

4 WE NEED SECRETS TO TRADE: The Beryllia Project

4.1 Introduction

The Australian Atomic Energy Commission, in 1954, had a head office, a scientific staff, most of whom were overseas training at Harwell, and a local administrative staff. It now needed a project. Ideally the project could be used for further training of staff, but more importantly it had to be in an area that was not the focus of other research groups. Since atomic energy research had come under the 'defence' banner on the international stage (not just Australia), Australia needed its own secrets to trade with other nations. Australia aimed to join the nuclear club^{xxxviii} as a full and independent member.

Australia also wanted a nuclear reactor. There was some debate as what type of reactor was wanted. Tom Playford, the Premier of South Australia had no doubts, he wanted a power reactor for his state. Playford was a great advocate of South Australian industrialisation, immigration and state economic independence. South Australia had the uranium deposits to run such a reactor and the state needed power to become industrialised. Further, as a state with very limited water supplies, a nuclear reactor sited near the ocean could also act as a desalination plant. Playford would attempt to convince the Commonwealth to allow a nuclear reactor to be established in South Australia. This reactor would never be planned let alone developed.

This chapter will focus on the research work that was conducted within the AAEC in the period up to approximately 1967. The early period of research

^{xxxviii} In 1954 the 'nuclear club' included the US, Britain, Canada, France, and the USSR. Other nations such as South Africa, China, Pakistan, India, and many western European countries were also attempting to obtain this technology.

was involved with a systematic study of materials, specifically beryllium and beryllium oxide (beryllia), and will be referred to as the Beryllia Project. This project included research into a variety of reactor types and the materials requirements for these reactors.

This period also saw the growth of the Commission into an organisation that required an administrator instead of a full-time Chairman and the need to have control of its own finances instead of being dependent on the Commonwealth government authorising all its expenditure.

4.2 AAEC Structure and Administration

As previously discussed, the Commission was made up of three commissioners: the chairman, Jack Stevens, Philip Baxter and Hugh Murray. The staff, in 1953, was initially made up of clerical and secretarial personnel, under the direction of the Secretary to the Commission, Patrick Greenland. Commission staff were housed at the Commission's Head Office, Cliffbrook, in Coogee. Stevens and Greenland had previously worked together in a similar partnership at the Overseas Telecommunications Commission¹.

The Commission functioned through three advisory committees which were set up over a period of three years:

- the Uranium Committee, chaired by Hugh Murray,
- the Scientific Committee, chaired by Philip Baxter and
- the Business Committee chaired by Jack Stevens.

These committees were purely advisory and had little long term effect on the direction of research taken by the Commission.

The period from 1953 to 1955 saw the Commission assemble scientific staff from the CSIRO personnel who were already training at Harwell and scientists from nuclear groups at other institutions, predominantly from Professor Martin's group at Melbourne University. Additional scientific staff were recruited and sent to Harwell for training and other officers (clerical, administrative and technical) would be recruited as needed. This period also saw the Commission develop its 'raison d'être' and start to implement the research directions that had been decided. These are discussed in the sections which follow.

The scientific and engineering recruits who were to become the professional scientific backbone of the Commission were sent almost immediately to Harwell to undertake their training since at this time the Commission comprised a Head Office and little else. The next group of recruits, who came to the Commission after 1955, began to establish a structure to the organisation. The positions of Chief Scientist and Deputy Chief Scientist and Chief Engineer (the latter two were filled by the same person) were established in 1955 and these positions were filled by Professor Charles Watson-Munro (1915 - 1991) and Dr Cliff Dalton (1916 -1961) respectively².

Charles Watson-Munro had been Professor of Physics at Victoria University College in Wellington, New Zealand³. He had been a member of a small group of New Zealand scientists who had been working on the Montreal Project, which was part of the larger Manhattan Project during the war. This group was involved with the design, construction and development of the first Canadian reactor which was built at Chalk River⁴. This reactor was a natural uranium heavy water reactor and was given the name ZEEP^{xxxix}. Watson-Munro worked on the engineering aspects of the ZEEP reactor which started

^{xxxix} ZEEP stands for Zero Energy Experimental Pile

up in September 1945⁵. It should be noted that ZEEP was the first reactor to go critical outside the US⁶.

Watson-Munro was also involved in the design and construction of the first British reactor, GLEEP at Harwell. He had returned home to New Zealand to take up a Chair in Physics and it was from this position that Australia recruited him⁷. Watson-Munro directed the construction of HIFAR^x while the development of the research program was Dalton's responsibility⁸. Watson-Munro was the first person who was involved in the design and development of the first nuclear reactors in three different countries on three different continents.

Cliff Dalton was also originally from New Zealand. He had been a Rhodes Scholar at Oxford and during the War was involved with research on radar. Dalton went to Harwell after the war and from '1947-48 *he was in charge of the Fast Reactor Group of the United Kingdom Atomic Energy Authority. This group carried out the early scientific work which led to the decision to construct the fast breeder reactor at Dounreay*⁹. He returned to New Zealand in 1949 to take up the position of Professor of Mechanical Engineering in Auckland from which position he, too, was recruited to the AAEC in 1955¹⁰. Dalton joined the AAEC staff at Harwell and '*helped shape the Australian research program from the beginning*'¹¹. The Commission had now recruited two individuals who could be regarded as being in the forefront of nuclear reactor technology. Both had been recruited from their academic positions in New Zealand. It seems that in the early 1950s Australia must have appeared as a nation that was rapidly advancing in areas of science and technology. These men also had the practical experience of developing and building nuclear reactors.

^x HIFAR stands for High Flux Australian Reactor.

During 1955 the Section Head positions were advertised but most were filled by existing staff who had been or were being trained at Harwell. Other positions were also being filled and the Commission staff in 1955 included twenty-four administrative staff housed at Coogee and thirty-five scientific and technical staff most of whom were at Harwell¹².

The Australian government began to realise that atomic energy was no longer a 'defence' subject since all the research taking place was for industrial, academic and other peaceful uses. To legitimise this trend the Prime Minister, Robert Menzies, *'announced on the 18th October (1956) that the ministerial responsibility for the peaceful development of atomic energy would be transferred from the Minister of Supply ... to the Minister for National Development'*¹³. The Commission came now under the control of Senator Spooner who was the Minister of National Development. Senator Spooner had been elected to Parliament as a Senator representing NSW in 1950. He had taken up the position as Minister for National Development in 1951.

The British atomic tests in Australia took place from 1952 and were completed in 1963. When the later tests were all located on the Australian mainland at Maralinga, the Commonwealth Government thought it necessary to monitor the safety aspects of these tests. The Prime Minister, in a letter dated 9th June 1955 to the Minister for Health, Sir Earle Page, stated

*'... the Australian Government has made available to the United Kingdom, facilities which will enable them to continue to conduct atomic tests in Australia in conjunction with our own people... before we will permit any such test to take place, we must be satisfied that it can be carried out with due regard for the safety of the Australian public'*¹⁴.

Australia consequently established a Safety Committee

'to examine information and other data supplied by the U.K.

*Government ... for the purposes of determining whether the safety measures proposed to be taken ... are adequate for the prevention of injury to persons or damage to livestock and other property as a result of such tests and to advise the Prime Minister ... whether alternative or more extensive safety measures are considered necessary or desirable'*¹⁵.

This committee was set up in May 1955 and it is the make-up of this committee which has resulted in accusations that the AAEC was involved in the British atomic tests. The committee included: Professor Martin, as the Chairman, Professor Titterton, Professor Baxter, Mr Butement, and Dr Eddy who was later replaced by Mr L.J.Dwyer¹⁶. Martin, Titterton and Butement had been observers at earlier British atomic tests. Baxter, was from the time of his appointment to the committee, a member of the AAEC. But by 1957 when this committee was made smaller, both Baxter and Martin were removed. Martin would later become a member of the AAEC. Titterton was the only individual who maintained his involvement as an AAEC scientific adviser and a member of the Safety Committee. In 1957 this Committee was reduced to three members and a larger National Radiation Advisory Committee was convened. This latter committee had a much broader representation than the original Safety Committee¹⁷.

In the period from 1953 to the end of 1957 most AAEC scientific staff were still at Harwell undertaking training, so none of them could have been involved with the tests. The only links between the British tests and the AAEC were Jack Stevens (when he was in Supply), Professor Martin (as an observer), Professor Baxter (as an observer) and Titterton who was little more than a member of the AAEC Scientific Advisory Committee from 1956 –1964 and

hence had little or no direct influence on the research programs at the Commission.

In September 1956 Sir Jack Stevens resigned as chairman of the AAEC, after a long career in the public service he took up an appointment in the private sector. His position on the Commission was filled by H.Raggatt. Philip Baxter was then appointed as chairman, a position he would retain for almost ten years. His influence would direct the Commission through some turbulent times. The Chairman's position now became part-time since Baxter was by now also Vice-Chancellor of the New South Wales University of Technology, later to become the University of New South Wales. To overcome the problem of an organisation such as the Commission working with a part-time leader, in 1958 the position of Executive Officer was created in an amendment to the Atomic Energy Act (1953) which states '*The Commission shall consist of a Chairman, a Deputy Chairman, an Executive Member and not more than two other members*'¹⁸.

Mr A.D.McKnight was appointed to this position on 30th April 1958. '*Mr McKnight joined the Commonwealth Public Service in 1939 and was previously Secretary to the Department of the Army*'¹⁹. Allan Douglas McKnight was a career public servant from 1939. He had legal qualifications and had worked in the Attorney-General's Department until 1951 when he was transferred to the Prime Minister's Department. In 1954, he had been Acting Secretary to the Cabinet and hence was privy to much of the discussion concerning the AAEC and the decisions to build a research reactor. He had worked in the Department of the Army from 1955.

The 1958 amendment also allowed for an increase in the number of Commissioners. Professor Martin became the fourth Commissioner. It is of

interest to note that, following the appointment of Raggett, there appeared to be a need to increase the number of Commissioners to four. Why there was a need to increase the size of the Commission has not been justified. The appointment of Martin to this position caused very little concern at the time but with hindsight it is relatively easy to make the false assumption that the Commission was involved with defence projects. As previously mentioned, Martin was the Defence Scientific Adviser and had also been involved as an Australian observer at the British atomic tests and Stevens had been involved with helping the British establish the sites for their atomic tests as part of his brief as Permanent Head of Supply. However, one must remember that while the British Atomic tests were being carried out most of the scientific and technical staff from the Commission were at Harwell, involved in the research activities which would ultimately result in the construction of a research reactor in Australia.

The presence of Stevens and later Martin on the Commission was possibly due to the simple fact that at this time there were very few individuals in Australia with the understanding and expertise to make any kind of contribution to the newly formed Commission. The most that can be made from the presence of these two individuals is to suggest that they may have kept the defence leaders abreast of any new nuclear developments within the Commission. One should be aware that in the 1950s the Cold War was still very much a lively political issue. The Korean War had just finished in a stalemate and the guerrilla insurgencies in Indochina and Malaya and China's additional atomic developments were beginning to affect foreign policy. Consequently the notion that one of the Commissioners may have a direct if secretive link to defence bodies would not be all that unusual, but to suggest that a specific 'defence agenda' existed in the area of nuclear research is somewhat extreme.

Senator Spooner, the Minister for National Development, stated in Appendix C of Cabinet Submission 1019 dated 7th February 1958 that '*there is at present, no military program at Lucas Heights, but the advantage to Australia, in the event that such a program was required, of having trained staff and facilities available is obvious*²⁰'. This statement was made in a secret Cabinet submission, which implies that the statement made by scientists from the AAEC that they were not involved in military work is true and not just a 'cover story' for the Australian media. Consequently, conspiracy theorists who believed that Lucas Heights was part of an atomic bomb project were and are completely wrong. There seem to be very few good reasons for a Minister to lie to his Cabinet colleagues in the secrecy of a Cabinet meeting. The statement made by Spooner also resonates with the statements made earlier by Ben Chifley who wanted Australia to have a trained staff and facilities to convert peace-time industries to military uses if required in the future.

As a consequence of the 1958 amendment to the Atomic Energy Act, the Commission was now given the ability to operate its own bank account, to invest its own monies and to borrow money, thus giving the Commission a more independent standing. Treasury still retained the overall financial control of the Commission since any financial transactions still required approval from the Treasurer. The Commissioners would still be expected to 'go cap in hand' to Canberra each year to justify their expenditure and argue for increased funding. This was not a simple exercise but one which required the production of lengthy reports to Treasury and submissions to Cabinet.

The Commission's Research Establishment was officially opened on 18th April 1958 by the Prime Minister, Robert Menzies²¹. Between 8th and 10th December that year the AAEC held the first of its many Open Days. The

research establishment was not open to the public; that would happen later. This first Open Day was to '*allow Professional Societies to visit Lucas Heights*²² and admission was by 'ticket only'.

*'The Commission has been considering methods of improving communications between the Commission and the Chief Scientist and his leaders of the research effort at Lucas Heights. The Commission has concluded that this will be best achieved by the establishment of a committee on which the Commissioners, the Chief Scientist and his immediate Headquarters staff and certain Section Heads will sit'*²³. This committee was duly formed and became known as Research Establishment Consultative Committee. It met for the first time on 24th August 1959. It met regularly on the Thursday prior to a Commission meeting and the Thursday following a Commission meeting. It would seem that this was the vehicle through which research projects and directions were communicated from the scientific staff and either endorsed or rejected by the Commission. This type of arrangement is consistent with the notion held by many who worked at the Commission that research programs came from the floor up to the Commissioners and not dictated from above.

In April 1960 H.Murray retired from the Commission and Mr B.F.Dargan was appointed to fill the vacancy²⁴. Watson-Munro was invited by Professor Harry Messel (b 1922), Head of the School of Physics at Sydney University, to take up the new Chair of Plasma Physics in the School of Physics and resigned from the Commission at the end of 1959. The position of Chief Scientist was replaced by that of Director of the Research Establishment and was taken up by Cliff Dalton in 1960 who remained in this position until his death in 1961. Keith Alder, Head of Metallurgy, was appointed Deputy Director of the Research Establishment during 1960²⁵.

Australia, primarily due to Ben Chifley's foresight, had been an active participant in nuclear energy issues from the first meeting of the United Nations Atomic Energy Commission to which, as mentioned in Chapter 2, Australia not only sent a delegation in 1946 but provided the first Chairman for the organisation. The United Nations formed the International Atomic Energy Agency (IAEA) in 1957 to replace the United Nations Atomic Energy Commission^{xii}. The purpose for which the IAEA was created was to *'control and develop the use of atomic energy'*²⁶. Australia was one of the seven nations which sponsored the draft resolution at the United Nations, one of the twelve nations which revised the statutes and one of the eighteen nations to ratify these, *'Australia was selected (to the First Board of Governors) as the most advanced country in South-East Asia and the Pacific'*²⁷. Before the first meeting of the General Conference of the IAEA, a temporary body had been established by the United Nations comprising the twelve nations who drew up the statutes with an additional six nations whose function was *'to set up the initial organisation, arrange for headquarters accommodation in Vienna, sketch out a preliminary program of Agency activities and designate members for the first Board of Governors'*²⁸.

Dr O.O.Pulley was Australia's first representative to the Board of Governors²⁹ and Australia has maintained a presence at the IAEA in Vienna ever since. Pulley was attached to Australia House as the Liaison Officer responsible for atomic energy. This position and his appointment to it in 1957 came about when Australia was in the process of building HIFAR, the nuclear reactor located at Lucas Heights which will be discussed later in this chapter.

^{xii} the United Nations Atomic Energy Commission was plagued with problems particularly when the members of the Security Council could not come to an agreement as to the purpose of the organisation.

The Australian Embassy in Washington was approached by the IAEA on 7th August 1960 seeking approval for McKnight's nomination as Chairman of the board of Governors³⁰. McKnight was the Executive Officer of the Commission at this time. *'After the Annual General Conference of the International Atomic Energy Agency in October 1960, the Executive Member of the Commission, Mr A.D.McKnight, was elected Chairman of the Agency's Board of Governors for the ensuing twelve months'*³¹. McKnight was the IAEA's fourth Chairman of the Board of Governors. Consequently McKnight took leave of absence from the Commission and on December 1960, a Deputy Executive Officer was appointed, Maurice Timbs³². Timbs had been First Assistant Secretary of the Prime Minister's Department.

McKnight completed his twelve-month term as Chairman of the Board of Governors but remained as Australia's representative on the Board of Governors and was also posted to London so his leave of absence was extended. McKnight was then appointed by the IAEA as its Inspector-General, a position he would hold from 1964 to 1968³³. McKnight would never return to the Commission and Timbs would later be appointed as the Executive Officer of the Commission and remain in this position until his resignation in 1973 when he accepted the position of Head of the Department of Services and Property³⁴. An interesting note concerning McKnight's relationship with Timbs is found in a letter from McKnight addressed to the Deputy Secretary of the Department of External Affairs dated 29th August 1967 *'...as you know, Maurice Timbs has possessed a certain animus against me for years ...'*³⁵. This sentiment would be shared by many who worked in the Commission during the time that Timbs held his position.

