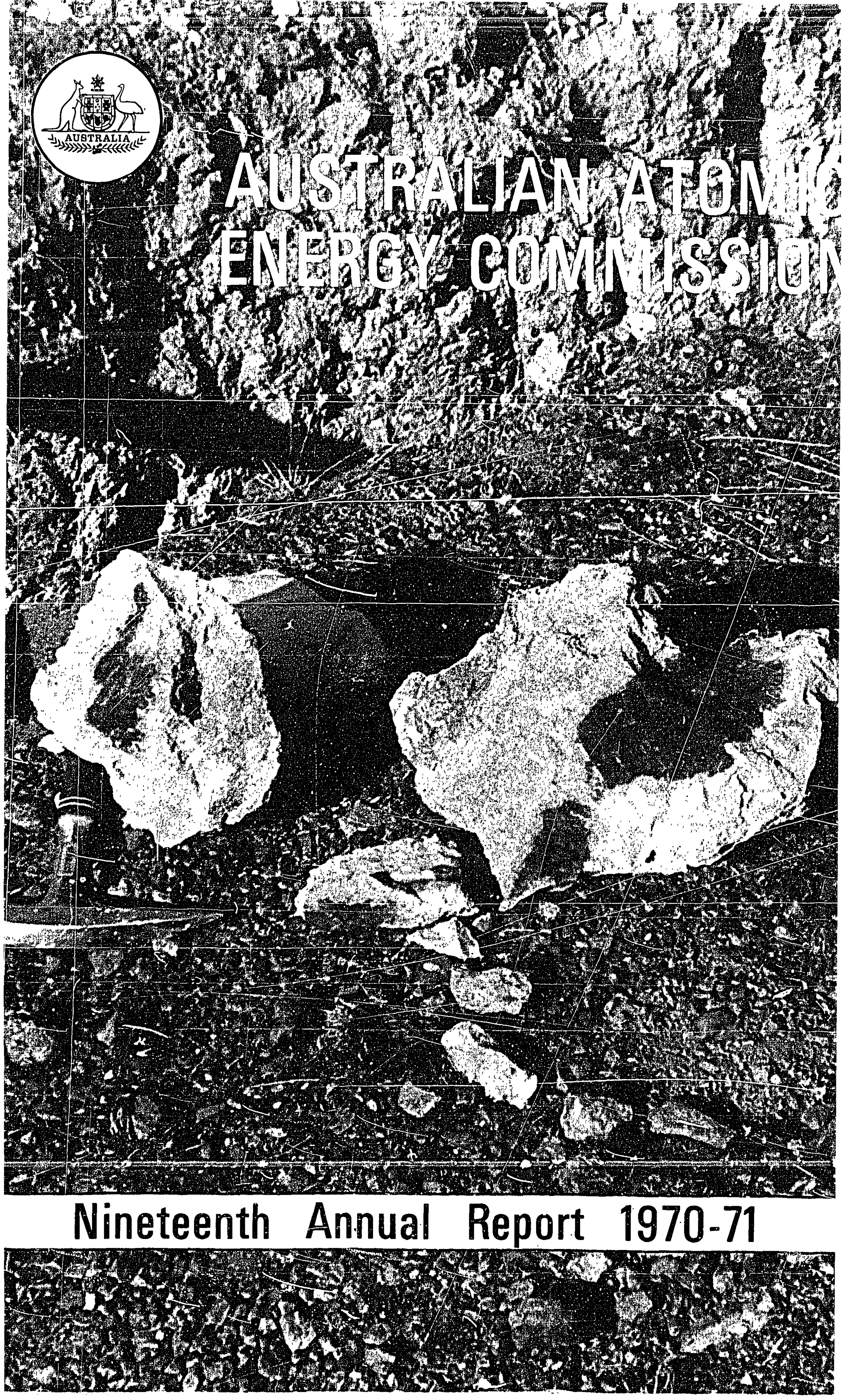
# AUSTRALIAN ATOMIC ENERGY COMMISSION



## Nineteenth Annual Report 1970-71

INIS-mf--186

Commonwealth of Australia

# AUSTRALIAN ATOMIC ENERGY COMMISSION

## NINETEENTH ANNUAL REPORT

Being the Commission's Report for the Year Ended 30 June 1971

# AUSTRALIAN ATOMIC ENERGY COMMISSION

**The Minister of State for National Development**

The Honourable R. W. C. Swartz, M.B.E., E.D., M.P.

**Members of the Commission During the Year 1970-71**

**Chairman**

Sir Philip Baxter, K.B.E., C.M.G., B.Sc., Ph.D.(Birm.), F.A.A., F.R.A.C.I.

**Deputy Chairman**

R. G. Ward, M.A., Ph.D.(Cantab.)

**Members**

K. F. Alder, M.Sc., F.I.M.

L. F. Bott, D.S.C., B.Com.

M. C. Timbs, B.Ec., A.A.S.A., F.A.I.M.
(Executive Member)

**Secretary**

W. B. Lynch, B.A.

Commonwealth of Australia

**AUSTRALIAN ATOMIC ENERGY COMMISSION**

To the Honourable R. W. C. Swartz, M.B.E., E.D., M.P.,
Minister of State for National Development,
Parliament House,
Canberra, A.C.T.

Sir,

In accordance with Section 31 of the Atomic Energy Act, 1953-66, we submit the Nineteenth Annual Report of the Australian Atomic Energy Commission, covering the Commission's operations for the financial year ended 30 June 1971.

Financial accounts for the year, with a report on the accounts by the Auditor-General as required by the Act, are appended to the report. A statement of the Commission's capital assets as at 30 June 1971 is also appended to the accounts.

Yours faithfully,

J. P. BAXTER, Chairman.
R. G. WARD, Deputy Chairman.
K. F. ALDER, Member.
L. F. BOTT, Member.
M. C. TIMBS, Executive Member.

45 Beach Street, Coogee, N.S.W. 2034
3 September 1971

# ADVISORY COMMITTEES

Appointed under Section 20 of the Atomic Energy Act, 1953-66

### Advisory Committee on Uranium Mining

H. M. Murray, C.B.E., B.Sc., B.Met.E., M.Aus.I.M.M., *Chairman.*

F. S. Anderson, C.B.E., B.Mech.E., M.I.M.M., M.Aus.I.M.M., M.I.E.Aust.

Julius Kruttschnitt, Ph.B.(Yale), M.I.M.M., M.Aus.I.M.M., M.Am.I.M.M.E.

*Function: To advise the Commission on uranium mining and the treatment of uranium ores.*

### Safety Review Committee

Professor Sir Sydney Sunderland, C.M.G., M.D., B.S., D.Sc., F.R.A.C.P., F.R.A.C.S., F.A.A., *Chairman.*

Dr. C. J. Cummins, M.B., B.S., D.P.H.

D. J. Stevens, O.B.E., B.Sc., A.Inst.P.

*Function: To review periodically the health and safety standards and procedures adopted by the Commission in the operation of its reactors and in the use of radiation, radioactive substances, and toxic materials.*

### Atomic Energy Advisory Committee

A. W. B. Coady, C.M.G., B.A., B.Ec.

Sir Willis Connolly, C.B.E., B.E.E., B.Com., M.I.E.Aust.

J. G. Phillips, C.B.E., B.Ec.

Sir Lionel Hooke, S.M.I.R.Amer., F.I.R.E.Aust.

Professor M. C. Kemp, B.Com., M.A., Ph.D.

Professor J. W. Roderick, M.A.(Camb.), M.Sc., Ph.D.(Bristol), F.A.A., M.I.Struct.E., M.I.C.E., A.F.R.Ae.S., M.I.E.Aust., M.A.S.C.E.

R. A. Simpson, B.E., F.S.A.S.M., M.I.E.Aust.

Professor R. Street, B.Sc., M.Sc., Ph.D.(Lond.)

L. W. Weickhardt, M.Sc., F.R.A.C.I., F.A.I.M.

*Function: To advise the Commission on scientific, industrial and economic matters relating to atomic energy research and development.*

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# INTRODUCTION AND SUMMARY

The year to 30 June 1971 was one of considerable activity, and included several developments of major significance in planning for the establishment of nuclear power and nuclear engineering in Australia.

## JERVIS BAY

Assessment of 14 Jervis Bay tenders began with a preliminary economic evaluation, leading to the comparison of the projected total costs of power stations developed from the tenders. It was carried out by the consultants, Bechtel Pacific Corporation Ltd., in association with the Australian Atomic Energy Commission and the Electricity Commission of New South Wales. At the same time, the Atomic Energy Commission, assisted by officers of the Electricity Commission of New South Wales, made a technical evaluation of the tenders.

Four tenders were then selected for further detailed assessment; viz., Pressurised Heavy Water Reactor (Canada); Steam Generating Heavy Water Reactor (Britain); Pressurised Water Reactor (Germany and U.S.A.). Subsequently, detailed discussions were held with each of the tenderers, who provided additional information on technical and other aspects of their proposals.

To study tenders, elicit further information, and analyse and evaluate the results, occupied some 70 officers of the AAEC and ECNSW for about four months. These officers were formed into ten specialist sub-committees, which were supported by detailed studies carried out at the Research Establishment and Electricity Commission. In the economic assessment, special steps were taken to place all four tenders on a comparable basis.

A condition laid down in the Invitation to Tender was that satisfactory arrangements should be made "for those operations required for local fuel preparation, including conversion and enrichment, if applicable, and fuel element manufacture". This would enable the power station to become fully independent of overseas fuel supplies and services in due course. The four tenderers, in concert with their Governments, each met this condition.

The Commission worked throughout in close association with appropriate Commonwealth and State bodies. An Interdepartmental Committee was established by the Commonwealth to study and negotiate the detailed financial and related arrangements between the Commission and the Electricity Commission of New South Wales.

The Commission took the initial steps to set up a team to supervise all stages of design, construction and commissioning. The ECNSW and other State generating authorities agreed in principle to attach staff to the team. During site selection, tendering and tender assessment and environmental surveys, officers from various Commonwealth and State Departments assisted the Commission in such matters as tender assessment, site planning and development, and environmental studies.

Detailed environmental studies of the Jervis Bay area continued throughout the year, under the guidance of a Commonwealth-State working party. The purpose of the studies was to ensure that any changes to the ecological system could be assessed and understood in the future.

On 9 June 1971 the Government announced that the studies had disclosed that the final cost figure would be higher than was expected in 1969 and, in the light of the current economic circumstances, it deferred a decision on the power station for 12 months and stated it would re-examine the matter in the light of the circumstances then existing.

## NUCLEAR POWER

Throughout the world, there has been intense activity in the nuclear power field. More new plants came into operation, were under construction, or on order, than in any previous year. The number of nuclear units (of more than 10 MW) now committed totals 298, with a combined capacity of over 170,000 megawatts. During the year, 40 new units were ordered or otherwise committed and 14 began operation. Many others are nearing completion.

Construction costs for all types of power station have risen sharply, particularly in the U.S.A. Nevertheless, nuclear power in that country has maintained its competitive position. The growth of the nuclear engineering industry will offer opportunities for cost reductions, through better production methods and replication of design. Nuclear power is expected to take a progressively increasing share of the load in all industrial countries of the world. Its value in combating pollution is also increasingly appreciated.

## RAW MATERIALS AND FUEL

In April, stockpiled uranium ore at Rum Jungle was exhausted and the treatment plant closed. The plant and equipment have since been sold by public auction.

Companies with established reserves have continued to seek export markets and Mary Kathleen Uranium Ltd. has secured contracts for the sale of 3,800 tons of uranium oxide between 1975 and 1979. Production is expected to begin in 1974.

Uranium discoveries of major importance were made in the Northern Territory as a result of company exploration. The extent of these deposits has yet to be defined, but they include some exceptionally high-grade ore. Significant discoveries of relatively low-grade ore have also been made in South Australia.

Australia's reasonably assured uranium resources, before the new discoveries, were estimated at some 22,000 short tons of uranium oxide recoverable at less than US$10 per pound (this includes an allowance for "possible" ore in known uranium occurrences). Following the new discoveries, however, although it is too early to indicate their extent, it can be predicted with confidence that Australia will rank as one of the world's major uranium producers.

This situation would provide the base for an Australian nuclear fuel industry to meet domestic requirements and for export. It also raises for study, the interesting possibility that Australia might, probably in association with other countries, enter the uranium enrichment field. The Commission has been studying aspects of such developments.

Exploration for uranium continued throughout the world and increased reserves have been reported. Nevertheless, there is likely to be a shortfall in supply during the 1980s unless further significant reserves are established in the next few years.

## RESEARCH

In the field of nuclear power, specialist staff at the Research Establishment devoted substantial effort to supporting the technical assessment of the tenders for the Jervis Bay nuclear power station and to carrying out environmental studies, as described above. A considerable amount of work was done on the broader aspects of nuclear power, such as development of reactor materials and fuel.

Reactor core designs offered by tenderers were in general developed from earlier nuclear stations. The designers' claims for improved performance were examined critically, and an independent evaluation was made of the operating margins in the various ratings and stability factors. Commission staff established methods of calculation which were used to good effect in analysing performance claims and in assessing the potential of each system for improvements in efficiency.

In the economical operation of a power reactor, it is important to guard from the outset against deterioration and failure of internal components. Some of these are under continuing high pressure and neutron irradiation, and are exposed to heat and temperature fluctuations. An important part of the Commission's research is devoted to study of the effects of these conditions on materials such as zirconium, aluminium and Australian steels, and to problems of corrosion.

Methods of fabricating reactor fuel elements were further studied at all stages from uranium ore concentrates to the finished fuel pin. Pilot-scale equipment has been established which could provide the information needed for the design of an industrial fuel fabrication plant. A program has been established for in-reactor testing of fuel pins. Uranium ores and zircon sands being plentiful in Australia, methods of extracting these materials and refining them to high standards of purity are being investigated.

In addition to the research related to nuclear power, many other subjects were studied. These included development of new radioisotope products, effects of radiation on living tissue, establishment of national radiation standards, improvement of radiation detectors, computer research, new methods of fabricating ceramic nuclear materials, and various physics studies.

The radioisotope X-ray analytical techniques developed by the Commission have become important in mineral processing. It is in routine use by several leading mining companies, and an agreement for the commercial exploitation of the techniques was concluded between the Commission, the Australian Mineral Industries Research Association Ltd., Philips Industries Ltd., and the Australian Mineral Development Laboratories. Philips will market the equipment world-wide.

Other research projects which have met with success or are well advanced, include a method of borehole logging for mineral content by means of an improved form of probe, and a method of intensifying under-exposed or faded photographs by making the silver grains of the image radioactive.

## RADIOISOTOPE PRODUCTION

An extension is being built to the radiochemical processing laboratories to help meet increasing demand. Radiopharmaceutical products in particular have shown an even steeper rise in demand than in previous years.

Total Commission production of all radioisotopes amounted to 10,491 shipments in the year ended 31 March — more than twice as many as in 1968-69. The great bulk continued to be for medical use. Short-lived radiopharmaceutical products account for about 85 percent of total shipments. Three cobalt teletherapy sources were despatched to hospitals in Australia and New Guinea.

Products based on technetium 99m have been in particular request for diagnosis. Improved methods of supplying technetium have been designed, including a new generator. Four new radiopharmaceutical preparations which have been developed or are in an advanced stage of development, are a tracer for flow studies of cerebrospinal fluid, and others for brain scanning, kidney diagnosis, and for locating malignant melanoma.

## INTERNATIONAL

Preparations were made for Australian participation in the Fourth Geneva Conference on the Peaceful Uses of Atomic Energy, September 1971. Five papers from authors in Australia were accepted by the Conference organisers. In addition, a senior Commission staff member is presenting on behalf of the International Atomic Energy Agency, a review of the application of nuclear explosions in civil engineering and mining.

The Commission Chairman or the Executive Commissioner represented Australia at the Annual General Conference of the International Atomic Energy Agency and at meetings of the Board of Governors of the Agency. Other Commission officers participated in committees and symposia. In March, an IAEA symposium was held at Lucas Heights.

Commissioners and Commission staff members visited other countries to exchange views and to keep in touch with latest developments. A number of distinguished visitors were also received by the Commission.

## GENERAL

The Commission awarded seven new research contracts to universities, and provided further support for five contracts previously awarded. The total sum granted was $102,611. The Commission also supported a wide range of university projects by contributions to the Australian Institute of Nuclear Science and Engineering for research and training.

The Australian School of Nuclear Technology held seven courses during the year in radioisotopes and in nuclear technology. There was a total of 93 participants.

# 2

# JERVIS BAY NUCLEAR POWER STATION

Early in 1969, the Commonwealth Government initiated discussions with the State Governments on the introduction of nuclear power into Australia. These were described in the Commission's 17th Annual Report, 1968-69. Subsequently, New South Wales was invited to collaborate in a study of the feasibility of establishing a Commonwealth owned, 500 megawatt electrical (MW) nuclear power station. The study was carried out by the Australian Atomic Energy Commission in collaboration with the Electricity Commission of New South Wales. Commonwealth and State Departments were consulted as necessary.

The Commission's 18th Annual Report, 1969-70, described the selection of the power station site at Jervis Bay and the announcement by the then Prime Minister in October, 1969, that the Commonwealth Government would "take Australia into the atomic age by beginning the construction of an atomic plant at Jervis Bay".

Replies to preliminary enquiries by letter to 14 leading nuclear engineering supply organisations in December, 1969, disclosed that an Australian invitation to bid would result in the following types of nuclear plant being offered by various vendors:

Pressurised Water Reactor (PWR).

Boiling Water Reactor (BWR).

Steam Generating Heavy Water Reactor (SGHWR).

Pressurised Heavy Water Reactor (PHWR).

The latter type included both pressure tube and pressure vessel reactors.

Following discussions with the Electricity Commission of New South Wales, it was decided to call bids in the first instance for the Nuclear Steam Supply System (NSSS) and for engineering services only (design, tendering and construction supervision) for the Residual of the Nuclear Island (RNI).* In this way the contractor would be responsible for the whole of the Nuclear Island, but tenderers were not required to bid firm prices for any plant and equipment other than the NSSS. However, tenderers were informed that the above extent of supply was a minimum requirement and that consideration would be given to bids covering an increased scope up to and including a complete station.

### Tenders

Detailed tender documents covering the above types of NSSS were prepared by the Commission aided by the Electricity Commission of New South Wales, and

* The NSSS consists of the reactor, steam raising plant and associated systems. The RNI consists of the reactor building and all other civil works, plant and equipment necessary for the safe and continuous operation of the NSSS. The complete Nuclear Island, which includes the NSSS, is equivalent to the boiler, coal and ash handling plant of a coal-fired station.

Commonwealth Departments and consultants (Bechtel Pacific Corporation Ltd.). These were issued on 28 February 1970 to those vendors who had stated their intention to bid.

Tenders closed on 15 June 1970. Fourteen tenders and one later "turnkey" offer were received from seven organisations in four countries, as follows:

**Canada.** Atomic Energy of Canada Ltd. offered a pressure-tube version of the pressurised heavy water reactor (PHWR). This system uses heavy water as the moderator and coolant, and natural uranium fuel. Two bids were submitted for essentially the one kind of station, but with different power outputs.

**West Germany.** Kraftwerk Union A.G. tendered for three systems — a boiling water reactor (BWR) and a pressurised water reactor (PWR), both of which employ ordinary water as moderator and enriched uranium fuel, and also a pressure vessel type of pressurised heavy water reactor (PHWR). Two bids for different size plants were submitted for the latter.

Kraftwerk Union also submitted subsequently a "turnkey" offer for a complete nuclear power station based on their tender for the PWR system.

**United Kingdom.** British Nuclear Design and Construction Ltd. and The Nuclear Power Group Ltd. each tendered for a steam generating heavy water reactor (SGHWR). The latter submitted four tenders — for two different sizes, and under two kinds of contracts. It offered a nuclear steam supply system in each size, and also offered "turnkey" proposals for the complete power station.

**U.S.A.** Combustion Engineering Inc. offered a PWR, General Electric Company a BWR, and Westinghouse Electric International a PWR.

## TENDER ASSESSMENT

Assessment of tenders received for the Nuclear Steam Supply System (NSSS) for the Jervis Bay Nuclear Power Station Project began immediately after tenders closed on 15 June 1970.

Preliminary economic evaluation leading to comparison of the projected total costs of nuclear power stations developed from the NSSS tenders, was undertaken by the consultants, Bechtel Corporation, in San Francisco. Bechtel was assisted in San Francisco by officers from the Commission and from the Electricity Commission of New South Wales. The Commission and the ECNSW also forwarded comments and information from Sydney.

In parallel with these studies, other officers of the Commission and the ECNSW made a technical evaluation of the tenders in Sydney. On the basis of the two sets of studies, the Commission recommended to the Commonwealth Government that further detailed assessment should proceed on a short list of four systems. These were:

Natural Uranium Pressurised Heavy Water Moderated and Cooled Reactor, pressure tube type (PHWR-CANDU) — Atomic Energy of Canada Ltd.

Steam Generating Heavy Water Reactor (SGHWR) — The Nuclear Power Group, U.K.

Pressurised Water Reactor (PWR) — Kraftwerk Union A.G., West Germany.

Pressurised Water Reactor (PWR) — Westinghouse, U.S.A.

This recommendation was accepted by the Government on 18 August 1970.

Detailed questions seeking clarification and further information from these four organisations on their NSSS tenders were prepared by the Commission and Bechtel and issued to the tenderers.

Representatives of each of the four tendering organisations successively attended discussions at the Head Office of Bechtel Corporation in San Francisco, and then proceeded to Sydney for discussions with officers of the Commission and the ECNSW. Officers of the Commission, the ECNSW and the Attorney-General's Department attended the discussions in San Francisco, and a representative of Bechtel assisted in the Sydney discussions and maintained liaison with Bechtel in San Francisco.

These discussions were held on the following dates:

At offices of Bechtel, San Francisco —

| | |
|---|---|
| AECL | 14-18 August 1970 |
| TNPG | 21-25 August 1970 |
| KWU | 28 August-1 September 1970 |
| Westinghouse | 8-10 September 1970 |

At offices of Commission, Sydney —

| | |
|---|---|
| AECL | 21-27 August 1970 |
| TNPG | 28 August-3 September 1970 |
| KWU | 4-10 September 1970 |
| Westinghouse | 14-18 September 1970 |

Three tenderers, TNPG, KWU and Westinghouse, sent additional specialists for later discussions on matters on which the initial delegations had been unable to provide adequate answers. Two Commission representatives visited Canada for further discussion.

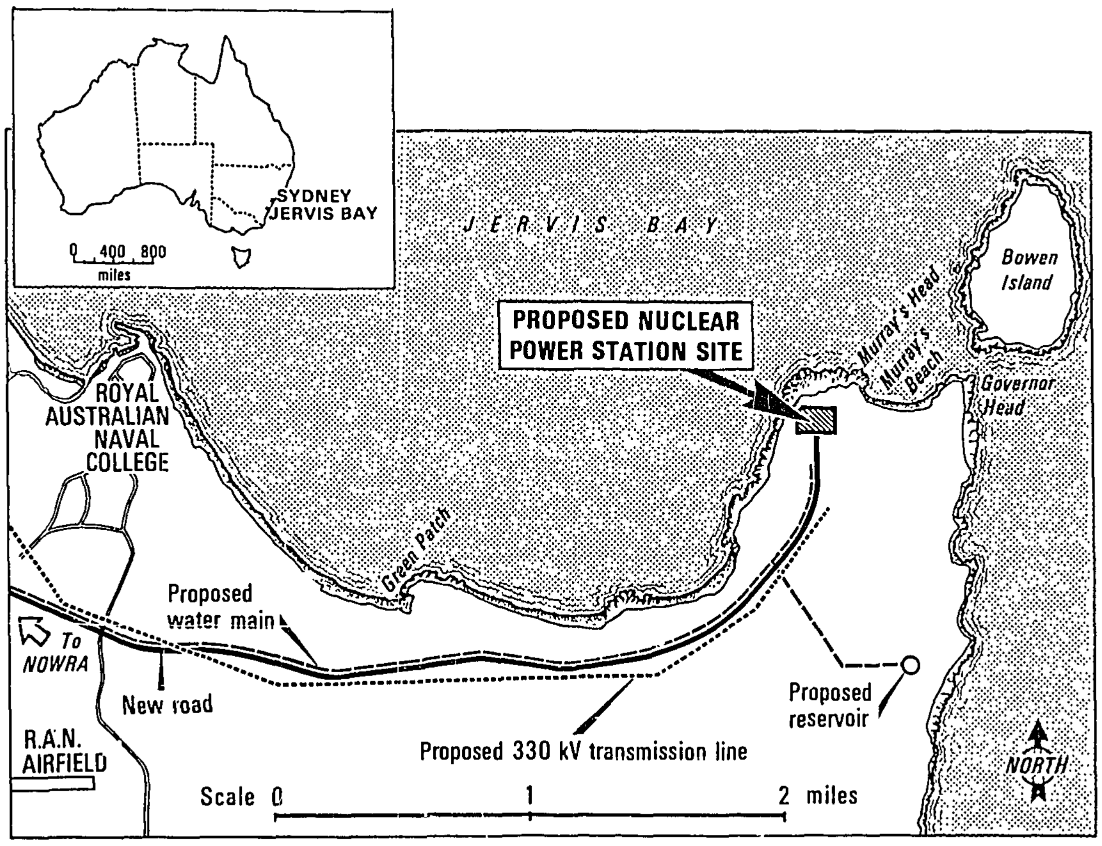
All tenderers were given the opportunity to forward additional written answers and information within a prescribed period after the close of the Sydney discussions. Most of the information sought was received by 30 September 1970.

