technology. This will require continued government funding of a research effort in both basic nuclear research and applied research using nuclear technology. The research effort must be linked to recent advances at overseas nuclear facilities. This will necessitate the provision of funding for Australian scientists to travel overseas to use facilities which are not available in this country as well as the provision of a world-class nuclear facility in Australia. It is important that the transfer of nuclear technology to industry be encouraged so that consequential economic advantages can be achieved. Australia also requires a pool of trained and experienced personnel to effect the transfer of nuclear technology both into and within Australia.
REFERENCE

1. E. W. Vogt, Director of TRIUMF, Vancouver, Canada, information provided to the ASTEC working party, 1985.
3 BASIC RESEARCH IN NUCLEAR SCIENCE

3.1 Introduction

3.1.1 Basic research in nuclear science is concerned with furthering knowledge of nuclear structure and nuclear dynamics and therefore seeks to expand our understanding of the fundamental nature of matter. The field is very broad and includes both a consideration of the atomic nucleus as a many body system and a study of the smallest sub-atomic particles. Nuclear science has strong links with solid state physics, atomic physics, astrophysics, plasma physics and fusion physics.

3.1.2 In this study, nuclear science is taken to comprise both nuclear physics and particle physics. Traditionally, nuclear physics has been more concerned with the behaviour of the nucleus as a whole, while the emphasis in particle physics has been on sub-atomic particles. As will be seen later, these two areas of research are converging.

3.1.3 Experimentalists and theoreticians need to work in close co-operation in nuclear science. Experimental nuclear scientists seek to support, refute, qualify or extend the mathematical predictions of theoreticians. The theoretical nuclear scientists in Australia comprise approximately 25 scientists employed at the level of lecturer or above in Australian universities and at the Australian Atomic Energy Commission. They are involved in theoretical nuclear and particle physics. Associated with these theoreticians are a proportional number of postdoctoral researchers and postgraduate students. This is a very active, if relatively small area of research in Australia and its members are well respected internationally. Unlike their fellow experimental nuclear scientists, theoreticians are not directly dependent on sophisticated and expensive research facilities although their need for more powerful computers will increase their capital requirements in the future.

3.1.4 The two centres of experimental basic nuclear science research in Australia are at the School of Physics at the University of Melbourne and the Department of Nuclear Physics at the Australian National University (ANU). The number of personnel involved in experimental basic research is again small, there being a total of 30 research staff, 27 postgraduate students and 24 technical staff (Table 3.1).
### Table 3.1

Staff and Students Engaged In Basic Experimental Nuclear Science Research in Australia (1985)

<table>
<thead>
<tr>
<th></th>
<th>School of Physics, University of Melbourne</th>
<th>Department of Nuclear Physics, ANU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research staff*</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Postgraduate students</td>
<td>21</td>
<td>6</td>
</tr>
<tr>
<td>Technical support staff</td>
<td>5</td>
<td>19</td>
</tr>
</tbody>
</table>

* lecturer and above and research fellows

Source: Figures from the University of Melbourne and ANU

3.1.5 The total annual budget of the Department of Nuclear Physics at the ANU for 1985 was $1.7 million. The total amount devoted to nuclear science research in the School of Physics at the University of Melbourne was $1.5 million, but only about 40% of the nuclear science research effort in this School may be categorised as experimental basic nuclear science. The Australian Research Grants Scheme in 1985 granted $137,000 to projects which may be described as basic nuclear science research.

3.1.6 In total, Australia’s annual expenditure on basic nuclear science experimental research is of the order of only $2.5 million or $0.13 per capita of the population. This is a very low rate of expenditure compared to other developed countries. The only major grant to this discipline for capital equipment in the last 20 years has been for the accelerator facility at the ANU which cost $2.2 million in 1969.

3.2 The Structure of the Atomic Nucleus[1, 2, 3]

3.2.1 In order to consider the nature of basic research in nuclear science it is first necessary to review briefly the current understanding of the structure of the atomic nucleus.

3.2.2 The nucleus contains positively charged particles called protons, and particles with no electrical charge called neutrons. The complete atom consists of a nucleus surrounded by a cloud of negatively charged electrons. Research at high and intermediate energy accelerators has identified a range of sub-particles. Neutrons
and protons are made up of smaller particles known as quarks. There are six different types of quarks, and for each quark there is a corresponding antiquark. In accelerator experiments, quarks exist in combinations other than protons and neutrons. All combinations of quarks are known as hadrons. Another group of exotic particles is known as leptons. There are six types of leptons and also corresponding antileptons. The electron is one type of lepton.

3.2.3 A view has developed that the six types of quarks and six types of leptons account for all matter. There are, however, another series of particles described only in recent years, which are believed to carry the forces governing the behaviour of atoms. These gauge particles are the W and Z particles carrying weak forces, the photons which carry the electromagnetic force and the gluons which carry the strong force which holds the nucleus together.

3.2.4 Theoretical and experimental physicists together have been able to build radical new theories to explain the interactions between matter. They have constructed a single framework for the fundamental force of electromagnetism and the so-called weak and strong forces. Arguably the most significant and exciting fundamental physics research in the future will be carried out with the objective of determining whether these theories are correct or in need of revision or extension.

3.3 Accelerator Facilities for Basic Research in Nuclear and Particle Physics

3.3.1 Basic research in nuclear science is carried out using particle accelerators. There are many different types of accelerators but their common function is to produce high energy, focussed beams of particles. The accelerators required to study the smallest sub-atomic particles accelerate beams of protons or electrons to extremely high energies of over $10^3$ GeV (1 gigaelectron volt = 1000 million electron volts). Some, like the linear accelerator at Stanford University in California, accelerate electrons along a straight distance of up to 3 km. Others, like the proton accelerator at CERN in Geneva, are circular. The CERN accelerator has two particle beams which are accelerated and steered in opposite directions by powerful electromagnets. Allowing the beams to collide doubles the effective energy to over 600 GeV[4].

3.3.2 The higher the energy of the accelerated beam projectile, the deeper it can delve into the atom. Energies in the MeV range are required to probe the nucleus, and in the GeV range, to propel particles with enough force to shatter protons and neutrons.

3.3.3 Research into sub-atomic particles at energies in the gigaelectron volt range traditionally is described as high energy or particle physics. Research at energies in the $10^2$-$10^3$ MeV range is described as intermediate energy physics, or sometimes intermediate energy nuclear physics. Research at energies of less than $10^2$ MeV might be called low energy nuclear physics. The distinctions between these three areas of research are fading and many scientists now regard the forefront of nuclear physics to be in the range of gigaelectron volts/nucleon (nucleon = proton or neutron). The division between nuclear physics and particle physics is now one of intent rather than energy range. Nuclear physics involves studying the nucleus and how it is constructed while particle physics is involved with the structure of the nucleon and with the leptons.
3.3.4 Facilities required to carry out research in the gigaelectron volt range are extremely expensive. Such facilities cannot be installed at every institution needing them, but rather they are centralised at the national or international level. The new electron collider (LEP) being constructed at CERN, for example, is an international facility which will cost in excess of $400 million. This cost is being born by a consortium of 13 European countries. Even so, one member, the UK, is re-evaluating its commitment to CERN[5].

3.3.5 Because high energy accelerator facilities are expensive and centralised, nearly all scientists who carry out experimental high energy physics research must take their research to facilities distant from their home institutions. This mechanism has come to be known as 'suitcase physics'.

3.3.6 Accelerators which operate at intermediate energies are less expensive, costing in the vicinity of $100 million. They are operated by many developed countries including Canada, the US, Germany, Japan and Italy.

3.3.7 Australia does not have an accelerator which operates in the intermediate or high energy range. The only major facility in this country at which basic research in nuclear physics can be undertaken is at the ANU. This accelerator presently operates in the low energy range and is designed for use in a particular area of nuclear physics research known as heavy ion research. Some research at higher energies is carried out by small groups of Australians who travel overseas to use foreign facilities. Accelerators with energies below the ANU level are used for applied research at other Australian centres; these are examined later.

3.4 Australian Research in Particle Physics

3.4.1 Australia has almost no involvement in experimental high energy particle physics. The exception is one academic staff member and one postgraduate student from the University of Melbourne who currently are attached to a research group at CERN. Australia is, therefore, virtually isolated from research at the frontier of the most fundamental area of physics.

3.4.2 Canada, by comparison, has 40 experimenters taking part in particle physics research at foreign facilities by the suitcase mode of operation.

3.4.3 It has been estimated by members of the physics community that it would cost about $0.5 million per annum to support a small group of Australian scientists to engage in particle physics research at CERN, a major international accelerator facility. Such a group might consist of three academics, three professional staff and a small number of postdoctoral fellows and graduate students[6].
3.5 Australian Research in Intermediate Energy Nuclear Physics

3.5.1 A group of three staff and, on average, about eight graduate students from the School of Physics at the University of Melbourne have taken part in intermediate energy nuclear physics research for over a decade. The group has used accelerator facilities at the Indiana University in USA and at TRIUMF (Tri University Meson Facility) in Canada.

3.5.2 Research has involved the measurement of nuclear structure and behaviour and comparison of these measurements with theoretical models. Studies have examined single particle aspects of nuclear structure using knock-out reactions, inelastic proton scattering and transfer reactions and the collective properties of rare earth nuclei using inelastic proton scattering. They are also proposing to use inelastic proton scattering at large momentum transfer to probe one aspect of the role of pi-mesons in nuclear reactions.

3.6 Australian Research in Low Energy Photonuclear Physics

3.6.1 A group of three staff members and nine postgraduate students at the School of Physics in the University of Melbourne is involved in basic research in photonuclear physics. Research is based on an in-house 35 MeV betatron accelerator and collaborative work at the linear accelerator facility at Tohoku University, Japan. The betatron is now obsolete and scientists are moving into research in the intermediate energy range using the Tohoku accelerator.

3.7 Australian Research in Low Energy, Heavy Ion Nuclear Physics

3.7.1 The 14UD accelerator at the Department of Nuclear Physics at the ANU was commissioned in 1974 and until the early 1980s it was the world's highest voltage tandem accelerator. Consequently, the Department became a leading centre for the study of heavy ion physics in the energy range around 8 MeV/nucleon. Heavy ion nuclear physics research in this energy range is concerned primarily with the collective behaviour of a large but finite system of strongly interacting particles.

3.7.2 Heavy ions are formed from elements such as lithium, oxygen and nickel by stripping atoms of electrons. The ions are accelerated and focussed onto target nuclei.

3.7.3 The nature of the interaction between the projectile heavy ions and the target nuclei varies according to the distance between the projectile and target nuclei. At relatively large distances (10^-10 cm) the projectiles interact only with the electrons surrounding the target nuclei. At closer distances, nuclei experience strong electrostatic repulsion between positively charged protons in both nuclei. These forces can excite either or both nuclei in short-lived excited states. Measurement of the amount of such Coulomb excitation reveals information about the shapes of the nuclei.
3.7.4 If the projectile nuclei are moving fast enough to overcome the electrostatic repulsive forces between nuclei, protons and neutrons may be exchanged resulting in the formation of 'exotic' nuclei. Alternatively, projectile and target nuclei may fuse to form an excited and rapidly rotating compound which then decays by neutron and gamma ray emission, by fission or by both. Measurements of the gamma rays or the fission fragments reveal how nuclear matter behaves when it is subjected to severe rotational stress. Researchers at the ANU have produced collisions between projectile nuclei of atomic number up to about 32 and target nuclei of heavy elements like lead. Different groups within the Department of Nuclear Physics are working on facets of all the processes resulting from the interaction of heavy ion beams and target nuclei including electron exchange effects, Coulomb excitation, single particle transfer reactions, exotic nuclei and the decay of the compound system by fission.

3.7.5 The 14UD accelerator facility at the ANU is the only major facility in Australia which is suitable for basic research in nuclear physics. The facility offers the opportunity for Australian postgraduate students to carry out fundamental research as part of their training in this country and is responsible for retaining some first class nuclear physicists in Australia.

3.7.6 Recently the frontiers in heavy ion nuclear physics research have moved beyond the ANU facility as the energies used in nuclear physics research move further towards the high energy physics range. New heavy ion accelerators such as those at Chalk River (Canada), Oak Ridge (USA) and Daresbury (UK) are able to obtain higher energies (up to 50 MeV/nucleon for light ions) and to accelerate heavier ions\[\text{IO}\].

3.7.7 The Department of Nuclear Physics has put forward a proposal to upgrade the 14UD accelerator by addition of a linear accelerator booster at an estimated cost of $6.6 million. This would double the existing energy and enable experiments at higher energies (up to 16 MeV/nucleon) and with heavier ions to be carried out. It would enable the ANU group to work at the forefront of their field for another decade. This proposal, and the other needs of the scientists in basic nuclear science research in Australia, are evaluated in Chapter 7.

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8. E. G. Muirhead, University of Melbourne, information provided to the ASTEC working party, 1985.

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4.1 Introduction

4.1.1 Australia's involvement in nuclear science and technology ranges from basic research pursued solely in order to obtain new knowledge, to applied research using nuclear technology and finally to the application of nuclear technology for social and economic benefit. Because these activities form a continuum, divisions between basic research, applied research and applications in industry, medicine and elsewhere are difficult to make and sometimes artificial. Such divisions are, nevertheless, useful because they facilitate a description and analysis of Australian nuclear science and technology.

4.1.2 In applied research, original investigations are undertaken in order to acquire new knowledge which is directed towards a specific practical aim or objective. It is undertaken either to determine possible uses for the findings of basic research, or to determine new methods or ways of achieving some specific and predetermined objectives.

4.1.3 The tools and techniques derived from basic research in nuclear science are used widely in applied research in Australia in many scientific disciplines as diverse as geology, medicine and microelectronics. Radioactive tracer techniques and particle beams and particle detectors, for example, are used in most areas of scientific investigation. Applied research in the discipline of nuclear science is also carried out in this country and includes, for example, the nuclear safeguards research programs of the Australian Atomic Energy Commission (AAEC) and the development of a proton microprobe at the University of Melbourne. Some of the many uses of nuclear technology in applied research in Australia are described in this chapter.

4.1.4 Because the technology of nuclear science is used in applied research in so many different disciplines and programs, it is difficult to calculate a national annual expenditure on applied research using nuclear technology. An indication of the level of resources committed to this area may be obtained by examining the expenditures of some government laboratories and institutes of higher education which operate nuclear facilities or which use nuclear facilities on a regular basis at other than their home institutions.

4.1.5 By far the largest Australian centre of applied research using nuclear technology is the AAEC Lucas Heights Research Establishment. The annual budget of the Commission in the 1984-85 financial year was $48 million. Not all this amount, however, was used to support nuclear science research. About $6 million was accounted for by non-nuclear research carried out by CSIRO at Lucas Heights and a further $6 million by the regulatory, health and safety and commercial activities of the AAEC. If overheads are split pro-rata between research and these other operations then the amount devoted by the AAEC to applied research using nuclear technology in 1984-85 can be estimated as $29 million. (Table 4.1).
Table 4.1
Annual Expenditure by the AAEC for 1984-85

<table>
<thead>
<tr>
<th>AREA</th>
<th>EXPENDITURE ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Research</strong></td>
<td>16.3</td>
</tr>
<tr>
<td><strong>Operations</strong></td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td>3.0</td>
</tr>
<tr>
<td>Support for CSIRO</td>
<td>5.8</td>
</tr>
<tr>
<td>Regulatory</td>
<td>0.6</td>
</tr>
<tr>
<td>HIFAR support to Commercial Products Unit</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Overheads</strong></td>
<td></td>
</tr>
<tr>
<td>Health and Safety</td>
<td>1.4</td>
</tr>
<tr>
<td>Engineering and Operational Support</td>
<td>9.0</td>
</tr>
<tr>
<td>(including operation of HIFAR)</td>
<td></td>
</tr>
<tr>
<td>Management resources</td>
<td>10.9</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>48.0</td>
</tr>
</tbody>
</table>

Source: Figures from the AAEC

4.1.6 The high flux atomic reactor (HIFAR), the smaller research reactor MOATA, and the 3MV accelerator at Lucas Heights are made available to scientists from a wide range of disciplines outside the AAEC through the Australian Institute of Nuclear Science and Engineering (AINSE). The facilities, therefore, service research not only within the AAEC but also receive over 300 visits each year from researchers from the institutions of higher education and CSIRO.

4.1.7 Other major accelerator facilities for applied research are at the CSIRO Division of Mineral Physics and Mineralogy, the Royal Melbourne Institute of Technology and the University of Melbourne.

4.1.8 The Australian research programs using nuclear technology are too numerous to describe individually in this report. Some of the larger, and hence more easily recognised groups which use nuclear techniques, but do not operate major nuclear facilities at their home institutions, are at the Australian Radiation Laboratories, CSIRO Divisions of Energy Physics, Mineral Engineering, Energy Chemistry and Chemical Physics and the School of Nuclear Engineering at the University of New South Wales.