Cliff Dalton died on 17th July 1961, he had been unwell for sometime prior to his final illness³⁶. In 1970, Dalton's widow, Catherine, published a book

entitled 'Without Hardware'^{xlii} in which she proposed that there had been some form of international conspiracy to murder her husband. The book is very poorly written and her argument can best be described as being barely coherent. Another member of the original Harwell team, George Page, like Dalton, had also died of stomach cancer. In the early hours of New Years Day 1962, Gilbert Bogle's body was discovered together with Margaret Chandler's body, in the Lane Cove River Park. Bogle was a New Zealand scientist who worked for CSIRO. Thereby starting one of the most puzzling murder investigations in the history of New South Wales. It appeared that both Bogle and his companion had died from some mysterious poison. But to date no exact cause of death has been determined, no motive for the murder has been found nor has any suspect been identified. The case is still open. All three men were originally from New Zealand which added to Catherine Dalton's conspiracy theory against the New Zealand scientists.

The position of Director of the Research Establishment became vacant. The search for Dalton's successor lasted six months and took Baxter overseas following his Minister's instructions. In a letter from Senator Spooner to the Prime Minister dated 31st July 1961, Spooner wrote '*...I might add that the Commission has given initial thought to the problem and finds that the only person suitable for appointment in Australia is the Acting Director, Mr K.F.Alder...*'³⁷. Australia and Australians always tend to think that the best possible people for highly technical or leadership positions are to be found overseas. Often local candidates are overlooked in favour of someone of no better stature but from overseas. It would appear that the best person for this position really was Keith Alder. Alder became Director of the Research Establishment in 1962 with Dr G.L.Miles being appointed as Assistant Director³⁸.

^{xlii} C. Dalton, 'Without Hardware' Nicholson Prints and Publishing, Canberra 1970

The Commission, in 1962, established a Safety Review Committee. The committee comprised *'three persons from outside the Commission'* and included; Professor Sydney Sutherland, Dean of the Faculty of Medicine, University of Melbourne; Dr C.J.Cummins, Director-General Department of Public Health, Sydney and Mr D.J.Stevens, Director of the Commonwealth X-ray and Radium Laboratories, Melbourne³⁹. The Committee was to review the radiation safety procedures and performances at the Research Establishment at Lucas Heights and to report their findings to the Commission.

The Commission had established its administrative structure and had established mechanisms by which scientists could communicate with the Commissioners. The Commission was next challenged with the establishment of its major research project. The research project which was decided upon while the Australian scientists were still at Harwell was an investigation of the use of beryllium metal, as well as the ceramic, beryllium oxide (beryllia), as possible moderators for nuclear reactors. Details of this project are discussed later in this chapter. In the nine years that Australians were working on this project considerable expertise was developed at Lucas Heights culminating in an International Conference on Beryllia. This was the climax and the conclusion of the project, so it was with some pride therefore that the Annual Report of the AAEC stated; *'The first International Conference on Beryllium Oxide, attended by scientists from six countries, was held at Newport, N.S.W. from October 21 to 25 1963 ... among the 100 scientists registered for full attendance at the Conference were 25 from overseas'*⁴⁰. Beryllia research was still considered of importance to others outside Australia which was noted by the attendance of the significant number of overseas delegates.

Training in this period was further extended beyond the formation of AINSE, which occurred in 1958 (discussed later in this chapter), to the extent that in 1963 *'in conjunction with the University of New South Wales, the Commission decided to establish jointly an Australian School of Nuclear Technology at the AAEC Research Establishment. The school is expected to open in 1965 and will provide formal training and education in nuclear technology and related subjects for Australian and overseas students'*⁴¹. This school was indeed opened and received students both from Australia and from some South-East Asian countries. It continued to function for the life of the AAEC.

The ultimate establishment of an Australian nuclear power reactor was again put on the political and organisational agenda when in 1963 *'with the assistance and co-operation of the State Generating Authorities, the AAEC has re-examined the prospects for nuclear power in Australia'*⁴². This resulted in the Commission establishing a task force to look into nuclear power generation, *'In the conviction that the stage is approaching at which atomic power will be an economic possibility in Australia, the Commission ... established a Special Projects Division at its Head Office ... and to examine the problems which will be involved in setting up atomic power installations in Australia'*⁴³. This would later develop into the Jervis Bay Reactor Project which is the subject of the next chapter.

The Commission also completed a small organisational restructuring when it became apparent that McKnight would not be returning to his previous position at the Commission, *'In October 1963 ... the Commission created in its central administration the position of General Manager and appointed to this position Mr Maurice Timbs'*⁴⁴. The Commission was becoming more aware of the need for public education and with this aim opened the research establishment to the public. The first of the Commission's Open Days which

were open to the public took place in 1963, each day was open to a specific group of people⁴⁵:

26th September for professional associations and university staff

27th September for science students and their teachers and

28th September for families and friends of Commission staff.

The general public were still not able to gain access to the Research Establishment, but school students and their teachers were.

On 10th June 1964 David Fairbairn succeeded Senator Spooner and was now responsible for the Commission⁴⁶. McKnight, who was now well established at the IAEA, *'resigned his office of Executive Member of the Commission to take effect from September 17, 1964 ... Mr M.C.Timbs was appointed Executive member of the Commission ... from October 24, 1964'*⁴⁷. Other changes to the Commission included the resignation of Raggatt in 1965 to be replaced by Mr R.W.Boswell who was Secretary of the Department of National Development.

The structure and nature of the Advisory Committees was changed as well in 1965; *'With the approval of the Minister ... the Commission established an Atomic Energy Advisory Committee to advise it on scientific, industrial and economic aspects of the development of atomic energy. ... and replaces two earlier and larger committees, The Scientific Advisory Committee and the Business Advisory Group'*⁴⁸. This somewhat benign statement masks a major crisis in the advisory committee structure. According to Moyal, by the mid 1960s the Commission saw the Advisory Committees as bodies that would endorse Commission policies. At a meeting of the Scientific Advisory Committee, Baxter and the other Commissioners expected the Committee to endorse a proposed extension of the High Temperature Gas Cooled Reactor (HTGC) program, but to their surprise a number of members of the committee

regarded this proposal as being unsound from a technical perspective and refused to support the Commission. Martin, who was in the chair, adjourned the Committee which was later reconvened with Baxter in the chair. *'Baxter sought the views of the Committee and promptly disbanded it'*⁴⁹.

The subsequent formation of the Atomic Energy Advisory Committee did not include the nuclear experts Oliphant, Titterton and Martin, but Martin would remain a Commissioner. Baxter had effectively silenced all opposition to his management of the Commission. According to Moyal *'Baxter ...saw himself ... as the central and sole source of policy proposals for nuclear developments in Australia. ...Decisions within the Commission emanated from the Chairman and the Commissioners'*⁵⁰. Since both the Science Advisory and Business Advisory Committees had little direct effect on the workings of the Commission this consolidation of committees had an additional benefit, that of perhaps saving money on the number of advisory committee meetings.

4.3 Recruiting and Training of Commission Staff

Keith Alder was one of the first of the new recruits to the Commission. He describes his first days with the Commission *'There were no laboratories. The Atomic Energy Commission consisted of the old house Cliffbrook at Coogee ... It was a Chairman, a secretary and a small office staff. That was it. That's all they had at the start'*⁵¹. He then describes his first few weeks working at the Commission, *'the first thing I did was report for duty at the beginning of January and then report in every couple of days until the ship sailed and we went straight off to England. We were seconded to Harwell nominally for two years which turned into four years to learn on the job'*⁵².

When he arrived at Harwell, Alder describes the attitudes of the Australians who were already there; *'the old hands then at Harwell were excited because the arrival of Warner and Alder signalled to them that something was happening, at last ... some of them had been in England since 1946 and at Harwell soon after it started ... they had made notable contributions to the British program but were anxious to return home to Australia'*⁶³.

Alder describes his first project after his initial training at Harwell:

*'the chief of the metallurgy division put me in the reactor fuel section under a fellow called Geoff Ball, who became the Professor of Metallurgy in London later and I was asked to develop methods for fabricating uranium metallic fuels with zirconium cladding. The cladding and the uranium (were) to be metallurgically bonded for good heat transfer. I worked on that for two years'*⁵⁴.

This initial work was part of a greater British project, but as with many projects undertaken at the time, it did not ultimately lead to new reactor technology. In the early 1950s reactor engineering was still in its infancy and many ideas were being explored in Britain, Canada, US and Europe. According to Alder *'You must recognise that in the 1950s new concepts in power reactors were invented every few days or every month and a certain amount of work would be done and they would die'*⁵⁵.

The AAEC, in its second Annual Report in 1954, had established the nature of the research in which it would participate: *'the research to be undertaken in Australia will be complimentary to the United Kingdom research effort, though it will be comprehensive enough to have a substantial measure of self-sufficiency'*⁵⁶. The research done in Australia was to be in an area that was not being done elsewhere, and specifically the research program should build

up a 'cadre of experts' in Australia. The training and development of expertise was regarded as a primary objective of research⁵⁷. By September 1954, arrangements '*for co-operation with the U.K. in atomic energy research and development were approved*'⁵⁸ with the result that Australia now had access to information on the industrial production and use of atomic energy that had been developed in Britain. All future Australian research results would in return be available to Britain⁵⁹.

*Alder continues 'After about two, I think it was about two, years the Commission then got around to appointing those who were to be the leaders of the future and I won the job of being the head of Metallurgy which later became Materials Division and as the first boss, Chief Scientist Charles Watson-Munro, had arrived by then and so we began in committee and personal work in the planning for Lucas Heights, its equipment, and its research program'*⁶⁰.

The group working at Harwell had expanded from eight to over fifty, in 1955. Included in this intake of staff were the two senior appointments; the Chief Scientist of the AAEC, Charles Watson-Munro and the Deputy Chief Scientist and Chief Engineer, Cliff Dalton. (see previous section). Two other senior positions were established and filled; the Leader in Chemistry, G.L.Miles and Leader in Chemical Engineering, Carl Berglin. The Leader in Metallurgy, Keith Alder, would later become the Director of the Research Establishment⁶¹. The other sections and their leaders were also appointed at this time. The list of sections and their leaders included:-

Chemistry	Grant Miles
Chemical Engineering	Carl Berglin
Radioisotopes	Jack Gregory
Metallurgy	Keith Alder

Technical Physics	George Page (also a New Zealander)
Engineering Research	Owen Pulley
Engineering Services	Bill Roberts
Medical Research	George Watson ⁶² .

Returning to Alder's version of events;

*'We had a research committee at Harwell, the future section heads and other seniors, I think there were nine of us in the research committee under Cliff Dalton and we cast around what could little Australia do in terms of our amount of effort and money we would be able to put into it compared to the big efforts of the United States and other European countries and that's why we picked on beryllium because as a sort of background to the program initially, as the only moderator that the bigger laboratories were not examining in detail ... And really the principle was, let's do something different, let's do something interesting ... looking at beryllium as a moderator there are simply only two ways to go; you could go gas cooled or you could go liquid metal cooling. And both of those were of course very much considered in reactor research development circles in both the United States and the United Kingdom'*⁶³.

It was decided that *'the Australian program should concentrate on the use of beryllium as a neutron moderator, and initially should be studied as part of two possible power reactor systems, a high temperature gas cooled reactor (HTGC) and a liquid metal fuelled reactor (LMFR). Both beryllium and beryllium oxide should be studied'*⁶⁴ (see section 4.6). Baxter, the chemical engineer, favoured the liquid-metal fuel reactor, while Dalton favoured the high temperature gas cooled reactor⁶⁵. These areas of research and investigation were started at Harwell in 1956⁶⁶.

Recruiting for the Commission continued even after the initial recruits had been sent off to Harwell. Some new recruits were already in Britain working for other companies when they decided to apply to the Commission. Doug Ebeling, was an Australian who had graduated from the University of Melbourne and had been working for ICI in Manchester. He described the manner of his recruitment in 1956:

'I was in Manchester at the time ...I saw an advertisement in the paper. They were looking for engineers to work on atomic energy. So I wrote an application ... and I received a request to attend an interview ... On the morning I left to go it snowed and when it snows the whole of British Railways goes into complete chaotic behaviour. The result was that I was four hours late for my interview ... they had waited patiently ...I was appointed as a senior technical officer at that time'⁶⁷.

Ebeling's project at Harwell was to work on the new research reactor that was being developed at Harwell at that time.

Australia had initially intended to build a power reactor, however certain events would lead to a change in the type of reactor finally decided upon (see section 4.4). Australian participation in the British research program was expanded and *'Australian scientists in the U.K. are being given assistance ...in the design of a large high-power research reactor to be constructed in Australia'*.⁶⁸ At that time the *'principal object of the Australian research program is to develop means for the economic production of industrial electric power from nuclear fuels'*⁶⁹. This would be the long term objective of AAEC staff until the early 1970s when the whole notion of an Australian power reactor or even the possibility of one would be dismissed and not taken up again.

According to Alder

'About half my time in 56, most of it in 57, at Harwell was spent on getting ready for Lucas Heights. I ran the equipment committee, ... sending instructions back on what to buy and we were heavily involved in the design of buildings ... corresponding with the architect back in Sydney and planning research programs. So I did a little bit of work on liquid metal. We started the liquid metal research program at Harwell and we were a team of nine at that time in my Metallurgy section, and three of them were involved in liquid sodium work and I participated in that on a part time basis and that was the last time beryllium came into it because I did a little bit of work on the compatibility of a sodium slurry uranium beryllide suspended in sodium in a beryllium loop and that was the end of that. We then packed up all our liquid metal equipment which we bought from Harwell and shipped it back to Australia, to give us a flying start back here. But by that time I was pretty much fully involved in planning for the future'⁷⁰.

Reactor technology schools were being established in both Britain and the US. One of the first was at Harwell which Alder participated in as a student shortly after his arrival in 1954. The course Alder attended was the first trial run of what was later to become Harwell's reactor training course. These courses quickly developed, attracting students from a number of different areas and consequently in 1955 four Commission staff were sent to the reactor school at Harwell and two, Ron Warner and Allan Wilson⁷¹, were sent to the reactor school at the Argonne national laboratories near Chicago⁷².

All the Australian seconded staff except two were working at Harwell on nuclear fuel and nuclear power. The two exceptions were Dr Jack Gregory who was working in isotope production and Mr Terry Sabine who was learning

how to diffract neutron beams as a new type of research tool⁷³. The Isotope Section within the AAEC would provide the first commercial application of nuclear science in Australia. Neutron diffraction was, in 1955, still in its infancy but would develop into one of the productive research tools of materials and biological science in the latter part of the 20th century. Both these projects will be discussed briefly in the next chapter.

1955 proved to be a very exciting year for anyone involved with nuclear science. Following from President Eisenhower's 'Atoms for Peace' proposal of 1953, the First International Conference on the Peaceful Uses of Atomic Energy was held in Geneva starting on 8th August⁷⁴. Australia was included when the United Nations decided that *'a committee of representatives of seven nations was appointed to arrange the Conference'*⁷⁵. Naturally Australia sent delegates to this committee but, more importantly, those young enthusiastic members of the AAEC scientific staff attended the conference.

Alder recalls

*'you have to recognise that in the beginning the whole jolly lot was secret. There is no doubt about it. It grew out of the wartime nuclear weapons business, the Manhattan Project and up until late 1955 that secrecy really had rubbed off on the civil. And then in late in 1955 ... we had the first genuine international conference on Atomic Energy in Geneva. ... There was another one in 58, one in 64 and I think one in 73. There were four of them in a row. I was fortunate to be at all of them. The first one was held while we were all in Harwell of course. That was the first time the lid came off and the French and the Russians and the Germans and the British, every nation that had an interest at all in atomic energy was there. There were five thousand delegates, it went on for two weeks and the scales fell from our eyes'*⁷⁶.

The training of these AAEC recruits was in a wide range of reactor science and engineering areas. The knowledge and training they received would ultimately result in the formation of a small group of individuals, each expert in their own area who could then teach others when they returned to Australia. Medical and industrial applications of reactor-based technology were being explored. From the very beginning of the research establishment, and during the next four decades, Australia would become established at the forefront of many of these areas, to such an extent that Australia developed a small export market in radioisotopes.

4.4 The Need for a Research Reactor

Australia wanted to become an independent member of the nuclear club. A vital part of this process was not just having information to exchange but having the facilities that could help provide this information. Initially this facility was to be a power reactor, possibly located in South Australia.

Howard Beale wrote to the Prime Minister who was in Britain at the time, in a letter dated 28th May 1953, concerning an approach to Stevens at the AAEC by members of the South Australian Government requesting a joint Commonwealth – State Program for the introduction of a power reactor in South Australia. Beale endorsed the project and suggested that the Commonwealth may support it also. He mentioned that Baxter would be in Britain from the 6th June and would be available for further discussions with the Prime Minister if required⁷⁷. When Baxter and White, who accompanied him, returned to Australia they wrote a report to their Minister which stated

'Britain has built four successful nuclear reactors ... and had developed technology in this field. ... None of the reactors built have been designed to produce electric power. They have been operated as

*plutonium producers for military and research purposes. Initially and as long as the military situation requires it, Britain will operate these reactors as plutonium producers for atomic weapons. This requires that the time cycle of the uranium in the reactor is a short one, so that plutonium 239 of military quality is produced. ... Plutonium produced in Fast Reactors will be of military quality*⁷⁸.