The study of tenders, preparation of questionnaires, discussions with tenderers, and subsequent analysis and evaluation of the large amount of information collected involved the full-time effort of approximately 70 professional officers of the Commission and ECNSW for about four months.

These officers were organised into ten specialist sub-committees responsible for the topics listed in the questionnaires. Sub-committee chairmen reported to a Technical Assessment Committee which co-ordinated their activities and their final reports. The specialist sub-committees were supported by appropriate detailed studies carried out within the Research Establishment and by engineering staff within the ECNSW.

### Economic Assessment

The economic assessment was carried out by Bechtel on a "levellised" basis, by developing and costing a balance of plant to apply to each nuclear steam supply system, and adjusting the scope of supply, technical features and commercial aspects to produce overall station costs. Special efforts were made to place all four tenders on an equitable comparative basis.




*Map showing the proposed nuclear power station site at Jervis Bay.*

The Commission then considered all economic and technical aspects of the systems, together with their long-term prospects. In considering the future of the Jervis Bay station, considerable attention was paid to the fact that the objectives of the project included demonstration of the safety and reliability of nuclear power in Australia, and the provision of training and experience to staff of the electricity generating organisations of the States.

Other important aspects considered by the Commission were the current status and the future potential of the systems. On one hand, the system chosen must be adequately developed and proven, so that a trouble-free design, construction and commissioning program, and reliable operation from the outset, were reasonably assured. On the other hand, it was borne in mind that this first station in Australia should provide experience relevant to future nuclear power stations constructed and operated by the States.

## Fuel Supplies

The Commission included the following provision in its Invitation to Tender.

"1.6 Indigenous Fuel Requirement

It is the intention that the Jervis Bay Nuclear Power Station shall become fully independent of overseas fuel supplies and services. The Commission may, at its discretion, authorise the purchase of overseas fuel supplies including fabrication for the first charge and replacement fuel for a period not exceeding five years after start-up.

The acceptability of any Tender will depend on satisfactory arrangements being made between the Tenderer and the Commission for those operations required for local fuel preparation, including conversion and enrichment, if applicable, and fuel element manufacture.

The Tenderer shall provide, as a part of his Tender, a comprehensive description of the plan and assurances by which he will meet the requirements of an indigenous fuel supply, including evidence of the agreement of the necessary government authorities."

The four short-listed tenderers, in concert with their Governments, fulfilled the conditions in various ways according to the type of fuel involved and the nature of the technologies involved. The offer from AECL did not involve enrichment technology since the fuel for CANDU reactors is composed of natural uranium. The British and West German submissions were accompanied by offers of enrichment technology, irrespective of the country which would be awarded the contract for the reactor. The United States offered enrichment services again irrespective of the origin of the power reactor.

Attention was given also to the fuel supply for the proposed station, and to the prospects for establishing a nuclear fuel industry in Australia.

### Reactor Safety

Particular attention was paid to reactor safety. Very stringent requirements were set for low radioactive releases, for engineered safeguards against accidents, and for containment of the products of any accidental failure of plant components. Two important topics which were subject to extremely close study and discussion were: (a) the integrity of the reactor primary coolant circuit and the in-service inspection required to ensure its continuing safety over the full lifetime of the station, and (b) the provision of adequate emergency core cooling systems, to prevent fuel over-heating and the release of radioactive fission products in the event of failure of a plant item causing loss of the main coolant.

## SAFEGUARDS

The Governments of all four countries of the short-listed tenderers made it a requirement of supply that the reactor and its fuel should be subject to Safeguards administered by the International Atomic Energy Agency. These safeguards would be to ensure that the nuclear material would not be diverted from peaceful uses to further a military purpose.

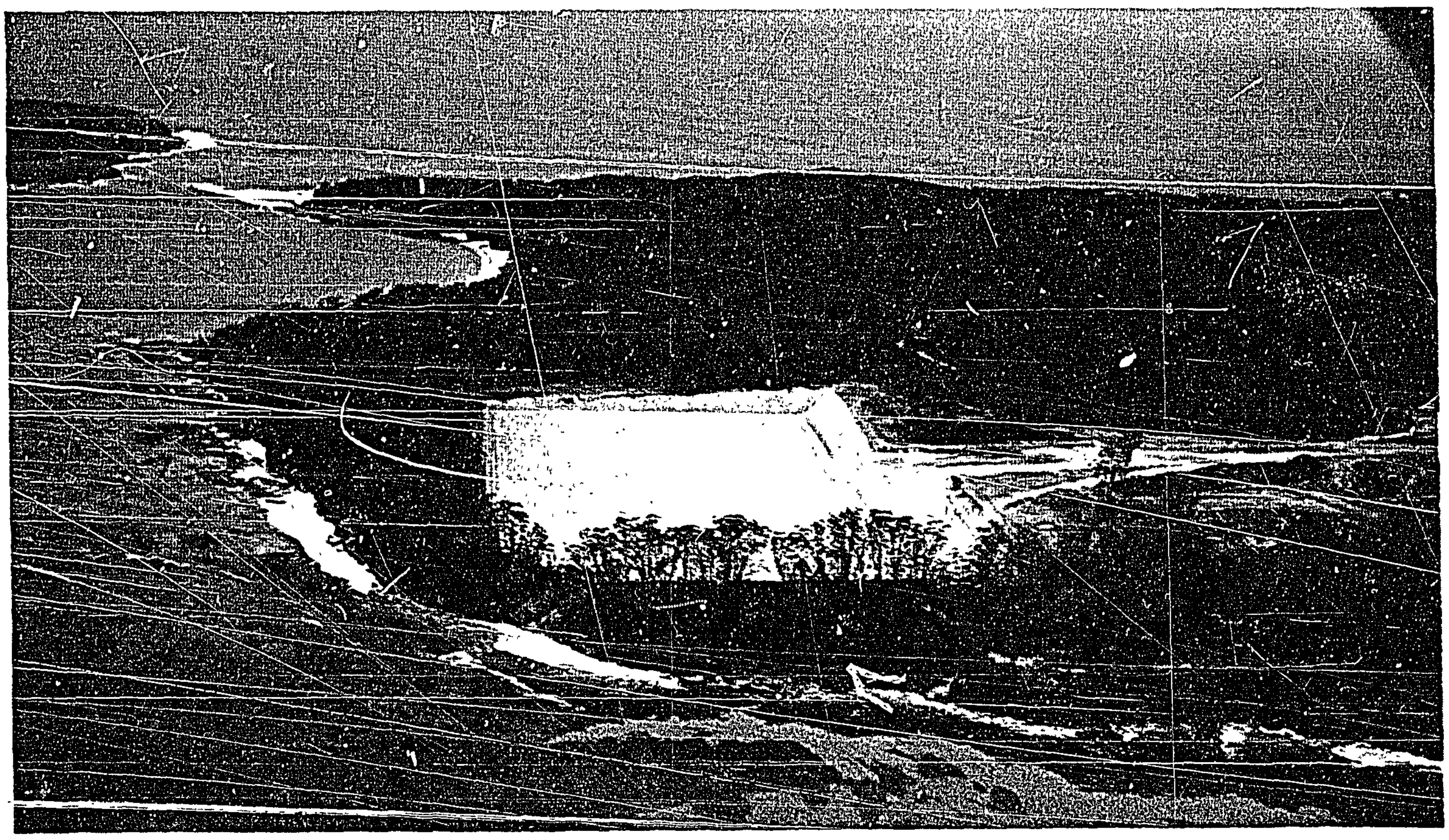
## ARRANGEMENTS WITH ELECTRICITY COMMISSION OF NEW SOUTH WALES

The Commission's 18th Annual Report, 1969-70, described the proposed arrangements for station management, as set out in the basis of agreement reached between the Commonwealth and New South Wales during 1969-70.

The Interdepartmental Committee, appointed by the Government to examine arrangements which should be made between the Commission and the Electricity Commission of New South Wales, held a number of meetings and completed its examination of the detailed financial and related arrangements. The Committee included members from the Department of the Prime Minister and Cabinet, Treasury, the Australian Atomic Energy Commission, and the Department of National Development. The Committee worked in close co-operation with officers of the Electricity Commission of New South Wales, and received valuable assistance from the Commonwealth Attorney-General's Department.

The Committee and the Electricity Commission finally agreed on a draft of detailed arrangements.

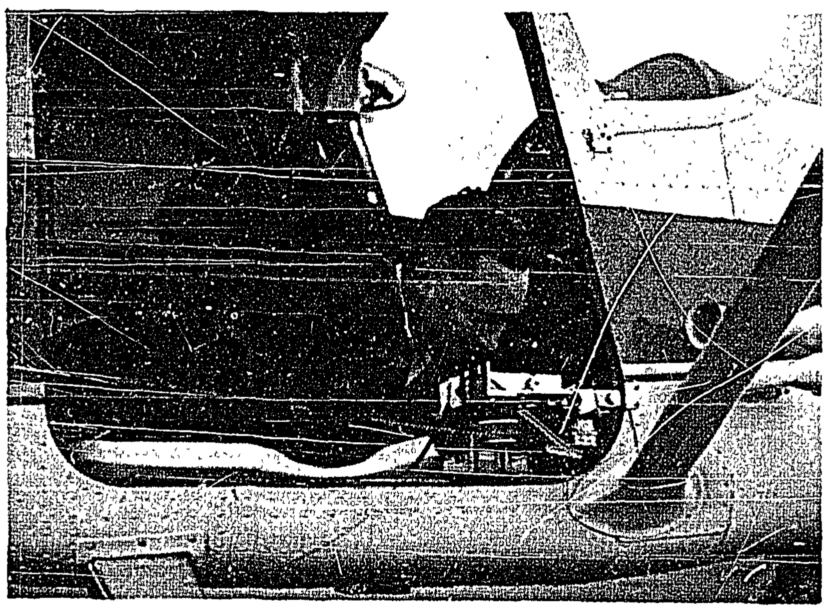
# ENVIRONMENTAL STUDIES AND SITE PREPARATION AT JERVIS BAY



*Aerial view of the nuclear power station site on the south-eastern tip of Jervis Bay. Murray's Beach and Governor Head (the Bay's southern headland), can be seen directly beyond the excavated area, with part of Bowen Island, top left.*

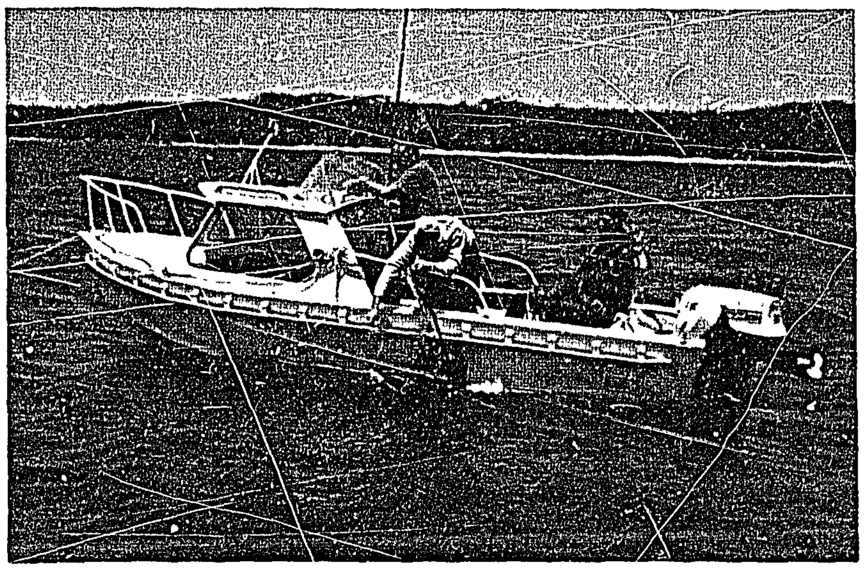
*Initial excavation of the 850 ft x 550 ft site of the 500 MW nuclear power station. The area has been excavated to a working level of 14.5 ft above mean sea level. Top soil has been stockpiled for future landscaping on completion of the station. Excavation of the rock provided foundation material for the four-mile-long access road.*

*Above: A harmless red dye was used in studies to determine efficient dispersion of warm water discharged from the steam condensers of the proposed power station. The studies were conducted in the bay and ocean to determine the best cooling water inlet and outlet locations. Dye dispersion was recorded by aerial photography.*

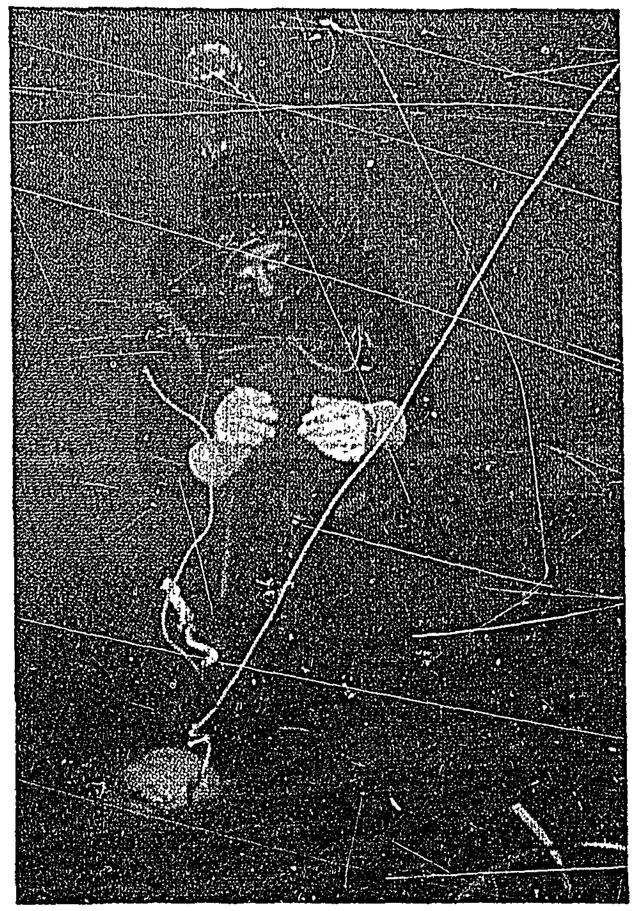


*Left: A 35 mm camera mounted in a high-wing monoplane is used for aerial photography of dye plume formation and dispersion. The camera also records displacement and direction of tethered drogues in and near the dye plumes. These show current direction and strength.*

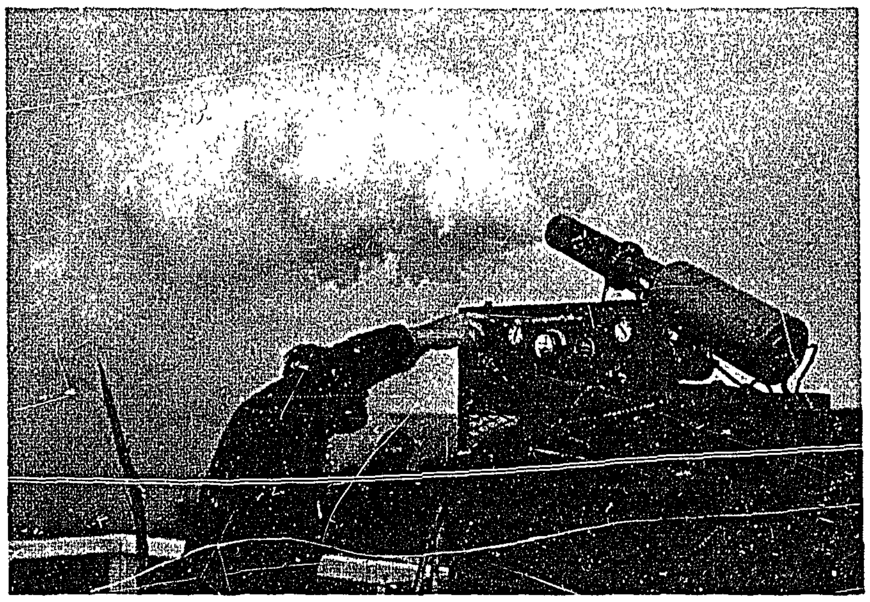
*Below: Aircraft carrying out a photographic run over the Gap — the narrow entrance between Governor Head and Bowen Island, Jervis Bay. A dye release can be seen almost directly below the aircraft.*



*Above: The Australian Atomic Energy Commission diving team undertakes a continuing detailed survey of the local marine environment as part of the Commission's ecological study of the Murray's Beach area at Jervis Bay.*

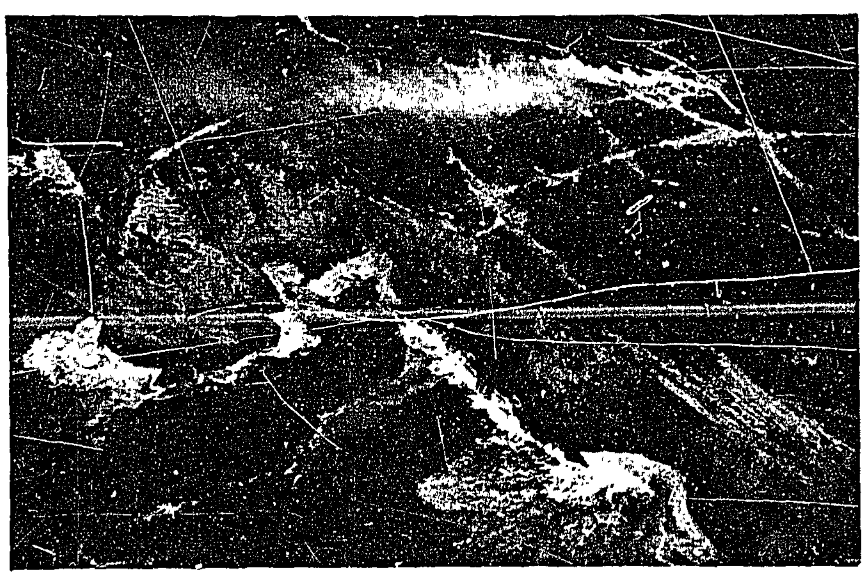


*Above: A diver records weed bed species and patterns in the Murray's Beach area. Other studies gather data on the migratory habits, life cycles and relationship to environment of a range of marine organisms, such as oysters and fish.*

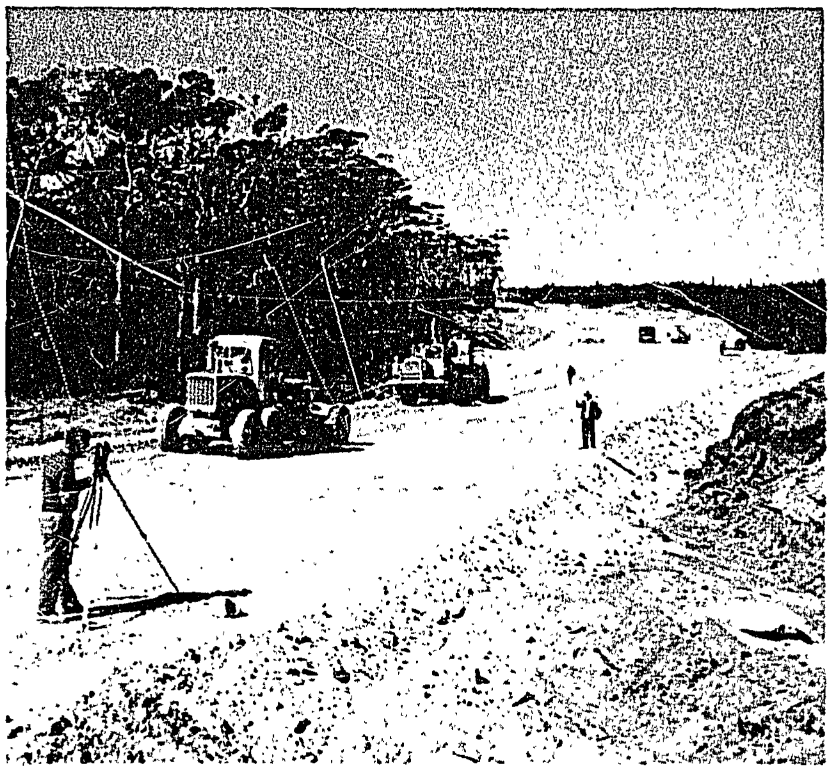


*Above: Wind direction and velocity affect wave and current patterns. Smoke plumes are generated for short periods to give additional data during dye releases.*

*Below: Aerial view of a proposed cooling water outfall location. Dye has been released from the base of the cliff to determine water currents in the area. The shore-based smoke generator is being used to show prevailing winds.*

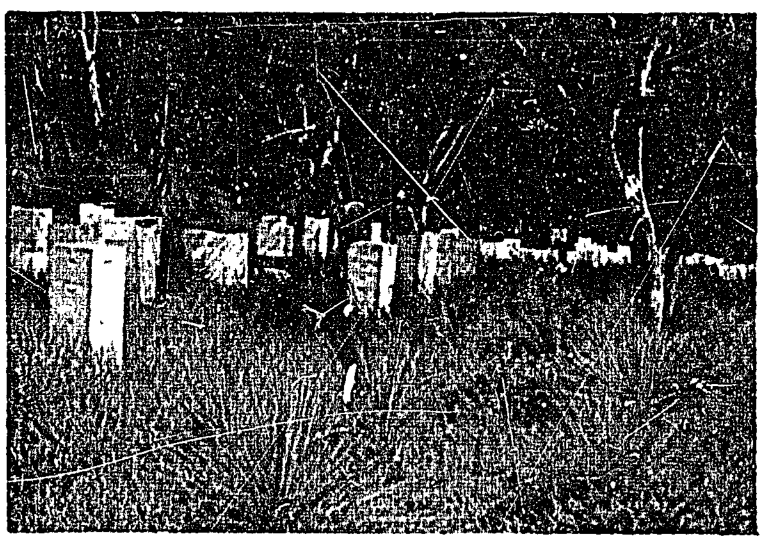


*Below: In addition to a semi-automatic recording meteorological station on high ground behind Murray's Beach, a smaller station has been set up near sea level on Bowen Island. The island's caretaker, Mr. J. Carrington, registers daily weather conditions.*

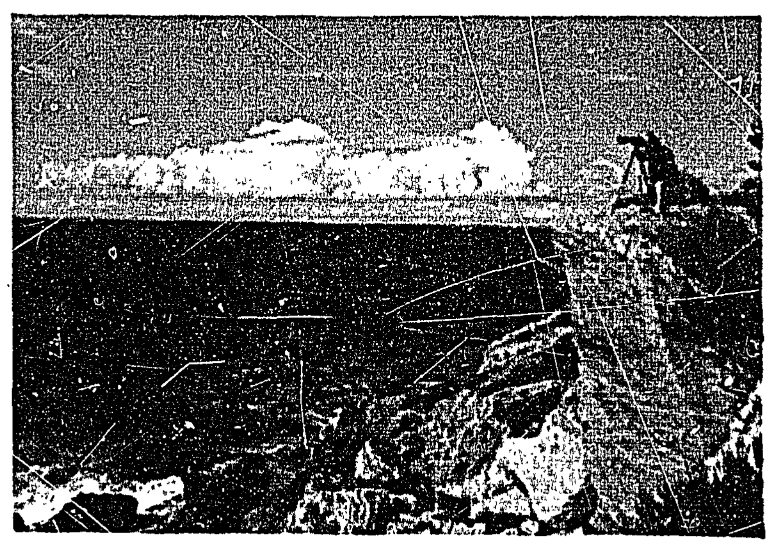


*Left: Building a four-mile-long, two-lane highway from the nearest main road to give access to the station site. Excavation of the site and road construction were complementary, the excavated material being used for the road foundations. This eliminated any need for soil disposal and kept overall disturbance of the area to a minimum.*

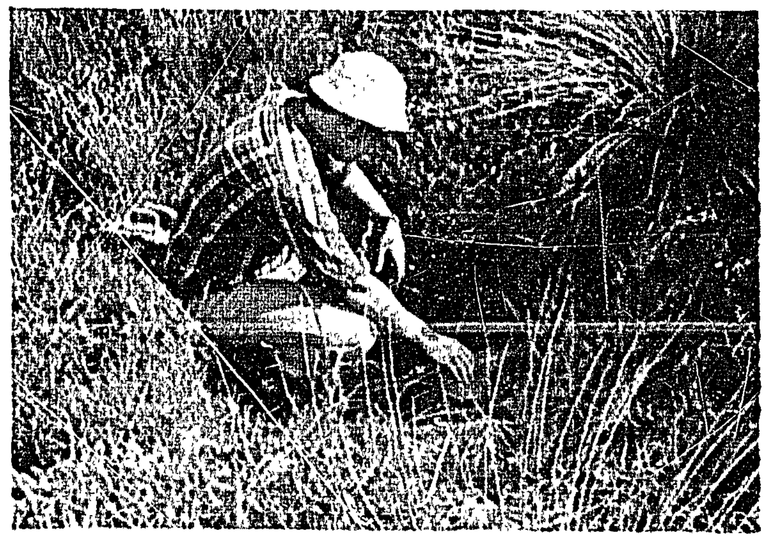
*Above: Department of Interior botanists collect soil samples for field examination and testing. Records are taken of type, depth, texture, moisture content and acidity.*



*Above: Environmental studies include data on food derived from the area. Near Murray's Beach, local heath and woodlands support commercial honey production in winter.*



*Above: Film crew member photographs scenes of current-flow studies at Jervis Bay for an AAEC non-technical colour film covering the project's ecological and environmental studies. This comprehensive 16 mm film is available for loan from the Commission's Head Office Film Library.*



*Left: To estimate the population of small nocturnal mammals in the area, officers of the Department of Interior lay traps overnight. Next morning, trapped animals are identified, recorded, and then released.*

During the whole of 1970-71, officers of the ECNSW collaborated with the Commission in tender assessment and, subsequently, in further analysis and evaluation of the information obtained as a result of tendering. This was in anticipation of the preparation of the final specifications and contractual documents.