4.1.9 The total national expenditure for 1984-85 on applied research using the technology of nuclear science is estimated to be in the vicinity of $31 million. This
was calculated as the sum of the annual expenditures on this research category by organisations which have a substantial research effort requiring the use of nuclear facilities (Table 4.2). It includes the cost of operating the nuclear facilities but not major capital costs.

4.1.10 Most applied research programs in Australia which use nuclear technology either use particle accelerators or else rely on HIFAR as a source of neutrons or radioisotopes. There follows an overview of Australian applied research programs which use nuclear technology. This is not intended to be a comprehensive catalogue of all such programs but rather aims to give an appreciation of the great variety of uses of nuclear technology in applied research. Proposals for new or upgraded nuclear facilities for applied research are mentioned in context.

4.2 Applied Research Programs which Rely on Reactor-produced Neutrons or Radioisotopes

Neutron beam research[1, 2, 3, 4]

4.2.1 Neutrons have a number of unique characteristics which make neutron beams very useful scientific tools in many disciplines. The wavelength of the thermal neutron is comparable to the interatomic spacing in condensed matter; the neutron has a magnetic moment and can be used in probing the magnetic properties of materials; the neutron carries no charge and therefore can penetrate deeply into materials unaffected by the cloud of electrons surrounding each atom; and finally, thermal neutrons cause less radiation damage in target samples than do X-rays or electrons.

4.2.2 Neutron diffraction (or neutron scattering) is a technique in which neutrons are used to examine the arrangement and vibrations of atoms in materials. For example, a beam of neutrons of fixed and relatively short wavelength is directed into a target sample. The neutrons penetrate the material and are scattered by the ordered array of atoms in it. A scanning detector counts the number of neutrons recorded at each angle from the beam, and by plotting neutron number against scattering angle, a characteristic pattern of peaks, called the diffraction pattern, is obtained. The positions of the peaks define the symmetry of the unit cell of the sample material. The relative intensities of the peaks provide information on the arrangement and types of atoms within each unit or, in metallurgical applications for example, the volume fraction occupied by different crystalline phases.

4.2.3 Australia has had a strong research effort in neutron diffraction for many years, the topics of interest ranging from analysis of the structures of metal hydrides, SYNROC and important minerals to the study of biological membranes.

4.2.4 There are currently about 20 research groups in Australia involved in carrying out research using neutron beams. These groups are members of the Australian Neutron Beam Users Group (ANBUG), an organisation formed to promote the interests of researchers in neutron scattering in Australia. The groups include biologists, chemists, geologists, metallurgists and physicists from the AAEC, CSIRO and Australian institutions of higher education.
<table>
<thead>
<tr>
<th>ORGANISATION</th>
<th>STAFF IN APPLIED RESEARCH USING NUCLEAR(1) TECHNOLOGY</th>
<th>POSTGRADUATE STUDENTS IN APPLIED RESEARCH USING NUCLEAR TECHNOLOGY</th>
<th>IDENTIFIABLE BUDGET FOR APPLIED RESEARCH USING NUCLEAR TECHNOLOGY $M (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAEC</td>
<td>310</td>
<td>NA(3)</td>
<td>29</td>
</tr>
<tr>
<td>CSIRO - Mineral Physics</td>
<td>4</td>
<td>NA</td>
<td>0.25</td>
</tr>
<tr>
<td>CSIRO - Chemical Physics</td>
<td>9</td>
<td>NA</td>
<td>0.05</td>
</tr>
<tr>
<td>CSIRO - Mineral Engineering</td>
<td>14</td>
<td>NA</td>
<td>0.9</td>
</tr>
<tr>
<td>CSIRO - Energy Chemistry</td>
<td>6</td>
<td>NA</td>
<td>0.4</td>
</tr>
<tr>
<td>ARL</td>
<td>28</td>
<td>NA</td>
<td>1.15</td>
</tr>
<tr>
<td>University of Melbourne - School of Physics</td>
<td>9</td>
<td>10</td>
<td>0.6</td>
</tr>
<tr>
<td>University of NSW - School of Nuclear Engineering</td>
<td>4</td>
<td>10</td>
<td>0.3</td>
</tr>
<tr>
<td>Royal Melbourne Institute of Technology</td>
<td>8</td>
<td>11</td>
<td>0.1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>420</td>
<td>31</td>
<td>30.5</td>
</tr>
</tbody>
</table>

(1) Includes professional and technical staff. Allowances are made for the proportion of time academic staff at the University of Melbourne devote to teaching.

(2) Excludes large capital items. Government laboratory expenditures are for the financial year 1984-85. Institution of higher education expenditures are for 1984 except in the case of RMIT which is for 1985.

(3) NA: not applicable

Source: Figures provided by organisations concerned.
4.2.5 Research using neutron scattering techniques is carried out in Australia at HIFAR. Scientists from outside the AAEC gain access to HIFAR through collaboration with AAEC staff and through AINSE. HIFAR is not suitable for all types of neutron beam research and a small number of scientists travel overseas each year to carry out their experiments.

4.2.6 HIFAR is a medium flux reactor producing a thermal neutron flux of $10^{14}$ neutrons/cm²/sec. Some experiments require the higher flux of $10^{15}$ neutrons/cm²/sec which is available at overseas reactors such as those at the Institute Laue-Langevin (ILL), Grenoble, France and the Brookhaven National Laboratory, USA. High flux neutron beams are also available at spallation neutron sources such as that recently completed at the Rutherford Appleton Laboratory, UK. Neutron beams from spallation neutron sources are not always a suitable substitute for neutrons from a reactor because spallation neutron sources produce a different spectrum of neutrons, and these are in a pulsed rather than a continuous stream. Neutrons are produced by spallation neutron sources by focussing short bursts of protons or electrons from an accelerator on a heavy metal target such as uranium.

4.2.7 HIFAR produces neutrons with short wavelengths (thermal neutrons) which are well matched to the interatomic distances in solids and liquids. Experiments which involve biological molecules, where interatomic spaces are greater, require neutrons with longer wavelengths (cold neutrons). These are only available in significant fluxes at overseas sources.

4.2.8 Australian scientists who travel overseas to use neutron beam facilities which are not available in Australia have received support for their travel from the Australian Research Grants Committee and from their home institutions. To date they have been able to use overseas neutron beam facilities at ILL and Oak Ridge without charge because of their association with overseas nuclear scientists (often on the basis of long-term personal friendships). There are indications, however, that in the future charges will be made for the use of some overseas neutron sources.

4.2.9 Consideration must be given to the future funding requirements of Australian scientists who travel overseas to use neutron beam facilities which are not available in this country. This issue will be addressed further in Chapter 7.

**Neutron activation analysis[5]**

4.2.10 Neutron activation analysis (NAA) is a highly sensitive multi-element analytical technique in which the sample is irradiated with neutrons in a nuclear reactor and the induced radioactivity measured by gamma spectrometry. Up to 40 elements, in concentration from parts per billion to per cent, can be determined simultaneously. The technique has the advantages that only small samples are required, there are few matrix interferences, no sample pretreatment is required, and the method is often non-destructive. In cases where interferences do occur, a post-irradiation separation of the desired radionuclides can be carried out. NAA has value for the analysis of gold, platinum-group metals and the rare earths.

4.2.11 Research using NAA is carried out at the CSIRO Division of Energy Chemistry, the AAEC Applied Physics Division, the University of Melbourne, ANU (Department of Geology) and the University of Tasmania.
4.2.12 The neutron transmutation doped silicon project of the AAEC is aimed at developing a commercial service based on HIFAR. Pure single crystals of the semiconductor silicon doped with phosphorus are widely used in the electrical power industry (for high voltage electrical switch gear, diodes and thyristors) and also in the electronics field. It has been found that the only practical method of achieving the precise and uniform levels of resistivity in the silicon crystals required for the above applications is by subjecting the silicon crystals to neutron irradiation in a reactor. During this irradiation, some of the silicon atoms capture a thermal neutron and are transformed into phosphorus atoms.

4.2.13 Scientists at the AAEC have proven the technical feasibility of the process and are currently negotiating with Japanese companies which require the service. The HIFAR reactor at Lucas Heights could handle up to 8 tonnes of silicon per year.

4.2.14 The Radioisotope Research Section of the Isotope Division of the AAEC has been involved in a wide range of applied research using radioisotopes or radioisotope techniques. Much of this research has been carried out in collaboration with other organisations.

4.2.15 Applied research using radioisotopes carried out by the AAEC for industry can be summarised under three headings:

- **flow studies** - flow rate measurements, residence time studies, leak detection, and wear studies;
- **environmental studies** - studies of waste water treatment plants, sewage and acid waste disposal and prediction of waste disposal programs; and
- **coastal engineering studies** - movement of sand in rivers, estuaries and near-shore areas, dredge spoil movement and sediment gauging.

4.2.16 A recent example of a research project in the first category is the study of residence times in blast furnaces which is being carried out in collaboration with BHP Steel. An environmental study in 1981 examined the dispersion and movement of acid effluent discharged into the ocean at Burnie in Tasmania. This study was carried out in collaboration with industry. An example of a coastal engineering study is a project being carried out with the Public Works Department of NSW to investigate major sand movement in Port Hacking.

4.2.17 The AAEC Nuclear Geohydrology Group has three main collaborative projects underway with the Bureau of Mineral Resources. This research is providing information which will lead to the improved management of water resources and wastes, and an increased understanding of processes such as the origin of subsurface saline water. Studies are taking place in the Amadeus Basin, the Great Artesian Basin and the Murray Basin. In addition, caesium-137 techniques are being used to study the cumulative effect of erosion and sedimentation.
4.2.18 A final example demonstrates the diversity of uses of radioisotopes in applied research. The Isotope Applications Research Group at the AAEC laboratories has, over the last 10 years, used radioisotope techniques to study termite infestation in historic Sydney buildings and the behaviour of termites in their natural environment.

Food irradiation[6, 8]

4.2.19 Radioisotopes produced in HIFAR are being used as sources of ionising energy for applied research into food irradiation.

4.2.20 The AAEC has carried out research into food irradiation in a number of areas which are considered to have application in Australia. The area of most immediate importance is in the disinfestation of fruit from the Queensland fruit fly (Dracus tryoni) before export. Previously this has been achieved using ethylene dibromide but US health authorities are now phasing out the use of this fumigant because it may be carcinogenic. It is anticipated that the use of ethylene dibromide will be totally banned in the US by 1986 and this will cause serious problems for Australia's fruit export market if an alternative method of disinfestation is not approved. Research at Lucas Heights has demonstrated that a wide range of fruits, including tomatoes, oranges, mangoes, grapes and rockmelons may be satisfactorily disinfested by low dosage irradiation. Injury to avocados and custard apples, however, was evident even at low doses.

4.2.21 Ionising irradiation is antibacterial and may be used to reduce counts of spoilage bacteria and pathogenic bacteria in foods. Some areas in which this property may have important application in Australia include the treatment of whole carcass chilled meat for export, the eradication of salmonella from dressed poultry and in reducing bacterial counts in crayfish, prawns and fish for export.

4.2.22 Legislation enabling the irradiation of food has not yet been approved in Australia. The National Health and Medical Research Council is currently working towards formulating regulations based on the provisions of the Codex Alimentarius Commission's General Standard for Irradiated Foods and the Recommended International Code of Practice for the Operation of Irradiation Facilities used for the Treatment of Foods. It is anticipated that their deliberations will conclude in 1986. Although irradiation has been shown to be a safe process for extending the life of food, public acceptance of the procedure has not yet been established.

The need to replace or upgrade HIFAR

4.2.23 HIFAR was one of six DIDO-class reactors designed in the 1950s and represents the technology of that era. It has been operating for 25 years and is currently being refurbished to ensure its safe operation into the 1990s. Although there is no evidence of deterioration which is likely to close down HIFAR in the next 20 years, the future needs of scientists engaged in reactor-based applied research must be considered[9].

4.2.24 The applied research programs described in the previous section illustrate the uses of HIFAR as a source of medium flux neutrons for neutron beam research and of radioisotopes for radioisotope tracer techniques. In Chapter 5 some applications of nuclear techniques in medicine and industry are described which also rely on the presence of a neutron source in Australia.
4.2.25 Alternative proposals have been prepared to refurbish and upgrade HIFAR (estimated cost $10 million), to replace HIFAR with a new reactor of equivalent neutron flux levels (estimated cost $80 million) or to replace HIFAR with a smaller reactor of the 5MW class (estimated cost $25 million). The latter proposal is coupled with provision for increased use of overseas neutron beam facilities. These proposals are evaluated in Chapter 7.

4.3 Applied Research Programs which Rely on Particle Accelerator Facilities

4.3.1 Applied research using particle accelerators in Australia is based on low energy accelerators at the CSIRO Division of Mineral Physics and Mineralogy, the University of Melbourne, the Royal Melbourne Institute of Technology and the AAEC (Table 4.3).

Table 4.3
Major Accelerator Facilities for Applied Research in Australia

<table>
<thead>
<tr>
<th>INSTITUTION</th>
<th>TYPE OF ACCELERATOR</th>
<th>MAXIMUM VOLTAGE (MV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAEC</td>
<td>Van de Graaff</td>
<td>3</td>
</tr>
<tr>
<td>CSIRO, Division of Mineral Physics and Mineralogy</td>
<td>Tandem</td>
<td>3</td>
</tr>
<tr>
<td>RMIT</td>
<td>Tandem</td>
<td>1</td>
</tr>
<tr>
<td>University of Melbourne, School of Physics</td>
<td>Pelletron</td>
<td>5</td>
</tr>
</tbody>
</table>

4.3.2 Uses of accelerator-based nuclear techniques in applied research are varied. They include the measurement of the composition of mineral samples, the quantitation of traces of cosmogenic isotopes in natural waters and soils and the characterization of surface modification induced by ion implantation and other techniques. Some of the most commonly used techniques are described below followed by a summary of applied research programs at the Australian accelerator facilities.
4.3.3 **Particle-induced X-ray emission (PIXE)**[10]. In this technique proton beams are focussed onto the sample being analysed causing X-ray emission. Such emissions are characteristic of the sample's constituent elements. The technique is important because it has a sensitivity of a few parts per million which is two orders of magnitude greater than can be obtained with alternate techniques. PIXE is especially useful for rapid multi-elemental trace analysis.

4.3.4 **Rutherford backscattering (RBS)**[10]. A beam of particles is focussed on the sample. As the beams enter the surface, a small fraction of them collide with the atoms and suffer classical 'billiard-ball' elastic backscattering. The ions are emitted from the surface with an energy lower than the incident energy and characteristic of the target atom; the heavier the target atom, the higher the energy of the backscattered ion. Most of the incident ions penetrate the surface atomic layer and scatter from successively greater depths, losing energy on their inward and outward paths due to collisions with the electrons in the sample. With a knowledge of energy loss per unit depth into the material (the stopping power), it is possible to deduce the depth at which an ion was backscattered. In this manner, RBS provides simultaneous elemental analysis and depth distribution information.

4.3.5 **Nuclear reactions analysis (NRA)**[11]. In a nuclear reaction, the incident ion usually combines with the nuclei of sample atoms and the resulting compound nuclei then break up producing one or more types of product radiation. Nuclear reactions useful for NRA can on this basis be divided into three categories — those leading to the emission of energetic ions, those leading to the emission of energetic neutrons, or those reactions that produce gamma-rays. The third type is sometimes referred to as Particle Induced Gamma-ray Emission (PIGE or PIGE).

4.3.6 Nuclear reactions can be produced most easily in light isotopes so that NRA is particularly useful for the determination of elements from hydrogen to aluminium.

4.3.7 The incident ions can be protons, deuterons or heavier ions with energies of the order of 1 MeV or greater. Because such ions do not penetrate very far into a sample (usually much less than 1 mm) they can be used to determine the composition of a thin layer or they can be used to obtain depth information in a manner similar to that for RBS. It is also possible to use a narrow peak or resonance in the yield of some kinds of reactions to probe the concentration of a target isotope at a specific depth below the sample surface. Depth profiling of specific isotopes, by measuring the energy of product radiation or by measuring the yield as a function of the energy of the incident ions, can be achieved for depths up to a few micrometers with a depth resolution in the nanometer range.