Baxter and White were well aware of the differences in reactors built for power and those built purely for plutonium production. The British had two plutonium producing reactors at Windscale which started operation in 1951. Their comments on the production of plutonium are directly related to the British atomic tests and the need for Britain to have a nuclear weapons capability.

The report concludes with '*Australia's first reactor should be a full-scale power producing reactor. On general consideration South Australia would seem to be the most attractive site for this reactor*⁷⁹'. It is quite apparent that had Baxter or White wanted a reactor for military purposes they would not have been as specific as mentioning a power reactor. These comments again were made in a report for their Minister and ultimately for Cabinet. The AAEC was going to build a reactor for peaceful purposes, and not military purposes; Australia needed a power reactor. The Baxter – White report further suggested that the AAEC '*set up laboratories in Sydney for research primarily in the fields of metallurgy, radioactive chemistry and chemical engineering*⁸⁰'.

Beale, in a submission to the Cabinet Committee on a Uranium Program for Atomic Development dated 15th September 1953 stated

'Based on information given by Professor J.P.Baxter and F.W.G.White... who were sent abroad in June to study the developments in atomic energy in the U.K., U.S.A. and Canada ... Britain has ... now decided to build a power producing reactor of a

*design which it is confident will be successful. ... the United States government does not appear to have an actual program for the immediate erection of power producing reactors ... Electric power for industry has, in some if not all of the Australian States, failed to keep pace with demand ... In South Australia, local deposits (of coal) are limited and of poor quality and there is no water for hydro-electric schemes... The Northern Territory is in a worse position so far as natural resources are concerned*⁸¹.

Beale concluded his submission with '*The program which it is suggested Australia should follow is the construction, at the very earliest reasonable date, of a full-scale power producing reactor ... this reactor would probably be located in South Australia*⁸²'. This final statement is reminiscent of both Marcus Oliphant and Thomas Playford who both believed that Australia needed a power reactor located in South Australia, but were both largely ignored by members of the Industrial Atomic Energy Committee.

The research laboratories in Sydney were agreed to by the Cabinet Committee on Uranium on 8th April 1954. In its report the Committee stated that '*the ANU, University of Melbourne and the University of Sydney were engaged in fundamental nuclear research and the Commission's proposed laboratories would not duplicate that effort*⁸³'. It is of interest to note that the Committee recommended that '*no publicity should be given to this decision at this stage*⁸⁴'. All appeared to be going well. Australian scientists were being trained at Harwell, working on a project which ultimately would lead to the design and development of a power reactor in South Australia. But all was not as it seemed.

It was initially thought that the British would allow the Australian project to proceed on British reactors, but, in a note dated 30th September 1954 to the

Prime Minister, Agendum 117 of the Cabinet Committee on Uranium stated *'whereas in April they (the AAEC) hoped that our scientists would be able to work in U.K. reactor plants, now they (the AAEC) have recommended that we set up an experimental reactor because they discovered in the U.K. that there would not be reactor capacity available there for our people to do this kind of work on; therefore we must have one as we cannot borrow the use of these facilities in the U.K.'*⁸⁵. The British had agreed to train Australian scientists, but now it appeared that facilities for them were not forthcoming. Australia needed a research reactor to provide the facilities required to continue with the work on an Australian power reactor.

A story concerning those early years at Harwell relates that a group of Australians had prepared a report to the British authorities. They sent it off to be typed by never saw it again. Some time later one of them attempted to discover what had happened to it, to his surprise he discovered that the report had indeed been typed but since it contained classified material and none of the Australians had the relevant security clearance they were not allowed access to it. The absurdity of the policy where an author did not have the security clearance to read his own work seems comical now.

The Australian scientists who had been sent to Harwell for training had participated initially on British projects and later started working on their own projects. It is at this point that the British decided that they could not give Australia the required reactor time. It is probable that Britain exploited the intellectual efforts of the Australians whilst they were 'training' but later were unwilling to provide them with the facilities they needed.

As a further insult, the British suggested that Australia purchase a research reactor 'off the plan'. At this time it was known as the E.443 and a prototype

had not been built. Australia decided to buy it. The reactor was later called the DIDO^{xliii} in Harwell but Australia would have HIFAR (High Flux Australian Reactor) but as with most prototypes when they are finally constructed the costs inflate as unforeseen problems arise and are corrected⁸⁶.

In the same document (agendum number 117 Cabinet Committee on Uranium) that suggested the purchase of HIFAR, as it became known, there are some ominous notes concerning political opinion at the time:

'the production of power and the production of plutonium, however appear likely to be inseparable for many years to come ... the Commission should adopt investigations into fluid fuel systems for reactors, this being one of the more important longer range projects designed to produce plutonium and power economically in the future. ... As an integral part of the program ... Australia should construct a small materials testing reactor, not to produce power, but to enable the research program on fluid fuels to be reasonably self-contained and independent of British irradiation facilities.'

The document then goes on to recommend the purchase of the British experimental reactor and concludes: *'It is suggested ... that the AAEC in conjunction with the Department of National Development, be authorised to discuss with the States the power position and the plans of the States to meet future demands in order to determine whether there is a possibility that circumstances may exist which would render practicable the economic production of plutonium by the Commonwealth ... to sell the by product heat to the States'*⁸⁷.

^{xliii} There were six reactors built to this design: two at Harwell (called DIDO and PLUTO), one at Dounreay, HIFAR in Australia, one in Julick, Germany and one in Riso, Denmark.

These later statements contradict the earlier Baxter – White Report that stated that Australia should have a power reactor which had been designed as such (this view was probably held more by White than Baxter). The author of the Cabinet submission document was probably Baxter but this is not certain. It is of interest to note that Baxter went to Britain in 1954 with Stevens and Professor Martin⁸⁸ and as a result of discussions with these two men the pendulum swung towards a defence agenda. Regardless of what may have been discussed or decided at an administrative level, the scientists at Harwell were not party to this discussion and probably knew nothing of it.

Baxter had been asked to attend and explain the submission to the Cabinet meeting which ultimately agreed to allocate funds for HIFAR. At this time Baxter was merely a Commissioner, he would not become Chairman of the Commission until 1957. Baxter recalled this Cabinet meeting:

'the Prime Minister called on each Minister in turn to comment. Most had a written brief from the department. They were all uniformly against it. There wasn't one who had a good word to say about it. Finally they finished and the Prime Minister asked if anyone had any comments ... the Prime Minister looked at the Committee and said 'Gentlemen, I'm sure we are all in favour of it, aren't we' and there wasn't a voice raised'⁸⁹.

HIFAR was to be a small research reactor that would provide a high neutron flux to study materials under extreme conditions and to provide facilities to produce isotopes. The reactor needed to be housed in some location that would be close to those scientists who wanted to work on projects at the reactor facility but far enough away from habitation so as not to pose a hazard to the local population. Lucas Heights, in 1954, seemed like an ideal position.

The land at Lucas Heights came from both the NSW State Government and the Commonwealth Government⁹⁰ (see Figure 4-1).



The Lucas Heights Atomic Energy Research Establishment: Map showing location of site.

Figure 4-1 Map of Lucas Heights

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The rationale behind the decision to place the reactor facilities at Lucas Heights is best described in a submission to Cabinet dated 13th April 1967. The submission includes the following background statement:

'when the Lucas Heights site was selected in 1954 the greater portion of surrounding areas for a number of miles was either Commonwealth owned land or State owned land under lease to the Army. The experimental reactor site was selected after careful safety assessments on the assumption that the Army would continue to control all of the Holsworthy training area and so provide a population free zone of at least one mile to the north, west and south of the reactor. The only residential area in the vicinity was the village of Engadine to the east with its western boundary approximately one mile from the site and the small village of Menai two to three miles to the north of the site. All the land in the area other than the Commonwealth owned or Commonwealth leased land formed part of what was to be a permanent 'green belt' established by the Planning Authority of the State at that time, the Cumberland County Council ⁸¹.

The Commission was, even in these early days, aware of public concerns on atomic energy and the possibility that the facility may have some strategic importance. It was with this in mind that the Commission stated that *'the establishment will be concerned only with peaceful atomic energy research and it is therefore unlikely to be a primary target for enemy bombers in the event of war* ⁸².

The Commission, through its Chairman, Stevens and Deputy Chairman, Baxter, discussed the proposal to build a reactor within the Sutherland Shire Council area, with the Shire Council and with the then Local Federal Member for Werriwa, Mr E.G. Whitlam, at a meeting of the Shire Council. According to contemporary reports *'in light of the discussion, the council unanimously adopted a resolution declaring that it considered no objection should be raised by the council to the establishment of the reactor* ⁸³.

The relations between the Sutherland Shire Council and the AAEC (and later ANSTO) would not always remain so warm. During the 1960s the army commenced its withdrawal from land that had been leased to it by the State Government. This meant that the land could now be placed on the market for development. Consequently the Commonwealth Government decided to acquire some of this land; 1700 acres to *'provide a permanent one mile exclusion area around the AAEC reactor HIFAR and to ensure that any development of the area beyond the one mile radius will take into account the existence of the special facilities at Lucas Heights and the hazards involved in intensive development of the area'*⁸⁴.

The issue of the exclusion zone around the Lucas Heights facility can be summarised in the words of Keith Alder;

*'We started with a three mile exclusion area, three mile radius with HIFAR as the centre. I can't remember what year it was, but eventually the local authorities and in particular Sutherland Shire Council urged on by citizen groups queried 'Do you really need a three mile exclusion radius'. Now we were constantly surveying and resurveying the safety aspect, there was a continuing environmental survey, and we had the natural background measured all around the place looking to see if anything was being released and so on. We were really forced into a position where we had to admit that we can't prove that we need a three mile radius. We feel we can prove that it would be less than prudent to have less than one mile. Really you could pin us down to one mile. We were forced into accepting that yes we could live within a one mile by the local authorities'*⁸⁵.

The official recommendations set out in the Cabinet submission of 13th April 1967 were as follows:

'The Commission suggested that the following criteria be observed by the State Planning body;

- 1. total exclusion area of one mile radius should be maintained permanently around the reactor*
- 2. settlements beyond a one mile radius should be restricted to the extent that the population living beyond the one mile limit and up to a limit of three miles should not exceed 5000 persons in any 20 degree sector of a circle with the reactor as its centre*
- 3. settlement in the Woronora Valley within a two mile radius of the site should be discouraged⁹⁶.*

Returning to Alder's reminiscences:

'there was a major safety review of HIFAR conducted under this pressure 'do you really need three miles?' and Alan Wilson who died about 5 years ago, Alan Wilson was the Head of Health Physics at the time and he and Bob Fry who was later Head of Health Physics ... They and the reactor crew Bob Carlson, Geoff Tingate, did a reassessment of HIFAR. The Commission then agreed, oh well, it looks from that we are 100% safe to live within one mile. So we gave in, but it was under pressure from the locals. We didn't initiate the drop from three. Then we did try to put on some (restrictions) and I don't know where this stands now; no biscuit factories, no food, no primary schools and so on within the area but I think that's gone too⁹⁷.

The Sutherland Shire Council appeared to ignore the recommendations made by the AAEC and has allowed residential development including the building of schools and other community facilities to come right up to the one mile

exclusion zone. Returning to Alder's comments *'I can remember one of the ladies who has been an opponent in the district out there for years saying 'day by day your reactor is getting closer to our houses' and Don George who was chairman at the time, this in a sort of quarterly meeting we used to have with the local people to tell them what we were doing and answer all their questions, and Don said ' Look the reactor hasn't moved an inch in twenty years, it's the housing that is getting closer to it'*⁹⁸.

A number of environmental groups continue to protest against the reactor being located close to residential properties but, as has already been discussed, the original location of the reactor was in isolated bushland into which the local council has allowed development to occur, and this process occurred against the recommendations of the state planning authorities. Further, the majority of staff employed by ANSTO now live within the Sutherland Shire Council administrative area so the research facility also provides employment for a number of local residents.

4.5 HIFAR is Born

The AAEC had originally decided it would establish its research laboratories at Maroubra. However, this site was not suitable for a reactor since it was too close to residential properties and the Lucas Heights site was procured. This also implied that the logical place for the research laboratories would also be on the Lucas Heights site. The land for the research establishment had, by 1954, been secured and the reactor site determined. The land on which the reactor and its fuel ponds would eventually sit was located on top of hard sandstone which would be impervious to water. This would mean that the reactor could not leak into the ground water supplies nor would there be any possible contamination source in terms of run off from the site and it was in a geologically stable stratum.

Bob Carlson, in a lecture on the 'History of HIFAR' delivered to the Australian Nuclear Association in Sydney on 9th November 1999, explained that the British had wanted to develop power reactors to replace coal fired conventional power stations. To assist in this project the British needed a research reactor that could provide a very high neutron flux to simulate in one year the equivalent of ten years worth of heavy neutron bombardment of graphite or any other material that could be used inside a reactor. At this time the behaviour of materials under extreme neutron bombardment was unknown and the source of many research projects. The original research reactor that the British had wanted was the NRX^{xliv} which had experienced a major accident in 1952. The NRX reactor was proving to be unsuitable since it was thought to be *'inherently unsafe because of the positive void co-efficient'*^{xiv} *and it would not be suitable to be placed at Harwell*⁹⁹.

The British were now in a quandary, they needed a research reactor to test materials and their best design was no longer suitable:

*'In 1953 the US released highly enriched fuel and the UK decided to adopt the design of the CP-5^{xlvi} at Argonne which was a beam reactor and had the capacity for materials testing. It was going to come to power in February 1954 and this would enable the British to observe the early operating experience of that reactor and this would help them with DIDO. Therefore the DIDO class reactors and HIFAR came into being'*¹⁰⁰.

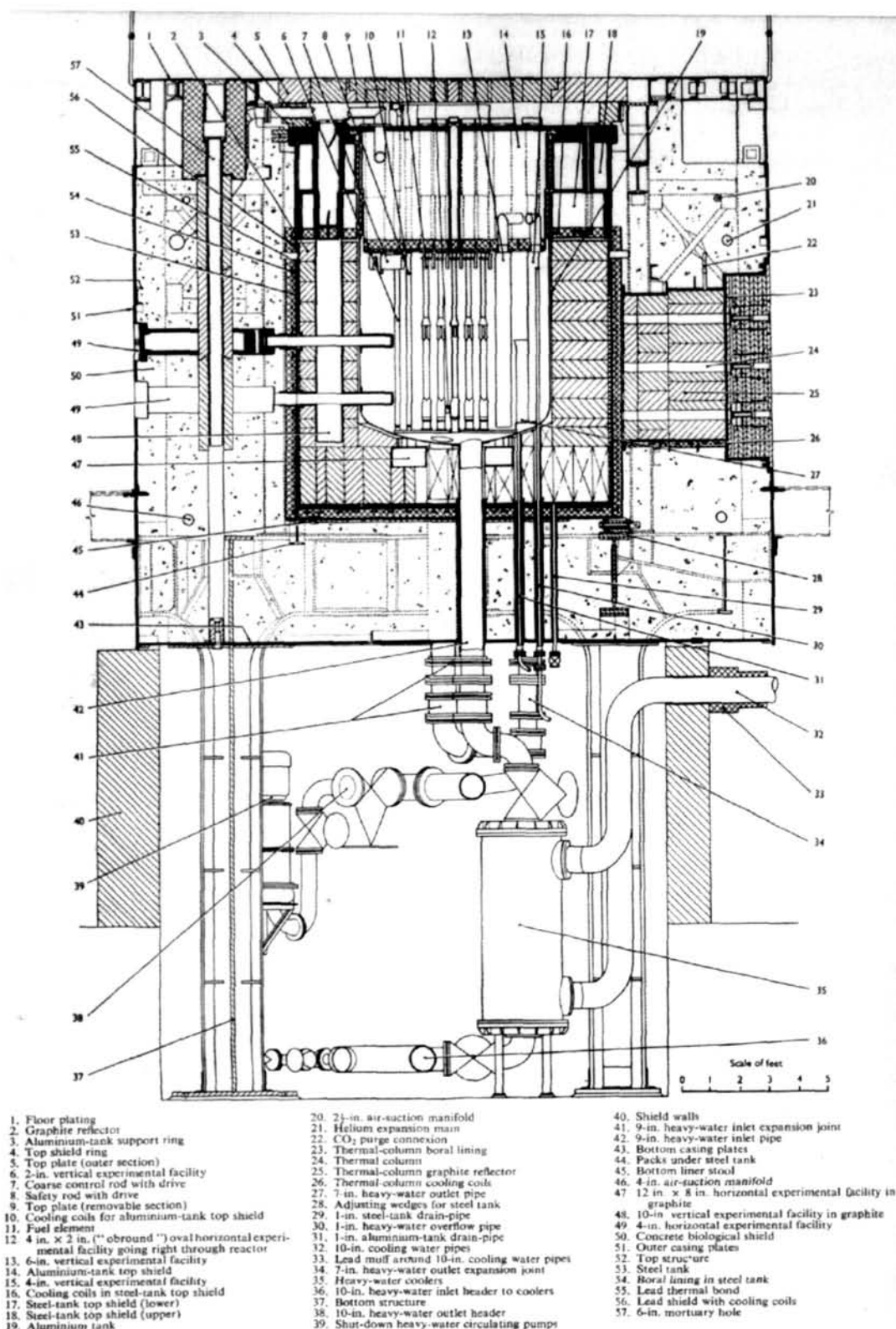
One of the advantages cited for using highly enriched uranium fuel was that the neutron fluxes produced were in the range of 10^{14} neutrons per square cm

^{xliv} NRX stands for National Research Experimental Reactor. The NRX reactor was built at Chalk River in Canada and completed in August 1947. It used natural uranium fuel and heavy water moderation.