Tentative arrangements were agreed also for the secondment of staff and for specialist services from the ECNSW in the final contract negotiation period.

## PROJECT SUPERVISION

The Commission took preliminary steps towards setting up a project team to supervise the Jervis Bay Nuclear Power Station project, in a surveillance role, through all stages of design, construction and commissioning. Final staffing and organisational arrangements were not completed, but the ECNSW and other State generating authorities had agreed in principle to attach appropriate staff to this team.

The principal functions of the proposed surveillance organisation would be to ensure that appropriate quality assurance was exercised, to monitor progress and financial aspects, and generally to assure the Commission that the specifications and contractual conditions would be fully satisfied.

Particular attention would be paid to safety matters, and to ensuring that all manuals and instructions relating to operation, maintenance, and safety were prepared at the appropriate time.

## COLLABORATION WITH OTHER DEPARTMENTS AND INSTRUMENTALITIES

During the site selection, tendering, tender assessment, and environmental surveys carried out as part of the Jervis Bay project, the Commission was assisted by officers of a number of Commonwealth and State Departments and instrumentalities. In addition to those already mentioned, these include assistance as follows:

| | |
|---|---|
| State Electricity Commission of Victoria. | Officers seconded for tender assessment. |
| Electricity Trust of South Australia. | Officers seconded for tender assessment and contract management. |
| Crown Solicitor's Office, Commonwealth Attorney-General's Department. | Officers seconded for tender assessment. |
| Commonwealth Treasury. | Economic aspects of tenders. |
| Commonwealth Department of the Interior. | Site planning and development, and housing. |
| Commonwealth Department of the Navy, and Commonwealth Department of Works. | Site development. |

| | |
|---|---|
| Bureau of Mineral Resources, Commonwealth Department of National Development. | Seismic studies. |
| Commonwealth X-ray and Radium Laboratory, Department of Health. | Environmental studies. |
| Commonwealth Department of Customs and Excise. | Customs matters. |
| Postmaster-General's Department. | Communications. |
| Commonwealth Bureau of Meteorology, Department of the Interior. | Environmental studies. |
| N.S.W. Department of Occupational Health. | Environmental studies. |
| N.S.W. Chief Secretary's Department, Fisheries Branch. | Environmental studies. |
| N.S.W. State Planning Authority. | Area development advice. |
| N.S.W. Department of Main Roads. | Road development. |
| Shoalhaven Shire Council. | Road, water, power services. |
| Australian National University. | Seismic studies. |

## WORKS AND SERVICES AT THE JERVIS BAY SITE

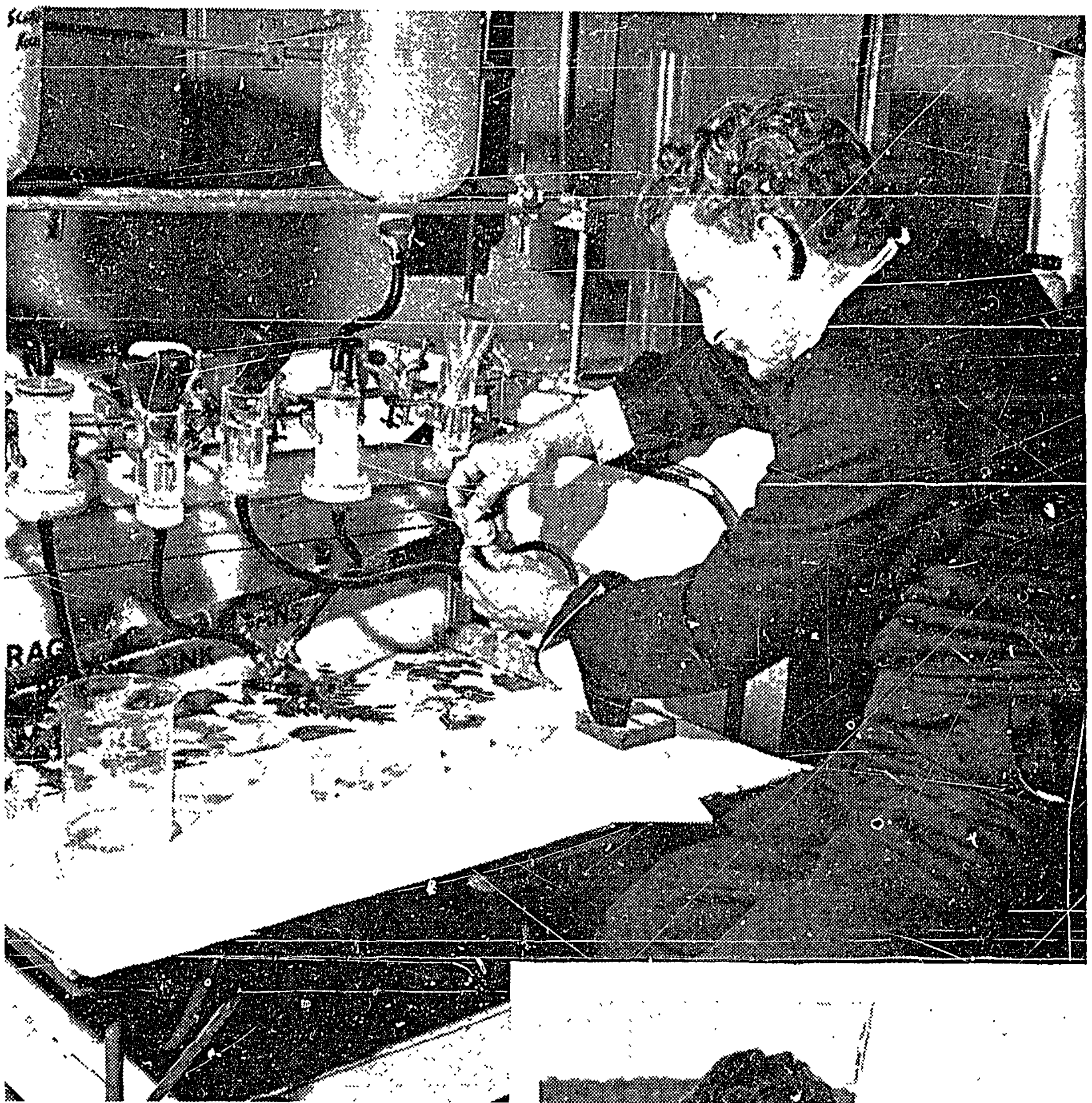
While the tenders were being evaluated, the way was being prepared to enable the successful tenderer to begin construction with the least delay. The Commission was responsible for all investigations at the site and for its preparation, including the provision of necessary services.

The site was excavated to a reference level, the material removed being used to build a four-mile-long, two-lane highway to N.S.W. Department of Main Roads standards, from the nearest main road (near the R.A.N. Naval College) to the station site. Top-soil was stockpiled to enable restoration and landscaping of the area with native plants on completion of the station.

Location of the access road was decided after full consideration of technical, environmental and conservation aspects. The study was made in association with the Department of the Interior. Excavation of the site in conjunction with construction of the road kept overall disturbance of the area to a minimum.

Services such as water, electricity, telephone and sewerage were provided or preparations made to provide them.

To accommodate project staff at Jervis Bay, the Department of the Interior planned to provide housing, a motel and shops adjacent to the existing village. Twelve houses were completed at the beginning of 1971. Houses in excess of present site maintenance requirements will be let temporarily to personnel of other Commonwealth Departments stationed in the area.



*Above: In a mobile laboratory at Murray's Beach, suction flasks are prepared for use in the measurement of plankton productivity and chlorophyll content of sea-water.*

*Right: Before sealing the four-mile-long site access road with asphaltic concrete, many samples were taken for compacted dry density tests of the road pavement.*

The Shoalhaven Shire Council, on behalf of the Commission, completed a feasibility study on future provision of water from the Nowra system for the power station. Financed by the Commission, the Council built a 33 kV power line to the Commonwealth Territory border. The line is energised to 11 kV. The Council also investigated the upgrading of the road within the Shoalhaven Shire to the Commonwealth Territory and surveyed the proposed route.

## ENVIRONMENTAL STUDIES

Detailed studies of the hydrography, meteorology and ecology of the Jervis Bay site, which began in January, 1970, continued throughout the year. The program was carried out under the review of a Working Party with representatives from the Australian Atomic Energy Commission, Commonwealth Department of Health, N.S.W. Department of Public Health, the Fisheries Branch of the N.S.W. Chief Secretary's Department, and the Electricity Commission of N.S.W. These environmental studies were carried out mainly by Commission staff, although the ECNSW undertook certain hydrographic studies.

The Commission also completed an agreement with the N.S.W. Chief Secretary's Department for the participation of their Fisheries Branch in the environmental studies program.

Considerable information was obtained on sea water current patterns in the vicinity of the Jervis Bay site. Measuring techniques used included tethered drogues and aerial photographs of dye release plumes. Continuous meteorological data is being collected from a small meteorological station erected on site. These data were supplemented by techniques using a small smoke generator and time-lapse photography.

The biological studies were concentrated on biological mapping, definition of key food resources and the investigation of related biology and concentration factors. In addition, eating and marketing practices relating to foodstuff derived from the district were investigated. The overall purpose of these intense studies is to ensure that no harmful contamination of foodstuff could occur from the operation of a nuclear power plant in this area, and that no harmful changes could occur in the ecosystem, especially from thermal discharges.

## GOVERNMENT DECISION

On 9 June 1971, the Minister for National Development, Mr. R. W. Swartz, announced that the Government had decided to defer a decision on the Jervis Bay Nuclear Power Station for 12 months and said the Government would re-examine the matter in the light of the circumstances then existing.

He said the final figure was higher than that expected in 1969. This result, viewed in the light of the current financial circumstances of Australia, made the Government feel it should not proceed with the project immediately. The deferment of action would also enable the Commission to study the matter further and to take account of continuing advances in nuclear technology, which could have a bearing on the Australian project.

Mr. Swartz said he understood that current planning of the Electricity Commission of New South Wales could accommodate the deferment now decided by the Government.

As a result of the Government's deferral, the Commission suspended all on-site work at Jervis Bay other than some environmental and ecological surveys and routine maintenance.

# 3

# NUCLEAR POWER—MANAGEMENT AND REGULATION

In earlier Annual Reports, the Commission has provided information and comment upon a number of matters related to the regulation and management of nuclear energy. These include safeguards against diversion of fissile or fertile materials to military uses[1], the Nuclear Non-Proliferation Treaty[2], Civil Liability for Nuclear Damage[3], Regulatory Control of Atomic Energy[4], Management and Control of the proposed Jervis Bay Nuclear Power Station[5].

## Regulatory Practices

It is essential that common regulatory practices and procedures be established in all States which introduce nuclear power in Australia. These procedures are necessary:

(a) To protect the health and safety of all members of the community;

(b) to protect property and resources from damage (including contamination by radioactive materials);

(c) to ensure reasonable arrangements for compensation in the event of injury or loss arising from nuclear accidents; and

(d) to prevent the loss or diversion of nuclear materials from peaceful uses to military purposes.

Regulatory procedures would cover the engineering design and construction of the plant, the adequacy of the protection system, including the containment and other engineered safety features, the selection of sites, environmental aspects and their effects on design and operating criteria, standards for safe routine operation and the training and licensing of operating staff.

Apart from the introduction of nuclear power stations, other fields requiring regulatory action are the handling, storage and transport of radioactive materials, and the disposal of radioactive wastes. Similar problems will arise when plants are built for the enrichment of uranium, the production of nuclear fuel, the chemical processing of irradiated nuclear fuel elements, and the treatment and storage of radioactive wastes.

The impact of the regulatory framework will vary according to the nature of the nuclear materials being handled, and to other circumstances at the time. For instance, there are only minor health hazards associated with the fabrication of nuclear fuel elements, since the uranium used is only very slightly radioactive, whereas the chemical processing of irradiated fuel elements involves the production,

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1. *Fifteenth Annual Report, 1966-67.*
2. *Sixteenth Annual Report, 1967-68.*
3. *Sixteenth Annual Report, 1967-68.*
4. *Seventeenth Annual Report, 1968-69.*
5. *Eighteenth Annual Report, 1969-70.*

as a by-product, of large quantities of highly radioactive fission products. Hence the controls required for operation of a fuel fabrication plant are relatively simple, and such a plant can be safely located in existing industrial areas. A chemical processing plant, however, must be located away from zones of dense population and the design and operation of such a plant must be subject to close control and supervision.

Regulations and procedures must also provide for accounting and inspection by international inspectors, of activities which are subject to international safeguards. At present not all activities are subject to international safeguards. For example, safeguards are not applied to the production of uranium concentrate ("yellowcake"). On the other hand, the processing or use of enriched uranium purchased in any form from the U.S.A. does attract international safeguards.

## Commonwealth-States Consultative Committee on Nuclear Energy

During the year, the Commonwealth-States Consultative Committee on Nuclear Energy established a Sub-Committee on Technical Aspects of Licensing and Regulation, to consider and report on the technical nature of the licensing problems, organisation and procedures required for the licensing of nuclear installations. The Sub-Committee comprised representatives of the Commonwealth and the States under a Chairman provided by the Australian Atomic Energy Commission. The Sub-Committee's findings have been presented to the main Consultative Committee.

Parallel with the work of the Commonwealth-States Consultative Committee, the AAEC in association with other departments intensified the study of questions relating to civil liability for nuclear damage.

In the case of conventional power stations where the question of civil liability arises, it would be open to an injured party under common law to sue for damages against a number of persons and authorities — for example, the owner of a truck, a railway authority, airline or shipping company, the designer or manufacturer of equipment, the operator, and so on. In the case of a nuclear power station, these legal variations would impose an unreasonable burden on plaintiffs, because of the difficulty of proving liability and the enormous sums which could be involved.

In other countries, these legal difficulties and the burden which they impose on plaintiffs have been eliminated by legislation. The operator of a nuclear power station or other nuclear installation has been made absolutely and solely liable for nuclear damage, i.e., all liability is channelled to the operator. Moreover, in other Western countries, experience has shown that even the pooled capacity of underwriters is insufficient to meet what is considered to be an adequate level of compensation, and some portion of the compensation has been made up by indemnities underwritten by governments.

Before finality is reached in Australia, it will be necessary to consider the extent to which the insurance market will be able to write policies covering nuclear risks. In addition, consideration will need to be given to the extent to which the State generating authorities and the State Governments can carry additional risks, and what residual liability, if any, should be accepted by the Commonwealth.

There are, in addition, international aspects to these issues arising out of import and export of fuel components and so on. Solutions to some of the questions involved have been codified in international conventions on civil liabilities for nuclear damage.

The Paris Convention is the earliest of these, and is now in force in most of the countries which are members of the Organisation for Economic Co-operation and Development (OECD). The Paris Convention, with the supplementary Brussels Convention, provides for cover of up to US$120 million (expressed actually as

120 million European Monetary Units. The Conventions provide that liability is channelled absolutely and solely to the operator of the nuclear installation. The financial guarantees and indemnities are defined, as also are the conditions and circumstances under which compensation would be paid, and the legal jurisdiction applicable in each case. For example, provision is made to cover liabilities and questions of jurisdiction when nuclear fuel is in transit between countries.

### The Vienna Convention

The Vienna Convention on Civil Liability for Nuclear Damage was prepared under the auspices of the International Atomic Energy Agency (IAEA). This Convention is almost identical with the Paris-Brussels Conventions, the main difference being the requirement in the Vienna Convention for a *minimum* cover of US$5 million, as against the Paris-Brussels *maximum* of US$120 million. The Vienna Convention is not in force, although it is open to all IAEA Member States, of which there are now over one hundred.

It is open to Australia to become a party to these conventions. Adherence to the Paris and Brussels Conventions will be facilitated now that Australia has become a member of OECD and its atomic energy organisation, the European Nuclear Energy Agency (ENEA). All countries of Western Europe (including the United Kingdom), the U.S.A., Canada and Japan are members of OECD. The membership of ENEA is the same, except that the three non-European countries are "associate" members.

These matters will come up for consideration by the Commonwealth-States Consultative Committee in due course.

### National Safeguards

The Commission is also developing procedures and organisational plans for the application of safeguards on a national basis. Steps were taken during the year to create a small nucleus within the Commission's Head Office to study what will be required as the nuclear industry develops in Australia, and particularly how best these national needs may be met with the minimum of inconvenience to the full and uninhibited development of nuclear technology and its exploitation in this country.

### Environmental Control

Of particular importance is the growing realisation throughout the world that special steps are necessary to preserve the environment, so that man may not only continue to live in a state of increasing good health and material well-being, but also will achieve the personal satisfactions and way of life which modern technology and discoveries make possible. The nuclear industry is fortunate in that it has been possible to plan for the protection of the environment, and this has been undertaken from the very beginning of the civil industrial uses of atomic energy.

The Commonwealth Government has set up a Committee to examine the question of environmental control. The Commission is increasing its research into all aspects of control of radiation arising from nuclear installations. These studies are wide ranging, and cover airborne and gaseous wastes as well as liquid and solid radioactive material. They embrace all aspects of the environment, including the marine environment and the protection of fauna and flora. At the appropriate time the Commission will be in a position to afford adequate support to the Committee established by the Commonwealth.

# 4

# NUCLEAR POWER AND THE ENVIRONMENT

The demand for energy in industrial countries is doubling every eight to 14 years. There are two main reasons for this rapid increase:

(i) Population growth, with a world doubling time of about 30 years; and

(ii) the urge to raise living standards, to expand industry and technology and to increase production and consumption.

Extrapolation of the present trend to the end of this century can produce some startling results, such as a possible increase in total world energy demand from about 1,000,000 megawatts (MW) in 1970 to 7,000,000 MW in 2000.

In 1968, the power generating industry in the U.S.A. alone discharged 24.4 million tons of oxides of sulphur, 10 million tons of oxides of nitrogen and 8.9 million tons of particulate matter into the atmosphere, together with many other airborne pollutants. If its future energy needs were to be met entirely by burning coal, the United States would need to mine and transport 10 million tons of coal each day by the year 2000. Emissions of sulphur and nitrogen oxides could rise to 122 million tons and 50 million tons per annum respectively as a consequence. A similar situation is also developing in Australia, although such detailed figures are not available.

Carbon dioxide is not normally considered a pollutant, but nevertheless concern is growing over the continued emission of this gas and its possible effect on the world's climate. Since the beginning of the century, the average concentration of carbon dioxide in the atmosphere has increased by eight percent, and the present rate of addition (6,000 million tons a year) is increasing at approximately the same rate as the demand for energy.

Environmental disturbances caused by pollution are becoming matters of grave public concern, and it is clear that the community is demanding a radical approach to this problem. Reduction of the pollution and environmental hazard caused by the effluents of coal and oil burning is technically possible in many cases (to a limited extent) but involves considerable effort, expense and consumption of still more energy. This is a vicious circle which requires to be broken.

Furthermore, the world's resources of fossil fuels are limited and irreplaceable, and in the near future may be regarded as invaluable chemical raw materials.

Nuclear power offers a solution to many of these problems. It is a clean source of energy which results in no emission of carbon dioxide, sulphur dioxide, oxides of nitrogen, toxic hydrocarbons or fly ash. With proper regulation, nuclear power stations present no hazard to the environment or to human health. They are not expected to displace coal and oil burning stations, but rather to offer a complementary source of energy production. By the end of the century nuclear power may well be supplying half the world's needs, the remainder coming from coal, oil, natural gas and hydropower.

However, nuclear power generation does produce radioactive by-products, mainly in the form of fission products, which must be contained and handled safely. Methods are available for achieving this objective on an industrial scale. These are discussed below.

## Sources and Control of Radioactive Waste from Nuclear Energy

The essential operations in a nuclear power program are:

(a) Mining and treatment of uranium ore.

(b) Uranium enrichment, and fabrication of nuclear fuel.

(c) Production of energy from fission in reactors.

(d) Reprocessing of spent fuel for the recovery of unused fissile material.

Pollution control measures are important during mining operations, particularly in preventing the tailings from contaminating surface waters. This is usually a chemical rather than a radioactive problem, and can be controlled effectively by appropriate mine management. The protection of uranium miners from the effects of radioactive radon gas is also a problem requiring control, but is a strictly local hazard confined to the mine.

Radioactive effluent is not a significant problem at fuel enrichment and fabrication plants and should not give rise to environmental pollution or public health hazards.

The major source of radioactive waste materials arising in the nuclear energy cycle is the fission product inventory. This is generated at the rate of about 1.5 kg per day in a 500 MW reactor. Only a relatively small number of the many fission product nuclides are of serious significance as environmental and public health problems, notably iodine 131 (8.5 days half-life), strontium 90 (28 years half-life), caesium 137 (33 years half-life) and krypton 85 (10.4 years half-life).

Fission products are retained by chemical and physical bonding within the structure of fuel, which in present-day reactors is usually the stable ceramic compound uranium dioxide. A further barrier in the form of a metal cladding is also provided around the fuel pellets. Small quantities of volatile fission products may escape from the fuel into the reactor coolant through imperfections which occasionally arise in the cladding during reactor operation. The coolant also will contain small quantities of other radioactive impurities derived from corrosion products. The coolant is continuously treated to remove these impurities, which are converted into solid wastes for permanent storage. A very small and carefully controlled amount of radioactive material (both airborne and liquid) may be discharged into the environment at levels specified in a discharge authorisation approved by appropriate health and other authorities. Experience has proved that neither stored nor discharged radioactive waste from a nuclear power station presents any threat to public health.

Spent nuclear fuel is removed from a reactor and reprocessed eventually for the recovery of uranium and plutonium. The fission products are removed also from the fuel in this process, and their safe handling and storage are an essential requirement of the industry. It has been normal practice to store these high-level wastes as liquids in holding tanks, placed within secondary catch tanks and monitored continuously to detect possible leaks. About 300 million gallons of high-level waste are currently stored in tanks in the nuclear countries. There have been no harmful releases of this waste.

Nevertheless, as some of the fission products have relatively long half-lives (of the order of 30 years), it is desirable to convert all high-level waste into non-dispersible solid forms suitable for long-term storage. Recent legislation in the

U.S.A. requires that all radioactive waste which cannot be safely discharged must be converted to solid form. Research programs therefore have been in progress for some time aimed at developing such solidification processes. Methods are now available at costs which will not significantly affect the economics of nuclear power.

By the time chemical reprocessing commences in Australia, proven waste solidification processes will be available. Based upon published predictions of the growth of nuclear power in Australia over the remainder of the century, and assuming an enriched fuel cycle, the accumulated volume of solid high-level radioactive waste requiring storage will be about 18,000 cubic feet by the year 2000. The rate of production will then be approaching 3,000 cubic feet per annum.

## Permissible Discharges

Allowable levels of discharge into the environment from nuclear installations are specified by a discharge authorisation approved by the appropriate Government authorities (e.g., Department of Health, pollution control agencies, Department of Agriculture, Fisheries Branch of the Chief Secretary's Department, etc.).

These authorisations are based on the capacity of the environment to accept radioactive discharges without exceeding the safe limits of public exposure established by the competent health authorities. In Australia such limits have been defined by the National Health and Medical Research Council, and conform to recognised international standards.

It is not possible to define a cut-off level below which radiation can be claimed to have absolutely no biological effect, even though no such effects can be observed at low doses. All humanity is continuously subjected to radiation from natural sources, made up of cosmic radiation, naturally-occurring radioactive materials in the earth's crust, and naturally-occurring radioactive elements (e.g., certain isotopes of potassium and rubidium) which are normal constituents of the human body.

Exposure varies considerably from one individual to another. For example, a person who lives near the top of a mountain, travels frequently in aircraft and dwells in a granite house near a radioactive mineral deposit, will receive more radiation than the person who dwells at sea level in a wooden house, does not fly, and is remote from radioactive mineral deposits. Although the variations in background level are considerable, no corresponding variation in human health has been observed. Additional exposure of the general public due to the nuclear power industry is small compared with this natural background level of exposure, even in the immediate vicinity of a nuclear installation, and is well within normal variations of background.