4.3.8 The characteristics of PIXE, RBS and NRA techniques are compared in Table 4.4.
Table 4.4
A Comparison of the Typical Properties of Some Ion Beam Techniques

<table>
<thead>
<tr>
<th>TECHNIQUE</th>
<th>ELEMENTS (Z) READILY DETECTED</th>
<th>ELEMENT IDENTIFICATION</th>
<th>MINIMUM DETECTION LIMITS (PPM)</th>
<th>DEPTH RESOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBS</td>
<td>Z &gt; 1</td>
<td>Fair</td>
<td>10-10000</td>
<td>10-400Å</td>
</tr>
<tr>
<td>NRA - particles</td>
<td>Li, Be, B, C, N, O, F, Na, Al, P</td>
<td>Good</td>
<td>1-1000</td>
<td>20-200Å</td>
</tr>
<tr>
<td>NRA - gamma rays</td>
<td>Li, B, F, Na, Mg, Al</td>
<td>Excellent</td>
<td>1-1000</td>
<td>100-1000Å</td>
</tr>
<tr>
<td>PIXE</td>
<td>Z &gt; 10</td>
<td>Excellent</td>
<td>0.1-100</td>
<td>approx 1μm</td>
</tr>
</tbody>
</table>

Source: Barfoot[10]

4.3.9 Channelling[10]. Rutherford backscattering can be used to obtain information on where the sample atoms are sited within the crystal lattice. This is especially useful in the control of methods such as doping by ion implantation, a technique whereby ions such as arsenic are accelerated to 100 keV and implanted into, for example, silicon to produce a well-defined, shallow and narrow dopant distribution. The questions that can be answered are whether the implanted atoms are sitting on substitutional or interstitial sites, especially after annealing, and whether there is any residual crystal damage from the implantation process. The method known as channelling consists of lining up a major axis of the crystal with the direction of the ion beam. If atoms are sitting on lattice sites (substitutional) they will remain almost 'unseen' by the aligned beam as they are hidden in the 'shadow' of the crystal structure at the surface. Atoms not on lattice sites located near the centre of the channels through the crystal will be seen much more readily. The fraction of atoms not on lattice sites is then determined by comparing the channelled result with one taken with a random alignment of the beam where all atoms are seen equally.

4.3.10 Accelerator mass spectrometry (AMS)[12]. Four steps are involved in the analysis of the isotopes of an element by mass spectrometry: volatilization and ionization of the element, acceleration of the ions through a potential field, separation of the isotopes and measurement of the intensity of the isotopes. Accelerator mass spectrometers accelerate ions to many times higher voltages than conventional spectrometers and have the advantage that much smaller samples may be examined in shorter times.
4.3.11 In the last decade nuclear physicists have been developing ways of applying AMS to many areas of applied science including geology. Cosmogenic nuclides which are produced by the interaction of cosmic rays with terrestrial and planetary matter, are used in terrestrial radiometric dating. Techniques have been established to utilize the isotope carbon-14 for dating. More recent work is developing techniques which utilize other isotopes, of which beryllium-10 and chlorine-36 have been the most important studied to date. These techniques have many applications including research on the atmosphere, the history of polar ice, manganese nodules and evolution of soil and its erosion. Particular Australian problems for which these techniques would be used are the availability and utilisation of groundwater resources, the problem of salinization of soil, and erosion of land and the coast. A unique opportunity was afforded by the marine nuclear tests in the mid-1950s. These released substantial amounts of chlorine-36 into the stratosphere. This pulse of chlorine-36 gradually settled into the earth entering the water table and provided the opportunity to follow the long-term movement of water through groundwater artesian systems.

4.3.12 Techniques for measuring chlorine-36 and beryllium-10 and other radioisotopes, especially at geological levels, are still in an early stage of development. It is not known what sensitivities ultimately will be achieved at different accelerator voltages.

4.3.13 Fast neutron beam facilities. Fast neutron beam accelerator facilities are important for applied research because of their application in the solution of problems relevant to the nuclear power industry, their use in the future development of fusion reactions and their value in radiobiological damage studies. Neutron beam facilities require extensive shielding to protect the personnel associated with the operation of the accelerator and are consequently not always available on accelerator facilities.

4.3.14 The availability of these different accelerator techniques at Australian applied research accelerator facilities is summarised in Table 4.5.
Table 4.5
Ion Beam Techniques Available At Major Australian
Applied Research Accelerator Facilities

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>RBS</th>
<th>NRA</th>
<th>PIXE</th>
<th>AMS</th>
<th>MICRO-PROBE</th>
<th>EXTERNAL</th>
<th>NEUTRON IRRADIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSIRO, Division of Mineral Physics</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>University of Melbourne</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RMIT</td>
<td>✓</td>
<td>✓</td>
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</tbody>
</table>

Source: Information provided by organisations concerned.

4.3.15 In 1983 a 3MV Tandetron accelerator was installed in the Heavy Ion Analytical Facility (HIAF) in the Division of Mineral Physics and Mineralogy at North Ryde. The aim of research at this laboratory is to develop applications of ion-beam techniques for energy and geoscientific research and ultimately to transfer these to industry. The facility already offers standard ion beam analysis techniques of PIXE, RBS and NRA. Scientists at HIAF are currently researching the development of the techniques of AMS to be used for carbon-14, beryllium-10 and chlorine-36 dating.

4.3.16 Three of a possible five beam lines are presently operational at HIAF. One is dedicated to a microprobe for use in mineralogical and geological studies. With the commissioning of the microprobe, programs involving trace element geochemistry, and directed towards advanced geochemical methods of exploration, have been undertaken. These include the diamond pathfinder study which is investigating the possibility of exploiting the trace element distributions in inclusions in igneous rocks to diagnose diamond-bearing kimberlites.

4.3.17 A number of collaborative programs with other CSIRO divisions are underway as well as five projects which are supported by CSIRO/universities collaborative funds. The latter include studies of amorphous semiconductors for electronic and optoelectronic applications; the characterization of new semiconductor material; ion-solids interaction studies; and a study of the diffusion of water in quartz.
4.3.18 The AMS program will be concentrated on the development of applications of beryllium-10 measurements to weathering studies around mineral deposits, in erosion studies and in studies of the evolution of sedimentary basins.

Applied research at the University of Melbourne accelerator facility[14]

4.3.19 The main use of the 5 U Pelletron accelerator at the University of Melbourne is for the development of the proton microprobe. This was developed in the School of Physics and is one of the most advanced proton microprobes in the world. It uses PIXE to map the spatial distribution of chemical elements in specimens, RBS to profile the depth distributions, and channelling contrast microscopy to study crystalline properties. It has applications in industrial, medical, biological, agricultural, geological, mineralogical, metallurgical, materials and semiconductor research. For example, it has been able to provide unique information on human genetic diseases, cancer cells, plant pollination, the cellular basis of Phytophthora cinnamoni (a disease causing major forest damage in Australia), wheat development, trace elemental distributions in terrestrial and lunar rocks, rare earths and precious metals and the depth profiles of dopant elements in semiconductor devices. The latter work is part of a collaborative program with the Commonwealth Microelectronic Special Research Centre in RMIT. The microprobe is currently involved in work for the Materials Research Laboratory in Melbourne and the Naval Research Laboratories in Washington on materials analysis (multiphase metals) and for A T & T Bell Laboratories in New Jersey and Hughes Aircraft Laboratories in California on laser annealing of semiconductors.

4.3.20 A Micro Analytical Research Centre has been set up within the School of Physics at the University of Melbourne to interface with users outside the School from both universities and industry.

4.3.21 The Physics School is building a second microprobe using university and Australian Research Grants Scheme funds. This will enable research on the microprobe itself to continue while freeing the main probe for industrial and scientific research. A contract has recently been signed by the University of Melbourne to supply a proton microprobe to the Institute of Physics in Beijing at a cost of $140,000.

4.3.22 It is anticipated that ultimately demand will make it no longer feasible to run two microprobe lines off the one Pelletron accelerator. Scientists at the Centre predict that by 1986-87 a case will be established for a second accelerator of equivalent energy (estimated cost $3 million in 1985 dollars).

4.3.23 Application of nuclear techniques of analysis to interdisciplinary studies using the Pelletron is not restricted to the microprobe but is carried out with higher intensity beams at the macro level using internal and extracted beam techniques.

Applied research at the Royal Melbourne Institute of Technology accelerator facility[15, 16, 17]

4.3.24 The Royal Melbourne Institute of Technology (RMIT) has a IMV Tandetron accelerator which is used for applied research in microelectronics. A project carried out in collaboration with the University of Melbourne is described in the previous section. The main research areas at RMIT using ion beam techniques are summarised below.
4.3.25 Ion implantation. Channelling, PIXE & RBS techniques are used to study the positioning of ions which have been implanted in semiconductors such as silicon and gallium arsenide.

4.3.26 Ion beam induced adhesion. Ion beams are used to induce adhesion of thin metal films onto semiconductor, insulator and metal surfaces in a process known as particle beam stitching (PBS). Research is seeking to elucidate the mechanisms of PBS and apply it to industrial processes.

4.3.27 Ion beam annealing. Damage to the crystalline structure of semiconductors caused by ion implantation is repaired by annealing at high temperatures. The regrowth layer is, however, often rich in defects. Research at RMIT uses RBS and channelling techniques to investigate these defects. Further research is using ion beam irradiation at high temperatures to stimulate the annealing process.

Applied research at the Australian Atomic Energy Commission accelerator facility[6]

4.3.28 A 3MV positive ion accelerator was installed at the Lucas Heights Research Laboratories in 1963. It was for many years the only facility in Australia where research and applications of fast neutron and ion beams could be carried out. Currently there are 11 fully developed beam lines on the accelerator dedicated to applied research. Techniques such as PIXE, RBS, channelling and fast neutron irradiation methods were pioneered in Australia on this facility and for the last 10 years or so have been available to the Australian scientific community as a service through AINSE.

4.3.29 There are currently 15 applied research projects in progress which involve developmental work by AAEC and AINSE staff, and a further 12 projects involving collaboration with other organizations in the application of ion beam techniques. These projects are too numerous to describe individually in this chapter but are listed in Appendix A. Some examples are given below to illustrate the variety of applied research undertaken at this facility.

4.3.30 Occupational health. Occupational exposure to heavy metals is measured using PIXE to analyse trace elements in hair, whole blood and serum. (Collaborator: Department of Industrial Relations, NSW).

4.3.31 Trace element analysis of Australian coal. PIXE and PIGME are used to analyse coal and provide mass balance of combustion products. (Collaborator: CSIRO Division of Energy Chemistry).

4.3.32 Crystalline rock analysis. PIXE and PIGME are used to measure element distribution in the region of microfissures in rocks from the Alligator Rivers region ore bodies and study trace element migration. This research is carried out for the US Nuclear Regulatory Commission. (Collaborator: Department of Soil Science, the University of Sydney).

4.3.33 South Western Pacific and Melanesian obsidian. PIXE and PIGME analysis of obsidian source and artefact collections is carried out as multivariate statistical analysis to produce a reference obsidian data catalogue. (Collaborators: Department of Prehistory, ANU and Department of Anthropology, Otago University).
The AAEC proposal for a new 8 MV tandem accelerator

4.3.34 The 3 MV accelerator at Lucas Heights has been totally superseded by tandem accelerators and is unsuitable for the development of the new field of accelerator mass spectrometry (AMS). A proposal has been put forward to government for a new 8 MV tandem accelerator to be installed at Lucas Heights at an estimated cost of $7 million.

4.3.35 Radioisotopes which can be determined at very low levels by AMS include beryllium-10, carbon-14, aluminium-26, chlorine-36 and iodine-129. Others such as calcium-41 are being investigated and other special applications are also being developed. Scientists at the AAEC Isotope Division have already taken part in collaborative research with the Bureau of Mineral Resources and the Universities of Arizona and Rochester in the early development of chlorine-36 and iodine-129 applications using a 10 MV tandem accelerator at the University of Rochester. One such application was in hydrology studies of the Great Artesian Basin in Australia. This work has stimulated interest in further applications in Australia.

4.3.36 The proposed 8 MV accelerator could contribute to more than half of the Commission's current research programs with special importance for research on the problems of soil salinity, erosion and the management of water resources. The solution of problems in such topics requires an understanding of the mechanisms involved in the movement of various elements through the atmosphere, geosphere and biosphere. It also depends on understanding the chronology of environmental changes in the Quaternary period (1.7 million years) and of geological changes on longer time scales. All of these areas can be advanced through the use of AMS. With existing technology, it is not possible to measure chlorine-36 at natural levels of concentration using accelerators less powerful than 8 MV.

4.3.37 The AAEC accelerator proposal is considered further in Chapter 7.

4.4 Applied Research Programs in Nuclear Science which do not Rely Directly on Reactor or Accelerator Facilities

4.4.1 There are some Australian applied research programs in nuclear science which are not directly dependent on either reactor or accelerator facilities. The AAEC SYNROC program, research and development work in support of the International Atomic Energy Agency (IAEA) safeguards, and environmental science associated with uranium mining are some important examples. Research efforts at the Australian Radiation Laboratory and the School of Nuclear Engineering at the University of New South Wales are also included in this category.

The SYNROC project

4.4.2 Waste management research at the AAEC Research Laboratories includes the SYNROC project. SYNROC is prepared by adding high level waste liquid to a mixture of the oxides of titanium, zirconium, calcium, barium and aluminium followed by drying, calcining and compacting of the resultant powder to high density in collapsible metal containers at 1150°C. These containers of dense SYNROC are finally sealed in thick-walled metal canisters for disposal.
4.4.3 SYNROC has achieved wide recognition as an alternative to borosilicate glass for the immobilisation of high level nuclear waste. The process is still in the research and development stage and a pilot plant to demonstrate the fabrication of SYNROC blocks containing simulated (non-radioactive) waste is under construction at the Lucas Heights site. Arrangements for collaborative SYNROC research and development have been negotiated with research organisations in Italy, Japan and the UK.

4.4.4 A related waste management project of the AAEC is the study of radionuclide migration in the vicinity of uranium ore bodies in the Northern Territory, as an analogue of a radioactive waste depository. This work is partly supported by the United States Regulatory Commission.

Safeguards instrument development[6]

4.4.5 The Federal Government has undertaken to assist the IAEA in measures to strengthen the international safeguards regime which has been established in support of the Nuclear Non-Proliferation Treaty. As part of this support program a number of novel scientific instruments are being developed at the AAEC. These include the following.

4.4.6 **A Gas Phase Enrichment Monitor** for the accurate measurement of the uranium-235 enrichment of uranium hexafluoride product at commercial gas centrifuge enrichment plants. This instrument has been delivered to the IAEA and has been accepted for safeguards use.

4.4.7 **GO NO-GO Monitors.** These instruments are being developed so that an inspector can verify that highly enriched uranium is not passing through the pipework in the cascade hall of gas centrifuge enrichment plants.

4.4.8 **Liquid Scintillator Neutron Coincidence Counter.** This instrument is being developed to allow accurate measurements of the plutonium content of the waste products from reprocessing plants.

Environmental science associated with uranium mining[6]

4.4.9 Scientists at the AAEC are carrying out applied research aimed at minimizing the environmental degradation associated with uranium mining. Research is concerned with the formation, detection and characterisation of pollutants, their geochemical fate and their toxicity. Topics studied include uranium mining and milling practices, leaching characteristics of Australian ores, alternative treatment processes, neutralisation of mill effluents, reduction of radon release from tailings dumps, determination of pollutant sources from open cut mining, transport of contaminants by ground and surface waters, soil-solute interactions, toxicity of heavy metals and the uptake of pollutants by flora and fauna.

The Australian Radiation Laboratory[19]

4.4.10 The Australian Radiation Laboratory conducts an applied nuclear research program involving the following elements:

- the development of national standards of ionising radiation dose and radioactivity;
public health hazards, dose levels and national standards of radiation dose in relation to uranium and thorium mining;

the physical aspects of the use of ionising radiation in the medical field;

the physical aspects of the use of radioactive materials in medical diagnosis and treatment;

public hazards due to microwaves and dose levels from sources of microwaves; and

public health hazards and dose levels of lasers.

The School of Nuclear Engineering at the University of New South Wales

4.4.11 Most current research programs in the School of Nuclear Engineering are of a theoretical nature although some include experimental research using nuclear technology. These are outlined in Chapter 6.

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11. J. R. Bird, AAEC, information provided to the ASTEC working party, 1985.


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19. W. H. Larkin, Australian Radiation Laboratory, information provided to the ASTEC working party, 1985.
5 MEDICAL AND INDUSTRIAL APPLICATIONS OF NUCLEAR TECHNOLOGY

5.1 Introduction

5.1.1 Nuclear technology has socially and economically important applications in medicine and industry in Australia. The applications of nuclear technology described in this chapter differ from applied research programs described previously in that they are not original investigations undertaken to acquire new knowledge, but rather they use established nuclear techniques in situations where the parameters of the norm are already well-defined.

5.2 Medical Applications of Nuclear Technology

5.2.1 Nuclear technology gained wide acceptance in medical diagnosis and treatment in the 1960s following the development of improved instruments for detection and mapping of radioactivity within the body, and of a range of short-lived radiopharmaceuticals.