^{xlv} See appendix 2

^{xlvi} CP-5 stands for Chicago Pile 5, it commenced operation in 1954

per second which at this time *'was one of the highest fluxes in the world ... and they could get that in about 10 megawatts of heat output as opposed to 40 in the NRX and the cost would be about 2 million as opposed to about 10 million'* pounds¹⁰¹. The Commission purchased the E.443 reactor in 1954¹⁰², this reactor became known as HIFAR, see figure 4-2.



Vertical cross-section diagram through British DIDO reactor which is the prototype for the HIFAR reactor being built at Lucas Heights.

By courtesy of Mr. H. J. Groul, U.K.A.E.A. and of the British Nuclear Energy Conference.

Figure 4-2 Schematic Diagram of HIFAR

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It was decided that the design of the specialised research laboratories that would be required in close proximity to the reactor should be similar to those at Harwell. The experience of the Australian scientists working at Harwell demonstrated that the design of these laboratories was not only functional but also the most modern for that time. The reactor was essentially a materials testing facility which produced a high '*fission product inventory*' and '*it was believed that certain operations such as fuel handling were chemically hazardous and ... in the event of fuel melting, radioactivity could be released*'. Consequently it was '*decided to place the reactor in a very high integrity low leakage steel containment*' building ¹⁰³.

Twelve members of the AAEC staff who were then stationed at Harwell were now directly involved with work on the construction of HIFAR which started in 1954¹⁰⁴. Essentially the Australian team was working alongside the British group on the DIDO prototype and when problems in the design or construction arose they were part of the group which provided the solution. This group would then be able to deal with similar situations in Australia if they arose¹⁰⁵.

Owen Pulley, a former member of this group, was now assigned to act as a liaison officer in London. He was located at Australia House and his functions included communicating and liaising with the Australian group at Harwell, liaising with both the Australian and British Governments and the procurement of specialised equipment and supplies for the Australian program which could then be sent to Lucas Heights. This position would later become a permanent one and filled by a succession of AAEC staff. It also led to the practice of appointing Liaison Officers at other important foreign legations¹⁰⁶.

Back in Australia, the architects who were to design the reactor housing and associated buildings were chosen: Stephenson and Turner¹⁰⁷. Within a few months the builders for the project had also been chosen, *'The successful tenderer was Hutcherson Bros Pty Ltd of Sydney. This firm was awarded on 10th October 1955, a contract for the simultaneous erection of research laboratories and reactor buildings'*¹⁰⁸. The local architects and builders were responsible for everything erected at the Lucas Heights site except the construction of the reactor itself. According to Hardy, *'a separate contract was let to Bernard Smith Pty Ltd for the supply and erection of the steel cylindrical shell to house the reactor'*¹⁰⁹.

Following the advice given by the UKAEC, the contract for the construction of the reactor itself was given to Head Wrightson Processes Ltd. This company had already had the experience of building a DIDO class reactor¹¹⁰. The reactor was imported in component form from England and assembled on site at Lucas Heights¹¹¹. The graphite blocks which would act as neutron reflectors were locally produced. The graphite in these blocks was required to have virtually no impurities and this achievement demonstrated that Australian technology could produce materials of a standard equivalent to that of the best in the world.

Construction of the reactor at Lucas Heights commenced in 1955¹¹² when the excavations for its foundations were started. Shipments of components for the reactor core began in February 1956 and the assembly of the reactor began in May that year¹¹³. AAEC staff in the UK involved with the construction of HIFAR made regular visits to the site until the actual assembly of the reactor was required. At this point they returned permanently to Australia.

According to the AAEC's Fifth Annual Report '*The Commission supervised construction of its research reactor, laboratories and buildings at Lucas Heights*'¹¹⁴. See figure 4-3.



Figure 4-3 HIFAR Under Construction

Courtesy of ANSTO

A bilateral agreement was signed with the US on 22nd of June 1956 to share the peaceful uses of atomic energy¹¹⁵. Before the agreement was finalised, the US had '*undertaken to sell to the Commission the quantity of heavy water required for*' the reactor¹¹⁶. The enriched fuel rods were supplied by Britain and this practice continues to this day. However, the level of enrichment has changed over the last forty years, '*HIFAR initially used 90% U^{235} but now uses less than 50% enrichment*'¹¹⁷.

During the period of construction, the AAEC *'transferred a proportion of its research team from Harwell in the United Kingdom to its own research establishment near Sydney'*¹¹⁸. Further, *'as the laboratories are completed at Lucas Heights, the research is being progressively transferred from Harwell, and at the close of the period about half of the Commission's senior scientific staff had returned to Australia'*¹¹⁹. The period in question was 1957.

Keith Alder recalls that during the construction period, all was not plain sailing, *'Bill Roberts, William Henry Roberts, was the first operations manager, he was head of engineering services. Bill was at Harwell. He came back as the office-in-charge of construction of HIFAR. ... We were, the metallurgists were looking at the building of the hot cells that I mentioned earlier and suddenly we realised that space was going to be a bit short in the area near the reactor where we were building the hot cells so we sent a cable out to Bill Roberts from Harwell saying 'move the pond', the fuel elements storage pond so many feet west and back came the shortest cable ... which said 'can't move, pond dug!' And there it is till this day. Because Lucas Heights was built on solid rock and ... he wasn't going to move the hole'*¹²⁰.

The work on the hot cells that Alder was referring to are best described in his words

'We wanted to build high activity handling cells, hot cells at Lucas Heights to handle the work on fuel elements and the research work done in HIFAR. At that time there were not any such hot cells in England they were just designing their own and there were none in Europe. But the Americans and Canadians had them so off we went. But we were quite worried that maybe we wouldn't have good access to American ideas and Canadian ideas because of security and in fact

we were amazed we were made highly welcome wherever we went; there were no inhibitions whatsoever, any questions were answered. If we asked questions that were a bit near to the bone they simply told us 'no we can't tell you that it's classified' but there was very, very little of it in 1957. And when we started work at Lucas Heights we made a deliberate effort right from the beginning to get rid of this secrecy label'¹²¹.

'By December 1957, the erection of HIFAR was completed to a stage which permitted process testing and approach to criticality to be carried out'¹²². The construction of the research laboratories and other buildings would continue for a number of years, a fact noted in the AAEC Sixth Annual report: 'during the past twelve months a number of major buildings was completed, and this enabled research staff to return from Harwell'¹²³. By 1958 virtually all the research staff had returned to Australia, joining a number of newly recruited local officers, one of whom, Arthur Pryor, recalls

'when I first turned up at Lucas Heights in January 1957 it was a raw site out in the bush with buildings going up, ... HIFAR being built and only a few scientists on site. A place of plans and hopes, not an operating laboratory. For my first six months or so I spent most of my time studying textbooks on reactors and nuclear physics and having a good look at the electronic instruments that were starting to come in'¹²⁴.

There appear to be two different versions of what occurred when HIFAR went critical and achieved the first controlled fission reaction in Australia. The official report (stated in the AAEC Annual Report) states, *'Criticality was achieved for the first time at 11.15pm on Australia Day, Sunday, 26th January, 1958, with the heavy water up to normal operating level and eleven out of the maximum of twenty-five fuel elements in the core'¹²⁵*. The other version,

probably the correct version (ie what actually happened), is reported by Keith Alder in his book and is best retold in his words:

'the start up of HIFAR took place in the early hours of Australia Day, January 26th 1958. Loading of the fuel began the previous evening, with the reactor tank already filled with the heavy water moderator, and with a neutron source present to initiate fission in the fuel. The fuel elements were added one by one after tests, measurements and calculations by the start-up teams. There were two separated groups, Watson-Munro doing it his way with a slide rule and a blackboard out on the operating room floor and John Parry and Colin McKenzie doing it their way locked in the control room free from interfering opinions. Only when both agreed were we allowed to load another fuel element, and gradually we approached 'criticality' ... Bill Wright and I had the honour of inserting the last fuel element, No13 as I recall...

Someone had started a lottery on guessing the control arm angle at which HIFAR would finally go critical, and as the night wore on the price of the ticket increased. It was very encouraging to note that the winner at about 2 a.m. ... was Colin McKenzie, who had done the calculations in the first place¹²⁶.

Australia's first nuclear reactor was then closely studied in a way that its British prototype had never been. During 1958-9 HIFAR was calibrated for use in materials testing and the investigation of metallurgical, chemical and structural behaviour of reactor materials under extreme radiation and temperature conditions¹²⁷. It operated at low power until 1960 because much of the specialist equipment such as the irradiation rigs and the hot cells were still under development or construction¹²⁸. In 1960, the reactor was ready to commence its work.

The AAEC decided to have its new research establishment officially opened not long after HIFAR went critical, despite many of the buildings and laboratories still being under construction and the site resembling that of a war zone rather than one of the most up-to-date laboratories and facilities. The positive publicity gained for both the politicians and the Commission as well as opening the establishment to the press for such an occasion was not lost on either Baxter or Menzies. The AAEC Annual Report merely stated that *'The Commission's Research Establishment at Lucas Heights was officially opened by the Prime Minister of Australia on 18th April 1958'*¹²⁹.

At the official opening of the Research Establishment, the Prime Minister was to also officially start-up the reactor by pressing a switch. When Mr Menzies pressed the switch, it alerted the operators to commence raising the control arms. Unknown to the official guests, hiding behind the curtain on the official dais were a number of engineers whose job it was to ensure that the 'audio' for the start-up worked. The reactor had a number of experimental holes through which neutrons from the reactor core could be extracted for experimental purposes. At one of these, a neutron counter had been set up and the pulses from this counter were amplified so that they could be heard on the loud speakers at the ceremony. The pulses began very slowly at first and built up over a minute or two – *'ominous knocks slowly increasing. Menzies remarked: "it's like the knocking at the gates in 'Macbeth'"*¹³⁰.

The first projects undertaken at HIFAR were paid commissions for the UK Atomic Energy Authority (UKAEA) and General Electric Co. These were undertaken as soon as HIFAR went to full power. The work for the UKAEA involved irradiating beryllium metal to see whether it would be suitable as a

cladding for uranium oxide fuel in the Advanced Gas Cooled Reactor^{xlvii}. It turned out that beryllium would not be suitable for such a cladding^{xlviii}. The work for the General Electric Company involved the irradiation of prototype fuel elements in a new hollow design for the first nuclear power reactor in Japan which was a 'Magnox' type reactor¹³¹.

The AAEC had some very clear ideas as to what use the reactor facilities could be put. Commercial applications were closely considered. One of the oldest notions was to use the '*irradiation facilities for studies in food preservation*'¹³². The irradiation facilities came from the spent fuel elements from HIFAR and utilised the gamma rays from these elements. Investigations in this area have continued for almost forty years but food preserved by irradiation has never been allowed to be sold to the consumer in Australia, although the use of irradiation for the purposes of sterilisation for medical supplies is now an accepted part of Australian life. The use of irradiation for agricultural purposes such as the sterilisation of bee hives infected by American Foul Brood Disease has saved the apiary industry of Australia thousands of dollars each year.

The use of radioactive isotopes was recognised from the time the Commission came into existence: '*isotopes are being used extensively in medicine and research and are being brought into use in industry*'¹³³. The Isotope Section of the AAEC started in July 1956 when the Commission employed Dr J.N.Gregory to head it. Gregory had been working on isotope production at Harwell prior to his promotion. The Commission stated in its Annual Report that '*commencing in the latter half of 1956, Dr Gregory will visit industrial establishments and other places throughout Australia where*

^{xlvii} see Appendix 3

^{xlviii} the reasons behind this are given on page 144

*isotopes might usefully be employed*¹³⁴. This entrepreneurial approach was quite unprecedented in the mid 1950s in Australia, but the Commission wanted to bring Australia to the forefront of scientific applications and was prepared to tout for work.

The emphasis on the isotope production capabilities of HIFAR was urged on the Commission by the Commonwealth Government. A meeting was held at the instigation of Senator Spooner with Leslie Martin and the Executive Commissioner, Mr McKnight, on 22nd August 1958. Spooner was particularly concerned about criticism of the Commission and the financial commitment made to it by the Commonwealth Government. He pointed out that *'there was an increasing disposition by the power authorities to say that the generation of electricity from nuclear power was just not on. Mount Isa had rejected the notion of installing a nuclear station, so had Consolidated Zinc at Weipa; similarly it seemed to be impracticable in South Australia ... there could be great criticism of the government for investing so heavily in the Commission's research establishment when no practical return in any shape... seemed possible within twenty or thirty years'*¹³⁵. Spooner then suggested that the production and use of isotopes could subdue this type of criticism.

Martin, to his credit, spoke highly of the work being done at the research facility and emphasised that research into nuclear science was by its nature a long term commitment. He went on to describe much of the work that was being carried out using HIFAR. The meeting concluded with Spooner emphasising that the Commission should endeavour to increase isotope activity *'particularly devoted to increasing the gross national product'*¹³⁶. Spooner had summed up the government's attitude to pure research; there was an expectation of a return, not just a return in terms of increased academic scholarship and prestige but a return which would earn export

dollars (pounds in those days) for the nation. The concept that research is only worthwhile if there is a financial return has its roots in the Menzies government not in the heady 'greed is good' days of the 1980s.

4.6 Beryllium and Beryllia

Beryllium is a metal with low atomic number which made it potentially a good moderator in a nuclear reactor while it also had an additional property that made it attractive to use in nuclear reactors; it had a very low neutron cross-section. A moderator is required in many nuclear reactors to allow the energetic fission neutrons which are essential to the fission process to be slowed down so they may be more easily captured by the uranium nucleus and hence cause fission, releasing energy and producing two fission products and more neutrons. An ideal moderator is made up of light atoms that allow the dissipation of large amounts of energy in collisions and it must also be a low neutron absorber. The following were considered as possible moderators: hydrogen, deuterium, carbon (graphite) and beryllium¹³⁷. The neutron cross-section refers to the ability of nuclei to absorb neutrons; the lower the cross-section the better the material is for use as a moderator or as cladding for the fuel elements.

Beryllium had been used as an initiator in Britain's first atomic bomb which was tested in 1953 at Monte Bello. During the period 1947-1953 much research work at Harwell was devoted to beryllium metallurgy for possible use in nuclear reactors, to uranium metallurgy and to the extraction of plutonium from irradiated uranium¹³⁸. Several Australians at Harwell were involved in this work, some of which was later applied in the weapons program, particularly in the production of plutonium and in the chemistry of polonium, which was used as an alpha source irradiating solid beryllium to produce

neutrons in early initiator devices¹³⁹. These Australians, who were not employed by the AAEC at this time, were soon to be joined by the first of the AAEC recruits who would arrive in early 1954.

*'All types of moderated and cooled reactors were being studied at the time:- light or heavy water moderation, graphite moderation, beryllium was a possible moderator that was not being studied elsewhere'*¹⁴⁰. Beryllium had other properties that could enhance its use as a moderator, *'some neutron capture in the beryllium leads to the production of yet more neutrons by a (n,2n) reaction'*. This type of reaction gave the possibility of *'neutron enhancement, ... , which could extend the fuel lifetime and, we believed, might even lead to the possibility of a 'thermal breeder' type of reactor, producing more fissile atoms than were burnt'*¹⁴¹.

In 1950 it was discovered that beryllium oxide is highly toxic if inhaled, hence it was required to limit the amount of beryllium oxide dust in the air to a very low level¹⁴². Working with beryllium was a hazardous affair with special safety requirements. Beryllium oxide or beryllia had some interesting properties as well. It was a good conductor of heat, better in fact than the metal, but it was also a good electrical insulator¹⁴³.

According to Alder, Baxter

'always hoped that the product of our efforts would be a design of a power reactor particularly suitable for Australian conditions. He had in mind particularly that the favourable nuclear properties of beryllium, the low neutron capture, good moderator, neutron enhancement characteristics, could favour a small reactor design, while the high coolant temperature should lead to a high thermal efficiency and

*therefore minimise the amount of waste heat dumped, so needing less cooling water and even allowing air cooling*¹⁴⁴.

The notion of a locally designed and produced power reactor was part of the reason that the research at the Commission was taking place.