Radioactive material discharged into the environment may be concentrated by biological processes (e.g., zinc 65 in shellfish and iodine 131 in milk), and consumption of such food must not cause people to receive any significant increase in radiation exposure over and above the normal background. Biological studies are therefore conducted which ultimately lead to the definition of certain critical groups of people receiving the highest exposure because of age, occupation, diet, location, or recreational habits. Such groups are designated "Critical Groups" and provide the reference standard for determining permissible levels of discharges.

The Critical Group is not necessarily exposed to radiation by ingestion of food. Inhalation, or even direct external exposure may be the limiting factor, especially for airborne releases. Hence the determination of a discharge authorisation requires a very detailed knowledge of the local ccology and environmental characteristics, and this must be obtained by surveys and other investigations before operations commence. A typical environmental studies program for a nuclear installation site would be as follows:

(1) Hydrographic and meteorological studies to determine dispersion characteristics and dilution factors.

(2) Biological mapping and ecological studies.

(3) Studies of the concentration factors for various radioactive materials in certain biological species.

(4) Investigation of marketing practices relating to local foodstuffs.

(5) General investigation of land and water utilisation and population distribution for the district.

### Actual Discharges

Operational experience at many nuclear establishments indicates that actual discharges are only of the order of 1-10 percent of the discharge authorisation. It is intended to set the operating guide lines for the Jervis Bay Nuclear Power Station at ten percent of levels derived from the National Health and Medical Research Council's recommendations.

Some concern has been expressed overseas (particularly in the U.S.A.) over the levels of krypton 85 discharged into the atmosphere from fuel reprocessing plant. This gaseous fission product is chemically inert and does not concentrate in food chains but, because of its ten year half-life, will become more or less evenly distributed throughout the biosphere and contribute to the natural background radiation. However, even at the present rate of discharge, this build up of krypton is extremely slow, and with the introduction of a recently developed clean-up system (developed at Oak Ridge National Laboratory, U.S.A.) this problem should be solved.

### Measures Taken to Protect Against Accidental Releases of Activity

Existing controls have reduced the effects on health arising from the normal operation of nuclear installations to well below many currently accepted conventional risks. It is also necessary to ensure that the public has adequate protection against the risk of accidental releases of radioactive materials.

This protection is ensured by the following means:

(i) Enforcement of very strict control of the standards of engineering design, construction and operation of plant, to minimise the risk of plant failures.

(ii) Provision of safety (or protective) systems completely independent of the basic plant process equipment, and designed to the same high standards of reliability.

(iii) Provision of a leak-tight containment building, equipped with air clean-up filtration plant, to enclose the plant and form a final barrier to any radioactive material which may be released.

(iv) Siting restrictions imposed around the nuclear installation to provide an exclusion zone, usually of about 1 km radius, between the installation and residential areas. (These restrictions are at present usually extended to ensure an area of low population density for a few miles between the exclusion zone and high density urban areas.)

Hence the overall philosophy of nuclear plant safety, applicable to both reactors and fuel reprocessing plants is:

(a) The provision of plant of high engineering quality and reliability, together with additional protective equipment to prevent accidents.

(b) Containment and siting restrictions to limit the consequences of accidents to acceptably safe levels.

To ensure the adequacy of these safety provisions, all nuclear plants are subject to licensing and regulatory controls throughout the operational life of the plant.

## Conclusions

The essential means of protecting the environment from the consequences of energy production is to control the effluents adequately and effectively. The nuclear industry has been carefully regulated from its inception, and all its waste arisings have been checked and disposed of under formal approvals. Low-level radioactive discharges are permitted to be released into the environment only at levels which comply with both national and international health standards.

Nuclear energy, therefore, can play a vital role in combating the serious problems of atmospheric and environmental pollution which arise from present-day methods of electricity generation using fossil fuels.

# 5

# NUCLEAR POWER DEVELOPMENTS

## WORLD SITUATION

The past year has been one of intense activity in the nuclear power field with more new plant coming into operation, under construction and on order than in any previous year.

The number of nuclear units (capacity above 10 megawatts) now committed throughout the world totals 298 with a combined capacity of over 170,000 MW. During the year, 40 new units— 45,000 MW total capacity — were ordered or otherwise committed. These were ordered mainly by the United States of America, Japanese and West German utilities, but also included the first orders placed by Austria and Brazil. Thailand and Yugoslavia expect to place orders shortly for their first stations. Government approval has been given. Fourteen new units (capacity 7,300 MW) commenced operating. Many other units, including the first in the 1,000 MW range, are nearing completion and will come on line later in 1971.

Table 1 tabulates the number of nuclear power units in operation, under construction, or definitely committed in the various countries. Table 2 groups the various plants according to reactor types. Table 3 lists the individual stations under countries. (See pages 36-41.)

## NUCLEAR STATION COSTS AND COMPETITIVENESS

Power station capital costs have escalated sharply over the past few years in most countries throughout the world, particularly in North America. Official United States Atomic Energy Commission (USAEC) estimates for 1,000 MW light-water reactors during this period are as follows:

| Date of Estimate | Construction Period | Cost |
|---|---|---|
| March 1967 | 1967-1970 | \$134 million[1] |
| Early 1969 | 1969-1973 | \$174-\$180 million |
| Mid 1969 | 1969-1975 | \$218-239 million[2] |
| Early 1970 | 1969-1975 | \$246 million[3] |
| Early 1970 | 1970-1976 | \$266 million[3] |

(1) In accordance with generally accepted practice at the time, the March 1967 estimate did not provide for escalation between ordering and commissioning.

(2) The two figures apply to escalation rates of 4½ and 7½ percent per annum respectively.

(3) These figures are based on 7½ percent escalation.

The increased cost is due to a number of different factors, the two most important being the much longer construction period and greatly increased labour costs. The longer construction period (mainly attributable to a longer delivery period of key components—turbo-generators, pressure vessels—licensing delays and shortage of skilled tradesmen) coupled with higher interest rates has resulted in "interest during construction" more than doubling; it has also increased the escalation component. Labour rates generally, and construction wages in particular, have soared and continue to do so.

The increased costs mentioned above are not confined to nuclear stations. Most, but not all, of the factors responsible for these increases also apply to conventional stations. In fact, the cost of coal-fired plant in the U.S.A. (till 1970 at least) tended to increase at a slightly higher rate than nuclear plant. Figures presented in early 1970 by the USAEC to the Joint Committee on Atomic Energy indicate costs for 1,000 MW coal-fired stations of $174.5 million for mid-1973 operation, $188.9 million for mid-1974, $196.6 million for early-1975 and $212.0 million for early-1976.

Despite the increased capital cost differential due to inflation, nuclear power in the U.S.A. has maintained its competitive position. Coal prices have been increasing for a number of years and, in 1969-70, there was a sudden jump of 35 percent in the average U.S. price — the highest rise reported for any commodity. Likewise, oil prices have risen considerably and are expected to continue to rise. Nuclear fuel cycle costs, on the other hand, have remained fairly stable. One component, enrichment, has increased but this has been offset by reductions in the prices for uranium, fabrication, conversion and reprocessing. U.S. utilities are unable to obtain long-term contracts for the supply of fossil fuels, but can obtain firm price contracts for a period of 12 years or more for nuclear fuel. Apart from this there is, or will be, world-wide competition for the supply of nuclear fuel and associated services, tending to keep prices down, whereas fossil-fired stations are in general tied to fuel supplies in the vicinity of the station, and all countries are concerned over rising fossil fuel prices.

In the U.S.A. there is also increasing concern over atmospheric pollution. In some areas there is a complete embargo on the construction of fossil-fuelled plant; in others, fuel can only be burnt if the sulphur content is below prescribed limits; alternatively, flue gas washing equipment must be installed. At the Navajo coal-fired plant being built in Arizona, some $90 million, or $40/kW, is being spent to make the plant environmentally acceptable.

Although the above relates to the position in the U.S.A., the same applies throughout the world to a greater or lesser degree.

Present-day nuclear plant costs are considered to be unduly high. Most reactor vendors have full order books and component manufacturers are loading prices because of the exacting quality control being insisted upon. Despite some attempt at standardisation, every plant built today involves very high design engineering charges. In Germany, nuclear investment costs (excluding clients charges) have risen from about $130/kW for the Stade and Wurgassen units ordered in late 1967, to more than $190/kW for the recently-ordered Neckarwestheim unit, despite its larger size.

As the industry becomes more mature, costs relative to fossil plants are expected to decrease. A report by the Reactor Assessment Panel of the Edison Electric Institute, published in 1970, gives an estimated cost for a twin-unit light-water reactor station of 2,300 MW (2 x 1,150) commissioned in 1975 of $220 ± $20/kW, including all client's charges and escalation, and states that manufacturers predict improvements of about $25/kW by 1980.

Despite its present high cost, compared with costs of three to four years ago, nuclear plant is becoming increasingly attractive in many areas relative to the alternatives offering.

Several countries (Japan for example) have announced accelerated nuclear construction programs. Manufacturers have revised upwards their estimates of nuclear power growth; for example, Westinghouse has increased its estimate of "nuclear's share of additions to U.S. power-generating capacity in the next two decades by some 140,000 MW as a result of supply and production problems being experienced with fossil fuels".

## NATIONAL PROGRAMS

### Argentina

Argentina has announced that it intends placing an order next year for its second station, 600 MW.

### Austria

Austria has entered the nuclear power field with the placing of an order with Kraftwerk Union of Germany for a 700 MW BWR station to be built at Zwentendorf, about 20 miles from Vienna. Completion is scheduled for 1976.

### Brazil

Brazil has placed an order for its first nuclear station — a 600 MW PWR. This will be located at Angra dos Reis, about 60 miles from Rio de Janeiro.

### Canada

The 250 MW Gentilly station (CANDU-BLW) and the first of the four Pickering units are now on line.

### Czechoslovakia

The 140/112 MW Bohunice heavy-water moderated gas-cooled station, which has been under construction since 1958, is now in operation. A duplicate of the U.S.S.R.-designed 2 x 420 MW PWR Bohunice 2 station has been ordered. It will be located at Dukovany.

### Finland

Finland has reached agreement with the U.S.S.R. to supply a second unit for the Loviisa station.

### France

Bugey 1 and St. Laurent 2, the last of the French natural uranium stations, are expected to be commissioned this year. The next phase of Electricité de France's program will be based on light-water reactors. It is planned to commit up to 8,000 MW of such plant over the next five years. The first station under this program, an 870 MW PWR, is under construction at the Fessenheim site. Two units of similar size are expected to be ordered for the Bugey site over the next two years.

## West Germany

The Stade and Wurgassen plants, the first large nuclear units of an economic size built in Germany, are expected to come on line late this year. Construction is under way on the 770 MW Biblis station; a second unit of 1,240 MW has been ordered for Biblis. Other recent commitments include: a 300 MW HTGR for Schemausen, an additional unit (864 MW) for the Philippsburg station, an 870 MW BWR for a station at Isar, one of 770 MW at Neckar, and a 1,240 MW PWR for a station at Nordenham on the Weser. Construction of BASF's twin unit PWR station at Ludwigshafen has been deferred.

## Italy

The Italian State Electricity Board (ENEL) has begun work on a new station, a 750 MW BWR, on the River Po near Cremona.

## Japan

The first two utility-financed stations, Kansai Electric's Mihama 1 (320 MW PWR) and Tokyo Electric's Fukushima 1 (440 MW BWR), are now operating. Kansai Electric has placed orders for a third unit (781 MW PWR) for the Mihama station, a second unit (also a 781 MW PWR) for the Takahama station, and two units, each of 1,150 MW, for the new Ohi station. These bring Kansai's total commitments to seven units, having a net electrical output of 5,433 MW. Tokyo Electric has ordered three more units (760 MW BWRs) for the Fukushima station. Other utilities to place orders include Tohoku (Onagawa 1 — 500 MW BWR), Shiboku (Ikata 1 — 500 MW PWR), and Kyushu (Genkai — 500 MW PWR), in addition to those previously reported. JAPCO is planning to build its third station (1,100 MW BWR) starting construction late next year.

The Central Power Council of Japan announced a new electric power development program which provides for the construction of 49 nuclear units having a combined output of 46,550 MW, during the 1970-79 period. Thirty-two of these (23,000 MW) units will be commissioned in this period. Installed nuclear capacity is expected to total 60,000 MW by 1985.

## Korea

Construction of the 564 MW PWR station at Pusan has started.

## Netherlands

Work has started on a new station (400 MW PWR) at Borselle. Construction of another new station of 600 MW capacity in the Noordbrabant province is expected to begin early next year.

## Pakistan

The 125 MW CANDU type station at Karachi has commenced operating.

## Spain

Nuclenor's 460 MW BWR Santa Maria la Gorona is now operating. Construction of the second unit (450 MW PWR) at Zorita de los Canes has started. Orders are expected to be placed this year for four 900 MW units for two new stations at Almarez and Lemoniz.

### Sweden

Orders for the third and fourth units of the State Power Board's Ringhals station are expected to be placed soon.

### Switzerland

The 306 MW Muehleberg plant and the 250 MW Beznau 2 unit are being commissioned. No final decision has yet been taken on the previously reported Kaiseraugst station to be built by a Swiss-French-German consortium.

### Taiwan

Taipower has ordered a second 604 MW BWR unit for its Chin San station. This company expects to have five units operating by 1985.

### Thailand

Construction of Thailand's first nuclear station, to be located near Bangkok, has been approved by the Government. A contract for a 500 MW plant is expected to be placed next year.

### United Kingdom

Wylfa, the last of the Magnox series of plants built by the Central Electricity Generating Board under its Stage 1 program is now operational. Construction has started on Heysham (1,250 MW) the fifth AGR station of the Stage 2 program. Sizewell "B", a four unit station of 2,640 MW, which was to have started this year, has been deferred.

### U.S.A.

During the year, five new stations came on line (Dresden 2 and 3, each 809 MW; Monticello, 545 MW; H. B. Robinson 2, 700 MW; Millstone Point 1, 652 MW; and Point Beach 1, 497 MW). Palisades, which has been completed for some time, is operating at low power but will not receive a full operating licence until closed cycle cooling plant is installed. Eight other stations are scheduled for operation in 1971. They are Quad Cities 1, Point Beach 2, Indian Point 2, Turkey Point 3, Oconee 1, Pilgrim, Vermont Yankee, Surry 1. Sixteen other units, including the first of the 1,000 MW class, are nearing completion and are expected to come into operation in 1972.

Twenty-three new units (24,011 MW) were ordered during the year. They are:

| | | | |
|---|---|---|---|
| J. M. Farley 2 | 829 MW | Hutchinson Is. 2 | 828 MW |
| New Bold 1 & 2 | 2,176 MW | Waterford | 1,165 MW |
| W. B. McGuire 1 & 2 | 2,300 MW | Mendocino 1 & 2 | 2,256 MW |
| Watts Bar 1 & 2 | 2,340 MW | Hanford 2 | 1,135 MW |
| Parr | 900 MW | TVA (No site, 2 units) | 2,402 MW |
| Comm. Edison (No site, 2 units) | 2,200 MW | White Oak 1, 2, 3 & 4 | 3,600 MW |
| | | North Anna 3 & 4 | 1,880 MW |

A number of repeat orders are being placed by some of the larger utilities. Commonwealth Edison recently ordered reactors for its fifth nuclear station, bringing the total number of nuclear units to 11 and capacity to almost 10,000 MW. In addition, they have options to purchase four further units each of 1,100 MW. The Tennessee Valley Authority has more than 10,000 MW of nuclear plant under construction or on order. Other companies with a large nuclear commitment include Consolidated Edison, Pacific Gas and Electric, Duke Power, Florida Power and Light. In addition to the above firm commitments, several utilities have announced their intention to install additional units, for example, Vepco has decided on two more units for its North Anna site.

### U.S.S.R.

The Soviet has announced that it will build two more large stations, each of 2 x 1,000 MW capacity, one at Kursk and one at Leningrad. Two other stations of similar size are planned for construction under the current five year program. All will employ graphite-moderated, water-cooled reactors.

Premier Kosygin recently stated that about 30,000 MW of nuclear plant would be commissioned over the next 10 to 12 years, mainly in the European part of the country.

### Yugoslavia

Yugoslavia has called bids for a 600 MW nuclear plant with a view to placing an order next year.

## URANIUM ENRICHMENT

The overall situation with respect to uranium enrichment in the Western World remained virtually unchanged during the past year. However, in June, the USAEC announced that it would provide access to its uranium enrichment technology to a limited number of U.S. owned companies desiring to carry out independent development work on uranium enrichment. Sensitive uranium enrichment technology, including such technology as might be developed by the participating industrial companies, would continue to be classified and require security protection. The selected companies would have access to USAEC data on both the gaseous diffusion and gas centrifuge processes for enriching uranium.

Present enrichment facilities in the U.S.A. consist of three gaseous diffusion plants which were built and have been operated by the USAEC primarily for defence purposes. The uranium enrichment activity is the only sector of the U.S. nuclear power industry still entirely operated by the U.S. Government. Participation by industry in the development of enrichment technology could lead, in the future, to the establishment of a private uranium enrichment capability.

The future market for enrichment services will be primarily as fuel for commercial nuclear power plants. The current forecasts indicate that new enrichment plant capacity could be required as early as 1980, and additional increments will be needed in subsequent years to meet the fuel needs of the rapidly growing nuclear power industry.

In line with the above, the U.S. recently appropriated funds to proceed with the Cascade Improvement and Cascade Uprating Programs (CIP and CUP), which are planned to increase capacity of U.S. diffusion plants from 17,000 tonnes separative work units per year to about 26,000 tonnes per year. By these measures, and by modifying plant operation to use a higher "tails" concentration, and by some pre-production, the USAEC considers it will be able to meet the forecast world demand for enrichment at least until 1980 and possibly longer.

The demand for enrichment in the Western World (including Japan) is estimated at 19,000 tonnes separative work units (SWU) per year in 1975, and 43,000 per year in 1980. An increase from the present value of 0.2 percent to 0.3 percent uranium 235 content of the depleted fraction would allow production to be increased by 25 percent, but would require an additional 20 percent feed of natural uranium for each kilogram of enriched product. The position will also be eased slightly by the recycling of plutonium instead of new enriched uranium feed in thermal reactors.

The USAEC has already announced two successive increases in its charges for enrichment services over the past 12 months. In late 1969, the Administration directed the USAEC to bring its financing of enrichment services into line with private ownership, by assuming some equity capital participation and a higher service charge on this capital. The net effect was to increase charges for enrichment from US$26 per kg SWU to $28.70 per kg SWU as from February 1970.

A second (and concurrent) trend influencing prices, is the increase in electricity costs from the Tennessee Valley Authority, which supplies the Oak Ridge enrichment plant and part of that of Paducah. TVA recently increased power costs by about 25 percent, and since power charges account for about 40 percent of the enrichment cost, further increases in charges for enrichment services could result. A proposal to increase enrichment prices to $32 per kg is likely to take effect in September 1971.

France is undertaking a detailed study of a project to construct a diffusion plant in Europe with capacity of about 6,000 tonne SWU a year, to begin operation around 1980. France has also expressed interest in possible collaboration in the construction and operation of an enrichment plant in another region.

Japan is continuing research in both the centrifuge and diffusion methods of enrichment, and has expressed interest in collaborating in the establishment of enrichment capacity in the Pacific area. Canada is also considering a collaborative project, based on U.S. technology, and the Canadian resources of uranium and cheap power.

In April 1971, the agreements relating to the Tripartite Organisation came into force, under which the U.K., Dutch and German Governments will collaborate on development of centrifuge enrichment technology. Plants are being constructed at Almelo (Netherlands) and Capenhurst (U.K.), each with capacity of about 50 tonnes SWU a year in 1972, with possible expansion to 200 tonnes a year by 1975.

South Africa has announced a new process for enrichment which is claimed to be competitive with other methods, but no details of the process have been released.

## HEAVY WATER

Heavy water remains in critical short supply. Countries which have adopted, or are contemplating installation of heavy-water moderated reactors, must have assured supplies of this material. The Canadian pressurised heavy-water cooled reactor (CANDU) requires 0.8 tonnes of heavy water per MWe of output, and the boiling light-water cooled versions (SGHWR and CANDU-BLW) require about 0.3 tonne/MWe as initial inventory.

Canada has in operation a plant producing about 400 tonnes per year of heavy water, and is constructing another plant to produce 800 tonnes per year. Because of technical problems the heavy water plant at Glace Bay, Nova Scotia, which was scheduled for commissioning in 1966, has not been brought into production and its future is uncertain. Already Canada is the world's largest producer of heavy water. The U.S.A. continues to produce about 180 tonnes/year, and smaller amounts are produced in Europe and India.

Until about the mid-1970s it is clear that heavy water will continue to be in short supply in the world. Thereafter, supply and demand are difficult to forecast accurately because national plans for the adoption of heavy-water moderated reactors have not yet become firm. Moreover, if Canada adopted the CANDU-BLW reactor in preference to the CANDU system, requirements of heavy water would be reduced, with the possibility of over-supply by the end of the 1970s.

The Commission continued to keep abreast of developments in the heavy water field, and advises interested companies in Australia on the possibilities of local production. If heavy-water moderated reactors are adopted for power generation in Australia, heavy water requirements for power reactors installed in Australia up to about 1980 will be imported. Thereafter, attention will need to be given to production of heavy water in Australia.