5.2.2 Nuclear medicine facilities are now available in over 50 hospitals throughout Australia and are used for diagnosis in some 150,000 patients annually. Diagnosis using radioisotopes is often superior to other methods because the technique is non-invasive and facilitates the early detection of functional as well as structural disorders. Radioisotopes may be incorporated into biologically active molecules which become concentrated in specific organs of the body. These organs can then be visualized using special cameras or scanning equipment and their functions and structures assessed. Radioisotopes are also used for the treatment of malignancy, metabolic disorders and the relief of the symptoms of rheumatoid arthritis.

5.2.3 The Australian Atomic Energy Commission (AAEC) has been a major force in promoting the development of nuclear medicine in this country. A significant proportion of radioisotopes used in radiopharmaceuticals in Australia are produced in HiFAR and the Commission also operates a nationwide radioisotope and radiopharmaceutical distribution service. Over 80% of radioisotope sales from Lucas Heights are of technetium-99m. The revenue derived from radiopharmaceutical sales by the AAEC for the 1984-85 financial year was $2.5 million, while the associated expenditure was $3.0 million. The production and distribution of radioisotopes and radiopharmaceuticals by the AAEC is supported by research into the development of new and improved products.

5.2.4 The wide range of diagnostic medical procedures which utilize radiopharmaceuticals is summarised in Table 5.1. The procedure known as positron emission tomography (PET) is not available in Australia at present. This procedure relies on short-lived neutron deficient radioisotopes which are produced in a
cyclotron. As there is no suitable cyclotron in Australia, these radioisotopes cannot be produced locally and, furthermore, they cannot be imported because of their short half-lives. Two proposals for the establishment of a medical cyclotron facility in Australia, which have been brought to Government, are described in the following section.

Proposals for the establishment of medical cyclotron facilities in Australia[1, 2, 3]

5.2.5 Proposals for the establishment of medical cyclotron facilities were submitted to the Commonwealth Government in late 1983 by both the AAEC and the Austin Hospital in Melbourne.

5.2.6 A cyclotron is a machine designed to accelerate charged atomic particles emanating from an ion source in the centre of the cyclotron. The particle beam is focussed onto suitable targets to produce radioisotopes. Some of the radioisotopes which can be produced by a cyclotron, cannot be produced in a nuclear reactor, while others can be produced in a reactor only with great difficulty.

5.2.7 Some cyclotron-produced radioisotopes are imported into Australia for use in conventional imaging techniques using equipment which is already available at a number of Australian centres. These photon emitting radioisotopes include gallium-67, thallium-201 and indium-111. Others which could be used in Australia with existing facilities, but which cannot be imported because of their short half-lives, include iodine-123 (half-life 13 hours) and krypton-81m (half-life 13 seconds). These have important applications in studies of the thyroid, brain, kidney and lung.

5.2.8 The imaging technique known as positron emission tomography (PET) utilizes a group of cyclotron-produced radioisotopes which decay by positron emission. PET requires special instrumentation which is not available in Australia. Many of the radioisotopes used in PET have such short half-lives that they could not be imported. Some such as carbon-11 (half-life 20 minutes), oxygen-15 (half-life 2 minutes) and nitrogen-13 (half-life 10 minutes) are so short lived that they would need to be produced in a cyclotron located at the same site as the PET instrumentation.

5.2.9 PET is used overseas for research into normal physiology and disease states. It has important research applications in the study of brain structure and physiology in relation to senile dementia, stroke and epilepsy. PET is used for studying other parts of the body, for example, in examining myocardial metabolism or blood flow. Although PET generally is considered to be primarily a research tool at present, it has potential application in medical diagnosis and can be used, for example, in locating epileptogenic foci in the brains of certain epileptic patients.
<table>
<thead>
<tr>
<th>ORGAN</th>
<th>TEST</th>
<th>TRACER</th>
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<tr>
<td>heart</td>
<td>gated heart pool scan</td>
<td>technetium-99m labelled red blood cells</td>
<td>• predictor of post infarction prognosis</td>
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<td>• assessment of ventricular function</td>
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<td>• serial monitoring of cardiac function</td>
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<td></td>
<td>first pass angiogram</td>
<td>technetium-99m labelled red blood cells</td>
<td>• diagnosis of intra-cardiac shunts</td>
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<td>• detection of fluid within the pericardial sac</td>
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<td></td>
<td>regional myocardial blood perfusion</td>
<td>thallium-201</td>
<td>• used with electrocardiograph in the investigation of ischaemic heart disease</td>
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<td></td>
<td></td>
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<td>• assessment of effectiveness of coronary artery by-pass grafts</td>
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<td></td>
<td>hot spot scanning</td>
<td>technetium-99m labelled pyrophosphate</td>
<td>• diagnosis of recent myocardial infarction</td>
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<tr>
<td>lung</td>
<td>perfusion lung scan</td>
<td>technetium-99m labelled protein microspheres</td>
<td>• diagnosis of pulmonary embolism</td>
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<tr>
<td>brain</td>
<td>positron emission tomography</td>
<td>fluorine-18 labelled fluorodeoxy-glucose</td>
<td>• identification of those patients with refractory epilepsy who will benefit from temporal lobe surgery</td>
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<td></td>
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<td>• diagnosis of cerebral tumours</td>
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<td>iodine-123 &amp;</td>
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<td>liver</td>
<td>liver scan</td>
<td>technetium-99m</td>
<td>. cancer diagnosis</td>
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<td>labelled sulphur colloid</td>
<td>monitoring of response to treatment</td>
</tr>
<tr>
<td>bone</td>
<td>bone scan</td>
<td>technetium-99m</td>
<td>. cancer diagnosis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>labelled phosphonate</td>
<td>monitoring of response to treatment</td>
</tr>
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Source: Smith[1], National Health Technology Advisory Panel[2], Austin Hospital[3] and information collected at interview.

5.2.10 The AAEC proposes that a dual purpose medical cyclotron facility be established at the Royal Prince Alfred Hospital in Sydney. The cyclotron would be used to produce radioisotopes for distribution to other centres and for on-site PET. The facility would incorporate a 40MeV cyclotron as well as a national nuclear medicine and PET research and training centre. The total capital cost of the facility, including buildings, is estimated as $11 million.

5.2.11 The Austin Hospital proposes that a centre based on a 16 MeV cyclotron be established at the Hospital for the sole purpose of supporting PET. The proposal also suggests that, if it is decided to establish a facility for producing other radioisotopes for distribution throughout Australia, then a second 40 MeV cyclotron should be installed at the Austin Hospital back-to-back with the dedicated 16 MeV cyclotron.

5.2.12 In September 1984 a Medical Cyclotron Committee was established on the recommendation of the National Health Technology Advisory Panel to carry out a technical and economic study to determine the costs and benefits for Australian health care of medical cyclotron facilities. This Committee has undertaken a detailed evaluation of the AAEC and Austin Hospital proposals.

5.2.13 ASTEC believes that the establishment of a medical cyclotron facility in Australia would provide scientific and social benefits. It would contribute to Australian medical research by making PET available for the investigation of an important group of diseases. It would provide certain short-lived, cyclotron-produced radioisotopes to be used in conventional imaging techniques, so increasing the range of available diagnostic techniques in nuclear medicine. It would also enable the development of PET for use as a routine diagnostic tool in this country.
5.2.14 ASTEC considers that the main justification for funding a medical cyclotron in Australia is based on the use of PET in medical research, therefore, medical cyclotron proposals must compete for resources with other medical research proposals. The relative importance of PET in medical research, and the two medical cyclotron facility proposals, can be best assessed by the Medical Cyclotron Committee on the basis of its detailed study. These issues will not be addressed further by ASTEC in this report.

5.3 Industrial Applications of Nuclear Technology in Australia

5.3.1 Many of the reactor and accelerator-based nuclear techniques which are used in Australia in applied research have important potential applications in industry. Some of these applications, which already are being utilized by Australian industry, are described in the following section.

5.3.2 Gauges[4] based on sealed radioactive sources are used widely by Australian industry. These might measure, for example, the thickness of paper in a paper plant, the level of powders in packets or the moisture content of stored grain (Table 5.2). Thousands of such gauges are in use in Australian industry and they contribute to productivity in many industrial sectors.

Table 5.2
Some applications of sealed radioactive sources in Australian industry

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>EXAMPLES OF USE</th>
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<tr>
<td>Level gauges</td>
<td>upper and lower levels on coal hoppers</td>
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<td>levels in cigarette and soap packages</td>
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<tr>
<td></td>
<td>determination of build-up of flue ash in boilers</td>
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<tr>
<td>Density gauges</td>
<td>concentration in liquid slurries</td>
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<tr>
<td>X-ray gauges</td>
<td>on-line analysis of mineral contents in liquid slurries</td>
</tr>
<tr>
<td>Moisture gauges (neutron and hard gamma sources)</td>
<td>road work and construction</td>
</tr>
<tr>
<td></td>
<td>management of farm resources</td>
</tr>
<tr>
<td></td>
<td>grain storage</td>
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<td></td>
<td>timber industry</td>
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</table>

Source: Information provided by the AAEC
5.3.3 On-line and bulk analysis of metalliferous ores and coal. The Australian mineral industry uses nuclear technology based on sealed radioactive sources for on-line and bulk analysis of metalliferous ores and coal. This results in increased recovery of coal and valuable minerals and more efficient operation of processing plants[5].

5.3.4 One of the more sophisticated systems for on-line analysis which has been developed in Australia is the ISA bulk mineral analyser which is manufactured by AMDEL under licence to the AAEC. The technique uses resonance scattering of gamma rays from a radioisotope source to measure the base metal content of mineral slurries. The systems cost $250,000 - $500,000 each and have been supplied to all major Australian mining companies. In addition, an export market worth about $2 million p.a. has been established for this and related products and it is expected this will increase to $3-4 million p.a. in the future.

5.3.5 A related technique for measuring ash in coal slurries is being commercialised by AMDEL and it is expected that this system will have an export market of $1-2 million in future years as well as supplying the domestic market[6].

5.3.6 An automated system for on-line analysis of ash and moisture in bulk coal streams is being produced by Coalscan Pty Ltd under licence to the University of Queensland and the CSIRO Division of Energy Chemistry. Coalscan units have been installed at five coal mines in New South Wales and Queensland. It is estimated that a one percent yield improvement achieved by Coalscan would be worth over $1 million annually to a coal mine with a throughput of three million tonnes per year[7].

5.3.7 Nuclear radiations[8]. Gamma rays from large cobalt-60 sources may be used in a variety of industrial processes known collectively as radiation processing. Radiation produces crosslinking or degradation in polymers, initiates polymerisation in monomers, destroys pathogens in medical products and renders ineffective certain spoilage organisms or processes in food. In Australia, two companies are using radiation processes to produce crosslinking in polymers (plastics). There are also four industrial gamma irradiation plants including one at the AAEC Research Laboratories. These are used mainly for sterilising medical and surgical products which cannot withstand sterilisation processes involving high temperatures.

5.3.8 Radioactive tracer techniques[9] are available to Australian industry through the AAEC. These techniques may be used for monitoring industrial processes and investigating changes in yield and efficiency. Radioactive tracer techniques have varied industrial applications including:

- flow rate measurements;
- leak detection;
- silt and sand movement studies;
- mixing studies;
- wear and material transfer studies; and
- metallurgical studies.
5.3.9 There has been little demand from industry, however, for the simpler routine applications of radioisotope tracing such as pipeline tracing. Larger one-off projects using radioisotope tracers undertaken for industry by the AAEC have been categorised as applied research and are described in Chapter 4.

5.4 Industrial Applications of Nuclear Technology Overseas

5.4.1 Australian industry makes much less use of nuclear technology than does industry overseas. Neutron diffraction techniques, for example, are being used by industry overseas to detect and identify phases in metallic alloys, to examine the microstructure and stability of metal welds, and to measure internal stresses of fabricated components. Foreign nuclear science centres such as Harwell in the UK are making their neutron scattering facilities and scientific expertise available to industry for use in solving materials problems[10]. Overseas industries utilize accelerator generated ion beams for ion implantation in the production of semiconductor devices and integrated circuits. The billion-dollar-a-year portable calculator industry, for example, relies on ion-implanted integrated circuits[11]. Potential applications of nuclear technology in Australian industry are discussed further in Chapter 7.

5.4.2 Commentators have suggested that there are two main reasons for Australian industry not taking full advantage of available nuclear technology. Most importantly, industry in this country does not employ scientists trained in nuclear science and, therefore, industry management is not aware of the potential applications of nuclear technology. There is also a degree of general mistrust of nuclear technology amongst the Australian community and this tends to cause industry management to be reluctant to introduce nuclear science based equipment and techniques into the workplace.

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6 ORGANISATIONS INVOLVED IN NUCLEAR SCIENCE AND TECHNOLOGY IN AUSTRALIA

6.1 Introduction

6.1.1 In this chapter an overview is presented of the various research groups and organisations which constitute the nuclear science and technology infrastructure in Australia. Included in this infrastructure are Commonwealth Government laboratories, institutes of higher education and organisations formed to facilitate the work and training of nuclear scientists.

COMMONWEALTH GOVERNMENT ORGANISATIONS

6.2 The Australian Atomic Energy Commission

6.2.1 The Australian Atomic Energy Commission (AAEC) was established under the Atomic Energy Act 1953. The Act is administered by the Minister of Resources and Energy and empowers the Commission, inter alia:

- 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;
- to arrange for the training of scientific research workers.

6.2.2 The Commission consists of the Chairman and not more than four members. It has usually been the practice for the Secretary of the relevant Department to be appointed to the Commission and the Director of the Research Establishment is also a member at present. Commissioners may be appointed for a term of up to seven years. The Commission controls the AAEC Research Establishment at Lucas Heights which is Australia's only national nuclear science laboratory. The Regulatory Bureau, housed separately at Mascot, Sydney, is responsible to the Commission, through the Chairman, for the regulation of specified Commission activities and for involvements in regulatory activities of national and international organisations.

6.2.3 It has been proposed that part of the Atomic Energy Act be repealed and new legislation enacted to enable a different structure and different functions for the AAEC. The proposed changes are reviewed in Chapter 7.
Historical Background[1, 2, 3]

6.2.4 Construction of the High Flux Atomic Reactor (HIFAR) at the Lucas Heights site commenced in 1956 and the reactor began operating as a high intensity neutron source for research purposes in 1960. The principal research aim of the Commission in the early years was to develop means for electricity production through the advancement of reactor design. It was then generally accepted in Australia that nuclear power based on thermal fission would become economically competitive with existing methods of generating electricity. Two systems were chosen for evaluation, one based on liquid metal cooling, the other on high temperature gas cooling (HTGCR). By 1958 research concentrated on the HTGCR concept using beryllium and later beryllium oxide as moderators.

6.2.5 In 1966 the Commission decided to phase out work on the HTGCR prototype because it had been found that the lifetime of beryllium oxide was too short for power reactor use. Research efforts were redirected towards the establishment of an Australian nuclear industry built around the introduction of overseas station designs. The new direction for the research program became high conversion efficiency, heavy water moderated reactors using natural uranium fuel. Teams of Australian scientists were attached to nuclear reactor programs in Canada and the UK.

6.2.6 In 1969 the Government announced its intention to provide financial support for the construction of a 500MW(e) nuclear power station at Jervis Bay as a lead station for the introduction of nuclear power in Australia. The project did not proceed, however, largely due to economic considerations. Coal was cheap and plentiful and there had been significant oil and gas discoveries in Australian territory, while nuclear power costs had greatly increased.

6.2.7 In the early 1970's the effort devoted to nuclear power reactors was scaled down and the freed resources redirected to other areas. These included the front end of the nuclear fuel cycle (uranium extraction, conversion and enrichment). Considerable uranium resources had been discovered and this offered the potential for Australia to become a major producer not only of yellow cake but also of upgraded products. The AAEC involvement in radiopharmaceuticals also expanded and a national service for the production and distribution of reactor-based radiopharmaceuticals was established.

6.2.8 For a time the AAEC became involved in the commercial aspects of the uranium industry including exploration and the establishment of mines and mills. The Commission was involved in the Ranger Project, Mary Kathleen and a joint venture to explore the Ngalia Basin but progressively withdrew from this area in the late 1970s.