The use of beryllium or beryllia in reactors lead to the development of two associated research projects; the Liquid Metal Fuel Reactor (LMFR) and the High Temperature Gas Cooled Reactor (HTGC)^{xlix}. These two projects with the associated beryllium and beryllia research were carried out simultaneously originally starting at Harwell and then transferred to Lucas Heights when HIFAR became critical. Part of the beryllium project was of interest to the British who

*'were looking at the advanced gas cooled reactor, they had already the magnox^l series of reactors, magnox is the magnesium alloy that is used as cladding in the original British power systems. To build the advanced gas cooled reactors they decided to try and use a beryllium cladding on a uranium oxide fuel and the question was 'how well will beryllium metal stand up to extensive neutron bombardment at a higher temperature?' We did all the tests for that in our reactor HIFAR under contract to the British, learning at the same time as well earning some money; with the reactor in its early days before we were ready to irradiate stuff ourselves other than isotope production'*¹⁴⁵.

This particular program not only earned Australia some money at a time when the use of nuclear technology was still seen as a form of pure research but also *'taught us that beryllium moderation was not suitable for what we had in*

^{xlix} see Appendix 3

^l magnox is a magnesium, aluminium and beryllium alloy and is short for Magnesium Non-Oxidisable. See Appendix 3.

*mind, for a gas cooled reactor, so it had to be the oxide. So that is where the BeO, beryllium oxide research program came from*¹⁴⁶.

Beryllium and its oxide were studied by Commission staff as both moderator materials and as fuel carriers. The materials were irradiated in HIFAR to determine their mechanical properties under intense neutron bombardment. Fuel samples of beryllium containing both uranium and thorium were produced and tested and oxide systems of beryllium, uranium and thorium were also investigated in detail¹⁴⁷. The following year the research direction focused on the dispersal of the fuel material within the beryllium oxide '*in terms of particle size, diffusional porosity, density and surface defects*' and '*some specimens of oxide fuels based on natural uranium dispersal in beryllia were prepared by hot pressing*¹⁴⁸'. The Commission scientists were also studying the chemical processing of fuel elements which included beryllium. The AAEC Annual Report noted that this type of work had not been carried out elsewhere.

Sample fuels elements were then produced using a beryllium matrix with dispersions of a uranium-thorium-beryllium compound. These techniques were developed using natural uranium. In early 1960 the first irradiation testing of both beryllium and beryllium oxide took place¹⁴⁹. By early 1961 ceramic beryllium oxide became the research focus; '*samples of ceramic fuels containing particles of solid solution of uranium and thorium oxides dispersed in beryllium oxide were prepared*', since it had been discovered that in beryllium metal '*the main problem was revealed to be the formation within the metal of new atoms of the gases helium and tritium. The creation of these gases by nuclear reaction leads to swelling and distortion of the metal*¹⁵⁰.

The metallurgy group studied the compatibility of uranium and thorium oxides with beryllium metal at temperatures comparable to those inside a reactor, but they found that at the lower operating temperatures, the material suffered from extensive swelling and cracking¹⁵¹. Beryllium failed to be the ideal moderator and it was found that beryllium suffered mechanical failure and became very brittle¹⁵². This research commissioned by the UKAEA continued until 1962 when it too came to a similar conclusion.

Two reactor systems were being considered that required the use of beryllium as a moderator and it was also thought that *'both systems will eventually operate most economically on the uranium233-thorium breeder cycle'*¹⁵³. As a consequence of this, the AAEC, through the Commonwealth Government, attempted to secure all Australian mineral deposits containing thorium or beryllium by stopping all exports of both materials; *'thorium is the only possible basis for the development of 'thermal breeder' systems which will be important in future years ...it appears that thorium is less plentiful than uranium... it is therefore, considered that thorium resources should be conserved for future Australian power requirements, and the Commonwealth Government decided to prohibit the export of monazite after 30th June 1957'*¹⁵⁴ and *"in order to safeguard Australia's potential requirements of beryllium for atomic energy purposes, its export from Australia has been prohibited"*¹⁵⁵. It is now believed that thorium is more abundant in nature than uranium.

The work carried out on the use of both beryllium and beryllium oxide as moderator materials and fuel in the form of thorium-uranium233 was not being duplicated elsewhere. Australian researchers were part of a unique group who were exploring a little-known area of nuclear reactor science and hence had something to share with the other nuclear literate countries. They were not

studying a second-rate or discarded aspect of applied nuclear science as has sometimes been suggested by such historians as Moyal; '*work on the properties and strengths of beryllium had gone forward and been abandoned overseas (notably in France and the USA ...)*'¹⁵⁶ and '*overseas centres were no longer working with beryllia*'¹⁵⁷. They were looking at real alternative materials and in some aspects complementing the work of others such as the British. As late as January 1961, the ICI produced magazine 'Endeavour' featured an article on beryllium in which it was stated '*a developing interest in new types of reactor ... is again bringing beryllium to the forefront of the American nuclear-energy program*'¹⁵⁸.

The beryllia project had three successful outcomes. The first was the Conference on Beryllium Oxide which was held in October 1963. The second was the recognition that the work carried out on beryllium oxide was not only of an internationally high standard but was recognised as being the best research carried out in Australia. This recognition came in the form of the awarding of the University of Melbourne's 1964 Syme Prize to B.S.Hickman, A.W.Pryor, T.M.Sabine and D.G.Walker¹⁵⁹. The final outcome was the discovery that neither beryllium nor beryllium oxide was a suitable material to use in reactors. Individuals who are not scientifically trained would see such an outcome as being a failure but it is in discovering what is not suitable for a particular application that often allows major advances to occur.

4.7 Reactor Research Projects

The work on different types of reactors and different delivery systems of fuel and moderators was all part of a much larger agenda. The purpose for establishing the Commission was to train Australian scientists in the area of

nuclear science so that Australia would not be left behind in technological advances. Members of both the Australian political and scientific communities wanted Australia to invest in nuclear power reactors, specifically nuclear reactors designed and built for Australian conditions which could service those areas of the continent which were isolated and lacking water for cooling purposes. The Commission had proposed to the Commonwealth Government a three-stage approach to achieve this.

Stage 1 of the plan included feasibility studies and basic scientific laboratory work on reactor systems. Stage 2 included zero-energy-assembly experiments and loop experiments in materials-testing reactors such as HIFAR, and Stage 3 was to include reactor experiments which produce no power, followed by the construction of a demonstration power reactor and finally building a commercial power reactor. However, Raggatt, in a note dated 13th March 1958, assured his Minister that *'if the government approved stages 1 and 2, it might have an obligation to find large sums of money for a reactor experiment and a demonstration power reactor. Professor Baxter made it clear that at no time had the Commission intended itself to go to Stage 3'*¹⁶⁰.

A nuclear power reactor was something that many politicians wanted but equally it was something that others opposed. Some politicians saw the advent of a power reactor as the basis for the development of nuclear weapons. One such politician was the idiosyncratic W.C.Wentworth who wrote to Prime Minister Menzies on 7th July 1958 requesting that Australia should purchase a power reactor. In this note he writes *'the possession of a reactor does not obligate one to make bombs; it gives us the capacity to make them, if, at some future date, circumstances warrant it'*¹⁶¹. Other letters followed in January 1962 and again in November 1962 until finally Menzies

replied in the negative on 15 November 1962¹⁶². Regardless of what the politicians were thinking, the scientific officers at the AAEC were busy exploring the possibilities of various types of power reactors, as part of the research into beryllia, and in the process developing an expertise in reactor technology as well as establishing themselves as part of the international nuclear science club.

The Liquid Metal Reactor Project was one of two reactor projects that were being considered by the Commission. Alder explained how the Liquid Metal Reactor Project was conceived, what was achieved and why it ended.

*'In the United States there was a major liquid metal reactor program at the Brookhaven laboratories but they were using liquid bismuth. Liquid bismuth will dissolve both uranium and thorium ... the only trouble is that liquid bismuth will dissolve most other things too. And so ... compatibility of liquid bismuth with the containment material was a major problem. Brookhaven did an enormous amount of work on that. I went over there to see it. Sodium didn't have that problem, on the other hand sodium doesn't dissolve uranium. If you are going to use sodium liquid metal you have to use it as a slurry and the trouble then is that sodium is a very light material and uranium is a very heavy material. So we came up with the idea of a compound, uranium beryllide UBe_{13} with density of only four as against a density of uranium which is 19 and you might be able to slurry it in liquid sodium and have a goer. So we did all sorts of clever experiments with suspensions of other things in liquid sodium. ... that was the work started at Harwell and carried on for a year or so at Lucas Heights till we realised that a small establishment ... as we were couldn't possibly support two reactor research programs'*¹⁶³.

The Liquid Metal Fuel Reactor (LMFR) system was seen as mainly suitable for a base load station of 100 megawatts or higher. The fuel in this system is carried as a solution or as a suspension, in the form of a slurry in the coolant. The coolant/carrier material, at this time was either bismuth or sodium and the moderators under consideration were graphite or beryllium¹⁶⁴. The slurry of fissile material in the liquid metal was pumped into the reactor core where it would 'go critical' and produce heat then passed through a heat exchanger to raise steam¹⁶⁵. The technology of liquid metals such as sodium and sodium-potassium alloy was relatively well known by the mid 1950s, with liquid metal fuel reactors, specifically the bismuth-graphite systems, being studied in both Britain and the US. Hence this Australian project, focusing on a sodium-beryllium system, was to complement work that was happening on the international scene¹⁶⁶.

The work on the LMFR was started at Harwell and in 1957 liquid sodium 'rigs' from Harwell were sent to Lucas Heights¹⁶⁷ so that it could continue. One of the first ideas was to convert the uranium metal into a very fine uranium powder. This project was undertaken by John W. Kelly. He discovered that this powder was 'pyrophoric' ie it would catch fire spontaneously if exposed to air. There were also problems due to the density differences between the powdered uranium and the liquid sodium. A sodium-uranium slurry had been successfully produced on a small scale by 1957¹⁶⁸. The team working on this project hoped to overcome these problems by alloying the uranium and thorium with beryllium¹⁶⁹.

The first sodium plant was assembled and commissioned in 1958¹⁷⁰. This large sodium loop was used to test the compatibility of proposed materials for the construction of a Liquid Metal Fuel Reactor¹⁷¹. In 1959 the LMFR project was terminated and all research effort was turned to the problems of a

beryllium moderated High Temperature Gas Cooled Reactor (HTGC)¹⁷². The AAEC Annual Report states that *'during the year preliminary exploratory studies on the liquid metal cooled reactor system reached the stage where it was shown that this system would require a longer period of development than the high temperature gas cooled reactor. Accordingly, increased emphasis was placed on the HTGC'*¹⁷³ or, in the words of Keith Alder, *'we scrapped the liquid metal thing as being the least promising of the two systems'*¹⁷⁴.

The High Temperature Gas Cooled Reactor was the second system that was being explored by the AAEC teams. A description from the AAEC Annual Report gives an indication of the background and the work that was to be carried out:

'two applications of the system have a particular interest to Australia:-

a)self-sustaining breeder types of reactors supplying base load electric power in the range 50-200 megawatts

b)small systems in the 5-10 megawatt range for remote localities.

These systems would have a conversion factor of less than one, and thus would not be self-sustaining in fuel; their fuel could be supplied from natural uranium or from breeder reactorsⁱⁱ located elsewhere in Australia

There are several technical variations of the High Temperature Gas Cooled Reactor:-

- 1. the neutron moderating material may be graphite, beryllium, beryllia or a mixture of these. Australia has a special interest in reactors employing some beryllia or beryllium because of the possibilities of being adopted to smaller power units*

ⁱⁱ see Appendix 3

2. *the coolant gas may be helium, hydrogen, carbon dioxide, nitrogen or possibly argon ...*
3. *the fuel element can take a variety of forms, but must provide for an element containing some fissile material (uranium-233, uranium-235 or plutonium) and some fertile material (uranium-238 or thorium). The element may be usefully constituted in some moderators, or as a ceramic...*

*The main investigation effort has been directed towards the fuel elements. Beryllia, beryllium and graphite have all been examined theoretically as fuel diluents on a thermal stress basis*¹⁷⁵.

The High Temperature Gas Cooled reactor was perceived as another candidate to become a suitable power source for isolated areas of Australia because the gas cooling aspect made it particularly so. The Commission admitted that in 1960 it was one of a few organisations in the world to investigate this type of reactor¹⁷⁶. The AAEC research program was centred around the technical and economic feasibility of developing this type of reactor system using beryllium oxide as the moderator and carbon dioxide as the coolant¹⁷⁷.

The HTGC program included a study of 'self breeding' fuels in which the fertile^{lii} element thorium was present in sufficient quantities that when the fissile uranium was 'burnt up' it was replaced by another fissile uranium isotope, uranium-233, which had been produced in the reactor by the bombardment of thorium by neutrons. This fertile-fissile fuel was to be dispersed in the moderator which in this case would be beryllium or beryllium oxide¹⁷⁸. According to Alder, '*although beryllium metal containing dispersed*

^{lii} see Appendix 2

*uranium and thorium was studied initially, it was soon realised that the temperature attainable would be severely limited by irradiation effects on the metal*¹⁷⁹ and then *'the program was ... to encompass studies of fuel fabrication and behaviour with a view to produce reactor fuels'*¹⁸⁰.

According to Moyal, two types of core type were considered; the parallel flow and the pebble bed¹⁸¹. The parallel flow reactor system was not discussed to any degree in the AAEC Annual Reports and one can only conclude that this type of reactor was not considered to any degree. The pebble bed type core seemed to be the better option for investigation. This type of reactor required the fuel in the form of thorium oxide and uranium or plutonium oxides to be embedded into the moderator which was beryllium oxide and this combination to be formed into spherical balls or pebbles of about one inch in diameter¹⁸². It was found that the coolant, carbon dioxide was compatible with beryllia at the high temperatures that would be attained in a power reactor and it was cheap and readily available. It was essential that beryllium oxide should be able to *'withstand irradiation damage after prolonged exposure to high neutron fluxes and to maintain integrity to retain the radioactive fission products within the fuel/moderator pebbles'*¹⁸³. See figure 4-4.

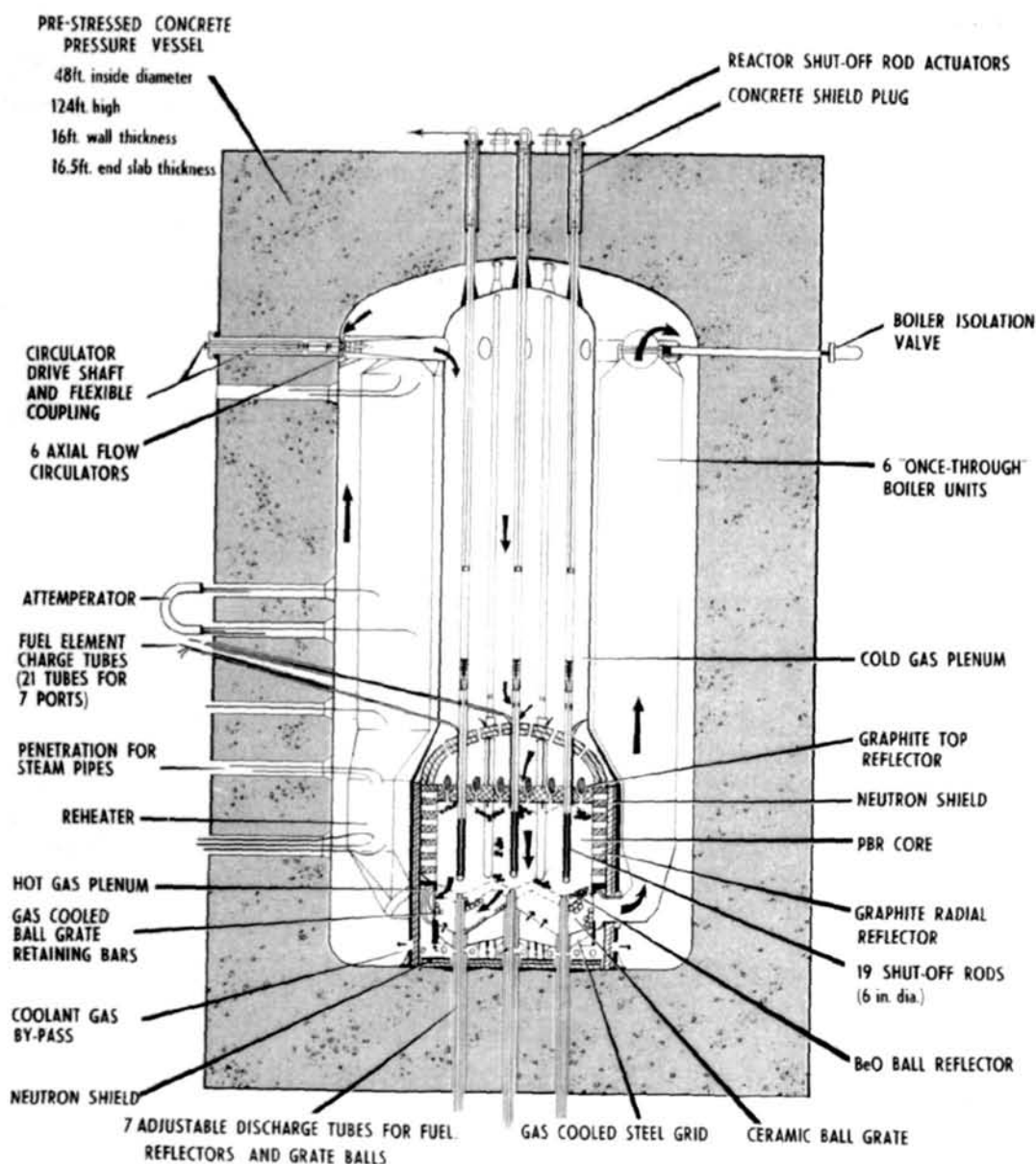


Figure 3: Conceptual arrangement of a downflow, high temperature, gas cooled, pebble-bed reactor.