Table 1

NUCLEAR POWER UNITS IN OPERATION, UNDER CONSTRUCTION OR ON ORDER IN VARIOUS COUNTRIES AS AT 30 JUNE 1971

| Country | In Operation | | Under Construction | | On Order | | TOTAL | |
|---|---|---|---|---|---|---|---|---|
| | No. | MW | No. | MW | No. | MW | No. | MW |
| Argentina | — | — | 1 | 319 | — | — | 1 | 319 |
| Austria | — | — | — | — | 1 | 700 | 1 | 700 |
| Belgium | 1 | 10 | 3 | 1,650 | — | — | 4 | 1,660 |
| Brazii | — | — | — | — | 1 | 600 | 1 | 600 |
| Bulgaria | — | — | 2 | 840 | — | — | 2 | 840 |
| Canada | 4 | 988 | 7 | 4,532 | — | — | 11 | 5,520 |
| Czechoslovakia | 1 | 112 | — | — | 4 | 1,680 | 5 | 1,792 |
| Finland | — | — | 1 | 420 | — | — | 1 | 420 |
| France | 8 | 1,648 | 4 | 2,183 | — | — | 12 | 3,831 |
| East Germany | 1 | 70 | — | — | 1 | 700 | 2 | 770 |
| West Germany | 6 | 883 | 7 | 4,148 | 6 | 5,284 | 19 | 10,315 |
| India | 2 | 380 | 3 | 606 | 1 | 202 | 6 | 1,188 |
| Italy | 3 | 608 | 1 | 35 | 1 | 750 | 5 | 1,393 |
| Japan | 5 | 1,269 | 10 | 5,692 | 6 | 5,101 | 21 | 12,062 |
| Korea | — | — | 1 | 564 | — | — | 1 | 564 |
| Netherlands | 1 | 62 | 1 | 450 | — | — | 2 | 512 |
| Pakistan | 1 | 125 | — | — | 1 | 200 | 2 | 325 |
| Spain | 2 | 613 | 2 | 930 | — | — | 4 | 1,543 |
| Sweden | 2 | 449 | 4 | 2,729 | — | — | 6 | 3,178 |
| Switzerland | 1 | 350 | 2 | 656 | — | — | 3 | 1,006 |
| Taiwan | — | — | 1 | 604 | 1 | 604 | 2 | 1,208 |
| United Kingdom | 29 | 5,384 | 11 | 6,463 | — | — | 40 | 11,847 |
| United States | 23 | 8,345 | 57 | 48,252 | 44 | 43,312 | 124 | 95,250 |
| U.S.S.R. | 11 | 1,580 | 12 | 7,170 | — | — | 23 | 8,750 |
| Totals | 101 | 22,876 | 130 | 88,243 | 67 | 59,133 | 298 | 170,252 |

## Table 2

## NUCLEAR POWER UNITS IN OPERATION, UNDER CONSTRUCTION OR ON ORDER AS AT 30 JUNE 1971—BY TYPE AND COUNTRY

| Reactor Type and Country | In Operation | | Under Construction | | On Order | | TOTAL | |
|---|---|---|---|---|---|---|---|---|
| | No. | MW | No. | MW | No. | MW | No. | MW |
| **LIGHT WATER** | | | | | | | | |
| (a) **PWRs** | | | | | | | | |
| Belgium | 1 | 10 | 3 | 1,650 | — | — | 4 | 1,660 |
| Brazil | — | — | — | — | 1 | 600 | 1 | 600 |
| Bulgaria | — | — | 2 | 840 | — | — | 2 | 840 |
| Czechoslovakia | — | — | — | — | 4 | 1,680 | 4 | 1,680 |
| Finland | — | — | 1 | 420 | — | — | 1 | 420 |
| France | 1 | 266 | 1 | 870 | — | — | 2 | 1,136 |
| West Germany | 1 | 328 | 2 | 1,780 | 3 | 3,250 | 6 | 5,358 |
| East Germany | 1 | 70 | — | — | 1 | 700 | 2 | 770 |
| Italy | 1 | 247 | — | — | — | — | 1 | 247 |
| Japan | 1 | 320 | 4 | 2,532 | 4 | 3,581 | 9 | 6,433 |
| Korea | — | — | 1 | 564 | — | — | 1 | 564 |
| Pakistan | — | — | — | — | 1 | 200 | 1 | 200 |
| Spain | 1 | 153 | 1 | 450 | — | — | 2 | 603 |
| Sweden | — | — | 1 | 809 | — | — | 1 | 809 |
| Switzerland | 1 | 350 | 2 | 656 | — | — | 3 | 1,006 |
| U.S.A. | 8 | 3,152 | 42 | 34,983 | 31 | 30,713 | 81 | 68,848 |
| U.S.S.R. | 2 | 630 | 6 | 2,420 | — | — | 8 | 3,050 |
| Totals | 18 | 5,526 | 66 | 47,974 | 45 | 40,724 | 129 | 94,224 |
| (b) **BWRs** | | | | | | | | |
| Austria | — | — | — | — | 1 | 700 | 1 | 700 |
| West Germany | 3 | 492 | 3 | 2,246 | 2 | 1,734 | 8 | 4,472 |
| India | 2 | 380 | — | — | — | — | 2 | 380 |
| Italy | 1 | 154 | — | — | 1 | 750 | 2 | 904 |
| Japan | 3 | 792 | 5 | 2,960 | 2 | 1,520 | 10 | 5,272 |
| Netherlands | 1 | 62 | 1 | 450 | — | — | 2 | 512 |
| Spain | 1 | 460 | — | — | — | — | 1 | 460 |
| Sweden | 1 | 440 | 3 | 1,920 | — | — | 4 | 2,360 |
| Taiwan | — | — | 1 | 604 | 1 | 604 | 2 | 1,208 |
| U.S.A. | 11 | 4,286 | 14 | 12,939 | 13 | 12,599 | 38 | 29,824 |
| U.S.S.R. | 1 | 50 | — | — | — | — | 1 | 50 |
| Totals | 24 | 7,116 | 27 | 21,119 | 20 | 17,907 | 71 | 46,142 |
| (c) **LWGRs** | | | | | | | | |
| U.S.A. | 1 | 790 | — | — | — | — | 1 | 790 |
| U.S.S.R. | 8 | 900 | 4 | 4,000 | — | — | 12 | 4,900 |
| Totals | 9 | 1,690 | 4 | 4,000 | — | — | 13 | 5,690 |
| **GAS COOLED GRAPHITE** | | | | | | | | |
| (a) **Natural Uranium** | | | | | | | | |
| France | 6 | 1,309 | 2 | 1,063 | — | — | 8 | 2,372 |
| Italy | 1 | 207 | — | — | — | — | 1 | 207 |
| Japan | 1 | 157 | — | — | — | — | 1 | 157 |
| Spain | — | — | 1 | 480 | — | — | 1 | 480 |
| U.K. | 26 | 5,238 | — | — | — | — | 26 | 5,238 |
| Totals | 34 | 6,911 | 3 | 1,543 | — | — | 37 | 8,454 |

**Table 2** *(continued)*

| Reactor Type and Country | In Operation | | Under Construction | | On Order | | TOTAL | |
|---|---|---|---|---|---|---|---|---|
| | No. | MW | No. | MW | No. | MW | No. | MW |
| (b) **Advanced Gas Cooled** | | | | | | | | |
| U.K. | 1 | 32 | 10 | 6,213 | — | — | 11 | 6,245 |
| (c) **HTGRs** | | | | | | | | |
| Germany | 1 | 13 | 1 | 22 | 1 | 300 | 3 | 335 |
| U.S.A. | 1 | 40 | 1 | 330 | — | — | 2 | 370 |
| Totals | 2 | 53 | 2 | 352 | 1 | 300 | 5 | 705 |
| **HEAVY WATER** | | | | | | | | |
| (a) **CANDU PHW** | | | | | | | | |
| Canada | 3 | 738 | 7 | 4,532 | — | — | 10 | 5,270 |
| India | — | — | 3 | 606 | 1 | 202 | 4 | 808 |
| Pakistan | 1 | 125 | — | — | — | — | 1 | 125 |
| Totals | 4 | 863 | 10 | 5,138 | 1 | 202 | 15 | 6,203 |
| (b) **SGHWR Types** | | | | | | | | |
| Canada | 1 | 250 | — | — | — | — | 1 | 250 |
| Italy | — | — | 1 | 35 | — | — | 1 | 35 |
| Japan | — | — | 1 | 200 | — | — | 1 | 200 |
| U.K. | 1 | 100 | — | — | — | — | 1 | 100 |
| Totals | 2 | 350 | 2 | 235 | — | — | 4 | 585 |
| (c) **$CO_2$ Cooled** | | | | | | | | |
| France | 1 | 73 | — | — | — | — | 1 | 73 |
| Germany | — | — | 1 | 100 | — | — | 1 | 100 |
| Czechoslovakia | 1 | 112 | — | — | — | — | 1 | 112 |
| (d) **Others** | | | | | | | | |
| Argentina | — | — | 1 | 319 | — | — | 1 | 319 |
| Germany | 1 | 50 | — | — | — | — | 1 | 50 |
| Sweden | 1 | 9 | — | — | — | — | 1 | 9 |
| Totals | 4 | 244 | 2 | 419 | — | — | 6 | 663 |
| **FAST BREEDERS** | | | | | | | | |
| France | — | — | 1 | 250 | — | — | 1 | 250 |
| U.K. | 1 | 14 | 1 | 250 | — | — | 2 | 264 |
| U.S.A. | 2 | 77 | — | — | — | — | 2 | 77 |
| U.S.S.R. | — | — | 2 | 750 | — | — | 2 | 750 |
| Totals | 3 | 91 | 4 | 1,250 | — | — | 7 | 1,341 |
| TOTALS ALL TYPES | 101 | 22,876 | 130 | 88,243 | 67 | 59,133 | 298 | 170,252 |

## Table 3

## WORLD NUCLEAR POWER STATIONS

The table lists nuclear power stations in operation, under construction or definitely committed. Stations of less than 10 MW have been omitted.

GC = Gas Cooled
G = Graphite Moderated
BW = Boiling Light Water
OM = Organic Moderated
PW = Pressurised Light Water
HW = Heavy Water Moderated
HW/HW = Heavy Water Moderated and Cooled
F = Fast Breeder
Op = Operating C = Under Construction Cm = Committed

| Name | Output MW | Type | State |
|---|---|---|---|
| **ARGENTINA** | | | |
| Atucha | 319 | HW/HW | C |
| **BELGIUM** | | | |
| Tihange | 870 | PW | C |
| Doel | 780 | PW | C |
| **BRAZIL** | | | |
| Angra dos Reis | 600 | PW | Cm |
| **BULGARIA** | | | |
| Kozloduy | 840 | PW | C |
| **CANADA** | | | |
| NPD | 22 | HW/HW | Op |
| Douglas Pt. | 208 | HW/HW | Op |
| Pickering 1 | 508 | HW/HW | Op |
| Pickering 2, 3, 4 | 1524 | HW/HW | C |
| Gentilly | 250 | HW/GW | Op |
| Bruce 1, 2, 3, 4 | 3008 | HW/HW | C |
| **CZECHOSLOVAKIA** | | | |
| Bohunice 1 | 112 | HW/GC | Op |
| Bohunice 2, 3 | 840 | PW | Cm |
| Dukovany 1, 2 | 840 | PW | Cm |
| **FINLAND** | | | |
| Loviisa | 420 | PW | C |
| **FRANCE** | | | |
| Marcoule G2, G3 | 72 | G/GC | Op |
| Chinon 1 | 70 | G/GC | Op |
| Chinon 2 | 200 | G/GC | Op |
| Chinon 3 | 480 | G/GC | Op |
| St. Laurent 1 | 487 | G/GC | Op |
| St. Laurent 2 | 518 | G/GC | C |
| Bugey 1 | 545 | G/GC | C |
| Chooz | 266 | PW | Op |
| EL 4 | 73 | HW/GC | Op |
| Phènix | 250 | F | C |
| Fessenheim | 870 | PW | C |
| **EAST GERMANY** | | | |
| Rheinsberg | 70 | PW | Op |
| Lubmin | 700 | PW | Cm |
| **WEST GERMANY** | | | |
| Gundremmingen | 237 | BW | Op |
| Lingen | 240 | BW | Op |
| Obrigheim | 328 | PW | Op |
| MZFR | 50 | HW/HW | Op |
| Neiderachbach | 100 | HW/GC | C |
| Stade | 630 | PW | C |
| Wurgassen | 612 | BW | C |
| Biblis 1 | 1150 | PW | C |
| Biblis 2 | 1240 | PW | C |
| Brunsbuettel | 770 | BW | C |
| Schemausen | 300 | G/GC | Cm |
| Philippsburg 1 | 864 | BW | C |
| Philippsburg 2 | 864 | BW | Cm |
| ISAR | 870 | BW | Cm |
| Neckar | 770 | BW | Cm |
| Nordenham | 1240 | PW | Cm |
| **INDIA** | | | |
| Tarapur 1, 2 | 380 | BW | Op |
| Rajasthan 1, 2 | 404 | HW/HW | C |
| Madras 1 | 202 | HW/HW | C |
| Madras 2 | 202 | HW/HW | Cm |
| **ITALY** | | | |
| Latina | 207 | G/GC | Op |
| Selni | 247 | PW | Op |
| Garigliano | 154 | BW | Op |
| Caorso | 750 | BW | C |
| Cirene | 35 | HW/BW | C |
| **JAPAN** | | | |
| JPDR | 11 | BW | Op |
| Tokai Mura | 157 | G/GC | Op |
| Tsuruga | 341 | BW | Op |
| Mihama 1 | 320 | PW | Op |
| Mihama 2 | 470 | PW | C |
| Mihama 3 | 781 | PW | Cm |
| Fukushima 1 | 440 | BW | Op |
| Fukushima 2, 3 | 1520 | BW | C |
| Fukushima 4, 5 | 1520 | BW | Cm |
| Shimane 1 | 440 | BW | C |
| Takahama 1, 2 | 1562 | PW | C |
| Genkai | 500 | PW | C |
| Onagawa 1 | 500 | BW | C |
| Hamaoka 1 | 500 | BW | C |
| Ikata | 500 | PW | Cm |
| Ohi 1, 2 | 2300 | PW | Cm |
| A.T.R. | 200 | HW/BW | C |

| Name | Output MW | Type | State |
|---|---|---|---|
| **KOREA** | | | |
| Pusan | 564 | PW | C |
| **NETHERLANDS** | | | |
| Dodewaard | 62 | BW | Op |
| Borselle | 400 | PW | C |
| **PAKISTAN** | | | |
| Karachi | 125 | HW/HW | Op |
| Roopur | 200 | PW | Cm |
| **SPAIN** | | | |
| Zorita 1 | 153 | PW | Op |
| Zorita 2 | 450 | PW | C |
| S. Maria la Gorona | 460 | BW | Op |
| Hospitalet | 480 | G/GC | C |
| **SWEDEN** | | | |
| Oskarsham 1 | 440 | BW | Op |
| Oskarsham 2 | 580 | BW | C |
| Ringals 1 | 760 | BW | C |
| Ringals 2 | 809 | PW | C |
| Barscbaeck | 580 | BW | C |
| **SWITZERLAND** | | | |
| Beznau 1 | 350 | PW | Op |
| Beznau 2 | 350 | PW | C |
| Muehleberg | 306 | BW | C |
| **TAIWAN** | | | |
| Chin San 1 | 604 | BW | C |
| Chin San 2 | 604 | BW | Cm |
| **UNITED KINGDOM** | | | |
| Calder | 185 | G/GC | Op |
| Chapelcross | 185 | G/GC | Op |
| Berkeley | 291 | G/GC | Op |
| Bradwell | 323 | G/GC | Op |
| Hunterston A | 320 | G/GC | Op |
| Hunterston B | 1250 | G/GC | C |
| Hinkley Pt. A | 524 | G/GC | Op |
| Hinkley Pt. B | 1260 | G/GC | C |
| Trawsfynnyd | 500 | G/GC | Op |
| Dungeness A | 550 | G/GC | Op |
| Dungencss B | 1200 | G/GC | C |
| Sizewell A | 580 | G/GC | Op |
| Oldbury | 600 | G/GC | Op |
| Wylfa | 1180 | G/GC | Op |
| Seaton Carew | 1250 | G/GC | C |
| Heysham | 1250 | G/GC | C |
| SGHWR | 100 | HW/BW | Op |
| DFR | 250 | F | C |
| **U.S.A.** | | | |
| Shippingport 1 | 90 | PWR | Op |
| Big Rock Pt. | 70 | BWR | Op |
| Humbolt Bay | 69 | BWR | Op |
| Enrico Fermi 1 | 61 | FB | Op |
| Peach Bottom 1 | 40 | HTGR | Op |
| La Crosse | 50 | BWR | Op |
| Dresden 1 | 200 | BWR | Op |
| Dresden 2 | 809 | BWR | Op |
| Dresden 3 | 809 | BWR | Op |
| Yankee | 175 | PWR | Op |
| Connecticut Yankee | 575 | PWR | Op |

| Name | Output MW | Type | State |
|---|---|---|---|
| Indian Pt. 1 | 265 | PWR | Op |
| Hanford NPR | 790 | C/PW | Op |
| San Onofre 1 | 430 | PWR | Op |
| Oyster Creek | 560 | BWR | Op |
| Nine Mile Pt. | 500 | BWR | Op |
| Ginna 1 | 420 | PWR | Op |
| Monticello | 545 | BWR | Op |
| H. B. Robinson 2 | 700 | PWR | Op |
| Millstone Pt. 1 | 652 | BWR | Op |
| Point Beach 1 | 497 | PWR | Op |
| Millstone Pt. 2 | 828 | PWR | C |
| Palisades 1 | 700 | PWR | C |
| Point Beach 2 | 497 | PWR | C |
| Browns Ferry 1 | 1065 | BWR | C |
| Browns Ferry 2 | 1065 | BWR | C |
| Browns Ferry 3 | 1065 | BWR | C |
| Fort Calhoun | 457 | PWR | C |
| Indian Pt. 2 | 873 | PWR | C |
| Indian Pt. 3 | 965 | PWR | C |
| Oconee 1 | 841 | PWR | C |
| Oconee 2 | 886 | PWR | C |
| Oconee 3 | 886 | PWR | C |
| Quad Cities 1 | 809 | BWR | C |
| Quad Cities 2 | 809 | BWR | C |
| Surry 1 | 780 | PWR | C |
| Surry 2 | 780 | PWR | C |
| Turkey Pt. 3 | 693 | PWR | C |
| Turkey Pt. 4 | 693 | PWR | C |
| Vermont Yankee | 513 | BWR | C |
| Main Yankee | 790 | BWR | C |
| Peach Bottom 2 | 1065 | BWR | C |
| Peach Bottom 3 | 1065 | BWR | C |
| Arkansas 1 | 820 | PWR | C |
| Cooper | 778 | BWR | C |
| Crystal River 3 | 858 | PWR | C |
| Cook 1 | 1054 | PWR | C |
| Cook 2 | 1060 | PWR | C |
| Fort St. Vrain | 330 | HTGR | C |
| Kewaunee | 540 | PWR | C |
| Prairie Is. 1 | 530 | PWR | C |
| Prairie Is. 2 | 530 | PWR | C |
| Pilgrim | 655 | BWR | C |
| Three Mile Is. 1 | 810 | PWR | C |
| Three Mile Is. 2 | 831 | PWR | C |
| Salem 1 | 1050 | PWR | C |
| Salem 2 | 1050 | PWR | C |
| Zion 1 | 1050 | PWR | C |
| Zion 2 | 1050 | PWR | C |
| Beaver Valley 1 | 847 | PWR | C |
| Calvert Cliffs 1 | 845 | PWR | C |
| Calvert Cliffs 2 | 845 | PWR | C |
| Diablo Canyon 1 | 1060 | PWR | C |
| Diablo Canyon 2 | 1060 | PWR | C |
| E. J. Hatch 1 | 786 | BWR | C |
| Rancho Seco 1 | 804 | PWR | C |
| Brunswick 1 | 821 | PWR | C |
| Brunswick 2 | 821 | PWR | C |
| Duane Arnold | 530 | BWR | C |
| Hutchinson Is. 1 | 828 | PWR | C |

| Name | Output MW | Type | State | Name | Output MW | Type | State |
|---|---|---|---|---|---|---|---|
| Sequoyah 1 | 1124 | PWR | C | W. B. McGuire 2 | 1150 | PWR | Cm |
| Sequoyah 2 | 1124 | PWR | C | Bailly | 660 | BWR | Cm |
| Fitzpatrick | 821 | BWR | C | Watts Barr 1 | 1170 | PWR | Cm |
| Enrico Fermi 2 | 1123 | BWR | C | Watts Barr 2 | 1170 | PWR | Cm |
| Davis Besse | 872 | PWR | C | Mendocino 1 | 1128 | PWR | Cm |
| Trojan | 1130 | PWR | C | Mendocino 2 | 1128 | PWR | Cm |
| North Anna River 1 | 845 | PWR | C | Hanford 2 | 1135 | BWR | Cm |
| North Anna River 2 | 845 | PWR | C | TVA (No Site) 1 | 1201 | PWR | Cm |
| North Anna River 3 | 940 | PWR | Cm | TVA (No Site) 2 | 1201 | PWR | Cm |
| North Anna River 4 | 940 | PWR | Cm | Comm. Edison (No Site) 1 | 1100 | PWR | Cm |
| Hutchinson Is. 2 | 828 | PWR | Cm | | | | |
| Shoreham | 819 | BWR | Cm | Comm. Edison (No Site 2) | 1100 | PWR | Cm |
| Arkansas 2 | 920 | PWR | Cm | | | | |
| La Salle 1 | 1078 | BWR | Cm | White Oak 1 | 900 | PWR | Cm |
| La Salle 2 | 1078 | BWR | Cm | White Oak 2 | 900 | PWR | Cm |
| Limerick 1 | 1065 | PWR | Cm | White Oak 3 | 900 | PWR | Cm |
| Limerick 2 | 1065 | PWR | Cm | White Oak 4 | 900 | PWR | Cm |
| Verplank 1 | 1115 | BWR | Cm | **U.S.S.R.** | | | |
| Susquehanna 1 | 1052 | BWR | Cm | Siberia (1-6) | 600 | G/PW | Op |
| Susquehanna 2 | 1052 | BWR | Cm | Novovoronezh 1 | 265 | PW | Op |
| Midland 1 | 492 | PWR | Cm | Novovoronezh 2 | 365 | PW | Op |
| Midland 2 | 818 | PWR | Cm | Novovoronezh 3 | 410 | PW | C |
| J. M. Farley 1 | 829 | PWR | Cm | Novovoronezh 4 | 410 | PW | C |
| J. M. Farley 2 | 829 | PWR | Cm | Melekess | 70 | BW | Op |
| Parr | 900 | PWR | Cm | Beloyarsk 1 | 100 | G/BW | Op |
| San Onofre 2 | 1140 | PWR | Cm | Beloyarsk 2 | 200 | G/BW | Op |
| San Onofre 3 | 1140 | PWR | Cm | Beloyarsk 3 | 600 | F | C |
| Forked River | 1140 | PWR | Cm | Kola 1 | 420 | PW | C |
| Zimmer 1 | 810 | BWR | Cm | Kola 2 | 420 | PW | C |
| E. I. Hatch 2 | 786 | BWR | Cm | Armenia 1 | 380 | PW | C |
| Central Aguirre | 583 | PWR | Cm | Armenia 2 | 380 | PW | C |
| Waterford | 1165 | PWR | Cm | Kursk 1 | 1000 | G/PW | C |
| Newbold 1 | 1088 | BWR | Cm | Kursk 2 | 1000 | G/PW | C |
| Newbold 2 | 1088 | BWR | Cm | Leningrad 1 | 1000 | G/PW | C |
| Bell | 838 | BWR | Cm | Leningrad 2 | 1000 | G/PW | C |
| W. B. McGuire 1 | 1150 | PWR | Cm | BN 350 | 150 | F | C |

# 6

# RAW MATERIALS

## EXPLORATION FOR URANIUM

The year saw a marked increase in tempo of uranium search by companies, particularly in the Northern Territory and South Australia, where significant additions to Australia's uranium reserves were recorded. By the close of the period, more than 80 companies were engaged in, or were about to commence, uranium exploration programs. Broad surveys, including aerial and ground-work, were carried out in a number of areas to provide guidance for more intensive prospecting.

This increase in exploration by companies took place within the framework of the Commonwealth Government's uranium exploration policy. Although it is too early to predict total reserves which will be proven in the new uranium discoveries in the Northern Territory and South Australia, it appears that major deposits will be proven in due course. The Commonwealth Government thus decided to amend its export policy in the light of these developments. Australian uranium reserves and export policy are discussed in Chapter 7.

In order to discharge its responsibilities under the Atomic Energy Act 1953-66, the Commission maintains close liaison with other organisations, including State authorities and companies. Because of its background of continuing experience in the uranium mining and treatment industry, the Commission is able to assist the industry in all aspects of these operations. The nature and products of radioactive decay give rise to a number of problems which are unique to uranium and thorium mining and processing. The solution to these problems requires experience also, and extensive laboratory equipment not available at present in industry. The Commission has these facilities and undertakes such investigations as a service to the mining and processing industries.

## COMMISSION PROGRAM

The Commission's uranium exploration program in the Rum Jungle area ceased on 30 June 1970. The land reserved for the Commission's exploration program will be released for private prospecting.

A formal announcement to this effect was made in a joint statement by the Minister for National Development and the Minister for the Interior in June, 1970. The announcement pointed out that the Rum Jungle area was one of significant geological interest, and that the Government hoped that further investigation of known uranium prospects, and additional discoveries by private enterprise, would lead to new developments in the areas to be released, and the continuance of Batchelor as a mining centre.

During the period under review, a report was compiled on the results of geological exploration carried out on behalf of the Commission by Territory Enterprises Pty. Ltd. (TEP) between October, 1969, and June, 1970.

## BUREAU OF MINERAL RESOURCES

### Northern Territory

#### Rum Jungle District

Although active prospecting for uranium by the Bureau of Mineral Resources in the Rum Jungle District ceased in 1970 in accordance with Government policy, certain geochemical and geophysical surveys begun in 1969-70 were continued and were complemented by auger and rotary drilling where necessary.

Two deep rotary percussion holes were drilled in the Shirley area east of Batchelor in the second half of 1970 as part of a more intensive study of the Crater Formation. The object of these holes was to locate the No. 1 Conglomerate of the Crater Formation and to provide core samples from the conglomerate for mineralogical and radiometric examination. In one hole, the No. 1 Conglomerate was intersected at 340 feet, and the hole was terminated at 358 feet. The other hole penetrated the Crater Formation and was completed after encountering the Celia Dolomite at 755 feet. Cores were taken for detailed examination and radiometric and electric logs were run in both holes. The gamma log showed a marked increase in radioactivity coincident with the No. 1 Conglomerate in both holes.

In the Stapleton area, further work was carried out to investigate the large Slingram anomaly over the Celia Dolomite. A radiometric traverse indicated an anomaly coincident with the boundary between the Celia Dolomite and the Crater Formation. This anomaly was investigated by shallow auger drilling. The radiometric logs and geochemical assays showed nothing of economic significance, but the geochemistry helped to distinguish between rock units in an area of poor outcrop.

Several of the anomalies located by the 1969 airborne gamma-ray spectrometer survey in the Rum Jungle area were investigated on the ground with a portable gamma-ray spectrometer. Geological mapping of the anomalies was completed, and samples were collected for radiometric assaying.

#### Tennant Creek Area

Two surveys were flown in the Tennant Creek area. The Bonney Well regional magnetic and spectrometer survey, which covered an area of about 560 square miles, aimed to delineate the structure of the Warramunga Geosyncline beneath the Cainozoic cover. Magnetometer and four channels (total, potassium, uranium and thorium) of spectrometer data were recorded. The area was found to be magnetically flat, and one isolated large anomaly in the centre of the area gave the only strong magnetic feature that may be attributable to major geosynclinal structure. No significant spectrometer anomalies were recorded.

In addition, a detailed spectrometer survey was flown over an area of about 60 square miles, records being taken of three channels with energy bands covering the main potassium, uranium and thorium peaks, and one covering the complete energy range. The data are being used to investigate the radioactive content of rock types found in the Tennant Creek field, especially the quartz-magnetite bodies and other rocks associated with known areas of copper-gold mineralisation. There are indications that it may be possible to differentiate between the various rock types by their gamma radiation. Anomaly continuity is good. The granites of the Tennant Creek Granite Complex have relatively high potassium content. Members of the Warramunga Group generate a low background in all channels, and elementary anomalies generated by the numerous dykes, veins, and beds of haematitic shale may allow spectral classification and resolution of these sources.