6.2.9 The Government's endorsement of many of the recommendations of the Ranger Uranium Environmental Inquiry of 1977 led to a substantial expansion of the Commission's research effort in environmental science, particularly the impact and control of uranium mining and processing. In 1979 the AAEC entered into a collaborative program with the Australian National University to study and develop the SYNROC concept for the immobilisation of high level wastes.
6.2.10 Although its role was confined by the Atomic Energy Act, the AAEC entered into some non-nuclear energy research in the mid 1970's, in response to national concern about Australia's future energy requirements. In 1979 a committee of the National Energy Research Development & Demonstration Council reviewed the research activities of the AAEC Research Establishment and recommended a diversification of the energy research effort. In 1981, the Government accepted the thrust of this recommendation, but decided that direct government participation in non-nuclear energy research and development should remain the province of the Commonwealth Scientific and Industrial Research Organisation (CSIRO). To achieve this, approximately one third of the AAEC's research staff were transferred to CSIRO as part of the Institute of Energy and Earth Resources. The staff transferred from AAEC remained at Lucas Heights, resulting in the co-location of AAEC and CSIRO units. The site is now known as the Lucas Heights Research Laboratories.

Current Research Program

6.2.11 The current research program of the AAEC is summarised in Table 6.1. Many of these programs have been described in some detail in Chapters 4 & 5.

Staff and Budget

6.2.12 The expenditure for the AAEC for the 1984-85 financial year was $48 million. Revenue from the operations of the Commission's commercial activities was $2.5 million. A further $5.8 million was contributed to the AAEC by CSIRO in return for services and facilities provided at Lucas Heights.

6.2.13 In 1984 the AAEC had a total staff ceiling of 1060 of whom 310 were professional and technical staff in the research area, 510 worked in the operational areas such as safety and radioisotopes, and 240 were support staff. The equivalent of 80 of the operational and support staff were dedicated to CSIRO programs and a further 90 were considered to provide site services to CSIRO.

6.3 The Commonwealth Scientific and Industrial Research Organisation

6.3.1 Radioactive tracer techniques are used by scientists working in many Divisions of CSIRO, especially in programs related to agriculture and biology. Four Divisions have research programs which are based on nuclear technology.

The CSIRO Division of Mineral Physics and Mineralogy, North Ryde, NSW

6.3.2 In 1983 this Division commissioned a 3 MV electrostatic tandem accelerator as the central part of the Heavy Ion Analytical Facility (HIAF) for use in mineralogical and geological research.

The CSIRO Division of Mineral Engineering, Lucas Heights, NSW & Port Melbourne, Victoria

6.3.3 Researchers at the Lucas Heights Research Laboratories and Port Melbourne are developing nuclear techniques for on-line and in stream coal analysis and also for on-line analysis of minerals.
<table>
<thead>
<tr>
<th>RESEARCH FIELD</th>
<th>ESTIMATED EFFORT (% TOTAL)</th>
<th>ACTIVITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Science</td>
<td>16</td>
<td>uranium environmental studies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>isotope hydrology</td>
</tr>
<tr>
<td>Waste Management</td>
<td>15</td>
<td>SYNROC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>study of radionuclide</td>
</tr>
<tr>
<td></td>
<td></td>
<td>migration in the vicinity of ore bodies</td>
</tr>
<tr>
<td>Medical Applications of new Radioisotopes and</td>
<td>13</td>
<td>development of</td>
</tr>
<tr>
<td>Radiation</td>
<td></td>
<td>radiopharmaceuticals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>radiation biology</td>
</tr>
<tr>
<td>Industrial Applications of Radioisotopes and</td>
<td>11</td>
<td>materials analysis</td>
</tr>
<tr>
<td>Radiation</td>
<td></td>
<td>radiisotope tracers for</td>
</tr>
<tr>
<td></td>
<td></td>
<td>sediment movement, dredging,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>sewage disposal, wear in moving parts, and termite studies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>food irradiation</td>
</tr>
<tr>
<td>Nuclear Technology</td>
<td>16</td>
<td>development of equipment for</td>
</tr>
<tr>
<td></td>
<td></td>
<td>monitoring material such as</td>
</tr>
<tr>
<td></td>
<td></td>
<td>enriched uranium and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>plutonium as part of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Australia's assistance to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the IAEA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>fusion physics</td>
</tr>
<tr>
<td>Underlying Research</td>
<td>10</td>
<td>strategic research providing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>background knowledge for</td>
</tr>
<tr>
<td></td>
<td></td>
<td>applied research</td>
</tr>
<tr>
<td>Scientific Services</td>
<td>19</td>
<td>mathematics &amp; computing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>instrumentation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>environmental monitoring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>metals fabrication</td>
</tr>
<tr>
<td></td>
<td></td>
<td>animal house</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HIFAR operation</td>
</tr>
</tbody>
</table>

The CSIRO Division of Energy Chemistry, Lucas Heights, NSW

6.3.4 The Division of Energy Chemistry was formed in 1981 as a result of the Commonwealth Government decision that resources should be transferred from the AAEC to carry on non-nuclear energy research under the auspices of CSIRO. The Division is located in the Lucas Heights Research Laboratories. Two of the major research programs of the Division utilize nuclear technology; these are the investigation of the structure of zeolite crystals by neutron powder diffraction and a series of collaborative projects using neutron activation analysis.

The CSIRO Division of Chemical Physics, Lucas Heights, NSW

6.3.5 A small group of scientists at the Lucas Heights Research Laboratories who work on ion implantation and radiation chemistry were attached to the Division of Chemical Physics in 1981.

6.3.6 The research activities of the ion implantation group are based on advanced materials development using ion implantation, and its unusual attributes, for surface modification of semiconductors, metals and ceramics. Nuclear technology is used to study the mechanisms by which ion implantation improves wear resistance of materials and enhances the fracture toughness of ceramics. The radiation group is involved in research using radiation facilities for irradiation chemistry studies and to investigate problems in various fields of chemistry and biology using radiation techniques to produce radicals and excited states.

6.3.7 Some of the nuclear technology based research programs of these four Divisions are described in more detail in Chapter 4.

Staff and Budget

6.3.8 A total of 33 research staff within CSIRO are involved in research programs which are based on nuclear technology (Table 6.2). The annual expenditure on these programs has been estimated as $1.6 million. In addition, CSIRO has recently established an accelerator facility at North Ryde. The replacement cost of the accelerator is $3 million.
Table 6.2

Staff and Budgets of Research Groups in CSIRO
Which Rely on Advanced Nuclear Technology

<table>
<thead>
<tr>
<th>CSIRO DIVISION</th>
<th>RESEARCH STAFF* USING NUCLEAR TECHNOLOGY</th>
<th>ESTIMATED ANNUAL EXPENDITURE ON NUCLEAR TECHNOLOGY BASED RESEARCH FOR 1984-85 ($m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral Physics and Mineralogy</td>
<td>4</td>
<td>0.25</td>
</tr>
<tr>
<td>Mineral Engineering</td>
<td>14</td>
<td>0.9</td>
</tr>
<tr>
<td>Energy Chemistry</td>
<td>6</td>
<td>0.4</td>
</tr>
<tr>
<td>Chemical Physics</td>
<td>9</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>33</strong></td>
<td><strong>1.6</strong></td>
</tr>
</tbody>
</table>

* Research staff includes professional and technical support staff members.
Source: Figures provided by relevant CSIRO Divisions

6.4 The Australian Radiation Laboratory

Historical Background[8, 9]

6.4.1 The Australian Radiation Laboratory originated in 1926 when the Federal Health Council, later to become the National Health and Medical Research Council, established a national 'radium bank'. To ensure that the radium was properly stored, maintained and distributed to hospitals for the treatment of cancer patients, the Commonwealth Government entered into an agreement with the University of Melbourne to establish a small section to undertake these functions. A more formal agreement with the University was made in 1929, and the Commonwealth Radium Laboratory, as it was then called, was given responsibility for the safe and equitable use of the radium. It also provided a radon service and gave advice on radium and radon dosimetry and on precautions to be taken in the use of radium.

6.4.2 Over the years the roles of the Laboratory were broadened. In 1973 it was renamed the Australian Radiation Laboratory with functions covering health aspects of ionising radiation, radioactive materials, microwaves and lasers. Current research projects being undertaken by the Laboratory include:
research, development and scientific advisory services on the public health hazards to Australians of ionising radiation, radioactive materials, microwaves and lasers;

- establishment of radiation protection standards for occupational health and public health and the preparation of codes of practice on the safe use of various sources of ionising radiation, radioactive materials, microwaves and lasers;

- research and development on, and surveillance of, the dose levels from the different sources of ionising radiation, radioactive materials, microwaves and lasers to which workers and members of the public are exposed;

- regulatory and compliance functions related to radiation safety, and to the quality assurance and use of radiopharmaceuticals;

- research and development on national standards of radiation dose and of radioactivity, and calibration against those standards of measuring instruments and systems for use in hospitals, medical practices, research and industry;

- research, development and scientific services on the physical aspects of the use of ionising radiation, radioactive materials, microwaves and lasers in medical diagnosis or treatment; and

- act as the focal point of national expert advice in the above fields, but not infringing on the responsibilities of the States.

6.4.3 A new staff organisation based on these functions was approved in 1975 and updated to include uranium mining responsibilities in 1980. Three Sections were formed - Standards and Compliance, Health and Safety, and Codes and Monitoring. The first two of these are concerned with R&D. The Laboratory is located organisationally in the Commonwealth Department of Health and its Director is responsible to the First Assistant Director General, Medical Services Division, Canberra.

Staff and Budget

6.4.4 In 1984 there were a total of 100 staff members at the Laboratory including 41 professional, 44 technical and 15 administrative staff; of these 56 were allocated to research. The total expenditure for 1983-84 was $3.81 million including $2.29 million for radiation health research activities covering both ionising and non-ionising radiations. Approximately half the research activities are based on nuclear technology.
INSTITUTIONS OF HIGHER EDUCATION

6.5 The Department of Nuclear Physics, Research School of Physical Sciences, the Australian National University

Historical Background[10]

6.5.1 The Department of Nuclear Physics at the Australian National University (ANU) began as one of the foundation Departments of the Research School of Physical Sciences. Research commenced in 1952 and was at first mainly confined to aspects of photodisintegration using two Cockcroft-Walton generators (0.6 MV and 1.2 MV) and an electron synchrotron (33 MeV). In 1961, an EN Van de Graaff tandem accelerator (5 MV) was commissioned and this operated for the following 16 years. A 14UD tandem accelerator was installed by 1974 using a grant of $2.2 million from the Australian Universities Council. Intense beam pulses of 50 picoseconds (50 x 10^{-12} sec) duration can now be produced making it possible to study very short-lived nuclear phenomena. A proposal to upgrade the 14UD accelerator by augmentation with a superconducting linac is described in Chapter 3.

Current Research Program

6.5.2 The main research direction in the Department of Nuclear Physics involves heavy ion reactions and nuclear structure and is outlined in Chapter 3. In addition some collaborative research programs have been established with, for example, the Universities of Melbourne and Auckland.

Staff and Budget

6.5.3 The Department of Nuclear Physics has a staff of 37 comprising 18 research staff and 19 support staff. Overall, the 14UD accelerator supports a research group of about 45 made up of ANU staff, external groups from Melbourne and Auckland and other visitors. At present there are 6 enrolled postgraduate students. The Department's total expenditure for 1984 was $1.7 million of which $1.4 million was consumed by salaries.

6.6 The School of Physics, the University of Melbourne

Historical Background[11]

6.6.1 The School of Physics was a small department in Melbourne University in the pre-World War II period. Expansion began in 1938 with the construction of a neutron generator. Over the next 20 years a number of facilities were built including a small electron cyclotron, a second neutron generator, a small 3 MV betatron, a 1 MV Van de Graaff accelerator, an 18 MeV electron synchrotron, a 750 KeV Van de Graaf accelerator and a variable energy 2 to 12 MeV cyclotron. Since then two 35 MeV betatrons have been purchased and in 1974 a 5U pelletron was obtained.
6.6.2 Research has diversified over the past 25 years. A high energy physics bubble chamber group ran for about a decade before being closed down in the late 1970's when changes in technology made its cost prohibitive. Theoretical physics as a recognizable, separate discipline began in 1942 and there now exists a theoretical physics group comprising seven staff members.

6.6.3 The School of Physics at the University of Melbourne has been, and continues to be, one of the leading centre of basic and applied research in nuclear science in Australia. The experimental nuclear science program is based on both in-house facilities and external facilities at the ANU and overseas. The two betatrons have now become obsolete and will be phased out by the end of 1986. This will affect the research activities of some staff and substantially reduce the facilities for the training of postgraduate students in basic nuclear physics (see Table 6.3).

6.6.4 From the next decade, a considerable number of senior professional staff members will retire from the School of Physics and it is likely that the introduction of new staff members also will influence the future research direction of the School.

6.6.5 In early 1984 an external review committee, set up by the University of Melbourne, considered future directions for the School of Physics. Recommendations of the committee, proposing the introduction of some new academic staff into the School, are being implemented.

Current Research Program

6.6.6 Basic research programs in particle physics, intermediate energy physics and nuclear structure are carried out by staff and research students of the School of Physics using external facilities together with the in-house betatron and pelletron accelerators. These programs and the applied research programs using the proton microprobe have been outlined in earlier chapters.

Staff and Budget

6.6.7 The distribution of staff and students between the various research areas in the School of Physics is given in Table 6.3. Eleven academics, at the level of lecturer or above, and the equivalent of 5.5 research fellows and 10 technical staff members are engaged in experimental nuclear science research. In addition 31 research students are working in this area.

6.6.8 The total budget for nuclear research for 1984 was $1.5 million of which about $1 million was consumed by salaries. The remainder comprised ARGSS grants ($258,000) and maintenance and equipment ($197,000). Approximately four fifths of the total budget, or $1.2 million, was devoted to experimental nuclear science and the remainder to theoretical nuclear science.
### Table 6.3

**Distribution of Research Staff and Students in Experimental Nuclear Science in the School of Physics, The University of Melbourne (1985)**

<table>
<thead>
<tr>
<th>RESEARCH AREA</th>
<th>RESEARCH STAFF *</th>
<th>RESEARCH FELLOWS</th>
<th>POSTGRADUATE STUDENTS</th>
<th>TECHNICAL SUPPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Energy Physics (CERN)</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Intermediate Energy Physics (Indiana &amp; TRIUMF)</td>
<td>2.5</td>
<td>1</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Nuclear Structure (ANU)</td>
<td>1</td>
<td>2.5</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Pelletron (Proton Microprobe)</td>
<td>2</td>
<td>1</td>
<td>9</td>
<td>6.5</td>
</tr>
<tr>
<td>(Astrophysics)</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>(Applied Nuclear)</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Betatron - Photonuclear &amp; Atomic</td>
<td>2.5</td>
<td>1</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>11</strong></td>
<td><strong>5.5</strong></td>
<td><strong>31</strong></td>
<td><strong>10</strong></td>
</tr>
</tbody>
</table>

* Lecturer and above

Source: Figures provided by the University of Melbourne
6.7 The School of Nuclear Engineering, the University of New South Wales

Historical Background

6.7.1 The School of Nuclear Engineering at the University of New South Wales was founded in 1961 and teaches only at the postgraduate level. It is the only school in Australia devoted to nuclear engineering, a discipline concerned with the practical realisation and optimal use of nuclear facilities, assemblies and components.

6.7.2 The Council of the University of New South Wales has accepted the recommendations of a Faculty Review Committee that the staff of the School be transferred to the School of Mechanical and Industrial Engineering. The Committee's further recommendation that the Chair not be refilled will be further considered following the retirement of the present incumbent. This implies that the School of Nuclear Engineering will be disestablished.

Staff and Budget

6.7.3 The total budget of the School of Nuclear Engineering for 1984 was $325,000 of which $283,000 was consumed by salaries. The School has an academic staff of four and ten postgraduate students.

6.8 The Royal Melbourne Institute of Technology[12]

Historical background

6.8.1 The Royal Melbourne Institute of Technology (RMIT) began educational and research programs in microelectronics in the early 1970s. In 1982 the Joint Microelectronics Research Centre (JMRC), covering microelectronics research at both RMIT and The University of New South Wales, was established under the Commonwealth Special Research Centres Scheme. Part of these research funds are used for applied research using nuclear technology. Staff and students from the Departments of Applied Physics, Communication and Electronic Engineering and Metallurgy are involved.

Current Research Program

6.8.2 An important part of RMIT's research program is centred on its IMV tandem accelerator and uses nuclear technology. These research programs are described in Chapter 4.

Staff and Budget

6.8.3 Six academic and two technical staff members and 11 postgraduate students are involved in research using nuclear technology at RMIT. The total expenditure for 1983, including salaries, in this area is estimated to be $100,000.
6.9 Smaller Programs in Nuclear Science Research

6.9.1 Other small research groups involved in experimental nuclear science are located at the following universities:

James Cook University;
Sydney University; and
The University of Western Australia.