Figure 4-4 Pebble-bed Reactor

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The HTGC project was finally phased out in 1966 as not being technologically or economically viable. The previous year the Scientific Advisory Committee of the AAEC decided not to endorse the extension of this program (discussed earlier in this chapter) resulting with the committee being disbanded. It is of interest to note that the pebble-bed reactor concept is currently being explored in South Africa and Europe.

The notion of a reactor for Australian conditions was far from dead. Alder, quoted in a discussion paper dated 19th October 1961, had stated that *'it must be kept in mind that for an efficient Australian nuclear power program there should be a national system with a number of reactors integrated into a national fuel cycle. The state power authorities understand the significance of this and they agree'*¹⁸⁴. A little later a note was sent from Maurice Timbs to the Prime Minister's Department concerning a possible reactor for South Australia which contained *'preliminary outline specifications for 134 megawatt Gas Cooled Reactor for S.A. just received from UKAEA,'* and further asks the Prime Minister's Department to send Thomas Playford a copy. On 30th July 1963 Playford met with Menzies which resulted in Menzies sending a note to Senator Spooner stating that *'Sir Thomas Playford called on the Prime Minister to discuss with him a number of matters including a proposal that the Commonwealth might offer the states some financial assistance in the construction of one nuclear power reactor for each state....'*¹⁸⁵. But by 10th June 1964 some attitudes had changed. The champion of nuclear power, Thomas Playford, was now losing interest in the project. The change in attitude is best described by Maurice Timbs who sent a note to the Prime Minister's Department which contained the statement *'...because Sir Thomas' enthusiasm for nuclear power has been dampened by gas'*¹⁸⁶. Natural gas had been found at Gidgealpa and Moomba in the Cooper Basin region of north eastern South Australia. The estimated quantity of gas was so large that a natural gas pipeline linking the field to Adelaide and Sydney became a possibility¹⁸⁷.

The Commission staff were also making some difficult decisions concerning the project. According to Alder, in 1966 *'we reported to the Commission that the HTGC did not seem to be a promising potential competitor for some*

already established systems such as the Westinghouse Pressurised Water Reactor^{lii} (PWR), the forerunner of the many PWRs now in service around the world and the research program was changed¹⁸⁸ and that 'Pressurised Water Reactors (PWR), Boiling Water Reactors^{liv} (BWR), heavy water reactors^{lv} (HWR) were seen to be the systems of the future¹⁸⁹. It appeared that the home grown product was no longer seen as viable. The Canadians had shown that they could run reactors on 'natural' uranium and 'the idea of fuelling Australian reactors with our own uranium, processed at home was attractive¹⁹⁰. Further, the technology of water-based systems used in electrical generating systems was well established¹⁹¹ and hence the Commission changed the direction of its reactor project. The Commission now turned its attention to water-cooled and moderated systems, with an emphasis on a heavy water system. These types of reactor can run on natural uranium whereas the other recently developed pressurised water reactors and the boiling water reactors required enriched uranium¹⁹².

The Commission's decision to change projects was not popular with staff¹⁹³ but this would be the first of many such changes in direction that would take place within the Commission. This change in direction was rarely a reflection on the quality of the research done within the Commission but had its main impetus from the changes in the direction of nuclear policy at a political level. There was also the unexpected discovery of natural gas and oil which would further affect the Commission's programs of research in the area of nuclear reactor technology. What appeared at one time to be an essential source of electrical power was later seen as a very expensive and possibly dangerous alternative. The real problem that the Commission suffered from was that it was answerable to a series of governments which were effectively

^{lii} see Appendix 3

^{liv} see Appendix 3

^{lv} see Appendix 3

scientifically illiterate and made their decisions based on electoral, financial and bureaucratic perceptions rather than the reality of what would serve the national interest best.

4.8 Electricity for the Bush

The idea that Australia needed power reactors for the bush would remain until early 1970. Members of the Commission and certain politicians just could not let go of the idea that an industrialised country such as Australia really did need a power reactor, and not just one but several. Consequently the work already started on heavy water reactors would continue and become the foundations of the Jervis Bay Project which will be discussed in Chapter 6.

Before leaving this period it would be of interest to conclude with an amusing story. Keith Alder became Director of the Research Establishment and he recalled that:

'the most worrying experience I ever had as director was the night of the lost pullover. One of our health physicists had a little spill, he was carrying some material back to the lab to measure it and he had for some reason or other got a spot of radioactive liquid on the shoulder of his pullover and he took the pullover off in the laboratory and left it on the bench. That was Friday night, and then he went home.

When we came in on Monday morning the pullover was gone and the dosage from that spot of radioactive material on the fellow's shoulder was enough to be of concern. What do we do now? We hunted high and low, we interviewed everybody who could possibly have had access to that laboratory in the weekend and we didn't find it. So I took a deep breath and I made a major announcement over the site public

address system and said 'unless this is recovered we will have to go public and this will be very bad for the image of the Commission and the image of the site and we will have to go to the press and the radio and the television and say that we have lost a radioactive pullover, you see. We appeal to whomever has pinched it could you please bring it back. If you bring it back anonymously no further action will be taken.'

I didn't sleep and at two o'clock in the morning the police rang me up and said 'someone has deposited a parcel on the nature strip outside the main gate and had driven away. May we open it?' and I said 'No' and I rang up Dr Watson who was the head of the health and safety division and said 'George, for Christ's sake get out to Lucas Heights quickly and see if that's the pullover.' And it was'¹⁹⁴.

4.9 We Can Hold our Heads up with Pride

The first fourteen years (1953-1968) of the Commission gained Australia membership of the nuclear club. Australia was now privy to much nuclear science and technology information from both the US and Britain. Australia had trained a cohort of scientists and engineers who could not only design a nuclear reactor but could construct and modify one. Australia had, by the end of this period, two functioning reactors^{mi} which were effectively paying their way from the uses to which they were put. Australian scientists had also conducted research into two different reactor systems neither of which had been previously explored. In fact Australia had completed some unique research in a very specialised field and was recognised for the value of this work through the acceptance for publication of papers in international journals.

^{mi} The second reactor MOATA will be discussed in the next chapter.

The Commission suffered a number of changes and much political interference. The government that brought it into existence wanted to control many aspect of the Commission's work and senior members of the research staff were frequently justifying their existence and the worth of their projects. Treasury seemed to have little understanding of what would, in the latter part of the Twentieth Century, be called 'big science'. Australia, and the world for that matter, had moved in a very short period of time from an era in which physics experiments were conducted on shoestring budgets to one in which equipment and facilities for the latest research would cost astronomical amounts of money. Australian politicians wanted Australian science to be at the cutting edge of research but their bureaucrats were reluctant to pay for it and more disturbingly wanted to control the type and direction of research that took place. This latter attitude would dog the Commission for the remainder of its existence.

The scientists at the workbench had an exciting time. They were involved in new research, they were involved in solving new problems in unique ways, and they had new laboratories with the latest equipment available. They built up a comradeship with one another that still exists today. They were not allowed to discuss their work openly but they were not caught up in cloak and dagger secrecy either; in today's terms their need for secrecy was more akin to 'commercial in confidence' rather than the wartime style of secrecy that has so often been attributed to them. Many of these young scientists effectively had only one employer and that was the Commission. By and large they were all happy in their work and proud of their accomplishments.

The only factor which led to any sort of unhappiness came when projects were cancelled. Many of the scientists were so committed to their work that

they did not want to let go of it. The cancellation of the beryllia project and the associated reactor projects was the product of experimental results and a realisation that no further work in the area was practical. The termination of these projects was at the direction of the senior scientists themselves. The termination of subsequent projects would be at the insistence of politicians and would cause great concern, but that was still in the future.

At the end of the beryllia project, Australia and Australians could indeed stand up and hold their heads high with pride in the work accomplished by such a young and dedicated group.

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- ¹ p15 Alder,
 - ² p61 AAEC 3rd Annual Report 1955
 - ³ p367 Moyal
 - ⁴ p276 Gowing
 - ⁵ p280 Gowing
 - ⁶ p11 Hardy 1999
 - ⁷ p55 Hardy 1999
 - ⁸ p368 Moyal
 - ⁹ National Archives of Australia; A987 item E1098 Part 3 'AAEC Lucas Heights Project'
 - ¹⁰ p16 Alder,
 - ¹¹ A987 E1098 Part 3
 - ¹² p61 AAEC 3rd Annual Report 1955
 - ¹³ p51 AAEC 5th Annual Report 1957
 - ¹⁴ National Archives of Australia A1209 item 1961/259 'Australian Atomic Weapons Tests Safety Committee'
 - ¹⁵ ibid
 - ¹⁶ ibid
 - ¹⁷ ibid
 - ¹⁸ An Act to amend the Atomic Energy Act 1953 assented to 1st April 1958
 - ¹⁹ p47 AAEC 6th Annual Report 1958
 - ²⁰ National Archives of Australia A4940 item C1730 Part 1 'AAEC Research Establishment Lucas Heights – Policy'
 - ²¹ p21 AAEC 6th Annual Report 1958
 - ²² National Archives of Australia A987 item E1098 Part 2
 - ²³ ibid
 - ²⁴ p53 AAEC Annual Report 1960
 - ²⁵ p43 AAEC 8th Annual Report 1960
 - ²⁶ profile of the IAEA web page www.iaea.org/worldatom/About/Profile
 - ²⁷ p40 AAEC 6th Annual Report 1958
 - ²⁸ p50 AAEC 5th Annual Report 1957
 - ²⁹ p67 Hardy 1999
 - ³⁰ National Archives of Australia A1209 item 1961/48 'IAEA - Board of Governors - Appointment of Allan D. McKnight as Chairman and Australian Governor'
 - ³¹ p76 AAEC 9th Annual Report 1961
 - ³² p76 AAEC 9th Annual Report 1961

-
- ³³ National Archives of Australia A1838 item 719/3/2 'IAEA - Appointment of Inspector - General Mr A.D.McKnight'
- ³⁴ p116-7 Hardy 1999
- ³⁵ A1838 719/3/2
- ³⁶ p75 AAEC 10th Annual Report 1962
- ³⁷ National Archives of Australia A1209 1961/978 'Baxter's Visit Overseas'
- ³⁸ p75 AAEC 10th Annual Report 1962
- ³⁹ p76 AAEC 10th Annual Report 1962
- ⁴⁰ p63 AAEC 12th Annual Report 1964
- ⁴¹ p11 AAEC 12th Annual Report 1964
- ⁴² p17 AAEC 12th Annual Report 1964
- ⁴³ p55 AAEC 12th Annual Report 1964
- ⁴⁴ p55 AAEC 12th Annual Report 1964
- ⁴⁵ p64 AAEC 12th Annual Report 1964
- ⁴⁶ p55 AAEC 12th Annual Report 1964
- ⁴⁷ p71 AAEC 13th Annual Report 1965
- ⁴⁸ p72 AAEC 13th Annual Report 1965
- ⁴⁹ p369 Moyal
- ⁵⁰ p370 Moyal
- ⁵¹ Binnie interview with Alder 1999
- ⁵² ibid
- ⁵³ p15 Alder
- ⁵⁴ Binnie interview with Alder 1999
- ⁵⁵ ibid
- ⁵⁶ p41 AAEC 2nd Annual Report 1954
- ⁵⁷ p20-21 Alder
- ⁵⁸ p37 AAEC 3rd Annual Report 1955
- ⁵⁹ p37 AAEC 3rd Annual Report 1955
- ⁶⁰ Binnie interview with Alder 1999
- ⁶¹ p61 AAEC 3rd Annual Report 1955
- ⁶² p19 Alder
- ⁶³ Binnie interview with Alder 1999
- ⁶⁴ p21 Alder
- ⁶⁵ p368Moyal
- ⁶⁶ p22 Alder
- ⁶⁷ Binnie interview with Ebeling 1999
- ⁶⁸ p37 AAEC 3rd Annual Report 1955
- ⁶⁹ p37 AAEC 3rd Annual Report 1955
- ⁷⁰ Binnie interview with Alder 1999
- ⁷¹ Binnie interview with Alder 1999
- ⁷² p40 AAEC 3rd Annual Report 1955
- ⁷³ p16 Alder
- ⁷⁴ p46 AAEC 4th Annual Report 1956
- ⁷⁵ p54 AAEC 3rd Annual Report 1955
- ⁷⁶ Binnie interview with Alder 1999
- ⁷⁷ A4940 C1730 Part 1
- ⁷⁸ ibid
- ⁷⁹ ibid
- ⁸⁰ ibid
- ⁸¹ ibid
- ⁸² ibid
- ⁸³ ibid
- ⁸⁴ ibid
- ⁸⁵ ibid
- ⁸⁶ ibid
- ⁸⁷ ibid
- ⁸⁸ Gissing, P; chapter 4 The Fabric of a Conservative Style of Thought' PhD Thesis, UNSW 1999
- ⁸⁹ National Library, TRC 777/7

-
- ⁹⁰ p42 AAEC 3rd Annual Report 1955
⁹¹ National Archives of Australia A4940/1 C1730 part 2 'Prime Ministers Department Cabinet Secretariat'
⁹² p45 AAEC 3rd Annual Report 1955
⁹³ p24 AAEC 3rd Annual Report 1955
⁹⁴ A4940/1 C1730 part 2
⁹⁵ Binnie interview with Alder
⁹⁶ A5619/1 C375
⁹⁷ Binnie interview with Alder
⁹⁸ ibid
⁹⁹ Lecture by R. Carlson, entitled 'History of HIFAR', delivered to the Australian Nuclear Association at Milsons Point on 9th November 1999
¹⁰⁰ ibid
¹⁰¹ ibid
¹⁰² p43 AAEC 3rd Annual Report 1955
¹⁰³ Carlson
¹⁰⁴ p367 Moyal
¹⁰⁵ p18 Alder
¹⁰⁶ p32 Hardy 1999
¹⁰⁷ p42 AAEC 3rd Annual Report 1955
¹⁰⁸ p31 AAEC 4th Annual Report 1956
¹⁰⁹ p44 Hardy 1999
¹¹⁰ p44 Hardy 1999
¹¹¹ Binnie interview with Alder
¹¹² p18 Alder
¹¹³ p31 AAEC 4th Annual Report 1956
¹¹⁴ p11 AAEC 5th Annual Report 1957
¹¹⁵ p48 AAEC 4th Annual Report 1956
¹¹⁶ p49 AAEC 4th Annual Report 1956
¹¹⁷ p30 Alder
¹¹⁸ p11 AAEC 5th Annual Report 1957
¹¹⁹ p26 AAEC 5th Annual Report 1957
¹²⁰ Binnie interview with Alder
¹²¹ ibid
¹²² p23 AAEC 6th Annual Report 1958
¹²³ p22 AAEC 6th Annual Report 1958
¹²⁴ p35 Pryor, A 'Scientist from a Queensland Bush Town' unpublished autobiography 2000
¹²⁵ p24 AAEC 6th Annual Report 1958
¹²⁶ p24 Alder
¹²⁷ p368 Moyal
¹²⁸ p25 Alder
¹²⁹ p21 AAEC 6th Annual Report 1958
¹³⁰ Conversation between Binnie and Arthur Pryor
¹³¹ p25 Alder
¹³² p43 AAEC 3rd Annual Report 1955
¹³³ p52 AAEC 3rd Annual Report 1955
¹³⁴ p44 AAEC 4th Annual Report 1956
¹³⁵ A987/4 E1098 Part 2 'Lucas Heights Project'
¹³⁶ ibid
¹³⁷ p21 Alder
¹³⁸ p13 Alder
¹³⁹ p13 Alder
¹⁴⁰ p21 Alder
¹⁴¹ p22 Alder
¹⁴² p13 Alder
¹⁴³ p22 Alder
¹⁴⁴ p27 Alder
¹⁴⁵ Binnie interview with Alder
¹⁴⁶ ibid

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- 147 p33-35 AAEC 6th Annual Report 1958
 148 p21 AAEC 7th Annual Report 1959
 149 p28-30 AAEC 8th Annual Report 1960
 150 p39-40 AAEC 9th Annual Report 1961
 151 p44 AAEC 9th Annual Report 1961
 152 p369 Moyal
 153 p27 AAEC 5th Annual Report 1957
 154 p25 AAEC 5th Annual Report 1957
 155 p20 AAEC 6th Annual Report 1958
 156 p369 Moyal
 157 p368 Moyal
 158 p11-2 McQuillan, M. and Farthing, T. 'Beryllium' in 'Endeavour' Volume XX Number 77
 January 1961 p11-18
 159 p369 Moyal
 160 A987/4 E1098 part 2
 161 A1209 1961/1107
 162 ibid
 163 Binnie interview with Alder
 164 p28 AAEC 5th Annual Report 1957
 165 p22 Alder
 166 p28 AAEC 5th Annual Report 1957
 167 p23 Alder
 168 p29 AAEC 5th Annual Report 1957
 169 p23 Alder
 170 p36 AAEC 6th Annual Report 1958
 171 p24 Alder
 172 p25 Alder
 173 p19 AAEC 7th Annual Report 1959
 174 Binnie interview with Alder
 175 p27 AAEC 5th Annual Report 1957
 176 p25 AAEC 8th Annual Report 1960
 177 p369 Moyal
 178 p33 AAEC 6th Annual Report 1958
 179 p22 Alder
 180 p28 Alder
 181 p369 Moyal
 182 p26 Alder and p27 AAEC 12th Annual Report 1964
 183 p26 Alder
 184 A1209/128 1961/1107
 185 ibid
 186 A1209/128 1961/1107
 187 p37 Barnett, D 'Minerals and Energy in Australia' Methuen Australia, North Ryde 1979
 188 p27 Alder
 189 p28 Alder
 190 p28 Alder
 191 p28 Alder
 192 p28 Alder
 193 p29 Alder
 194 Binnie interview with Alder

5 THE COMMISSION; A Hive Of Activity

5.1 Introduction

The major focus of the Commission in its first decade was the beryllia project and its associated reactor projects. However, within the Commission other research was taking place which would have a significant long-term impact on Australian society, specifically irradiation, radioisotope production and their applications. The newly installed HIFAR reactor would provide the irradiation facilities and would be used in the production of radioisotopes. Neutron diffraction would also be established as an experimental technique utilising the high neutron flux from HIFAR.