## Services for Prospectors

The Darwin Uranium Group continued to provide services for prospectors and mining companies and for Bureau field parties operating in the Northern Territory. These services include radiometric assaying using a 256-channel gamma-ray spectrometer, instrument repair, and maintenance of an AFMAG (audio-frequency magnetics) station near Batchelor.

## Queensland

A detailed airborne magnetic and gamma spectrometer survey was flown in the Cloncurry region over an area consisting of two strips each about 70 miles by four miles.

Most of the area is magnetically disturbed; anomalies are largely attributable to basalt members of the Soldier's Gap Formation and to dolerite dykes. The basalt-free member of this formation corresponds to a broad magnetic low. The basic members of the Soldier's Gap Formation appear to underlie a shallow cover of sediments, mainly Corella Formation, to the west and south of Cloncurry.

In the Mary Kathleen area, the magnetic anomalies are attributed to basic rocks, primarily in the Leichhardt Metamorphics-Kalkadoon Granite complex and to a lesser extent to the Argylla Formation. The Corella Formation and the Wonga and Burstall Granites are magnetically flat except for anomalies over the amphibolites, gabbros, and dolerites in the Corella Formation in the east of the area. The metamorphic zone, which includes the Mary Kathleen uranium deposit, gives rise to a broad elongate N-S anomaly of 300-400 gammas.

The radiometric data have been zoned on the basis of character and amplitude of the anomalies. The granites give rise to high thorium anomalies, with a lesser potassium contribution and only a small uranium component. There appears to be no difference between the western and eastern Burstall Granite — with which the Mary Kathleen uranium deposit is believed to be associated — and the Wonga Granite to the west.

## South Australia

An airborne magnetic and radiometric survey of the Cook, Ooldea and Barton 1:250,000 map-sheet areas in the eastern part of the Eucla Basin, to determine basement structure and depth and to detect surface radioactivity in rock outcrops, was completed and interpreted.

In the areas of basement outcrop or near-outcrop in the Barton map-sheet area, the magnetic interpretation took the form of zoning based on differences in magnetic intensity and in linearity of magnetic anomalies. Each zone was characteristic of a rock type, and the zones could be roughly correlated with Bouguer gravity anomalies available from regional gravity surveys.

Depth estimates were made for the source of anomalies within the basin and contours of magnetic basement depth were constructed. Several significant features are apparent in the basement topography. A north-striking trough about 10,000 feet deep is interpreted as passing centrally through the Ooldea sheet area, the remainder of the area showing rather shallow basement. In the Cook map-sheet area, a trough about 8,200 feet deep strikes northwest across the central part. These features all have broadly corresponding gravity expression.

The radiometric results indicated that the sandstone outcrops in the northeast of the Barton map-sheet area, and the salt lakes, give rise to radioactive highs. The general background radioactivity of the Tertiary Nullarbor Limestone, which occupies the Cook and most of the Ooldea sheet areas, was found to be appreciably higher than that of the Quaternary sand and alluvium to the east.

# COMPANY EXPLORATION

## Queensland

In Queensland, the areas of most active uranium exploration were the Mt. Isa-Cloncurry and Westmoreland districts where further additions to Australia's uranium reserves were recorded. In both areas the most active company was Queensland Mines Ltd.

**Mary Kathleen Uranium Ltd.**

The treatment plant and township at Mary Kathleen, Queensland, were kept on a care and maintenance basis pending an improvement in the uranium sales market.

A substantial drilling program to test for extensions of the Mary Kathleen orebody, and a computerised study of the geological data obtained from this program to determine ore reserves and pit design, were completed in 1969. Reserves are currently stated by the company at approximately 10,000 short tons uranium oxide ($U_3O_8$).

In May, 1967, the company was granted permission to export 5,000 short tons $U_3O_8$ subject to satisfactory safeguards and price arrangements. Approval to export a further 2,000 short tons $U_3O_8$ under the same conditions was granted to the company in September, 1970. In March, 1971, the Government again increased its approval to export to cover any amount of contained uranium oxide which did not exceed 15,000 tons in total.

Discussions were held with a number of possible buyers during the period under review, and contracts have been negotiated for the delivery of 2,757 short tons $U_3O_8$ between 1975 and 1979. As a result of these contracts, the company announced that it expects to begin production of uranium concentrates in 1974. The company has also reached agreement for a third contract of 1,100 short tons $U_3O_8$ for delivery between 1977 and 1981, and further contracts are under consideration.

Because of the high rare earth content of the Mary Kathleen orebody, the company is undertaking metallurgical research into the possible development of a process for the economic extraction of rare earths in conjunction with its uranium production.

**Queensland Mines Ltd.**

The company continued its program of intensive exploration in the Westmoreland area, but reduced its operations in the Mt. Isa area due to the necessity to divert staff to assist in the evaluation of the Nabarlek discovery and surrounding areas in the Northern Territory.

Despite this curtailment of activity, the company completed developmental drilling on 14 of its 42 mineral leases in the Mt. Isa area and, as a result, the company intends to carry out further evaluation of six of these leases by diamond drilling. Previous drilling in the Valhalla leases had outlined 1,910 short tons of $U_3O_8$ at an average grade of 3 lb $U_3O_8$/ton and the company intends to carry out further drilling to determine the extension of mineralisation at depth.

A total of 25 diamond drill holes and 176 percussion drill holes, totalling 53,871 feet, were completed in the Mt. Isa area. The company believes that there are good possibilities of increasing its reserves of 6,200 short tons $U_3O_8$ at a grade of 3-4 lb $U_3O_8$/ton during 1971.

An intensive systematic drilling program began in the Westmoreland area in May, 1969, to evaluate the Red Tree deposit and the adjacent secondary deposit, and 403 rotary percussion and diamond drill holes have been completed to date. As a result of this drilling program, the company has announced proven reserves of approximately 14,000 short tons $U_3O_8$ at a grade of +3 lb $U_3O_8$/ton. Recent drilling has located new secondary deposits on the side of the joint zone which have no associated surface radioactive expression, and core from current drilling is giving higher grades.

Approximately 80 percent of the primary Red Tree joint zone has now been drilled. The remainder will be tested during the current field season. In addition, the company plans to carry out an intensive drilling program in the shallow alluvial cover overlying the north-easterly extension of the joint system.

Prospecting at Long Pocket, 14 miles to the east of the Red Tree deposit, has outlined the presence of a dyke structure similar to that at Red Tree, with both primary and secondary mineralisation. Subsequent drilling has indicated that this extensive surface mineralisation does not persist with depth. The average grade of the material outlined by the drilling program in this area was just over 1 lb $U_3O_8$/ton and is not considered economic at current world market prices. Drilling was suspended because of the grade, after indicated reserves of approximately 2,000 short tons $U_3O_8$ had been outlined. The company plans to investigate three other anomalous areas in the Westmoreland area during the current field season.

During 1970, the company completed 65 diamond drill holes, totalling 36,435 feet, and 137 percussion holes totalling 14,202 feet.

## Northern Territory

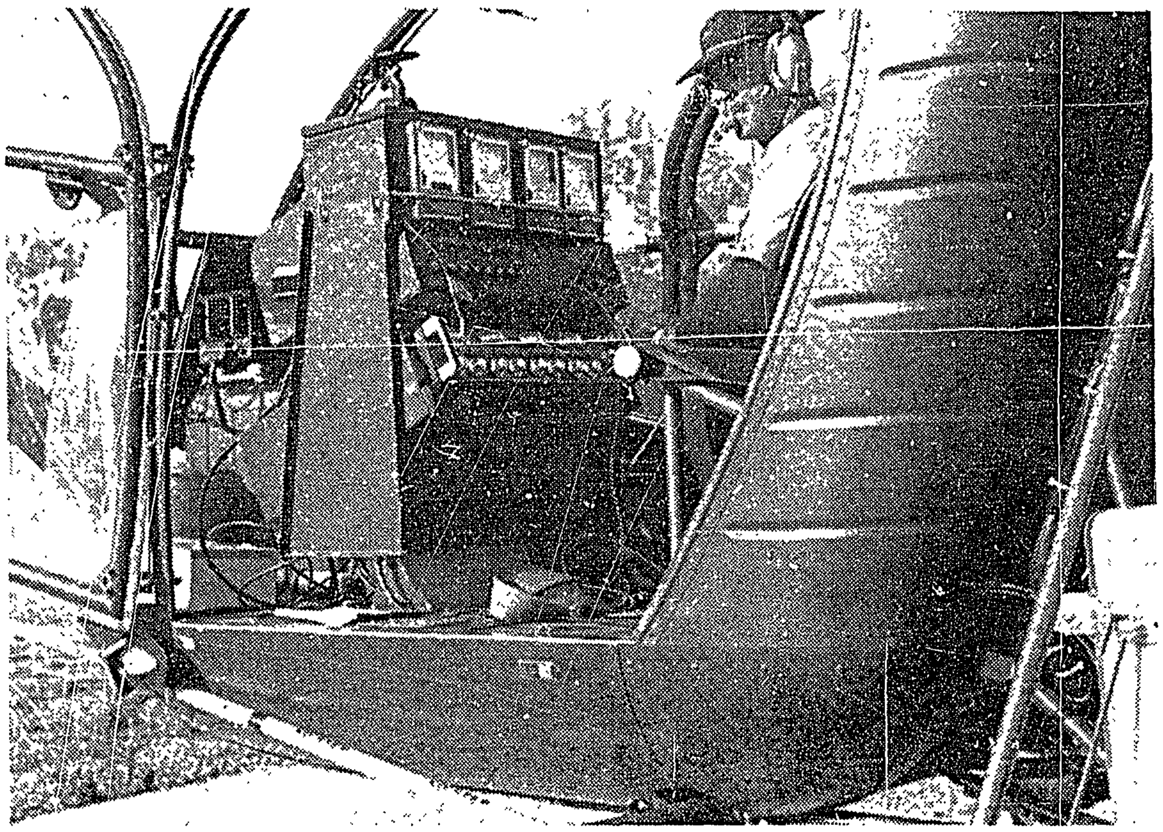
Exploration for uranium was particularly active in the Northern Territory, especially in the newly emergent Alligator Rivers Uranium Field, where significant additions to Australia's uranium reserves were announced by the companies undertaking exploration in this area. Although it is too early to predict total reserves which will be proven in these areas, it appears likely that major world deposits will be proven in due course.

### Queensland Mines Ltd.

Geological reconnaissance was undertaken on areas now held in the Northern Territory, after which the company began an intensive exploration program in the Oenpelli region to test a number of anomalous areas discovered during an airborne gamma-ray spectrometer survey in mid-April, 1970.

A very prominent radiometric anomaly was located at Nabarlek, some 18 miles east of the Oenpelli Mission. Several costeans were excavated across the anomaly and encountered high-grade uranium mineralisation near the surface. Channel samples were collected for assay and a diamond drilling program to test this discovery began on 23 July 1970.

As a result of costeaning work it was found that the mineralised zone consisted of a central solid pitchblende lode, approximately two feet thick, surrounded by a zone of orange uranium ochres (gummite). This orebody extended to within four feet of the ground-surface, had a strike of 330 degrees and an average dip of 45 degrees to the northeast. Drilling revealed that, on each side of this central core



*Helicopter equipped with a gamma-ray spectrometer for airborne radiometric surveys to establish the presence of anomalies. Detailed examination of these areas is undertaken later by ground parties. (Photo: Queensland Mines Ltd.)*

consisting of pitchblende lenses, the metamorphic host rocks contained patchy pitchblende giving a high-grade mineralised zone with an average combined width of 28 feet.

An all-weather airstrip, camp site, and other facilities were established. Supplies flown in by helicopter enabled exploration and drilling to be maintained throughout the wet season. The subsequent drilling program has shown that the orebody has a length of 830 feet, and consists of a number of individual lenses and ore shoots. The grade of the pitchblende is quite variable, ranging from 10 lb $U_3O_8$/ton to 1,480 lb $U_3O_8$/ton. In view of the grade variation, drilling is currently being undertaken on 50 foot centres.

A dolerite sill, some 700 feet thick, was encountered at a depth of 210 feet in the centre of the deposit. The metamorphics occur again beneath this sill and a deep drilling program to test for the possible continuation of the uranium mineralisation at depth will be undertaken at a later stage.

The company has located four additional radiometric anomalies in metamorphic rocks in an inlier to the southeast of the Nabarlek deposit. An economic assessment of these anomalies will be carried out during the current dry season.

In addition, several radiometric anomalies have been disclosed as a result of airborne scintillometer surveys in the company's 2,155 square mile Authority to Prospect to the south of the Nabarlek area. Follow-up ground reconnaissance is in progress to assess these anomalies.

Aerial and ground radiometric surveys in the Katherine area failed to discover any economic uranium mineralisation and the areas have been surrendered.

The company is undertaking a joint exploration program with Australian Aquitane Petroleum Pty. Ltd. in the Rum Jungle area.

**Peko Mines N.L.**

At about the same time as Queensland Mines Ltd. announced its discovery, Peko Mines N.L. announced that its joint exploration program with the Electrolytic Zinc Company of (A/asia) Ltd. had located a series of radiometric anomalies near Mudginbarry Station, some 30 miles southwest of the Nabarlek deposit.

One of these anomalies, Ranger I, had a strike length of 20,000 feet and varied in width from 660 to 3,300 feet. A detailed radiometric survey revealed the presence of three areas of high radiometric intensity within the Ranger I anomaly. The No. 1 anomaly area is located at the mid-point of the Ranger I prospect and appears to be marginally the most important of the three anomalies. The second most important anomaly is the No. 3 anomaly which occurs in the northernmost section of the Ranger I prospect, whilst the No. 2 anomaly, which lies to the south of No. 1, has not yet revealed positive ore potential.

The company began a percussion drilling program to test the three anomalies and 39 holes totalling 12,685 feet have been completed to date. An ore zone some 985 feet wide and 1,000 feet in strike length was outlined in the No. 1 anomaly by percussion drilling involving 20 holes totalling 6,732 feet to an average depth of 335 feet. The average grade of ore, based on percussion drilling sampling, was 6 lb $U_3O_8$/long ton.

Sixteen percussion holes were drilled on the No. 3 anomaly to an average depth of 328 feet, and outlined the presence of two discrete ore zones. This deposit has a surface zone of mineralisation approximately 10 feet thick at an average grade of 3-4 lb $U_3O_8$/long ton, below which occurs a barren zone varying in thickness from 66 feet to 115 feet. This is succeeded by an ore zone, similar in nature and grade to that in the No. 1 deposit, which has not yet been bottomed.

As a result of this preliminary drilling program, the company announced that it had discovered an indicated resource of 77,000 short tons $U_3O_8$ in the No. 1 and No. 3 anomalies at Ranger I.

A program of diamond drilling to further delineate and evaluate the orebodies is in progress and 21 drill holes totalling 17,773 feet had been completed by the end of the period under review. Recent assay results have indicated a grade somewhat in excess of the initial 6 lb $U_3O_8$/long ton obtained from the percussion drilling program The company estimates that detailed testing of the Ranger I prospect will require at least two years of intensive drilling and that production would not begin before 1976.

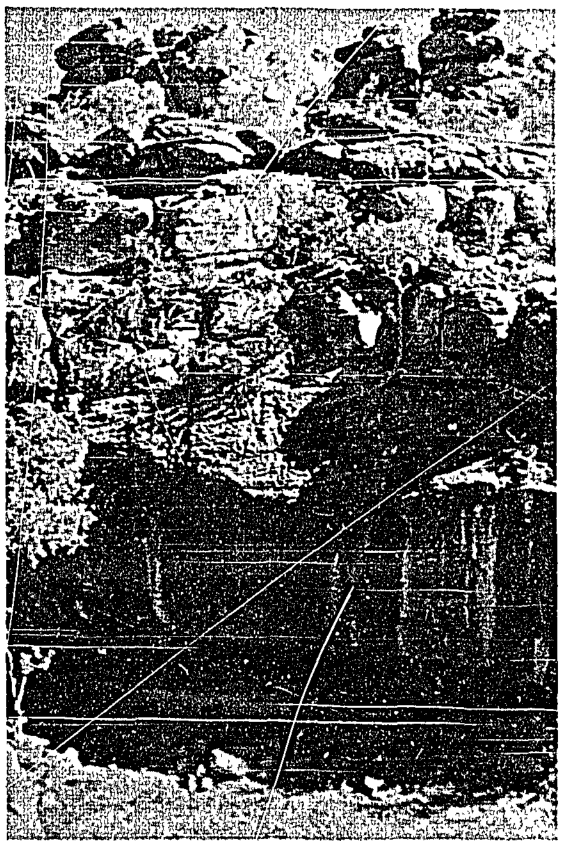
The Ranger I prospect is located in the southeast corner of the company's 961 square mile Authority to Prospect, and the remaining airborne anomalies in this region will be investigated duing the current field season. All-weather roads, airstrip and camp site were constructed to enable exploration and drilling to be maintained throughout the year on the Ranger I prospect.

The company maintained its joint venture with United Uranium N.L., Newmont Pty. Ltd., and the Electrolytic Zinc Company of (A/asia) Ltd., over areas of good uranium potential in the South Alligator River Valley and Pandanus Creek areas during the period under review (United Uranium N.L. is the operator for this venture). The company is also involved in joint ventures for uranium in a number of other areas in the general vicinity of the lower reaches of the South Alligator River area.

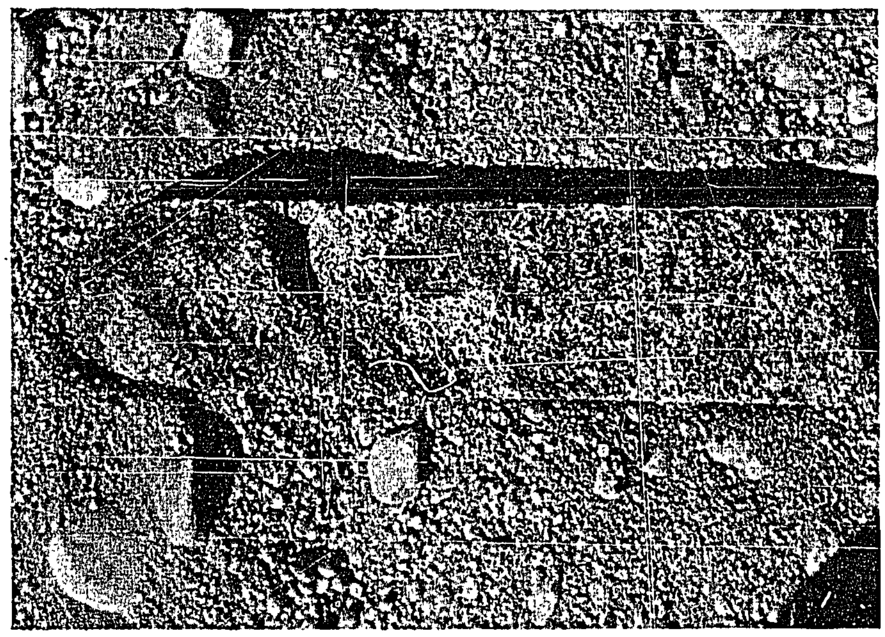
**United Uranium N.L.**

Pending resumption of uranium mining, the company has been treating base metal ores in the treatment plant at Moline, N.T., for several years. Treatment of

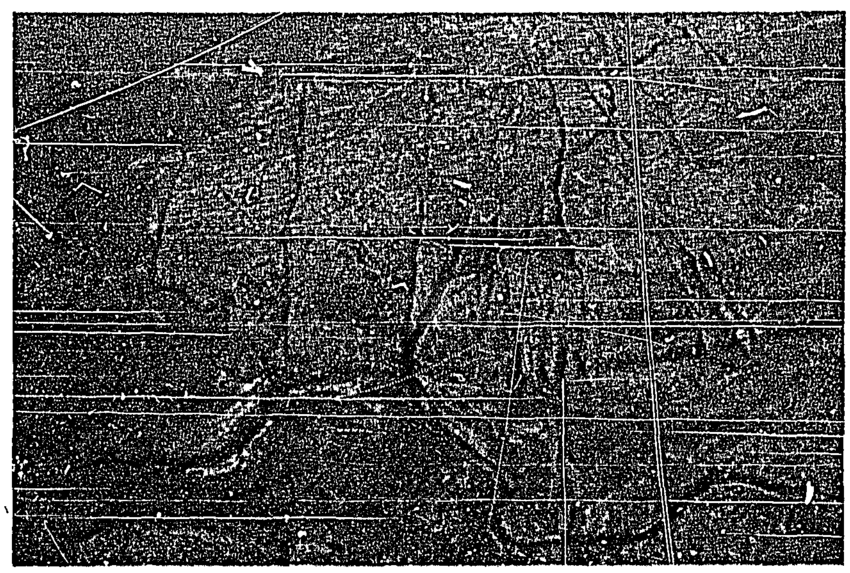
## URANIUM EXPLORATION



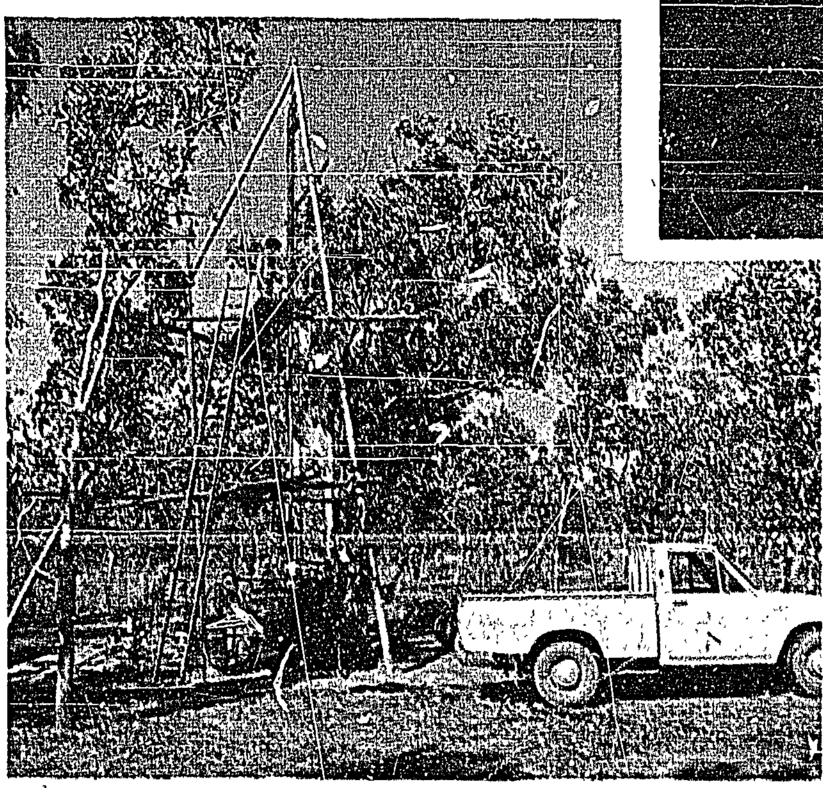
*Above: Site of occurrence of secondary uranium mineralisation in coarse conglomerate, Westmoreland area, northwest Queensland.*



*Above: Diamond drill core from the Queensland Mines Ltd. Red Tree uranium deposit at Westmoreland.*

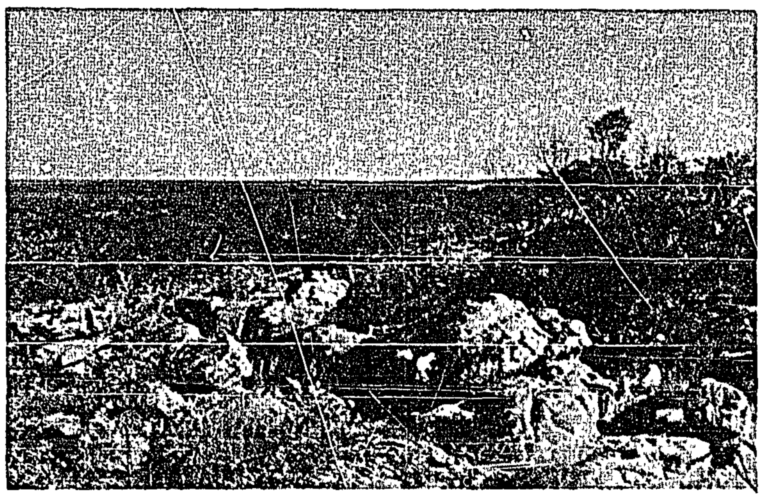


*Above: Aerial photograph showing the typical extensive jointing in the Kombolgie Sandstone Formation of the Arnhem Land Plateau, in an area near the Katherine River, Northern Territory.*