OTHER ORGANISATIONS FORMING PART OF THE NUCLEAR SCIENCE INFRASTRUCTURE

6.10 The Australian Institute of Nuclear Science and Engineering

6.10.1 The Australian Institute of Nuclear Science and Engineering (AINSE) was established in 1958 with the major objective of ensuring that universities and similar organisations in Australia would have direct access to special facilities being installed at the AAEC Research Establishment at Lucas Heights and that active co-operation in research and training in the nuclear field would be encouraged between all the organisations in Australia with interests in this area. Today AINSE has twenty member organisations comprising the AAEC, CSIRO and eighteen universities. It is governed by a Council consisting of four representatives of the Commission and one representative from each of the other member organisations.

AINSE Member Organisations

James Cook University
University of Queensland
Griffith University
University of New England
University of Newcastle
Sydney University
University of New South Wales
Macquarie University
University of Wollongong
Australian National University
University of Melbourne
Monash University
La Trobe University
University of Tasmania
University of Adelaide
Flinders University
University of Western Australia
Murdoch University
Australian Atomic Energy Commission
CSIRO
6.10.2 AINSE grants, projects and visitors. AINSE provides some funds to member organisations for the purchase of specialized equipment for their own laboratories or for use at Lucas Heights. AINSE grants may also include credits from which the Institute may make payments towards the cost of using Lucas Heights facilities, travel and accommodation. Typically over 300 visitors work at Lucas Heights per year for a total of over 2000 man-days. AINSE grants are currently giving some support to over 100 projects in areas including radiation biology, nuclear and neutron physics, nuclear techniques of analysis, radiation chemistry and radiation damage studies, plasma physics and fusion related studies, and neutron diffraction.

6.10.3 AINSE groups and equipment. AINSE provides a small number of staff based at Lucas Heights to assist visiting scientists from member organisations. Two scientists and two technicians are provided to assist in neutron diffraction projects. They advise on the design and conduct of experiments and are responsible for the installation and operation of 10 neutron diffractometers associated with HIFAR and all associated equipment. A further two AINSE staff members assist visitors using any one of the three particle accelerators at Lucas Heights. The accelerator-based projects involve very close co-operation between university research groups, AAEC staff, CSIRO and AINSE.

6.10.4 AINSE Conferences. Biannual and triannual working conferences are held in each of six recurring series. AINSE contributes to the travel costs of participants from member organisations.

6.10.5 AINSE Studentships and Research Fellowships. The Institute awards one or two postgraduate studentships each year. They are for higher degree studies which require the students to spend at least one quarter of their time using the specialized facilities at Lucas Heights. Usually one or two postdoctoral fellowships are awarded semi-annually. They are tenable for two years and usually involve the use of Lucas Heights facilities and/or co-operation with Lucas Heights research staff.

6.10.6 Other AINSE Operations. These include sponsoring lectures and seminars, the provision of special materials such as heavy water for specified projects, liaison between member organisations and provision of technical reports from research receiving AINSE assistance.

Budget

6.10.7 Annual membership subscriptions to AINSE for 1984 totalled $423,000 comprising $225,000 from the universities and CSIRO and $198,000 from the AAEC. In addition, $300,000 was provided by the AAEC as the annual contribution for research and training. The Cabinet appropriation to the AAEC for this purpose has been increased to $400,000 for 1985 which will return the AAEC contribution to AINSE to the 1983 level.

6.11 The Australian Neutron Beam Users Group[14]

6.11.1 The Australian Neutron Beam Users Group (ANBUG) is an association of scientists who use neutron scattering techniques in their professional work. The Group has 80 members in at least 20 research groups at universities, colleges
of advanced education, CSIRO and the AAEC. The principal objectives of ANBUG, as given in its Constitution, are:

- to promote and further the development of high standards of activity in neutron scattering research in Australia;
- to encourage the provision and maintenance of adequate facilities and resources for such research;
- to encourage the support and development of new techniques stemming from either Australian initiative or international research which will enhance the potential of neutron beam research in both the basic and applied areas;
- to have discussion within the Group of material relating to neutron scattering and its applications; and
- to make representations on behalf of neutron beam users in Australia to those national bodies responsible for the financing and development of policies in relation to scientific research.

6.11.2 Research using neutron scattering techniques is carried out in Australia at the HIFAR reactor at Lucas Heights. ANBUG members gain access to this facility through AINSE or the AAEC. Some members also travel overseas to neutron beam facilities which are not available in Australia. The research activities of ANBUG members are described in Chapter 4.

6.12 The Australian School of Nuclear Technology[15]

6.12.1 The Australian School of Nuclear Technology (ASNT) was established in 1964 by the University of New South Wales and the Australian Atomic Energy Commission. It provides a teaching basis for the transfer of aspects of applied nuclear technology to organisations within Australia and to 32 overseas countries. The School provides a significant contribution to Australia's overseas aid program, particularly in the South East Asian area. The School is located at Lucas Heights and is controlled by a Board consisting of representatives of the University of NSW, the AAEC and AINSE. The small permanent staff of the School are permanent employees of the AAEC.

6.12.2 In establishing the School it was recognised that the high cost of providing facilities such as the HIFAR reactor precluded the possibility of traditional educational institutions undertaking the necessary level of instruction in nuclear science and engineering. ASNT generates its own funds through course fees obtained from participants from outside AAEC. These funds amount to approximately $70,000 per annum and cover the cost of isotopes, lecture fees for external lecturers, stores and consumables. Overseas participants are generally supported by fellowships provided under the Colombo Plan or by the International Atomic Energy Agency. Australian participants are normally sponsored by their employer organisations.
6.12.3 Courses aim to provide intensive instruction in the application of nuclear science and technology at the undergraduate and postgraduate levels. Teaching staff are drawn from the AAEC, universities, CSIRO, private companies, and the NSW Health Department. The major teaching emphasis has been in the application of radioisotopes and radiation in industry and medicine. The courses offered for 1984/85 were:

- Radioisotope Course for Graduates;
- Radionuclides in Medicine;
- Nuclear Techniques in Industry;
- Introductory Nuclear Technology;
- Commercialisation of Ionising Energy Treatment of Foods;
- Nuclear Safeguards;
- Radiation Protection;
- Radioisotope Course for Non-graduates;
- Introductory Atomic Energy; and
- Reactor Operator Training.

6.13 The Nuclear and Particle Physics Group of the Australian Institute of Physics

6.13.1 The Nuclear and Particle Physics (NUPP) group was formed in 1972 to provide a forum for the community of nuclear and particle physicists from Australia and New Zealand. The aims of the group are as follows:

- to encourage future development of nuclear and particle physics in Australia;
- to provide a vehicle for communication among nuclear and particle physicists in Australia and New Zealand; and
- to organise a biennial school in nuclear and particle physics which would educate graduate students and professional physicists in recent developments in the subject.

The NUPP schools are the most significant of the group’s activities. These last for one week and are attended between 60 and 100 graduate students and professional physicists. Speakers include eminent overseas physicists.
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11. Report of the Physics Forward Planning Review Committee to the Joint Committee on Policy and the School of Physics, University of Melbourne, 1984.


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7 DISCUSSION AND RECOMMENDATIONS

7.1 Nuclear Science and Technology in Australia Today

7.1.1 This study has examined Australia's participation in nuclear science and technology. The spectrum of activities in nuclear science in this country ranges from basic research, to applied research using nuclear technology, to applications of nuclear technology in medicine and industry.

7.1.2 Australia's experimental basic research effort in nuclear science is very small. The total national annual expenditure in this area is of the order of $2.5 million which represents a far lower per capita expenditure than that of other developed countries. The only major facility in Australia which is suitable for basic research in nuclear science is the 14 UD accelerator in the Department of Nuclear Physics at the Australian National University (ANU). This accelerator operates in the low energy range and is used by nuclear physicists from the ANU and elsewhere, mainly for heavy ion research. A group of experimentalists at the School of Physics at the University of Melbourne carries out basic research in nuclear science using overseas accelerator facilities as well as the ANU accelerator and two, now obsolete, betatron accelerators located at the University of Melbourne.

7.1.3 There are about 20 theoreticians working in basic research in nuclear science in Australia in conjunction with the experimentalists. The theoreticians do not rely directly on the availability of nuclear facilities and, therefore, were not a primary subject of this study.

7.1.4 By far the greatest proportion of the total effort in nuclear science in Australia may be categorised as applied research using nuclear technology. It is estimated that the national annual expenditure in applied research using nuclear technology is in the vicinity of $31 million and this accounts for about 90% of the total national annual expenditure in nuclear science and technology research.

7.1.5 Many applied research programs using nuclear technology are actually utilising the tools and techniques of nuclear science to solve problems in other disciplines as diverse as geology, environmental science, materials science, microelectronics, biology and medicine. Relatively few of the applied research programs using nuclear technology are aiming to solve problems in nuclear science. Once applied research facilities in nuclear science have passed from the early development phase, their principal users are, therefore, researchers from other areas of science.

7.1.6 Much of Australia's funding for applied research using nuclear technology goes to the Australian Atomic Energy Commission (AAEC). The Commission's expenditure on applied research for 1985 was $29 million out of a total budget of $48 million. Scientists employed by the AAEC are involved in a wide variety of applied research projects such as uranium environmental studies, the SYNROC
program, radioisotope tracer studies and food radiation. The reactor and accelerator facilities at Lucas Heights also serve scientists from other government laboratories and institutions of higher education. Access to these facilities by outside users is mediated by the Australian Institute of Nuclear Science and Engineering (AINSE). Visitors include members of the Australian Neutron Beam Users Group (ANBUG) who use the nuclear reactor HIFAR as a source of neutrons for neutron scattering experiments in geology, chemistry, biology, metallurgy and other areas of science.

7.1.7 Other centres of applied research using nuclear technology are at the Australian Radiation Laboratory, the School of Physics at the University of Melbourne, the Royal Melbourne Institute of Technology and in four divisions of CSIRO.

7.1.8 The Australian Radiation Laboratory carries out research and development related to public and occupational health matters and the maintenance of national radiation standards. Researchers at the University of Melbourne have an advanced proton microprobe which maps the distribution of chemical elements in a variety of specimens. The Royal Melbourne Institute of Technology has an accelerator which is used for applied research in semiconductors and other materials. Within CSIRO, the Division of Mineral Physics and Mineralogy is using its heavy ion accelerator facility to develop applications of ion beam techniques for energy and geoscientific research. Scientists in the Division of Mineral Engineering are developing nuclear techniques for mineral and coal analysis. The Division of Energy Chemistry has two programs which utilise nuclear technology. These are an investigation of zeolite structure and projects using neutron activation analysis. A group of scientists in the Division of Chemical Physics uses nuclear technology in ion implantation and radiation chemistry research.

7.1.9 Nuclear science has important applications in medicine in Australia, nuclear techniques being used for diagnosis of about 150,000 Australian patients each year. A significant proportion of radiopharmaceuticals used in Australia is produced by the AAEC. Australian industry utilises nuclear technology through the widespread use of radioisotopes in level, density and moisture gauges. Many nuclear techniques such as neutron diffraction analysis and ion implantation, which are used in applied research in Australia, have great potential for exploitation by industry.

7.1.10 The two leading centres of tertiary education in nuclear science in Australia are the School of Physics, Melbourne University and the Department of Nuclear Physics in the Research School of Physical Sciences, ANU. Melbourne University takes in about 400 physics students each year and currently has 31 postgraduate students working in experimental nuclear science. The Department of Nuclear Physics, ANU, teaches only at the postgraduate level and currently has 6 postgraduate students. In addition, the Royal Melbourne Institute of Technology has 11 postgraduate students who are using nuclear technology in their research. The School of Nuclear Engineering at the University of New South Wales teaches only postgraduate students and has 10 enrolments at present. A recent Faculty Review Committee, however, has recommended that staff members of the School of Nuclear Engineering be transferred to another school and that the Chair of Nuclear Engineering not be refilled on the retirement of the present holder.
7.2 Should Australia Continue to be Involved in Nuclear Science and Technology

7.2.1 Australia is a relatively small country and cannot support a major research effort in every area of science and technology. The first question which this study must answer, therefore, is whether Australia should continue to be involved in nuclear science and technology. This question is particularly important in view of the increasing expense of many nuclear science research facilities.

7.2.2 ASTEC believes it is important for Australia to maintain a suitable level of involvement in nuclear science and technology for the following reasons:

- **Economic advantages** are to be gained by the transfer of nuclear technology to Australian industry;
- **Scientific advantages** are available based on the use of nuclear technology in applied research in many areas of science and on the intellectual value of basic research in nuclear science;
- **Social advantages** are offered by the use of nuclear technology in medical diagnosis and treatment and in environmental science; and
- **Foreign policy advantages** can be achieved which are related to Australia's influence in the International Atomic Energy Agency and other international forums concerned with aspects of the nuclear fuel cycle.

**Economic Advantages**

7.2.3 Nuclear technology is already being used in Australia for economic advantage. Although Australia is not involved in the nuclear fuel cycle other than as a uranium supplier and does not have a nuclear industry, many areas in the mining, manufacturing and agricultural industries benefit from the use of nuclear technology especially for measuring and monitoring processes. Level gauges, density gauges and moisture gauges, for example, contribute to productivity in many different sectors.

7.2.4 Important economic advantages are to be derived from the use of nuclear technology in studies of the environment. Some examples of such studies include tracing the movement of industrial effluent in coastal waters, monitoring the flow rates of ground waters in the Great Artesian, Amadeus and Murray Basins and tracing soil erosion in the Hunter Valley[11]. ASTEC believes that there will be many similar applications of radioisotope tracer techniques in environmental science in the future. Environmental studies related to Australia's program of uranium mining are, and will continue to be, particularly important.

7.2.5 The Australian mineral industry also benefits from the use of nuclear technology in the on-line and bulk analysis of coal and metalliferous ores. Measurement of the ash content of coal by a gamma-ray transmission technique is an important means of ensuring the quality of Australia's coal exports. The use of
on-line ash gauges in coal washeries can lead to significant improvements in recovery. On-stream elemental analysis of mineral slurries using X-ray fluorescence and gamma-ray absorption leads to increased recovery of valuable minerals[2].

7.2.6 Techniques of mineral analysis using ion beams are already available at several accelerator facilities in Australia and these, in competition with other non-nuclear analytical techniques, offer potential economic advantage to the mineral industry. Opportunities exist for the provision of ion beam analysis techniques on a fully commercial basis.

7.2.7 The potential economic advantages to be derived from nuclear technology in Australia are far greater than those already realised. In general, Australian industry has not yet taken as much advantage of the expertise and facilities in nuclear science which are available to it as has industry overseas.

7.2.8 Arguably, the greatest area of potential economic advantage to Australia from the application of nuclear technology is in materials science. Techniques in neutron scattering which were developed in basic research ten years ago are now being used for industrial applications at overseas centres. Neutron scattering is being used, for example, in the pharmaceutical industry to determine the structure of drugs and drug receptor sites. Ion beam techniques also are being used in structural determinations especially in solid state research and the investigation of advanced materials such as new ceramics, an area in which Australia has a genuine opportunity for commercial success.

7.2.9 Overseas companies are using accelerator generated ion beams for routine analysis especially in the microelectronics, metals and ceramics industries. The main uses are in the examination of surface properties and coatings. Successful companies have been established in the USA which are based on the provision of ion beam analysis services.

7.2.10 In addition to materials analysis, nuclear technology can also be used for materials modification. Overseas centres are using modified low energy accelerators for ion implantation especially in the microelectronics industry. Accelerators operating in the 1 to 10 MV range are able to implant ions at depths of several microns below the surface[3]. In the near future, this technology will be required increasingly by new as well as established microelectronics firms in Australia. There is also a growing export market opportunity for companies which produce accelerators modified for ion implantation and Australia already has the competence to contemplate entering this market.

7.2.11 Radiation processing using gamma-rays from cobalt-60 sources is used in a variety of industrial processes overseas. The most successful application of radiation processing has been in sterilisation, curing of coatings and the cross linking of polymers[4].

7.2.12 There are at present four industrial gamma irradiation plants in Australia, including one at the AAEC, which carry out irradiation of medical and other products. There are many more opportunities for the application of radiation processing in Australian industry which may be taken up in the future. The disinfection of food for export is likely to become one of the more economically important applications of radiation processing in the next decade. Applied research at the AAEC has already established the technology for the irradiation treatment of a range of fruits, grains and meats[5].
7.2.13 ASTEC believes that a base of competence in nuclear science and technology must be maintained in Australia. Australian industries will then have access to new nuclear technologies which will be essential for product and process innovation in some sectors. It will not be satisfactory to rely on imported nuclear technology as often this will not be suitable for application to Australian needs. In addition, market niches for scientific instruments based on nuclear technology have been identified which could be filled by the further development and commercialisation of technology already in use in Australia. The opportunity to develop export markets based on nuclear technology should be exploited.

Scientific Advantages

7.2.14 Nuclear science and technology already provides useful tools and techniques for research in many areas of science in Australia. Accelerator-based analytical techniques and radioisotope tracer studies are just two examples of important uses of nuclear technology in applied research.