This was also a period in which nuclear explosives were seen as alternatives to the use of chemical explosives for civil engineering purposes. Schemes which today seem far-fetched included the use of nuclear explosions for building harbours. These schemes were all placed under the title of 'Project Plowshare' and were seriously researched and considered overseas. In Australia such schemes were given a cursory examination but little more.

The new Professor of Physics at the University of Sydney, Harry Messel, wanted to bring this moribund department into the forefront of physics which included nuclear science and technology amongst other disciplines. He wanted his staff and students to have access to the nuclear physics facilities being developed at Lucas Heights. When it appeared that the facilities would not be made available quickly enough for him, he sought assistance from abroad to obtain reactor facilities for his own department. This action led to two quite different outcomes. The first was the establishment of an organisation, the Australian Institute for Nuclear Science and Engineering

(AINSE) which would allocate research time to HIFAR and would act as a facilitator between university academics and the Commission. The second was the purchase of a second small reactor, MOATA, by the Commission.

5.2 Irradiation, Isotope Facilities and Neutron Diffraction

HIFAR provided not just a materials testing facility, its high neutron flux also made it ideal for the production of radioactive isotopes which have applications in industry and medicine. When spent fuel rods were removed from the reactor, they still had the ability to produce high levels of gamma radiation which has the ability to kill most living organisms including viruses and bacteria without destroying other materials. These two possible functions allowed HIFAR to be much more than just a materials testing reactor.

The production of isotopes was possibly the first use that was envisioned for HIFAR. The Isotope Section of the Commission was formed in 1956. It was known that *'isotopes are being used extensively in medicine and research and are being brought into use in industry'*¹ but much work was still required to determine which isotopes should be produced to provide a reasonable return to the Commission. The Commission consequently decided that Jack Gregory should find out who his potential customers were and what isotopes they may want. In order to do this the Commission decided that *'commencing in the latter half of 1956, Dr Gregory will visit industrial establishments and other places throughout Australia where isotopes might be usefully employed'*².

The following year, in 1957, the AAEC established its Isotope Advisory Service *'to encourage the use of radioisotopes in industry and research'*³. This service saw to it that industry had a good uptake of the new isotope technologies that were made available to it. Production of isotopes did not

start until after 1960 when HIFAR was operating at full power. The first radioisotope produced for medicine at Lucas Heights was cobalt-60 which was used then in the treatment of cancers. The first cobalt-60 removal from HIFAR took place on September 1961 and was delivered to St Vincent's Hospital in December⁴. Cobalt-60 production continues to the present time because of its wide application in cancer treatment^{lvii} and for the sterilising of instruments and dressings. Medical isotope production was complemented by the production of isotopes to order for both industry and research establishments. By the end of its first year of isotope production the AAEC produced and delivered more than 143 sources to their customers⁵ producing an income of 55,243 pounds⁶. This was the Commission's first source of income.

Australia now produces and uses isotopes for many applications in medicine (diagnostic and therapeutic), industry, agriculture, environmental management and research. Australia is also a major exporter of radioisotopes to the Asia-Pacific region. In 1986, isotope production earned the Commission a total of \$3,262,344⁷ which made up 60% of earned income for the Commission^{lviii}.

Food preservation was seen as a possible application for the use of the irradiation facilities that would become available from the spent fuel rods⁸. The CSIRO sent two staff members from their Division of Food Preservation and Transport to Lucas Heights to be attached to the research establishment. Their duties included studies in the use of irradiation for insect control in fruit and the use of irradiation for food preservation⁹.

^{lvii} Radiation treatment by use of Cobalt-60 for cancers is being replaced by the use of other forms of radiation.

^{lviii} Most of the Commission's operating revenue came from the government as a parliamentary appropriation.

In 1961, radiation technology was being applied to the destruction of insect pests, to food preservation by the inhibition of sprouting of potatoes and to the sterilisation of medical and pharmaceutical goods¹⁰. By 1964 work in the area of food preservation was now focusing on the physical and chemical changes that may occur in a variety of foods when irradiated. The foods under investigation included oranges, bananas, tomatoes and a variety of grains¹¹. Food irradiation would continue to be one of the main research areas for the remainder of the century, although the commercial use of food preservation by irradiation, as mentioned above, has never been allowed in Australia.

The work on the production of sterile male fruit flies had some success. The initial study demonstrated that fruit fly numbers could be controlled by irradiating fruit fly pupae thus sterilising the flies¹². The irradiation facilities at Lucas Heights proved the utility of such a facility. Today a number of small privately owned and run irradiation facilities are used by a variety of industries to sterilise pharmaceutical and medical supplies and equipment.

The use of neutron diffraction as an experimental tool was considered at Harwell. As previously mentioned, one Australian scientist at Harwell was being instructed in the use of neutron diffraction techniques. This was Terry Sabine who as a young graduate was recruited to the Commission in 1956 and sent to Harwell. At Harwell he joined the Metallurgy Section of the AAEC under Keith Alder. Sabine was assigned to work in the neutron diffraction group at Harwell. Neutron diffraction was, in the early 1950s, seen as an area of pure research to which the AAEC had deliberately decided to allocate a '*small fraction*' of its resources¹³.

The HIFAR reactor had holes or ports from which neutrons could be obtained from inside the reactor. The neutrons then passed through diffractometers

from which these neutrons were directed to their targets. Neutron diffraction techniques were used during the studies on beryllia and beryllium¹⁴. This technique allowed for studies on crystal structures of a variety of materials to be made which proved to be more accurate and more penetrating than other methods available. Specifically this technique allows for the structural analysis of crystals containing light atoms such as hydrogen which cannot be done using the older X-ray diffraction technique. Today neutron diffraction is so widely used that it is one of the main tools used by researchers in the biological sciences.

5.3 Project Plowshare

Project Plowshare is one of the more bizarre projects related to nuclear energy. It came into existence at the time when discussions were under way into a nuclear-test-ban treaty which would effectively stop all atmospheric explosions of nuclear devices. This project came into being when *'in 1957, the United States Atomic Energy Commission initiated a scientific program known as Project Plowshare to explore the possible civil uses of nuclear explosions'*¹⁵. One of the possible civil uses of these explosions was the building of deep water harbours to allow for the anchoring of large cargo vessels. Other possibilities included the building of canals and other types of water-ways to connect oceans (a new Panama Canal) or just to connect rivers to each other. In short any type of major civil engineering project that may require huge quantities of earth to be excavated.

In November 1962 the Australian Government received a note from Dr Seaborg from the USAEC outlining proposals on the peaceful uses of nuclear explosions which included the possibility of dam building. This was followed up by a suggestion of a possible *'mutual US – Australian experimental*

program' in this area¹⁶. The Australian government was naturally cautious and requested more information without making any commitment to the project. Consequently 'in September 1963, at the initiation of the Chairman of the United States Atomic Energy Commission, The Australian Government sent a group of scientists and engineers to investigate current research associated with the Plowshare Project'¹⁷.

There was much public discussion through the print media during the following few years on the possibilities of these types of explosions. These discussions were not all of a theoretical nature, as an extract from the AAEC Annual Report 1965 demonstrates: *'recent statements by the Minister for Industrial Development in the Western Australian Government have referred to the possibility that nuclear explosives might be used to excavate a harbour in North-Western Australia to serve the iron ore industry'¹⁸.*

The AAEC was taking the proposal quite seriously, to the extent that in its 1966 Annual Report there are detailed descriptions of the different effects that could be achieved using different types of explosions and included the following justifications for such explosions:

'to ameliorate problems arising from low rainfall, or the seasonal flow of rivers and wastage of water in the wet season, nuclear explosives may have application for the formation of deep craters, rubble chimneys or dams for water conservation. ... Nuclear explosives could be used with advantage to form new harbours in remote locations'¹⁹.

The attitudes expressed by these statements followed the general attitude of the community. This was a period before the community at large became aware of environmental concerns and land was seen as something to tame for the purposes of progress and prosperity. The notion that the environment should be considered before any major project was undertaken was not even

conceivable, let alone considered. The concept of attempting this type of environmental manipulation would not be as easily accepted in the current century.

Such explosions could also release large amounts of unwanted radioactive materials into the atmosphere which the nuclear-test-ban treaty was attempting to stop. Some of the explosions could take place underground producing cavities underground. *'Progress in the Plowshare program has been retarded to some extent by the Limited Test Ban Treaty' which 'prohibits nuclear explosions which release radioactivity beyond territorial limits'*²⁰. The AAEC did note that *'there are indications that bona fide peaceful applications of nuclear cratering may be accommodated by some relaxation of the treaty'*²¹. The possibility of such explosions remained under public discussion until in 1968 *'the Premier of Western Australia requested the Commonwealth to undertake a feasibility study of the excavation of a harbour by nuclear explosives at Cape Keraudren in North-Western Australia for the shipment of iron ore'*²². According to Hardy the study was undertaken as a joint exercise by the AAEC and the USAEC, but the US Company which was to mine the iron ore changed its program and the study was abandoned²³.

The final agreement of the Non-Proliferation Treaty and Australia's ratification of it in 1973 closed this chapter of Australia's involvement in nuclear explosions; peaceful or otherwise. Attempts to resurrect Plowshare were made at the IAEA in the 1970s, being renamed Peaceful Nuclear Explosions (PNE), but Australia and other members of the IAEA were no longer interested.

5.4 Harry Messel and the Ford Foundation

Harry Messel was born in Manitoba, Canada in 1922. Both his parents had been brought to Canada from the Ukraine by their respective parents in the 1890s. He was admitted to the Royal Military College in Canada and was later educated at Queens University in Ontario. He then attended both St Andrews University in Scotland and the Institute of Advanced Studies in Dublin. During the war he served in the Canadian armed services. In 1951 he was recruited as a Senior Lecturer in Theoretical Physics by the University of Adelaide.

Messel, after only a year in Adelaide, became restless and was looking for another position, preferably overseas. In August 1952 he left Australia to visit a number of nuclear physics laboratories with this end in mind, but during a stop over at Sydney, he was offered the position of Head of the School of Physics at the University of Sydney. He accepted the position, on the proviso that the University agree to certain conditions which he stipulated and these included the establishment of a number of Professorial Chairs within the School of Physics. To his amazement the University agreed and Messel returned to Australia as Professor of Physics at the University of Sydney²⁴.

When Messel returned to Sydney he immediately started to set his agenda for physics at Sydney. At a graduation address on 29th April 1953 Messel stated that *'rapid advances had been made in atomic (nuclear) physics and nuclear power for industrial purposes and these were ideal for Australia given that it was a dry continent and had ample reserves of uranium'*²⁵. Messel wanted a nuclear physics group within the University. He was also aware that this would cost a considerable amount of money to establish, especially if he was to provide facilities for these researchers. On 24th August 1953, the Senate of the University of Sydney approved the Constitution of what was then a unique establishment but would later be mirrored by many other institutions both in

Australia and abroad: the Nuclear Research Foundation²⁶. Messel now set out to raise the funds that he saw necessary to establish his Foundation, using the context of nuclear power as his selling point. He did not restrict himself to Sydney-based companies but went further a field to the commercial establishments in Collins St, Melbourne, thus raising the ire of some physicists at the University of Melbourne, especially Professor Leslie Martin. According to James McCaughan, *'Messel had in fact challenged the conventional wisdom on the role for State Universities as well as who should decide the atomic power question'*²⁷.

Messel started writing to members of the newly established Australian Atomic Energy Commission, initially requesting information on the availability of studentships and other research activities but Baxter replied that nothing had as yet been done in this area²⁸. Messel then wrote to the Chairman of the Commission, Stevens, this time requesting donations for his Foundation and stating his desire to train nuclear physicists. Stevens replied stating that he would pass on the request to the Scientific Advisory Committee but also noting that the AAEC did not need nuclear physicists²⁹. By this stage Messel realised that if he wanted to have a nuclear physics group within his department he would receive no assistance from the AAEC.

Messel continued to make enquiries into the area of nuclear physics training, specifically on costs of establishing and running research reactors. He sent out a number of such enquiries in February 1954³⁰. Even before the Foundation's inaugural meeting and dinner, Messel had managed to get complete funding for a computer for the School of Physics. Messel, amongst his many attributes, was excellent at networking; whilst overseas he had managed to form a close association with a number of scientists and administrators. One of these included the Chairman of the United States

Atomic Energy Commission from whom Messel managed to get the blueprints for ILLIAC, the new Commission's computer that was being designed by the University of Illinois³¹. The University of Sydney version was SILIAC and was the first computer to be used in Australia for the analysis of commercial data: the Post Master General's Department bought computer time to analyse data from its Telephone Traffic Section in Sydney.

The Nuclear Research Foundation had its inaugural meeting and dinner on 11th March 1954. Its first Chairman was Mr Parry-Okeden (1900-78). Parry-Okeden was an English businessman who had arrived in Australia in 1923. In 1940 he had become Chairman and Managing Director of Lysaght's Newcastle Works Ltd and the Commonwealth Rolling Mills Pty Ltd. The Lysaght company was based in Britain and the Australian company manufactured sheet steel and galvanised iron. Parry-Okeden was appointed, in 1949, to the Council of the newly established University of Technology, N.S.W. He was also President of the New South Wales Chamber of Manufacturers during the period 1951-53.

At this first meeting and dinner the Premier of NSW, the Honourable John Cahill, presented the Foundation with a donation of fifty thousand pounds for '*carrying out its work in the field of nuclear research*'. Other attendees at this dinner included Thomas Playford, Howard Beale, Arthur Fadden and William McMahon. Shortly after this meeting Messel started making public his belief in the need for Australia to have a nuclear power station. Specifically he is reported as stating that a nuclear power station should be built immediately in the Snowy Mountains area and should be used in conjunction with the hydroelectric power stations when they came on line³².

The University of Sydney had been left out of the nuclear energy advances associated with the establishment of the Australian Atomic Energy Commission. When the Commission established its Scientific Advisory Committee, a representative from the University of Sydney was notably absent. This of course is hardly surprising since at the time physics at the University of Sydney had a low profile in terms of scholarship and Harry Messel had only recently been appointed. Consequently in '*September 1954 the Foundation and the University Senate had resolved to send Messel and Professor D.M.Myers of Electrical Engineering at Sydney on an overseas mission to help establish the feasibility of constructing an experimental nuclear reactor within the University*³³. The Australian government was not only aware of Messel's mission but was willing to support it to the extent that a note was sent to the Australian Embassy in Washington stating that the government and the AAEC were supporting Messel's enquiries but not sponsoring him³⁴.

Needless to say, the two professors discovered that not only was a nuclear reactor feasible but that two would be ideal; '*the availability of two reactors ... one reactor should have a high neutron flux , ...and (the other should be) a graphite moderated assembly seems to be the most simple and versatile*³⁵. The University Senate at its 7th December meeting 1954 resolved that '*two low power nuclear reactors would be built which would complement*' the Australian Atomic Energy Commission's new HIFAR reactor. Essentially one of the reactors would be a training reactor and the second would be research reactor.