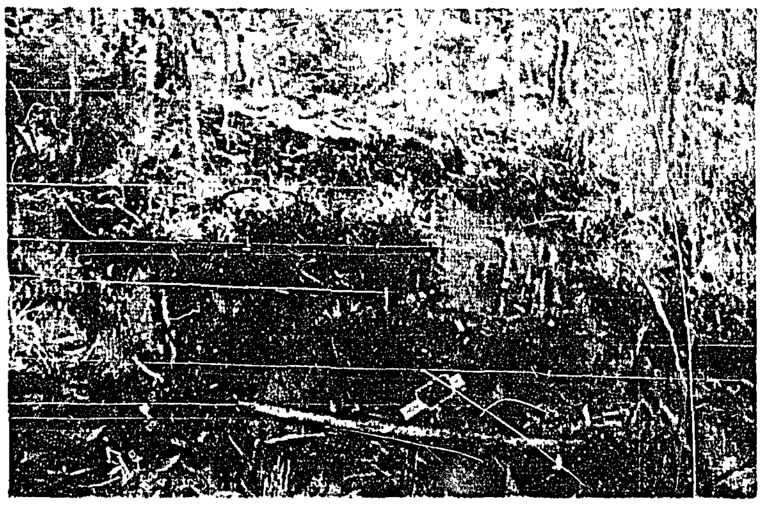
*Left: Diamond drilling in the Northern Territory on the Peko-E.Z.'s Ranger I prospect near Mudginbarry Station, 140 miles east of Darwin. (Photo: Peko Mines N.L.)*

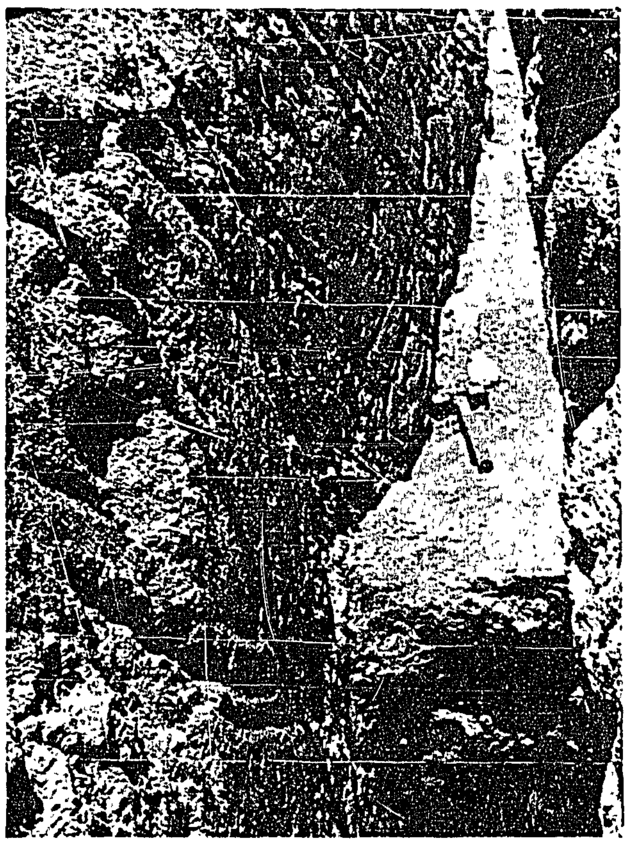
PLATE 6



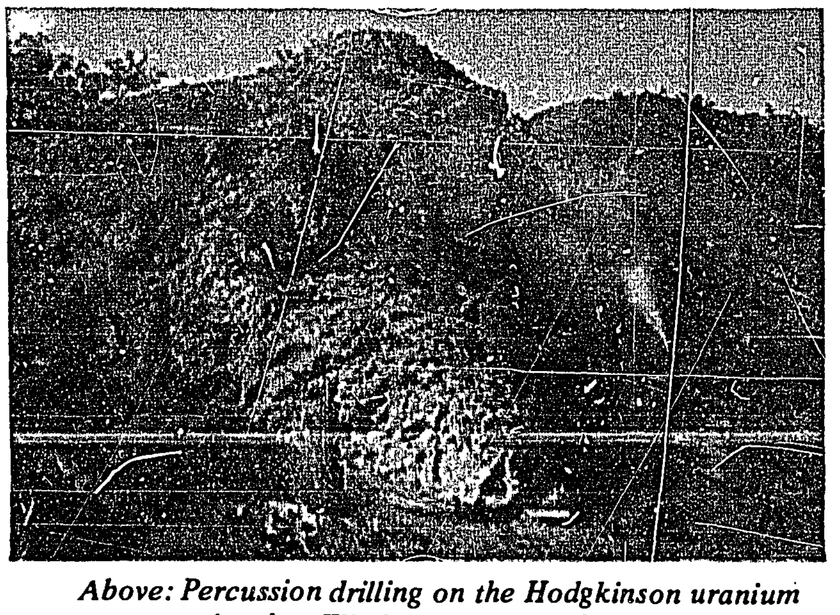
*Above: Typical outcrop of Roper Group sandstone in the Limmen Bight area, Northern Territory. Exploration in this area is being carried out by Kratos Uranium N.L., Pechiney (Australia) Exploration Pty. Ltd., and Wyoming Mineral Corp. (a wholly owned subsidiary of the Westinghouse Electric Corp.). (Photo: Pechiney.)*

*Below: A radioactive spring in Kratos Uranium N.L.'s Authority to Prospect in the Limmen Bight area, Northern Territory. Various techniques are being employed to trace the origin of the radioactivity in the water. The Commission is assisting with the analysis of samples. (Photo: Pechiney.)*

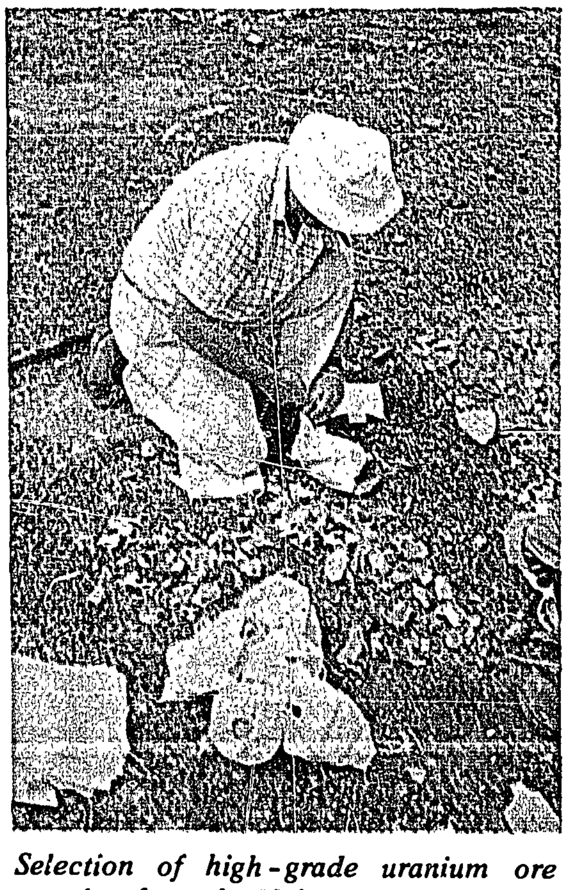




*Above: Uranium ore exposed in a costean at the Queensland Mines Ltd. uranium prospect at Nabarlek, Northern Territory. (Photo: Queensland Mines Ltd.)*



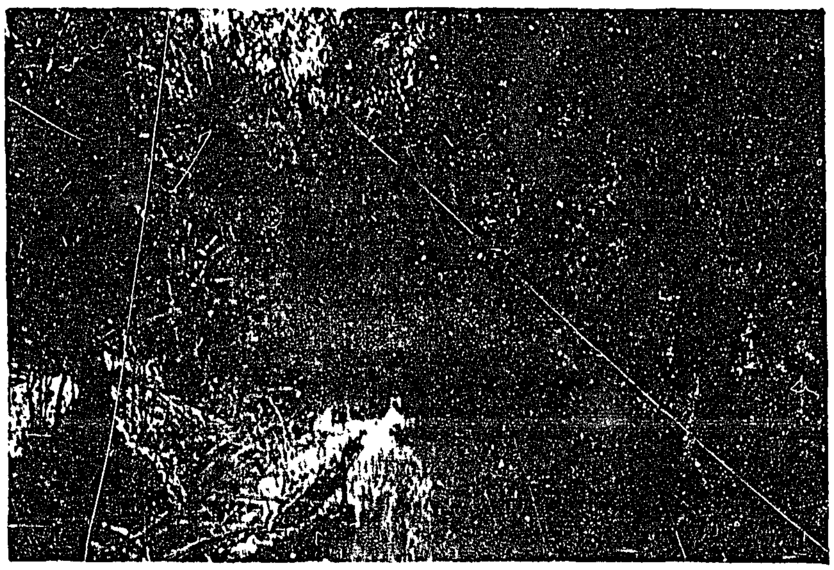
*Above: Percussion drilling on the Hodgkinson uranium prospect in the Flinders Ranges, South Australia. Exploration in this area is being undertaken by Exoil N.L.-Transoil N.L.*

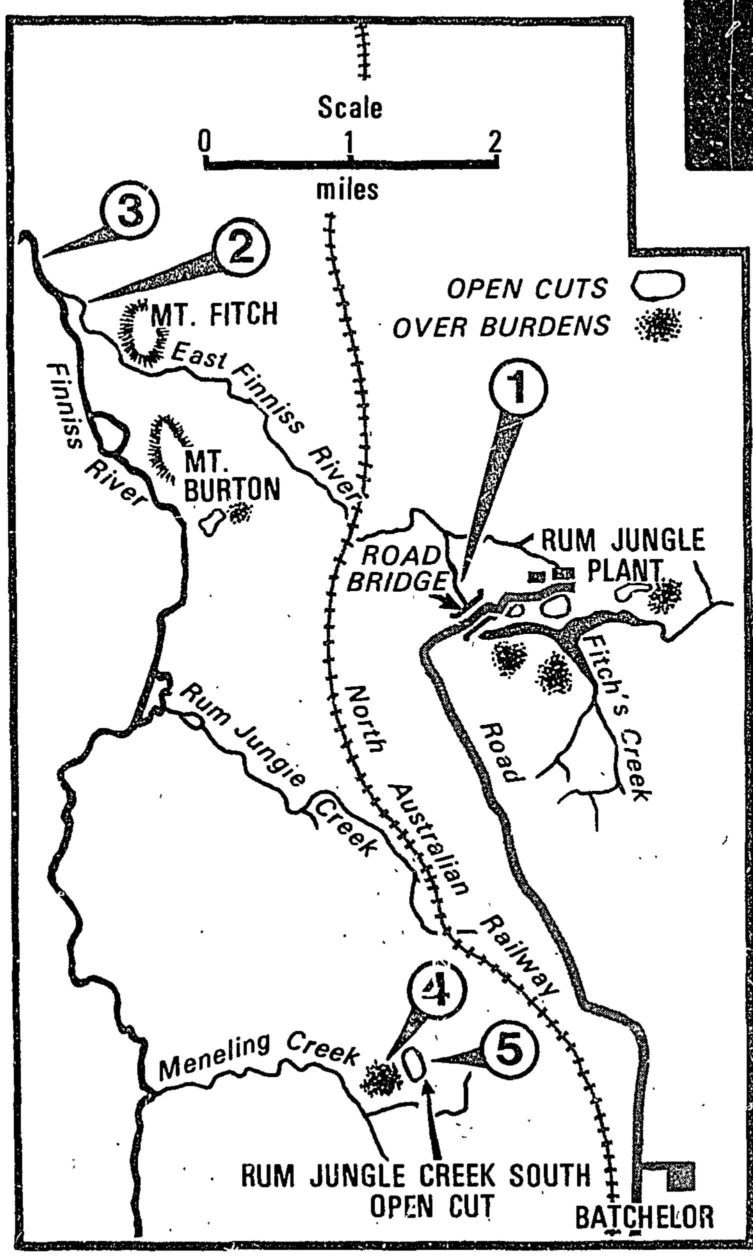


*Selection of high-grade uranium ore samples, from the Nabarlek prospect, for metallurgical test work. These tests were carried out at the Rum Jungle treatment plant during the period under review.*

## RUM JUNGLE AND ENVIRONS

*Uranium was first discovered at Rum Jungle in 1949. Mining began in 1954 and processing continued until April 1971, when stock-piled ore was exhausted. See section on Rum Jungle Environment pages 52-54.*






*Top: A billabong on the East Finniss River, a tributary of the Finniss River, ¼-mile downstream from the roadbridge. See map. September 1970.*

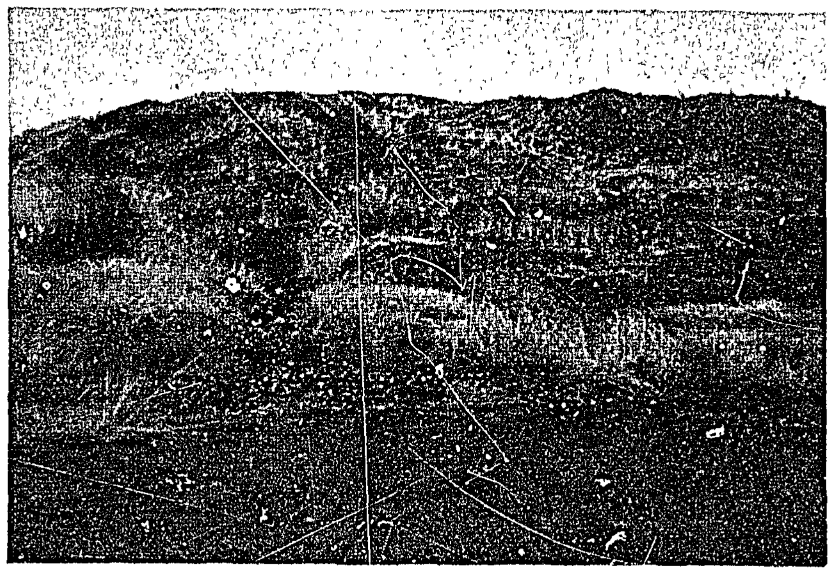
*Above:The East Finniss River, six miles downstream from the roadbridge. September 1970.*

*Left: Sketch map of the Rum Jungle area.*

PLATE 8

*Left: Billabong on the Finniss River, near junction with the East Finniss River. Crocodiles and large fish inhabit all parts of the main river. September, 1970.*

*Rum Jungle Creek South overburden heap showing grass cover. Photograph taken in May 1971 at end of the wet season.*



*Rum Jungle Creek South overburden heap, June 1971. The water-filled Rum Jungle Creek South open-cut, at the foot of the overburden heap, is now used for swimming and boating. This artificial lake has a surface area in excess of 50,000 sq. yards.*

silver-lead-zinc ore from the Evelyn Mine ceased towards the end of 1970 when the company commenced treatment of copper ore from the Mt. Diamond mine.

Uranium exploration in both the South Alligator River and Pandanus Creek areas was aimed at extending geological mapping of selected areas and drilling of indicated targets. In addition, an airborne radiometric survey was undertaken over 1,500 squares miles in late 1970.

Follow-up drilling at Coronation Hill, Scinto VI and on the South Alligator Fault failed to detect any significant anomalous uranium mineralisation.

Extensive geological mapping and radiometric gridding was carried out in the Monolith-Koolpin-Scinto, Scinto Plateau, Stockpile and Saddle Ridge areas, but no significant anomalous radioactivity was encountered.

A number of airborne radiometric anomalies were located in the South Alligator Valley as a result of a recent survey, and will be investigated in the current field season.

Follow-up ground radiometric surveys and drilling in the Pandanus Creek area outlined several areas of anomalous radioactivity, which will be further investigated during the current year.

Previous drilling at N.E. Westmoreland encountered widespread low-grade uranium mineralisation up to 3.3 lb $U_3O_8$/short ton in a number of holes. Similar intersections were again encountered in the current season's drilling program.

Follow-up drilling at El Hussen and Cobar II failed to detect significant anomalous radioactivity.

An extensive and complex airborne anomaly was located in the vicinity of the Fish River Gorge and preliminary radiometric gridding and pitting is in progress. Further evaluation will be carried out on this and a number of other anomalies during the current year.

## Western Australia

Almost all favourable areas for uranium were under intensive exploration during the year. The main emphasis changed from the Kimberley area, where exploration is difficult because of the effect of tropical leaching on surface rocks and the widespread occurrence of thorium, to the Pilbara-Nullagine and Yilgarn-Yalgoo-Mt. Margaret Goldfield areas of the State.

Although a number of companies are carrying out uranium exploration, most exploration programs are at an early stage of development and no significant uranium mineralisation has been located to date. Anomalous radioactivity has been recorded from a number of areas, and follow-up drilling will be undertaken in most of these in the current year.

## South Australia

The year saw a marked increase in the tempo of uranium exploration in South Australia, especially in the Mt. Painter-Lake Frome area where significant additions to Australia's uranium reserves were recorded.

### Petromin N.L.

This company, in conjunction with Exoil N.L./Transoil N.L., continued its major drilling program to evaluate what appear to be significant sedimentary uranium deposits in the Lake Frome area.

These uranium deposits appear to be syngenetic in origin, having been removed from their original granite source rocks in the adjacent Flinders Ranges and redeposited in the sediments in which they are now found. Two orebodies have been discovered to date in this area by follow-up drilling. The ore zone in the Beverley prospect occurs at an average depth of 400 feet and has an average thickness of 14 feet. The company recently announced that indicated reserves of 5,600 short tons $U_3O_8$ had been outlined by drilling. To date 98 drill holes totalling 47,530 feet have been completed. Further drilling to delineate the limits of the orebody is in progress.

A potentially larger deposit has been located some three-quarters of a mile north of the Beverley prospect, and the company has announced that initial drilling results have established indicated reserves of 5,300 short tons $U_3O_8$ at an average grade of 3.1 lb $U_3O_8$/ton over a thickness of 20 feet. The company is maintaining an intensive drilling program on this prospect and reserves are being increased. A total of 102 holes totalling 46,920 feet has been drilled on this prospect to date and further drilling is in progress.

**Exoil N.L.-Transoil N.L.**

This partnership has carried out an intensive uranium exploration program in the Mt. Painter area of the Flinders Ranges during the past four years. During this period, the companies have located uraninite-hematite-chlorite-sulphide mineralisation, which replaces conglomerate layers within an unmetamorphosed sequence of granitic rocks (interpreted as acid volcanics); minor sandstone and siltstone are also present. The Mt. Gee, Armchair-Streitberg Ridge and Radium Ridge deposits are of this type.

A second type of mineralisation occurs at Hodgkinson Prospects, where granitic rocks have been brecciated and replaced by silica, pyrite and uraninite. Later brecciation has allowed a secondary enrichment of sooty uraninite, chalcedony and pyrite.

The old workings in the East Painter area are of a third type of mineralisation, viz., the occurrence of torbernite in shear zones close to the layered deposits. It appears that the uranium has been leached from the layers and redeposited in the shear zones.

As a result of this exploration and drilling program, the partnership has outlined four orebodies in this area to date, and indicated reserves of 8,025 short tons $U_3O_8$ were announced by the companies concerned in December, 1970, as follows:

| *Orebody* | *Quantity of Ore* (tons) | *Grade* (lb $U_3O_8$/ton) |
|---|---|---|
| Hodgkinson | 250,000 | 5.0 |
| Mt. Gee | 3,000,000 | 2.0 |
| Armchair-Streitberg Ridge | 2,000,000 | 2.0 |
| Radium Ridge | 4,000,000 | 1.2 |

Although the reserves are substantial, they are probably uneconomic at this stage having regard to the size and grade of the recent discoveries in the Alligator Rivers Uranium Field and the Lake Frome areas and the immediate market position. The future of these prospects will to a large extent, depend on the market resulting from substantial increases in world demand forecast for the late 1970s. The company, therefore, has decided to reduce its level of exploration activity in this area pending an improvement in the world uranium sales market.

### Other States

Some uranium prospecting was carried out in New South Wales and Victoria but no significant uranium mineralisation was discovered during the period under review.

## PRODUCTION OF URANIUM

Production of uranium chemical concentrates in Australia was again confined to the Commonwealth-owned plant at Rum Jungle. Since January, 1969, below-ore-grade uranium-bearing material, which was stockpiled when the Rum Jungle Creek South and Dyson's orebodies were mined, has been blended with normal-grade ore and treated in the plant. In consequence, the head feed grade to the plant has been lowered and output was somewhat less than in previous years. The uranium concentrate produced was stockpiled.

Territory Enterprises Pty. Ltd. (TEP), the wholly-owned subsidiary of Conzinc Riotinto of Australia Ltd., continued to manage the Rum Jungle Project on behalf of the Commonwealth. The Commission would like to place on record its appreciation of the manner in which the company has discharged its responsibilities since the inception of the Rum Jungle Project. Investigations of the economic and technical feasibility of a number of proposals to continue uranium production at Rum Jungle resulted in a particularly active year for staff at Rum Jungle.

When the Rum Jungle Creek South (RJCS) orebody was mined in 1961-62, some 4,870,000 tons of mullock was stockpiled in a large overburden heap by the open-cut mine and, as part of the Commission's continuing research into the extractive metallurgy of uranium included heap-leaching, the Commission requested TEP to investigate the possibility of heap-leaching the mullock heap. Auger drilling totalling 3,000 ft was undertaken to assess the uranium grade of the mullock heap, and this showed that the main mullock heap contained 1,948,000 lb uranium oxide ($U_3O_8$) at a grade of 0.40 lb uranium oxide per ton. Laboratory test-work showed that, using realistic assumptions, it was economically and technically feasible to produce uranium at less than $7/lb by heap-leaching the RJCS mullock heap. The remaining mullock heaps in the Rum Jungle area were drilled to ascertain if they could also be exploited economically.

A pilot-scale heap-leach test was then undertaken on 293 tons of material from the RJCS mullock heap. A recovery of 50 percent of the contained uranium was obtained after 90 days continuous leaching, using both spray and flood irrigation. This pilot plant test again confirmed the economic and technical feasibility of heap-leaching the mullock heap and a detailed proposal was prepared and evaluated. At about the same time, Queensland Mines Ltd. approached the Commission concerning the possibility of toll treatment of uranium ore from its Nabarlek deposit, Northern Territory, in the Rum Jungle treatment plant. The Commission authorised TEP to undertake metallurgical tests on high-grade uranium ore from the Nabarlek deposit. This program showed that the Nabarlek ore was amenable to treatment in the Rum Jungle plant, and an evaluation was made of heap-leaching the RJCS and Dyson's mullock heaps in conjunction with toll treatment of Nabarlek ore in the Rum Jungle treatment plant. Although for technical reasons it was preferable to treat the Nabarlek ore in conjunction with low-grade material in the Rum Jungle area, an assessment was also made of the feasibility of treating Nabarlek ore by itself in the Rum Jungle plant. The tests showed that in either situation a good recovery could be achieved. However, the company decided for a number of reasons not to proceed with the venture. The Government then decided to close down the Rum Jungle operation and the treatment plant and other assets were sold by public auction after the close of the year under review.

### Significance of Rum Jungle Project

Since its inception in 1952 the Rum Jungle Project has been of importance in the development of the Northern Territory and, until recently, was the largest single industrial enterprise in the Territory. Treatment of uranium ore has taken place continuously since mining operations began in 1954.

In 1968, the Government authorised the Commission to undertake a pre-mining evaluation of the Mount Fitch uranium deposit, to continue treatment of the Rum Jungle Creek South below-ore-grade uranium mineralisation, and to refer to the Government proposals to mine and treat any proven additional economically recoverable uranium reserves in the Rum Jungle area.

The evaluation of the Mount Fitch orebody was undertaken by TEP, in consultation with the Australian Mineral Development Laboratories, and was completed early in 1970 within the approved budget. The study showed that it was technically feasible to treat this ore in the Rum Jungle plant. Total uranium oxide production was estimated to be 950 short tons uranium oxide. It was decided not to proceed with the mining and treatment of the Mount Fitch orebody because of the high cost of production.

Over the years, the Rum Jungle Project has made significant contributions to research and development in uranium exploration, mining, extractive metallurgy and waste disposal. The research and development projects undertaken in the field and the laboratories at Rum Jungle have been important, and are comparable with the advances made in the search for oil and natural gas, which were also supported by the Government. Development of heap-leaching, *in situ* underground leaching, flotation, electronic and colorimetric ore sorting and other advanced beneficiation techniques can be expected to be important, not only to the Australian uranium mining industry, but also to the mining industry generally.

Recent research projects include bore-hole logging techniques in sedimentary uranium deposits, metallurgical and petrographical studies on a number of refractory and low-grade uranium orebodies, rapid and non-destructive assaying of uranium ores by delayed neutron activation analysis, waste disposal management and rehabilitation studies associated with the mining and milling of radioactive ores.

## RUM JUNGLE ENVIRONMENT

The Rum Jungle operation has now ceased and a chapter in the history of uranium production in Australia is finished. The main ore bodies — White's, Dyson's and Rum Jungle Creek South — have been mined and the uranium extracted.

In the course of exploration, apart from valuable and significant discoveries of uranium, a lead orebody, a copper orebody and a silver-lead-zinc orebody were also discovered.