7.2.15 Recent basic research at overseas high energy particle accelerators has led to the formulation of radical new theories about the composition of matter and its interactions. No other area of science could claim to be investigating more fundamental laws of nature. The answers to questions now being asked in high energy physics research will in the future affect our understanding of all areas of science.

7.2.16 Unfortunately, the facilities required for carrying out research at the forefront of high energy physics are very expensive and can only be supported at an international level. ASTEC believes, however, that the intellectual value of this area of nuclear science is great and that Australia must participate, at least to the extent that our scientific community can remain informed about current thinking on the subject.

7.2.17 It has been the pattern in the past that the nuclear technologies which are developed in basic research later become the technologies of applied research and applications. It is important for this reason also that Australian scientists remain in touch with current basic research in nuclear science.

7.2.18 ASTEC believes that Australia should not become isolated from international advances in nuclear science because the knowledge and understanding being acquired through basic research at a relatively small number of overseas centres is integral to the whole of science. Centres of nuclear science and technology also should be supported in Australia at which nuclear technology can be developed and utilised by researchers from the many other scientific disciplines which benefit from the use of nuclear techniques and facilities.

Social Advantages

7.2.19 Nuclear technology is an important part of research, diagnostic and some treatment procedures in modern medicine and it is necessary to maintain a high level of competence in this area if Australia is to continue to offer an acceptable standard of health care. ASTEC believes that the production of radiopharmaceuticals in Australia by the AAEC should continue. If this activity were to cease in Australia, patients would be deprived of certain important short-lived radioisotopes and also be vulnerable to the interruption of supply of long-lived isotopes from overseas.
Environmental studies using nuclear technology have obvious social benefits as well as the economic advantages described earlier.

Foreign Policy Advantages

There are also foreign policy reasons for retaining and developing expertise in nuclear science and technology in this country. Australia is a party to and strong supporter of the Treaty on the Non-Proliferation of Nuclear Weapons, the safeguard provisions of which are administered by the International Atomic Energy Agency (IAEA). The direction and operation of the IAEA is managed by a Board of Governors. Australia, which is a member of the IAEA's South East Asia and Pacific Regional Group, has been a member of this Board since the inception of the IAEA. Under the IAEA statute, Australia is one of thirteen countries designated as members because of their achievement in the technology of atomic energy, including the production of source material. Australia's designation depends largely on its position as a supplier of uranium and also on the research and development activities of the Australian scientific community especially at the AAEC.

ASTEC has pointed out in a previous report ("Australia's Role in the Nuclear Fuel Cycle", May 1984) that it is clearly desirable that Australia should maintain and enhance its credentials for continued membership of the Board. This assessment is based on the fact that Australia's designated seat provides an important platform from which we can support the international non-proliferation effort. Other countries which are also members of the South East Asia and Pacific Regional Group are increasing their competence in nuclear science and technology. Indonesia, for example, is building a research reactor together with an extensive range of laboratory facilities. An aspect of Australia's credentials for its designated seat on the Board, as well as Australia's influence in other international forums related to the nuclear fuel cycle, could be weakened if Australia does not maintain and further develop its level of research and development in nuclear science.

Public awareness of nuclear technology

ASTEC is concerned that the Australian public is, in general, poorly informed about the realized and potential uses of nuclear technology in science, medicine and industry. Public debate of issues related to nuclear science and technology has been limited to nuclear weaponry, uranium mining and nuclear power generation while important applications of nuclear technology in environmental science, medicine and scientific research are not widely appreciated. ASTEC encourages responsible bodies in their role in increasing public awareness of the broad applications of nuclear technology. These bodies should continue to strive to inform and educate through the mass media, the provision of materials to schools, participation in public discussion and other available mechanisms.

Resources and Facilities Required by Nuclear Science and Technology in Australia

The second of the terms of reference of this study is to consider, and make recommendations on, the resources and facilities which will be necessary for the optimum future participation by Australia in nuclear science and technology. In
carrying out this task, ASTEC has taken account of the existing nuclear science and technology infrastructure in Australia, the strengths and weaknesses of Australia's current research effort in nuclear science and technology, the economic climate in Australia, and, most importantly, the areas of nuclear science and technology in which an active participation will yield the most advantages to Australia.

7.3.2 ASTEC considers that research directions in Australia should not be limited by facilities available within the country but rather Australian nuclear scientists should be encouraged to maintain good contact with overseas nuclear research and to use overseas nuclear facilities where this is necessary. In addition, domestic accelerator and reactor facilities must be available to support a base of world-class basic and applied research in Australia.

Resources and Facilities for Basic Research

7.3.3 ASTEC believes that it is important to establish and maintain an appropriate balance between basic and applied research in nuclear science in Australia. Basic research in nuclear science is considered to be of significant intellectual value and the findings of such research have important implications for all areas of science. Some of the most exciting developments in basic research are taking place at overseas high-energy accelerator facilities such as CERN in Switzerland. Such high-energy accelerators are very expensive and can be supported only at an international level. ASTEC believes that a significant basic research effort in nuclear science should be maintained in Australia but this should not develop in isolation from radical new developments in the field and at overseas facilities. For Australia to become a full member of CERN, however, would cost about $10 million per annum[7] and ASTEC does not recommend this.

7.3.4 It has been estimated that the minimum effort required to keep Australia in touch with basic research in high-energy physics would be to support one group of Australian scientists to work collaboratively in a first rate experiment at CERN or in the USA. Such a research unit would need to consist of at least six permanent members and have a budget of about $0.5 million per annum. This amount would cover non-academic salaries, travel and subsistence, computer needs and small capital items. A number of postdoctoral fellows and postgraduate students also should be attached to the unit. The unit would comprise both experimentalists and theoreticians in a ratio of about 2:1[7]. It is essential that the unit should act as a national resource encouraging the participation of scientists from different universities, and actively disseminating information obtained through their collaborative research. The University of Melbourne and Flinders University have expressed interest in the joint establishment of such a research unit.

7.3.5 The proposed high energy physics research unit is similar to existing units set up in Australian universities under the Commonwealth Special Research Centres scheme. These concentrate research workers and resources with the aim of pursuing, in an international context, research which is of outstanding quality and likely to lead to the acquisition of significant new knowledge. Under the existing scheme, however, research groups are selected for funding as Commonwealth Special Research Centres on the basis of their research excellence, irrespective of the area in which they work. It would not be appropriate, therefore, to nominate a particular scientific sector such as high energy physics for funding under the present scheme. ASTEC believes, nevertheless, that a high energy physics research centre should be funded in a manner analogous to, although outside, the existing Commonwealth Special Research Centres scheme.
ASTEC recommends:

(i) That the Minister for Education undertake to fund a special research centre for high-energy physics.

(ii) That funding for the centre be provided at the rate of approximately $0.5 million per annum for five years in the first instance.

(iii) That the progress of the centre be reviewed after 3 years and continued funding be dependent on the satisfactory establishment of collaborative basic research projects of a world standard and evidence of the diffusion of the knowledge so acquired through the Australian scientific community.

7.3.6 Important advances in basic research in nuclear science are also being made at foreign intermediate energy accelerator facilities such as TRIUMF in Canada. Intermediate energy accelerators cost in the vicinity of $100 million and it is unlikely that funds for such facilities will be available in Australia in the next decade. ASTEC believes that travel funds should be made available to Australian scientists who need to travel to such facilities to carry out research which is assessed to be of world class. This matter is addressed further at 7.3.35.

7.3.7 Access to overseas accelerator facilities alone is not sufficient to support an Australian participation in basic experimental research in nuclear science. It is necessary to have in Australia an accelerator facility at which nuclear scientists can be trained in basic research and where they can gain sufficient experience and recognition to be accepted at overseas facilities. ASTEC believes that Australian nuclear scientists should have access to a domestic accelerator facility at which world class basic research can be carried out.

Resources and Facilities for Accelerator Based Applied Research

7.3.8 Many important applied research programs are based on domestic accelerator facilities, the most important of which are at the University of Melbourne, The Royal Melbourne Institute of Technology (RMIT), the AAEC and the Division of Mineral Physics and Mineralogy in CSIRO. These facilities serve researchers from a range of different sectors including geology, microelectronics and biology. ASTEC believes that co-operation between researchers using and operating accelerator facilities should be encouraged so that the maximum use of existing resources can be made. ASTEC recognises that for progress to continue in applied research using nuclear technology in the next decade, scientists will need access to an accelerator which operates at a higher energy than those currently available to them. Scientists at the AAEC and RMIT, for example, have identified a need for an accelerator in the 8-10 MV range for research in resources management, materials science and other important areas.

A National Accelerator Facility

7.3.9 ASTEC believes that most of the further needs of scientists in both basic and applied research for a domestic accelerator facility can be met by one accelerator which is suitable for research at appropriate energies and is operated as a national research facility.

7.3.10 As outlined in a previous ASTEC report ('Guidelines for the Operation of National Research Facilities', January 1984), the primary criteria for a national
research facility are that the facility is specifically identified as being for national use, and that it is made available to scientists according to the merit of their proposals. A steering committee would be established to develop policy guidelines for the long-term operation of the accelerator facility; to determine an appropriate level of charges to users; and to allocate the time available on the accelerator. The committee would comprise representatives of user groups and should operate independently.

**ASTEC recommends:**

(i) *That the Government provide funds for the establishment of a national accelerator research facility to support basic and applied research of world standard.*

(ii) *That the facility be operated as a national research facility, with an independent steering committee and serving the needs of researchers from a broad range of scientific disciplines.*

**Current Proposals for New or Upgraded Accelerator Facilities in Australia**

7.3.11 Two proposals for new or upgraded accelerator facilities are before Government at present. These are reviewed below.

**The Proposal to Upgrade the ANU Accelerator[8]**

7.3.12 The 14UD accelerator in the Department of Nuclear Physics at the ANU was commissioned in 1974 and, until the 1980s, was the world's highest voltage tandem accelerator. More recent developments in accelerator engineering, however, have surpassed the capabilities of the 14 UD. More powerful tandem accelerators are now coming into operation in the USA, Japan, the UK and Argentina.

7.3.13 A proposal to upgrade the accelerator facility has been prepared by the ANU. It is proposed that the 14 UD accelerator be used as an injector for a newly designed linear accelerator resulting in doubling of the beam energy. The estimated cost is $6.6 million over 3 years which compares favourably with a cost of $30 million to construct a new stand-alone accelerator of the same beam energy.

7.3.14 The research program in nuclear physics at the ANU is based on heavy ion physics and is described in Chapter 3. The higher energies made available by the upgrading of the 14 UD would yield two benefits to future research programs. Firstly, it would be possible to initiate reactions with heavier ions. The energies available at present are insufficient to overcome the strong repulsion between heavier projectiles and target ions (the Coulomb barrier). Secondly, higher energies would allow current experiments on lighter ions to be carried out at energy levels where entirely different phenomena occur.

7.3.15 Australian scientists using the ANU facility have made contributions to the understanding of the mechanisms of heavy ion reactions and nuclear structure which have been recognised by the international nuclear science research community. The research activities of the ANU group and the availability of the 14 UD accelerator have been responsible for attracting some first class nuclear physicists to Australia.
7.3.16 ASTEC believes that Australia should retain a competence in basic research in nuclear science but it also recognises that the frontiers of basic research in nuclear science are passing beyond the heavy ion research which is conducted in Australia. An upgraded facility such as that proposed by the ANU should be considered, therefore, as an Australian centre of basic research through which Australia can link into the international effort in basic research in nuclear science. As such, it would function to train postgraduate students and young nuclear physicists in basic research and provide an opportunity for Australian scientists to carry out research which will lead to their acceptance by the international nuclear science community.

7.3.17 ASTEC has recommended at paragraph 7.3.10 that funds be given to support the establishment of an accelerator facility in Australia where world class research can be conducted. The Council considers, however, that such a facility should be operated as a National Facility and be open to as wide a user group as possible. The ANU accelerator facility has not served a wide base of Australian users. Since commissioning in 1974 the 14 UD accelerator has been used by only two research visitors for periods of longer than one month. In addition, there has been ongoing collaboration with a group from Melbourne University and occasional short visits from other centres including the AAEC and the Department of Geology at Melbourne University.

7.3.18 The AAEC has proposed that an 8 MV tandem accelerator be installed at Lucas Heights at an estimated cost of $7 million. The accelerator could contribute to more than half of the fields within the Commission's current research program with special importance to research centred on the problems of soil salinity, erosion and the management of ground water resources. The Commission proposes that the accelerator should offer a national radioisotopic dating service using the technique of accelerator mass spectrometry (AMS). Researchers from outside the AAEC would gain access to the service through the Australian Institute of Nuclear Science and Engineering. About 60% of the accelerator's operational time would be devoted to external users. Scientists at the AAEC have established a long standing reputation in the development of ion beam analytical techniques. More recently, they have collaborated in the early development of chlorine-36 and iodine-129 applications in AMS at the University of Rochester, US.

7.3.19 The technique of radioisotopic dating by AMS is described in Chapter 4. Techniques for measuring two isotopes of special interest, chlorine-36 and beryllium-10, at geological concentrations are still being developed. With current technology it is not possible to make such measurements on accelerators operating below 8 MV.

7.3.20 The Department of Nuclear Physics at ANU has announced it will make time available on the 14 UD accelerator for a collaborative program between the AAEC and the CSIRO Division of Soils in Adelaide to develop and demonstrate AMS techniques for dating using chlorine-36. It is anticipated the program will run for at least three years. Scientists at the heavy ion accelerator facility at the CSIRO Division of Mineral Physics and Mineralogy are also working on developing techniques for AMS for detecting and measuring beryllium-10 at lower accelerator...
voltages. The full potential of this facility for carrying out radioisotopic dating has not yet been determined. ASTEC encourages collaboration between scientists at different Australian laboratories so that the provision of accelerator facilities can be rationalised.

Comment on the ANU and AAEC Accelerator Proposals

7.3.21 ASTEC concludes that neither the ANU nor the AAEC accelerator proposal meets Australia's need for a national accelerator facility. Neither proposal seeks to serve the broad future requirements of scientists engaged in both basic and applied research in Australia, to actively link into international research programs or to encourage the rationalisation of existing accelerator facilities in this country.

ASTEC recommends:
That establishments which have the desire and competence to operate a national accelerator facility be invited to prepare proposals to this effect which take account of the broad future requirements of Australian scientists as outlined in this report.

Nuclear Reactor Based Applied Research

7.3.22 The only major neutron beam facility in Australia is the 25 year old 10 MW nuclear reactor HIFAR at Lucas Heights. HIFAR was established as a testing facility for new reactor materials but this function was abandoned as the research direction of the AAEC changed. At present HIFAR is used primarily for the production of radioisotopes and for research[10]. Many of the research programs which are based on HIFAR such as the neutron scattering work and the SYNROC and food irradiation programs are described in Chapter 4.

7.3.23 HIFAR belongs to the DIDO-class of reactors which were designed in the early 1950s and it represents the technology of that time. A series of refurbishment programs carried out on HIFAR, including one presently under way, ensure that HIFAR can be operated safely and efficiently into the mid 1990s. Consideration must be given to the future of HIFAR beyond that time[11].

7.3.24 ASTEC considers it essential that a neutron beam facility be maintained in Australia. Neutron scattering techniques play a central role in advanced research in materials science. Australia has already a small group of internationally recognised experts in this field. This core of expertise should be nurtured, not only because of the scientific excellence of the research, but also because of the potential economic advantages arising from industrial applications of neutron scattering technology outlined previously.

7.3.25 A range of isotopes currently is produced at HIFAR for use in medical diagnosis, in industry and in applied research in many fields. Many of the isotopes produced in a reactor cannot be produced in a cyclotron. The absence of a nuclear reactor in Australia would, therefore, preclude the local production of some important isotopes such as technetium-99m, the radioisotope of choice for the majority of medical diagnoses.

7.3.26 The operation of a research reactor such as HIFAR also serves to maintain a national knowledge of fission technology and supports Australia's eligibility for membership of the IAEA Board of Governors by demonstrating the competence of nuclear science in this country.
Three options for providing a neutron beam source in Australia in the medium term future have been proposed:

- replacement of HIFAR with a reactor which produces at least equal neutron fluxes at an estimated capital cost of about $80 million;
- replacement of HIFAR with a smaller 5 MW reactor at a capital cost of about $25 million, together with a guarantee of access to overseas high flux continuous and pulsed neutron sources; and
- further refurbishment of HIFAR to upgrade the instrumentation and to ensure continuing safe operation, at an estimated cost in the vicinity of $10 million over the next ten years.

ASTEC considers that replacement of HIFAR with a reactor which produces an equivalent neutron flux is not feasible in the present Australian economic climate.