The task now was to determine what type of reactor would best suit the needs of the University. In early 1955, a number of companies involved in the construction of research reactors approached Messel with information on their

reactors. Once it was known that Messel was in the market for a reactor prospective staff also offered their services to him. It appeared that Messel was well on the way to establishing his nuclear physics group at the University of Sydney. Justification for University-owned and controlled reactors was made in July 1955 in a report of the Joint Committee of the Senate and the Nuclear Research Foundation at the University of Sydney; *'it is the opinion of this Committee that it may not be possible for the Atomic Energy Commission to provide the access and facilities for independent lines of research. It is concerned that access will be inadequate ...it is still concerned regarding continuity of policy under political control'*³⁶. The rationale and justification for independent scholarly access to reactor facilities was now on the table. In short, the University of Sydney was not convinced that the AAEC and the Government would allow researchers to follow their own lines of enquiry and there was the additional suspicion that there may be political interference in who and what projects were given priority for reactor access.

The minutes of a meeting of the Council of the Nuclear Science Foundation held on 30th August 1956 record that *'the program of the Australian Atomic Energy Commission at Lucas heights had slowed down and that there had been no further meeting between representatives of the universities and the Commission'* and that the Chairman, Parry-Okeden would send a letter of complaint to the Minister responsible. A letter dated 5th of October 1956 was duly sent to Mr Beale and a copy was also sent to the Prime Minister, *'expressing the concern of the Council over the delays which have occurred in the construction of this vital project'* the latter continued to voice concern at the delay in training Australian scientists and engineers and with the lack of radioisotopes for industry and medicine³⁷.

Messel was clearly anxious that Australia, and more importantly his department, would have the best physicists doing state-of-the-art research on the best facilities. The delay in building HIFAR would put his agenda behind. Messel wanted reactor facilities and he wanted them now. The Foundation was still searching for funding for his research reactors and in so doing was actively seeking advice from key players in the US. One such player was a Mr Oscar Ruebhausen, who was connected to the Ford Foundation. It was he who, on 23rd October 1956, sent the Foundation copies of the procedures under which the US would give aid to assist in the purchase of nuclear reactors. Further correspondence indicated that the Ford Foundation would be willing to provide the funds for a reactor if there was also support for it from the Commonwealth Government³⁸.

The Foundation was under the impression that the Australian Atomic Energy Commission was considering requesting the gift of a swimming pool reactor^{lix} and hence the Foundation decided to attempt to procure a complementary reactor, the CP-5. This latter reactor was expensive to build and maintain. It was reported to the Foundation in January 1957 that members of the Foundation had met with Baxter '*who had expressed enthusiastic support of the Foundation's proposal to obtain a CP-5 reactor*', and the Foundation had asked that the reactor be located at Lucas Heights³⁹. Baxter had organised a meeting between Senator Spooner, the new Minister, and some members of the Foundation with the result that it was suggested that the Foundation make a formal proposal and request for funds from the Commonwealth Government⁴⁰.

The Foundation made its application to the Commonwealth Government and by March 1957 it was noted '*that the Australian Atomic Energy Commission*

^{lix} See Appendix 3

and the Minister for National Development, Senator W.H.Spooner, had recommended approval of the request'. Everything appeared to be going well, Messel was under the impression that the Ford Foundation would be willing to provide major funding for this project with additional support from the Commonwealth Government. During April and May 1957 members of the Nuclear Research Foundation lobbied the Commonwealth Government to provide the funding necessary to run the reactor. Finally, on 14th May, Baxter, on behalf of the Government, wrote to James Kirby, who was now Chairman of the Foundation, stating that some finances would be made available but the extra funds required would have to come from other universities and industry⁴¹.

The Commonwealth Government was prepared to encourage Messel with negotiations with the Ford Foundation, but the encouragement was little more than giving its approval that the Ford Foundation reactor could be erected at the AAEC Research Establishment at Lucas Heights⁴². The July 17th meeting of the Foundation noted that firstly the Australian Institute for Nuclear Science and Engineering (AINSE) (see next section) had been established by the Commonwealth and that the Commonwealth was willing to contribute to the running costs of the Ford Foundation reactor. Finally, it was noted that *'it had been discovered that the Government had decided not to ask for a swimming pool reactor from American sources and the Chairman had reminded Council that its proposal for a CP-5 reactor had been based on the assumption that there would be available a swimming pool reactor. It now seemed more important to obtain the latter*⁴³. A letter was subsequently sent to Ruebhausen on 11th June stating that the requirements of the Foundation were for the much cheaper swimming pool reactor.⁴⁴

The September 11th 1957, meeting of the Foundation had an air of optimism; the Ford Foundation appeared to be willing to give some major funding to the reactor project, the Commonwealth Government was also willing to help finance it and, further, it was willing to approach the US Government for additional funding from the Eisenhower 'Atoms for Peace' Plan. A formal proposal was still to be made to the Ford Foundation on which all this was dependent. Baxter was to visit New York in late October at which time it was expected that he would meet with Mr Ruebhausen to discuss the proposal⁴⁵. Letters passed between the Foundation and both Ruebhausen and Baxter arranging this meeting. An air of expectancy fell on the Foundation. Then in December a letter arrived for Kirby, the Foundation Chairman. Ruebhausen wrote *'today I talked with officials of the Ford Foundation concerning your project and I regret to advise you that, because the Ford Foundation does not have a program for Australia within which your proposal could fall, and for other policy reasons, it is clear that the filing of an application would be futile'*⁴⁶.

The Foundation, at its January 1958 meeting noted that *'acting on advice from the Ford Foundation ... there would be no good purpose served in making official application at the present time. It was agreed that the matter be left in abeyance for the time being'* and by March the mood had changed even more *'conditions in the US have changed radically and it now appears unlikely that we will receive the assistance previously anticipated'*⁴⁷. Additional funds from other government sources, universities or industry were not forthcoming and the project collapsed⁴⁸.

What had caused the change of heart on the part of the Ford Foundation?

The events recorded suggest that the funds for the new reactor were almost there for the taking, but somehow after Baxter's visit things changed

dramatically. Could Baxter have effectively stopped the funding? That is a possibility. After all, Messel had upset the Melbourne establishment, including people such as Leslie Martin. An earlier incident recorded by Miller suggests that Menzies was upset by Messel's fund raising approach, and lastly, Baxter was probably threatened by having Messel wanting to have a nuclear science group at the University of Sydney. The motive was certainly there, but the question will remain: was Messel betrayed by those who offered support? Messel did have 'the last laugh'; he became a member of the Commission, but that was not until later.

5.5 The Birth of the Australian Institute for Nuclear Science and Engineering, AINSE

The Lucas Heights reactor facility was seen as a facility not just for AAEC staff but as a research facility for university-based researchers. Consequently, in 1955 '*Universities ... (were) invited to state what facilities they expected to require for research and teaching , and the numbers of research workers and students for which the facilities would be required*⁴⁹'. Despite this general invitation to universities, there still appeared to be some suspicion as to whether the research that would be carried would be truly independent. The University of Sydney, as has already been mentioned, was not convinced that its researchers would be able to set up their own programs and wanted its own reactor. Those universities, whose staff were also a part of the AAEC structure through membership of either the Commission itself or through membership of the Scientific Advisory Committee, probably did not feel threatened as they had their advocates already there.

The Commission established 15 postgraduate studentships and 12 undergraduate bonded scholarships in 1955 to assist in the training of future scientists⁵⁰. One of the first scholarship holders was Neil McDonald who

received an AAEC Undergraduate Scholarship in metallurgy at the University of Technology, NSW. McDonald would continue his involvement with the Commission completing his postgraduate training at the Commission and working for the Commission until his retirement in 2001⁵¹. The following year the AAEC noted in its Annual Report that '*Australian universities are now considering the establishment of postgraduate and other courses in nuclear science and technology*⁵². The reality was that the University of Sydney and the NSW University of Technology were already attempting to establish joint courses on the Introduction to Engineering and Technology of Atomic Power⁵³.

The problem of allocating reactor time and administering reactor research projects still had to be solved. According to Moyal, in 1956 AINSE was founded for joint administration of a reciprocal training scheme between universities and the AAEC, allowing universities access to the research facilities at Lucas Heights⁵⁴. The inception of AINSE may well have occurred then but it is generally agreed that AINSE was established on 14th May 1957 when the Cabinet met and approved its formation and allocated finances for the construction of its headquarters at Lucas Heights⁵⁵.

The organisation of AINSE allowed for representation from both the AAEC and all the universities which had at this time been established. As more universities came into existence AINSE's membership grew. It was governed by a Council which would determine the allocation of reactor time to research projects. *'The inaugural meeting of the Council of the Institute was held on December 4, 1958. Council members representing each Australian university and four representing the Australian Atomic Energy Commission were present*⁵⁶.

The universities now had an organisation which was essentially divorced from the political priorities of Canberra and governed by academics who would have a better understanding of research projects submitted for approval. AINSE remains today an independent organisation located outside the main gates of the research establishment at Lucas Heights.

5.6 One Reactor is not Enough; the arrival of MOATA

HIFAR had been designed, purchased and built as a materials testing facility and as such produced a very high neutron flux. As has already been discussed in this chapter, it became apparent that another type of reactor would be required for other aspects of nuclear science work. This new reactor would be smaller, have a lower neutron flux, produce less thermal power, and would be more flexible in its core structure than the main reactor HIFAR.

At meeting of the AAEC's Scientific Advisory Committee held on 17th September 1959, Marcus Oliphant was in the chair since Leslie Martin was absent. There was a discussion as to the future needs of the Commission which included the possible purchase of a new reactor. The meeting recommended '*the additional low-powered reactor facility should be installed as soon as possible*⁶⁷. By this time it was well known that Professor Harry Messel from the University of Sydney had some years earlier recommended that the University of Sydney procure two research reactors, one complementing the other. Messel's plans never came to fruition. No one argued against the need for this new reactor and finances readily became available.

The AAEC Annual Report of 1960 states that '*a contract was signed with Advanced Technology Laboratories of the United States for a 10 kilowatt*

*graphite moderated reactor,... the reactor is based on the 'Argonaut'^{lx} design evolved at the Argonne National Laboratory, USA'⁵⁸. The new reactor was given the name MOATA which was an aboriginal term for 'fire sticks' or 'gentle heat'⁵⁹. MOATA was designed to have a maximum thermal neutron flux of 10^{11} neutrons per square centimetre per second. It was also '*designed for flexibility of core and reflector arrangements*'⁶⁰. The Commission justified the new reactor in the following terms; '*the new reactor will be much simpler, and will be used for many tests and measurements where the intense radiation of HIFAR is unnecessary and often undesirable. These will include physics studies of reactor materials and sample cores ... for future power reactor systems. It will also be useful for training*'⁶¹. This reactor was so small that it could be safely housed in a conventional building and did not require additional shielding. Its new home was to be the newly completed Reactor Physics Building at Lucas Heights.*

A statement issued by Senator Spooner on 3rd March 1960 stated;

'A second reactor is being installed at Lucas heights... It would be used in the Commission's general program for the development of a high temperature gas cooled reactor and would be complementary to HIFAR.

The new reactor would produce 10kwatt of heat ... It would be employed for many tests and measurements where the intense radiation of HIFAR was unnecessary. These would include physics studies of reactor materials, and sample cores (fuel assemblies) for future power reactor systems ... providing a readily varied source of neutron flux ... the contract to supply and commission the reactor had

^{lx} see Appendix 3

been awarded to Advanced Technology Laboratories, a division of American Standard of Mountain View, California'⁶².

The 10kW stated in Senator Spooner's statement was the maximum power level of MOATA. It operated at a much lower power for most of its working life.

See Figure 5-1.



The new reactor Moata, showing the neutron time-of-flight spectrometer installed. The beam tube extends from the reactor face to the beam trap. Associated counting equipment is nearby.

Figure 5-1 MOATA

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MOATA went critical at the expected time on 10th April 1961 and was announced to the Australian public through a press release from Senator Spooner which simply stated '*Australia's second atomic reactor, MOATA, went critical today*'⁶³. The work that MOATA was put to was essentially associated with the beryllia project. However, such a versatile tool had other

uses. According to the AAEC Annual Report, by 1963 the experiments carried out on MOATA included:

'the determination of neutron diffusion length in a block of beryllium oxide,
the measurement of neutron density distributions for various beryllium oxide-uranium-235 sub-critical assemblies,
the use of the neutron converter for fast neutron detector development,
time of flight spectrometer tests on a neutron beam originating from the core of MOATA,
pneumatic carrier tube irradiations for activation analysis,
damage studies on solid state counters,
mineralogical studies for the Australian National University,
studies on trace elements in teeth for the Sydney Dental Hospital and
*calibration irradiation of foils for the Thai Atomic Energy Commission*⁶⁴.

This work gave the Commission additional finances and kudos in the Asia-Pacific region. According to Arthur Pryor, MOATA operated at such low power levels that it was never necessary to change the fuel elements or to reprocess the fuel and it did not even require cooling⁶⁵. MOATA would remain as the low-powered workhorse at the Commission until the 1980s when it was finally decommissioned and dismantled.

¹ p52 AAEC 3rd Annual Report 1955

² p44 AAEC 4th Annual Report 1956

³ p11 AAEC 5th Annual Report 1957

⁴ p55 AAEC 10th Annual Report 1962

⁵ p55 AAEC 9th Annual Report 1961

⁶ p80 AAEC 9th Annual Report 1961

⁷ p125 AAEC 34th Annual Report 1986

⁸ p43 AAEC 3rd Annual Report 1955

⁹ p44 AAEC 8th Annual Report 1960

¹⁰ p50 AAEC 10th Annual Report 1962

¹¹ p52 AAEC 12th Annual Report 1964

¹² p67 AAEC 13th Annual Report 1965

¹³ p106 Sabine, T 'Neutron Diffraction in Australia' in Bacon, G. (editor) 'Fifty Years of Neutron Diffraction' Adam Hilger, Bristol

- 14 Sabine
- 15 p78 AAEC 10th Annual Report 1962
- 16 National Archives of Australia A1858/370 item 720/10/10 Part2 'IAEA Peaceful Nuclear Explosion in Australia - Operation Plowshare'
- 17 p11 AAEC 12th Annual Report 1964
- 18 p76 AAEC 13th Annual Report 1965
- 19 p33 AAEC 14th Annual Report 1966
- 20 p32 AAEC 14th Annual Report 1966
- 21 ibid
- 22 p80 Hardy 1999
- 23 ibid
- 24 p8 Millar, D editor 'The Messel Years; The Story of the School of Physics and its Science Foundation within the University of Sydney 1952-1987' Pergamon, Sydney 1987
- 25 p9 Millar
- 26 p11 Millar
- 27 p13 Millar
- 28 letter sent to Baxter from Messel, dated 6th October 1953 and a reply from Baxter dated 12 October; from the University of Sydney Archives Agency G47 Box 244
- 29 letters between Messel and Stevens dated 19th and 23rd November 1953 respectively; from the University of Sydney Archives Agency G47 Box 244
- 30 from the University of Sydney Archives Agency G47 Box 244
- 31 p16-18 Millar
- 32 National Archives of Australia A5954 2165/2
- 33 p 20 Millar
- 34 National Archives of Australia A1209/23 1957/4127
- 35 note from Myers to Registrar dated 21st March 1955; from the University of Sydney Archives Agency G47 Box 244
- 36 University of Sydney Archives Agency G47 Box 244
- 37 University of Sydney Archives Agency G47 Box 62
- 38 ibid
- 39 National Archives of Australia A1209/23 item 1957/4127 Training of Technical Personnel for Atomic Energy Work (Peaceful)
- 40 University of Sydney Archives Agency G47 Box 62
- 41 A1209/23 1957/4127
- 42 National Archives of Australia A5619/1 C375
- 43 University of Sydney Archives Agency G47 Box 62
- 44 ibid
- 45 National Archives of Australia A987/4 E1098
- 46 University of Sydney Archives Agency G47 Box 62
- 47 ibid
- 48 p21 Millar
- 49 p44 AAEC 3rd Annual Report 1955
- 50 p46-7 AAEC 3rd Annual Report 1955
- 51 Binnie interview with McDonald
- 52 p37 AAEC 4th Annual Report 1956
- 53 from the University of Sydney Archives Agency G47 Box 244
- 54 p368 Moyal
- 55 National Archives of Australia A5619/1 item C375 'Prime Ministers Department Cabinet File'
- 56 p 35 AAEC 7th Annual Report 1959
- 57 National Archives of Australia A1209/128 1961/1107
- 58 p 34 AAEC 8th Annual Report 1960
- 59 A987/4 E1098 part 3
- 60 p34 AAEC 8th Annual Report 1960
- 61 p24 AAEC 8th Annual Report 1960
- 62 A987/4 E1098 part 3
- 63 A987/4 E1098 part 3
- 64 p 54 AAEC 11th Annual Report 1963
- 65 Pryor in conversation with Binnie