Replacement of HIFAR with a 5 MW reactor would mean that very few of the international standard research programs carried out at HIFAR could be continued in Australia. While guaranteed access to overseas facilities would enable these experiments to continue in foreign laboratories, ASTEC considers that this is not a suitable mechanism for maintaining and further developing a national competence in reactor-based technology. It is unlikely that technologies developed by a small group of Australian scientists working exclusively at overseas facilities will be transferred effectively to Australian industry. In any event, a 5 MW nuclear reactor would not be suitable for most industrial applications. Neutron scattering is becoming a common research tool in many fields of science in Europe and in the US. This will not occur in Australia if there is not a suitable domestic neutron beam source to which scientists have ready access.

Another disadvantage of replacing HIFAR with a 5 MW reactor is that some of the short-lived radioisotopes such as copper-64 which are currently produced by HIFAR, but could not be produced economically using a 5 MW reactor, would no longer be available in Australia.

ASTEC believes, therefore, that the preferred option for providing an adequate neutron beam source in Australia in the medium term future is to retain HIFAR and provide a regular budget for the continuation of upgrading and maintenance. Upgrading should include modification to improve the neutron beam instrumentation on HIFAR as well as to ensure continuing safe operation. The cost of this would be much less than a 5 MW replacement reactor. Old reactors in Germany, Japan, US, Sweden and the Netherlands are currently being upgraded to increase reactor power and/or instrumentation[12].

**ASTEC recommends:**

That the Minister for Resources and Energy make funds available to maintain and upgrade HIFAR so that its continued safe operation can be guaranteed and improvements made to the neutron beam instrumentation; this will ensure a continued Australian capability in neutron beam research and application and radioisotope production.
7.3.32 While it is important to support a neutron source in Australia, ASTEC believes that Australian researchers should not work in isolation but should maintain active contact with overseas researchers in their field. Neutron sources in other countries provide neutron fluxes which are not available at HIFAR but which are required for some neutron scattering research projects. It is not economically feasible to establish such facilities in Australia. The high flux reactor at the Institute Laue-Langevin in Grenoble, France (ILL) for example, produces a neutron flux of about $10^{15}$ neutrons/cm$^2$/sec. This is an order of magnitude greater than the neutron flux available at HIFAR. The ILL facility is supported jointly by France, England and Germany, each country contributing $10$ million annually. The spallation neutron source which recently was completed at the Rutherford Appleton Laboratory in the UK produces pulsed beams of high flux neutrons. This neutron source was constructed at a cost of more than sixty million pounds[13].

7.3.33 At present a small number of Australian scientists travel overseas each year to use facilities at ILL. They are sometimes accompanied by postdoctoral workers and postgraduate students. To date they have been able to use the ILL facilities without payment but there are indications that this fortunate position will not continue. The ILL reactor is currently closed down for maintenance and it is predicted that when it reopens in late 1985 it will begin to charge non-member countries for use of its facilities. Likewise the Rutherford Spallation Neutron Source is seeking payment for the use of beam time either by direct charges to users or by other mechanisms such as the provision of equipment to the facility.

7.3.34 ASTEC believes that the Government should provide funding to enable Australian scientists to carry out research at overseas neutron beam facilities provided such research is of a world class standard and cannot be performed within Australia.

Travel Funds for Australian Scientists Using Overseas Nuclear Facilities

7.3.35 ASTEC recognises the importance of maintaining within Australia a nuclear research effort in both basic and applied research which is in contact with the forefront of research at overseas centres. The Council also recognises that because of the cost involved in constructing and maintaining large nuclear facilities, this will only be possible by encouraging some Australian nuclear scientists to adopt the suitcase mode of research. A recommendation has been made already for enabling Australian scientists to work at foreign high energy accelerators by establishing a special research centre for high energy physics. A need has also been recognised for the provision of funds to support the travel of scientists who use overseas intermediate energy accelerators or neutron beam sources in order to continue in world class research.

7.3.36 ASTEC considers that the best mechanism for delivering funds to this group of scientists is by the appropriation of new dedicated funds to the Australian Research Grants Scheme (ARGS). The Australian Research Grants Committee (ARGC) already has broad experience in the assessment and evaluation of research proposals in many scientific disciplines including nuclear science. It is important that travel funds only be awarded to projects of a high scientific merit and the ARGC would be in a good position to assess this relative to programs in other areas of science.
7.3.37 In order to use overseas nuclear facilities, Australian scientists will first need to have their research proposals accepted by the program committees of the foreign facilities. After approval is granted, scientists might need to proceed promptly with their research at the time allocated by the program committee. It would be necessary, therefore, for the ARGC to act with a degree of flexibility in the way in which travel grants are awarded so that scientists could co-ordinate their acceptance by overseas program committees with their receipt of ARGS travel funds.

7.3.38 It is envisaged that the dedicated nuclear science and technology funds would provide travel and subsistence for a number of small teams to work overseas each year. The salaries of travelling scientists would continue to be met by their home institutions. Scientists who wish to work at a foreign neutron beam and accelerator facilities would compete against each other for funds. Scientists who were supported by the proposed special research centre for high energy physics would not be eligible for support through the ARGS dedicated nuclear science and technology funds.

**ASTEC recommends:**

(i) That an additional amount of $250,000 per annum be appropriated to the Australian Research Grants Scheme (ARGS) for the establishment of a dedicated nuclear science and technology travel fund.

(ii) That this fund be used to support the travel of Australian scientists whose projects have been determined to be of the highest international standard and require accelerator or neutron beam facilities which are not available in Australia.

**Payment of Charges for the Use of Overseas Nuclear Facilities**

7.3.39 In addition to supporting the travel of Australian scientists using overseas facilities it is necessary to consider the provision of funds or alternate mechanisms to meet charges which will in future be levied by overseas nuclear facilities. The Rutherford Appleton Laboratory, for example, has indicated clearly their intention to levy payment for overseas users of their spallation neutron source. Payment could be negotiated in terms of a financial commitment, the provision of ancillary equipment or possibly by offering the reciprocal use of advanced Australian facilities to British scientists without payment. Australian scientists currently are able to use overseas intermediate energy accelerator facilities such as those at TRIUMF in Canada without payment to the host institutions. It is likely, however, that payment also will be required for the use of these accelerator facilities in the near future.

**ASTEC recommends:**

(i) That the Minister for Science endeavour wherever possible to secure access for Australian scientists to overseas neutron beam and accelerator facilities by the negotiation of reciprocal arrangements between foreign nuclear facilities and Australian scientific facilities.

(ii) That where such reciprocal arrangements are not possible, and charging by foreign accelerator or neutron beam facilities is instigated, the dedicated nuclear science and technology fund of the ARGS should extend its funding to include such charges in addition to travel expenses.
That should these circumstances arise, the appropriation to the ARGs for the nuclear science and technology fund should be increased by an appropriate amount.

The Australian Atomic Energy Commission

7.3.40 The AAEC Research Laboratories at Lucas Heights constitute the largest centre of nuclear science and technology in Australia and as such warrant special attention in the context of considering Australia's future participation in nuclear science and technology. The present ASTEC study, however, has sought to examine and make recommendations on the broad field of nuclear science and technology in Australia rather than conduct a detailed investigation of the AAEC or any other individual organisation. Accordingly, it is not appropriate to make explicit recommendations on the structure and function of the AAEC Research Laboratories on the basis of the present study. This should be taken up at a later stage as part of ASTEC's ongoing review of government funded research and development in Australia.

7.3.41 In the course of interviews and discussions carried out in this study, however, ASTEC became aware of some aspects of the AAEC's functioning which require comment at this stage. Firstly the Commission is seeking to define clearly its future research direction. Historically, the AAEC has suffered as a result of the redirection of its research by changes in government policy and economic factors. Decisions not to proceed with nuclear power or, more recently, uranium enrichment in Australia, and the transfer of some of the Commission's resources to the CSIRO, are notable examples of such redirection. Such changes have reduced the morale and sense of purpose of AAEC staff.

7.3.42 Another feature of the Commission's research effort which concerned ASTEC was the age of much of the equipment in use. The Commission has not purchased a major item of equipment (costing in excess of $250,000) in the last 12 years. This is not commensurate with an organisation with an annual budget of over $40 million.

7.3.43 The AAEC was established under the Atomic Energy Act 1953. The Minister for Resources and Energy has proposed that part of the Act be repealed and replaced by legislation establishing an Australian Nuclear Science and Technology Organisation (ANSTO).

7.3.44 The proposed functions of ANSTO are:

- to undertake nuclear science and technology research and development;
- to provide products and services relating to its functions; and
- to provide advice on nuclear matters (including the nuclear fuel cycle and safeguards technology).

7.3.45 ANSTO would be permitted to undertake non-nuclear work at the direction of the Minister for Resources and Energy, where the Minister is satisfied that:

- this would ensure the effective use of ANSTO's staff and resources; and
it will not result in unnecessary duplication.

7.3.46 It is proposed that ANSTO be able to retain all or part of its commercial revenue, without appropriation offset, where this is agreed by the Minister for Resources and Energy and the Minister for Finance.

7.3.47 It is also proposed that provision be made for:

- a governing Executive including a majority of members from outside the Lucas Heights Research Establishment; and

- a part-time Advisory Council to assist the Executive and the Minister; membership to include a majority of members from outside the Lucas Heights Research Establishment and at least one staff member.

7.3.48 ASTEC agrees with the direction taken by these proposed amendments to the Act. The amendments are consistent with the Council's opinion that a base of competence in nuclear science and technology be maintained in Australia, that world class nuclear technology should be made available to industry and the scientific community, and that domestic isotope production should continue. The provision to allow ANSTO to undertake non-nuclear work within clearly defined limitations, will encourage more rational and effective use of ANSTO's facilities and expertise to be made. ASTEC considers, however, that the main thrust of ANSTO's research effort should continue to be nuclear science and technology. ASTEC believes that permitting ANSTO to retain all or part of its commercial revenue will stimulate interaction between ANSTO and industry and provide an incentive for scientists to direct nuclear research towards the needs of industry. Ultimately this will lead to increased transfer of nuclear technology to Australian industry. The retention of commercial revenue also will assist in the upgrading of some of the superseded equipment at the Lucas Heights Research Establishment.

7.3.49 ASTEC welcomes proposals to change the governing Executive of ANSTO. The extension of the Executive to include seven members, a majority of whom must be appointed from outside the ANSTO, will ensure that the research directions of ANSTO will reflect the needs of user groups from industry and other areas of science. ASTEC believes that such a governing body alone represents an appropriate top management structure for ANSTO and that addition of an advisory council is unnecessary.

7.3.50 ASTEC notes with approval that the proposed amendments to the Act remove outmoded provisions which have enclosed much of the work of the AAEC in a veil of secrecy. The repeal of these provisions will facilitate programs to educate the Australian public in the many important and peaceful applications of nuclear technology. The advantages of such a course were referred to earlier in this chapter.

REFERENCES

1. P.M. Kelly 'The Use of Radioisotopes and Radioisotope Techniques in Areas of Industrial or Economic Importance', AAEC Research Establishment Minute Paper, 1985.


7. A. Thomas, A. Clark and S. Tovey, 'The Case for Australia Participation in High Energy Physics Research', a paper prepared for the Nuclear and Particle Physics Group of The Australia Institute of Physics, 1984.

8. Department of Nuclear Physics, Research School of Physical Sciences, the Australian National University, 'Proposal for Upgrading the Accelerator Facility at the Australian National University', 1984.


APPENDIX A

AAEC AND AINSE PROJECTS INVOLVING USE OF
THE AAEC ACCELERATOR FACILITY

A1. PIXE Spectrum Analysis - programs for PIXE spectrum modelling have been produced and are now available on tape for supply to selected laboratories around the world.

A2. Occupational Health - with the Department of Industrial Relations (NSW) - using the PIXE technique to monitor occupational exposure to heavy metals through trace element analysis of hair, whole blood and serum.

A3. PIXE Cross-Sections - collaboration with the Department of Physics, University of Melbourne to produce accurate ionization cross-sections for a wide variety of ion species.

A4. Trace Element Analysis of Australian Coal - coal products and oil shale - with the CSIRO Division of Energy Chemistry - using PIXE-PIGME analysis to characterize the coal and provide mass balance of the combustion products.

A5. Microtopology and Depth Profiles - with the Department of Physics, NSWIT - using NRA and RBS to study surface roughness and depth profiles for elements such as H and O in metal surfaces used in solar technology.

A6. Studies of Prehistoric Pottery from Motupore Island (PNG) - with Department of Prehistory Latrobe University - using PIXE-PIGME to source pottery artefacts from local and distant sites in PNG to production centres in Motupore Island.

A7. Environment Aerosol Filters - with the State Pollution Control Commission (NSW) using PIXE and PIGME for compositional analysis of collected aerosol material resulting from environmental and pollution control studies.

A8. Crystalline Rock Analysis for the US Nuclear Regulatory Commission, with the Department of Soil Science, University of Sydney - using a PIXE-PIGME analysis with the AAEC mini beam facility to measure element distributions in the region of microfissures in rocks from the Alligator Rivers region ore bodies and study trace element migration.

A9. Environmental and Modelling Studies of Oxygen Profiles in rough surfaces - with the Department of Physics UNSW, using the manipulator facility, RBS and NRA synthesis programs.

A10. Determination of Oxygen-18 in Water - with the Department of Zoology, University of Western Australia - for the studies of metabolic rates in small animals.
A11. Composition Studies of Desert/Rock Varnish - with the Department of Geography, University of Sydney - using PIXE, HIXE, and RBS for analysis of thin varnish layers on rocks in arid areas of Australia.

A12. Characterisation of SE USA Pottery - with the Florida State University - to compare thin and thick sample PIXE analysis.

A13. Study of Prostheses - using PIXE-PIGME to study possible leaching of metals from prostheses to the surrounding tissue - with Sydney Hospital.


A15. SW Pacific and Melanesia Obsidian - with the Department of Prehistory ANU and the Department of Anthropology, Otago University - PIXE-PIGME analysis of obsidian source and artefact collections, as multivariate statistical analysis to produce a reference obsidian data catalogue.
APPENDIX B

WORKING PARTY ACTIVITIES

B1 A preliminary review of nuclear science and technology in Australia was carried out by an ASTEC working party consisting of the following members:

- Professor J. H. Carver (Convener and Deputy Chairman of ASTEC)
- Mr P. M. Trainor
- Mr D. S. Adam
- Professor P. I. Korner
- Professor H. Bolotin (University of Melbourne)

B2 In February 1985 a second ASTEC working party resumed and expanded the study and, at the completion of their investigations, prepared this report. Members of this working party were:

- Professor G. A. Rigby (Convener)
- Mr R. Woodall
- Professor D. H. Green
- Professor P. S. Kincaid-Smith
- Mr P. M. Trainor (until July 1985)

B3 Dr Pamela Stark and Dr Phil Price (until November 1984) of the ASTEC Secretariat acted as secretaries to the working parties.

B4 During the course of the study the working party visited Australian centres of nuclear science and technology and held discussions with a broad range of people who have an interest and expertise in nuclear science and technology. These included the following:

- Professor B. H. J. McKellar
  School of Physics
  University of Melbourne
  Physical Sciences Sub-Committee
  ARGC

- Professor B. M. Spicer
  School of Physics
  University of Melbourne

- Professor A. W. Thomas
  Department of Physics
  University of Adelaide

- Dr T. M. Sabine
  New South Wales Institute of Technology
  President, Society of Crystallographers in Australia
  President, Australian Neutron Beam Users Group

- Professor R. Brown
  Chemistry Department
  Monash University
The working party also received written submissions from the following:

- Dr E. W. Vogt
  Director
  TRIUMF
  Canada

- Professor R. S. Levin
  Physics Department
  Brown University
  Rhode Island, USA
Dr G. H. Lander
Argonne National Laboratory
Illinois, USA

Professor A. Zeilinger
Atominsttitut der Oesterreichischen Universitaeten
Wien, Austria

Dr A. W. Hewat
Institut Max Von Laue-Paul Langevin
Grenoble, France

Professor B. P. Schoenborn
Brookhaven National Laboratory
New York, USA

Dr I. F. Koetzle
Brookhaven National Laboratory
New York, USA

Dr M. S. Lehmann
Institut Max Von Laue-Paul Langevin
Grenoble, France

Dr D. E. Cox
Brookhaven National Laboratory
New York, USA

Dr H. G. Smith
Oak Ridge National Laboratory
Tennessee, USA

Dr J. W. White
Research School of Chemistry
Australian National University

Professor B. M. Spicer
School of Physics
University of Melbourne

Professor B. H. J. McKellar
School of Physics
University of Melbourne

Professor T. M. Sabine
Faculty of Science
New South Wales Institute of Technology

Australian Neutron Beam Users Group

Nuclear and Particle Physics Group
Australian Institute of Physics