The widespread geological and geophysical investigation of the area, one of the most intensive carried out in Australia, provided a testing ground for many new ideas and practices relating to the search for minerals.

The township of Batchelor with its woodland setting and excellent amenities of many kinds, including shops, school, hospital, swimming pool, cinema, playing fields, and a high standard of housing, showed for the first time that people from the more-temperate parts of Australia could live, work and be happy in the tropical climate of the Northern Territory and conduct a mining industry under suitable conditions.

The mining operations involved a treatment plant, three opencut mines, two close to the plant and one a little distance away. Opencut mining inevitably disturbs the countryside. This problem is increased in the north by the annual wet season when all rivers run in flood, and all low ground is waterlogged, if not flooded, for about three months a year.

The East Finniss River passes close to the first opencut mine. This river is normally a dry watercourse, with an occasional billabong, and stretches for about six miles to its junction with the Finniss River. In the early days of the mine, some local pollution of the East Finniss River took place during the wet season when unexpectedly heavy rain breached containing walls and other works. Some trees were killed in the vicinity of the plant and the mine, partly by flooding and partly by chemical effects. However, steps were taken to minimise these effects and to provide better control.

A program of sampling and analysis of surface water in the area, carried out under difficulty in the wet season, has indicated that there is some minor pollution of the East Finniss River. This arises from natural leaching during the wet season of the rocks and overburden heaps in the vicinity of the treatment plant. The quantities of contaminants involved are not large, and they are diluted greatly in the river flows during the wet season. Damage is limited, local and temporary. There is no permanent effect on the Finniss River nor is there a danger to human, animal or fish life in the area. During the dry season, creeks adjacent to the plant and also the East Finniss River cease to flow and the billabongs continue to evaporate. In the dry stream beds and around some of the remaining water pools, a whitish incrustation may form. Visually this deposit could be taken as a consequence of pollution. However, it is composed mainly of calcium and magnesium sulphates, which are innocuous, and dissolve readily when flow recommences in the wet season. These deposits do not constitute a danger to flora or fauna in the area.

Towards the end of the 1970 dry season, a further inspection of the East Finniss-Finniss River system was made. No widespread destruction of trees or other flora was observed along the river banks; numerous fish were observed in the billabongs and Finniss River and several crocodiles were disturbed and entered the water. The water was quite potable. Photographs taken in 1970-71 show the natural bush at several places along the rivers, and also growth of vegetation on overburden heaps. (See colour Plates 7 and 8.)

During the past year, Territory Enterprises Pty. Ltd. has been authorised by the Commission to undertake a further program of work at Rum Jungle to prevent any occurrence of local pollution after shut-down, and to ensure the general rehabilitation of the area. Work carried out has included raising the retaining wall of White's opencut, earthworks to reduce its overflow into the East Finniss River, planting of trees and grass on the tailings area, removal of trees killed by flooding in low-lying areas, and general clean-up around the plant by removing the accumulation of discarded equipment, scrap iron, etc.

In the vicinity of the opencut mines there is some scouring, as well as overburden heaps. Both must be expected to result from any large-scale opencut operation. There is no question, on economic grounds, of returning the overburden into the opencuts. Some natural leaching is inevitable during the wet season. The effects are not widespread and, in any case, they are expected to decrease with time. Grasses and trees are already growing naturally on the overburden heaps. Further growth is expected and this should rehabilitate these areas in a short period, making them indistinguishable from the surrounding country.

Recreational facilities, including fireplaces, diving board, and planted trees and grass have been established near the water-filled opencut at Rum Jungle Creek South. Staff and visitors regularly use this area for swimming and boating.

The rehabilitation program will be completed by the time the Commission and Territory Enterprises Pty. Ltd. vacate the area after disposal of the assets. It is expected to lead to adequate pollution control and rehabilitation.

# POLLUTION CONTROL AND SAFETY IN URANIUM MINING

The Commission has a background of continuing experience in all aspects of health and safety, and pollution control, arising from its own mining and treatment operations in the Northern Territory at Rum Jungle, from its association with similar uranium operations in the South Alligator River Valley and Mary Kathleen areas, and its contact with practices in the uranium mining industry throughout the world.

Pollution problems may arise in a number of ways during mining, transport, storage and treatment of uranium and other radioactive ores. Some of these problems are similar to those associated with other minerals, such as waste disposal of effluents containing mill reagents, but there are aspects unique to radioactive materials because of the nature and products of radioactive decay. For the detection, analysis and control of potential sources of radioactive pollution, specialist knowledge of how to interpret and apply the approved standards and limits is required. This knowledge must be supported by appropriate analytical skills and equipment. The Commission is able to assist the uranium mining industry in these matters.

## CODE OF PRACTICE FOR HEALTH AND SAFETY

The Commonwealth Government has established a committee to assess and report on the possible hazards involved in the mining and processing of radioactive mineral deposits. A working panel, on which the Commission is represented, has been formed to formulate an Australian Code of Practice.

Uranium ores (and to a lesser extent all materials of the earth's surface) contain, in addition to uranium, other radioactive elements which are the products (daughters) of radioactive decay. Radon gas emanates from exposed ore surfaces, giving rise to its daughters in the mine atmosphere. Radon can also travel long distances dissolved in groundwater, being released when the pressure on the water is lowered. Ores show a wide range of uranium concentrations and of emanating properties. Once the natural situation is disturbed, the radioactive equilibrium between uranium and radon (and its daughters) may be changed, thereby causing further variability of the emanating rate for a given amount of uranium and also of the gamma radiation level associated with the ore.

In addition to the occupational hazards of conventional mining, the mining of radioactive ores poses problems of radiation exposure. Mining operations may release radon and its daughters into the atmosphere. If inhaled, these can be deposited in the respiratory system. Thus, radon gas, together with its radioactive daughters, is a hazard in the mining and milling of radioactive ores. Such miners are also exposed to silica dust, powder gases, oxygen-deficient atmospheres and the probability of mechanical accidents. The normal safe practices for dust control must be observed rigidly and, in some cases, may have to be strengthened in the uranium mining industry. Several techniques are used, or have been tried, to control the exposure of workers in uranium mines. By far the most important of these is adequate ventilation. Adequate routine monitoring is essential, and local monitoring is also required to identify areas of unsatisfactory ventilation and high radon levels. Local air filtration can be used to reduce the level of radon daughters in the mine atmosphere, and other forms of protection may be needed in some cases.

In view of the recent discoveries of uranium in Australia and their possible exploitation in the near future, the formulation of a Code of Practice is important. Its purpose is to ensure the continued safety of workers engaged in the uranium and thorium industries.

## OVERSEAS DEVELOPMENTS

Uranium exploration is at a record high and intensive exploration was undertaken in a number of countries during the year, particularly the U.S.A., Canada and Africa. Although increases in uranium reserves were recorded by countries on all continents during the period under review, unless further significant reserves are found in the next few years, shortage will be possible during the 1980s.

To determine future uranium requirements, the United States Atomic Energy Commission estimates of installed nuclear generating capacity may be taken as a guide. Based on the median figure of 150,000 MW for the U.S.A., and 300,000 MW for the Western World by 1980, a total of 73,000 short tons of uranium oxide ($U_3O_8$) per year will be required by 1980 to attain this level of nuclear power generation. Of this quantity, 34,000 short tons per year will be required by the U.S.A. alone. These estimated annual uranium requirements are based on the assumption that plutonium recycle will be employed beginning about the mid-1970s. If plutonium is not recycled, the projected uranium requirements will be about ten percent higher by 1980.

The total present Western World reserves recoverable at less than US$10 per lb have been estimated at 840,000 short tons and should be compared with estimated cumulative requirements for the period 1970-1980 of 416,000 short tons. Moreover, existing government stockpiles would provide no more than 100,000 short tons. For technical and forward planning reasons, production rates must be backed by adequate forward reserves to enable the mining industry to meet anticipated requirements. An eight to ten year forward reserve is considered appropriate in uranium mining. Moreover, the interval between initial discovery of a major uranium deposit and the ensuing production of uranium oxide is usually five years or more.

The maximum rate at which the various deposits known could be economically exploited has been estimated reliably at 50,000 short tons uranium oxide a year, and this is an even more restrictive factor.

### U.S.A.

Total domestic production during 1970 was 12,500 short tons of uranium oxide, of which the United States Atomic Energy Commission purchased 3,600 short tons, the remainder going to private buyers. The current domestic uranium industry processing capacity is approximately 15,000 short tons of uranium oxide annually. It is expected that an additional 4,000 tons capacity could be added during the next two years.

As at September, 1970, sales and commitments to domestic buyers totalled 99,000 short tons. In addition to these commitments, 5,800 short tons were committed to foreign buyers. Sale prices are generally not disclosed, but prices of less than $6 per lb have been made under some early contracts or for a few spot sales, whereas later contracts and material scheduled for later delivery, have been at higher prices — up to $7-$8 per lb.

Domestic uranium reserves in the category "less than $10 per lb" were estimated at the end of 1970 at 250,000 short tons uranium oxide. Reserves available at a price of $8 per lb were estimated at 204,000 short tons uranium oxide. Although no major discoveries were reported during the year it appears there will be substantial reserve additions again in 1970. Because of the large quantity of data being generated, and because of the time lag in obtaining information and performing ore reserve calculations, the current estimate is believed to understate the situation by 50,000 short tons uranium oxide.

Uranium exploration activity dropped below the 1969 level, with surface drilling amounting to 23.8 million feet compared with 29.9 million feet in 1969 and 23.8 million feet in 1968.

The United States Government's uranium procurement program was terminated at the end of 1970 and the USAEC stockpile is currently estimated at 50,000 short tons uranium oxide.

Construction delays of nuclear power plants on order, coupled with the termination of the USAEC procurement program and the construction of new mines and mills, has resulted in a surplus of uranium concentrates that may remain for a few years. The excess is expected to exceed 20,000 tons by the end of 1975, and it is estimated that it will take until 1978 before orders and demands are in balance, assuming no more orders are placed, no foreign uranium is admitted, and no sales are made from the USAEC stockpile before then.

Although the long-term picture appears good for the uranium supply industry, the market could be depressed for the next few years. To protect the United States uranium mining and milling industry, sales of foreign uranium to United States domestic users are not permitted at present. The USAEC has not announced yet a firm date for removal of this restriction, but has indicated that some relaxation should be possible by 1973 or earlier. The method and timing for removing restrictions on enrichment of foreign uranium for domestic use, and for the eventual disposal of the national stockpile, are still under consideration. Disposal of the excess uranium from the national stockpile in significant quantities before the latter half of the 1970s could seriously affect the uranium industry.

Sixteen uranium ore processing mills were in operation during 1970. Dawn Mining Company re-opened its mill at Ford, Washington. A new mill with a nominal capacity of 1,000 tons a day was opened at Ray Point, Texas, and four new mills planned for 1972 start-up are under construction.

## CANADA

Canadian production of uranium oxide in 1970 was above 4,765 short tons in three plants and, in addition, Stanrock Uranium Mines Ltd. continued recovery of uranium from mine water. Deliveries to the Canadian Government's stockpile continued until 30 June 1970, by which time it is estimated that the Government will have accumulated 9,500 short tons uranium oxide. The quantities of uranium concentrates delivered under this program have been significantly below permissible quotas, largely because of economic considerations.

The impending legislation changes concerning foreign ownership of uranium property resulted in exploration activities being severely restricted during 1970.

The failure to discover worthwhile deposits in Quebec is disappointing. The Agnew Lake low-grade project has been suspended, exploration in the Northwest Territories has not been encouraging, nor has exploration in the Beaverlodge area of Lake Athabasca. The only highlight on the uranium exploration scene during the year was Gulf Oil's Rabbit Lake deposit, where reserves of 20,000-25,000 tons of uranium oxide have been outlined to date. A mill to produce 2,000 short tons uranium oxide a year is expected to be in production by 1974 to exploit this deposit.

At the end of 1970, domestic uranium reserves exploitable at up to $10 per lb were estimated at 232,000 short tons uranium oxide. More than 80 percent of these reserves are contained in Precambrian quartz-pebble conglomerates in the Agnew Lake-Elliot Lake area of Ontario. Most of the remainder in this price range are pitchblende-bearing vein-type or related deposits which occur mainly in Saskatchewan, British Columbia, Newfoundland and the Northwest Territories.

Developments in the Canadian uranium industry have paralleled those in the U.S.A. in that exploration has continued at a reduced level, production was higher in 1970 than in 1969, and plans are in hand for expansion and/or reactivation of existing facilities. Should contemplated plans for expansion, reactivation and development proceed as expected, the industry could attain an annual productive capacity of 13,000 short tons uranium oxide by 1975. Certain of these proposed developments would, however, be contingent upon sales contracts being negotiated at prices somewhat higher than those currently prevailing. Any expansion beyond 13,000 short tons a year would depend on new discoveries.

## SOUTH AFRICA

South African uranium production during 1970 remained at about 4,000 short tons uranium oxide. A proportion of this total was stockpiled against future orders, but figures for exports and stockpiled quantities have not been released. At present, some 11 mines are producing uranium for treatment in mine extraction plants as a by-product of gold production. Two plants began operations in the first quarter of 1970, and a further two plants are scheduled to come on stream in 1971. South African production is expected to expand to an annual rate of 6,000 short tons uranium oxide by 1975.

South Africa has abundant reserves of low-grade uranium ores, both in surface dumps and underground, and a major metallurgical research program is being undertaken to see whether these resources, which are contained in tailings dumps, slimes dams and newly-mined submarginal ore, can be exploited economically.

A large, low-grade uranium deposit near Swakopmund, South-West Africa, has been under investigation for the past two years. Construction of a pilot plant for metallurgical test work is scheduled to begin in the spring of 1971. If the deposit proves economic, it will be exploited by open-pit mining at a production rate of 2,500 tons per year in 1975, increasing to 5,000 tons a year in the late 1970s.

## FRANCE

Production of uranium concentrates in Metropolitan France was held at about 1,600 short tons uranium oxide in 1970, and the output over the next five years is expected to remain at the same level. In France, concentrates are produced at three plants which have a combined annual capacity of 2,300 short tons uranium oxide. There are no plans to increase productive capacity beyond this level during the next few years. Installation of additional capacity would probably not be considered unless further new large discoveries were made in Metropolitan France. Gabon continued to supply uranium oxide concentrates to France.

In France, reserves of approximately 45,000 short tons uranium oxide can be produced at less than $10 per lb. In addition, France controls large reserves in Gabon, Niger and the Central African Republic. Ore reserves in the category less than $10 per lb are estimated at 13,500 short tons uranium oxide in Gabon, 26,000 short tons uranium oxide in Niger (Arlit deposit), and 10,400 short tons uranium oxide in high-grade phosphate ores in the Central African Republic.

Production in France and Gabon, together with French-controlled plants to be set up in Niger and the Central African Republic, will amount to 5,800 short tons uranium oxide in 1974-75. The annual French military and power needs are of the order of 2,500 short tons uranium oxide. Thus, France should have a surplus of upwards of 3,300 short tons uranium oxide a year for export by 1974-75, and a government marketing organisation, URANEX, was established for this purpose in 1969. In addition, France has access to extensive additional resources in the less than $10 per lb category in both Metropolitan France and in Africa.

## OTHER COUNTRIES

In Portugal domestic ore reserves in the category less than $10 per lb were estimated at 9,600 short tons uranium oxide. Production is being maintained at 100 short tons a year and the output stockpiled for a reactor planned for the late 1970s. Plans are in hand to increase this productive capacity to 200-300 short tons uranium oxide a year in the near future.

An enormous low-grade deposit occurs in the Billingen area of central Sweden. At the present plant capacity of 160 short tons uranium oxide a year, uranium concentrates cannot be produced economically. Sweden hopes that this resource can be developed economically by large-scale production techniques. A three-year program is under way to evaluate the economic and technical feasibility of exploiting this deposit. The treatment plant and mill at Ranstad at present is operated only to the extent necessary for the evaluation of this development program.

In Spain, the Andujar mill continued to operate at a rate of 70 short tons uranium oxide a year. Construction of a 440 ton capacity mill to treat ore from the Ciudad Rodrigo deposits in Salamanca is expected to be completed by 1972. Another mill to treat ore from the El Lobo mine is expected to begin production in 1973. These developments will give Spain an annual productive capacity of 550 short tons uranium oxide.

Argentina's uranium reserves in the less than $10 per lb category are estimated at 10,000 short tons uranium oxide. Most of this occurs in continental sandstones in the Sierra Pintada district of Mendosa Province. Uranium production, at present 55 short tons uranium oxide a year, is stockpiled for use in the Atucha Power Station which is scheduled to come into operation in 1972.

Mexican uranium reserves in the less than $10 per lb category are estimated at 1,300 short tons uranium oxide. The Aldama mill continued to operate at 60 short tons uranium oxide a year and an additional plant, planned to begin operations in 1971, will increase Mexico's annual productivity capacity to 150-160 short tons uranium oxide.

A 120 short ton uranium oxide a year plant is scheduled to commence production in Italy in 1973. Some production was undertaken in Japan.

## WORLD URANIUM RESOURCES SURVEY

In August, 1965, a report entitled *World Uranium and Thorium Resources* was published by the European Nuclear Energy Agency (ENEA). When it was decided to up-date this report, a joint study group was arranged with the International Atomic Energy Agency (IAEA) in June, 1967. In December, 1967, a report, *Uranium Resources, Revised Estimates,* was published jointly by the ENEA and the IAEA.

The AAEC's Head, Nuclear Materials Section, attended the group's definitive meeting in June, 1967, and the Commission's Nuclear Materials Section has been associated with all subsequent ENEA-IAEA meetings to produce and maintain up-to-date reports on the world's uranium resources.

The world's production of uranium and probable demand over the next decade were related in a joint ENEA-IAEA report, *Uranium Production and Short Term Demand,* published in January, 1969. However, some of the conclusions reached in this report on the relationship between uranium supply and demand were not valid, as the short-term demand failed to match expectations. A revision of the reports on the world's uranium resources and possible future demand was undertaken by the ENEA and the IAEA in April, 1970. The Commission's Nuclear Materials Section again supplied information on Australia and, after some further consultations, the results of the study were embodied in a report entitled *Uranium Resources, Production and Demand, September, 1970.* This report, which will be revised from time to time in the light of further discoveries, can now be regarded as the authoritative reference for data on the Western World's uranium resources.

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# NUCLEAR FUEL RESOURCES AND DEVELOPMENT

## AUSTRALIAN URANIUM RESOURCES

In mid-1970, Australia's estimated uranium resources were as follows:

**Recoverable at less than US$10/lb $U_3O_8$**

Reasonably Assured — 21,700 short tons $U_3O_8$.
Estimated Additional — 6,700 short tons $U_3O_8$.

**Recoverable at US$10-15/lb $U_3O_8$**

Reasonably Assured — 9,200 short tons $U_3O_8$.
Estimated Additional — 6,600 short tons $U_3O_8$.

These figures pre-date the announcements referred to in Chapter 6 concerning major new discoveries in the Northern Territory and in South Australia.

Since the closure of the Rum Jungle uranium processing plant, it is unlikely that the remaining known resources in that area will be recovered in the future at less than $10/lb $U_3O_8$. The tonnage involved is not large, but it should now be regarded as being in the category of resources recoverable at $10-15/lb $U_3O_8$.

However, the alterations necessary to the above figures are transcended completely by the recent discoveries. On the basis of the available data, it would not be unreasonable to expect that over and above the presently proven resources, an additional 100,000 short tons of uranium oxide will be proven in the Nabarlek-Ranger I area in the Northern Territory within about two years at the present rate of exploration. All of this additional resource should be recoverable at less than US$10/lb uranium oxide. The Alligator Rivers Uranium Field must be regarded as most promising and one of major world importance. With continued exploration in the area more discoveries would seem likely.

At this stage, it is not possible to give definite categories for the other recently-discovered substantial resources announced by companies in the Northern Territory and South Australia, nor to give estimated costs of recovery of these resources.

## EXPORT POLICY

In April, 1967, the Minister for National Development announced a policy for the export of uranium from Australia. The policy was designed to stimulate exploration for uranium and, at the same time, ensure that Australia's future requirements of uranium would be met from domestic resources. The policy statement was reproduced in the Commission's Fifteenth Annual Report, 1966-67. While retaining a system of export controls, the policy permitted limited exports from new discoveries in amounts which were related to the size and location of these deposits.

The search for uranium has increased in recent years and important new discoveries have been made. Although these reserves are not yet delineated fully, it is clear that they will put Australia amongst the leading uranium producers in the world.

On 18 February 1971, the Minister for National Development issued a statement on uranium export policy. In part, this read as follows:

"Uranium is not only a valuable mineral, and the probable future source of much of the world's future industrial power, it is also a material of strategic importance.

"The Government has decided, in common with the Governments of practically all other uranium exporting countries, to maintain a system of export control. For the present this will not involve any quantitative restriction upon exports.

"However, a close watch will be maintained on proven reserves and the amount exported, to ensure that adequate supplies are retained for our future requirements.

"As with the previous policy, all contracts for the export of uranium will be subject to the approval of the Minister for National Development. This will ensure that the price negotiated for the sale of the uranium is satisfactory. Appropriate safeguards, to ensure that the materials exported are used for peaceful purposes only, will be mandatory."

It is not over-optimistic to expect that further discoveries of uranium will continue to be made in Australia. The present export policy provides a satisfactory basis for mining companies to undertake further exploration and to enter into commitments for export of uranium when reserves are delineated.

## LOCAL FUEL INDUSTRY

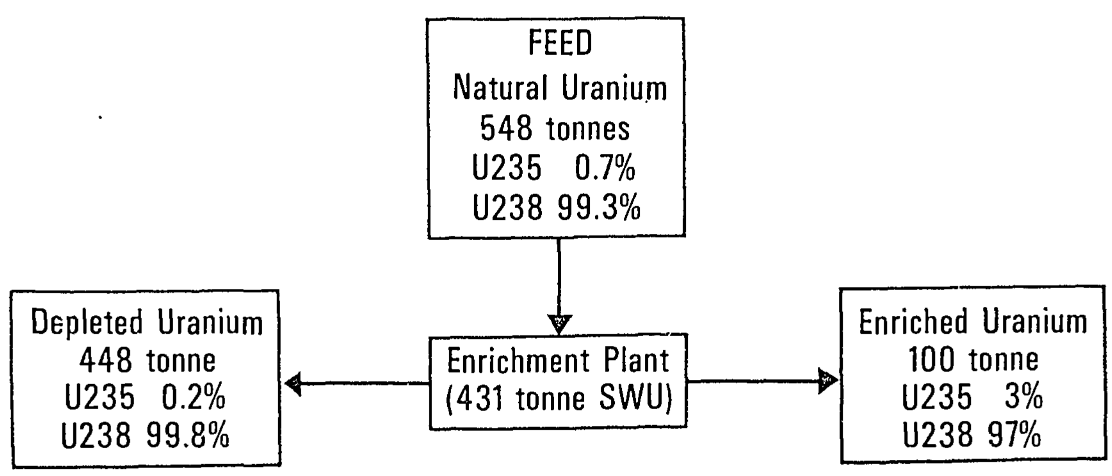
Demand for uranium by the Western World is expected to rise rapidly from 37,000 short tons uranium oxide ($U_3O_8$) a year in 1975, to 73,000 short tons a year in 1980, and to approximately 130,000 short tons a year in 1985. After 1985, the demand should stabilise between 130,000 and 150,000 short tons a year, or possibly fall slightly towards the end of the century due to the replacement of thermal reactors by fast breeder reactors. The total Australian domestic demand should be 2,000 to 3,000 short tons uranium oxide a year by 1990 with a cumulative demand to the end of the century of 50,000 short tons. The graph on page 63 illustrates estimated future Western World demand for uranium.

Assessments of the uranium market have shown few prospects of sales for delivery before 1975, although one Australian company has obtained modest orders for delivery from 1974 onwards. Beyond 1975, heavy commitments to nuclear power programs overseas will provide opportunities for sales at a firm price which is expected to be somewhat above the present level of $6-7 per pound $U_3O_8$. These sales are likely to be to Europe, Japan and the U.S.A. Access to the U.S. market is dependent in the short term on the relaxation of import restrictions in that country. In the longer term (to 1985), the U.S. is likely to experience some pressure on its resources of low-cost uranium unless further discoveries are made in the near future.

By 1985, Australian exports of uranium are anticipated to be about 20,000 short tons uranium oxide a year, representing annual sales of about $240 million at present-day prices (and considerably more at prices likely at that date).

The Commission is actively examining the feasibility of upgrading yellowcake into other forms of uranium. The initial stages of upgrading involve the preparation of uranium hexafluoride which is the feed to isotope enrichment plants. Hexaflouride is prepared by dissolving yellowcake in nitric acid and purifying by solvent extraction, followed by denitration, hydrofluorination and fluorination. The installation of hexafluoride conversion plants in Australia would broaden the basis for sales of uranium and allow significant economies to customers in terms of inventory, transport and administration charges. Although the added value is relatively low (about $2 per kilogram uranium), the venture is assessed to be economically attractive at outputs between 3,000 and 10,000 tonnes uranium a year.

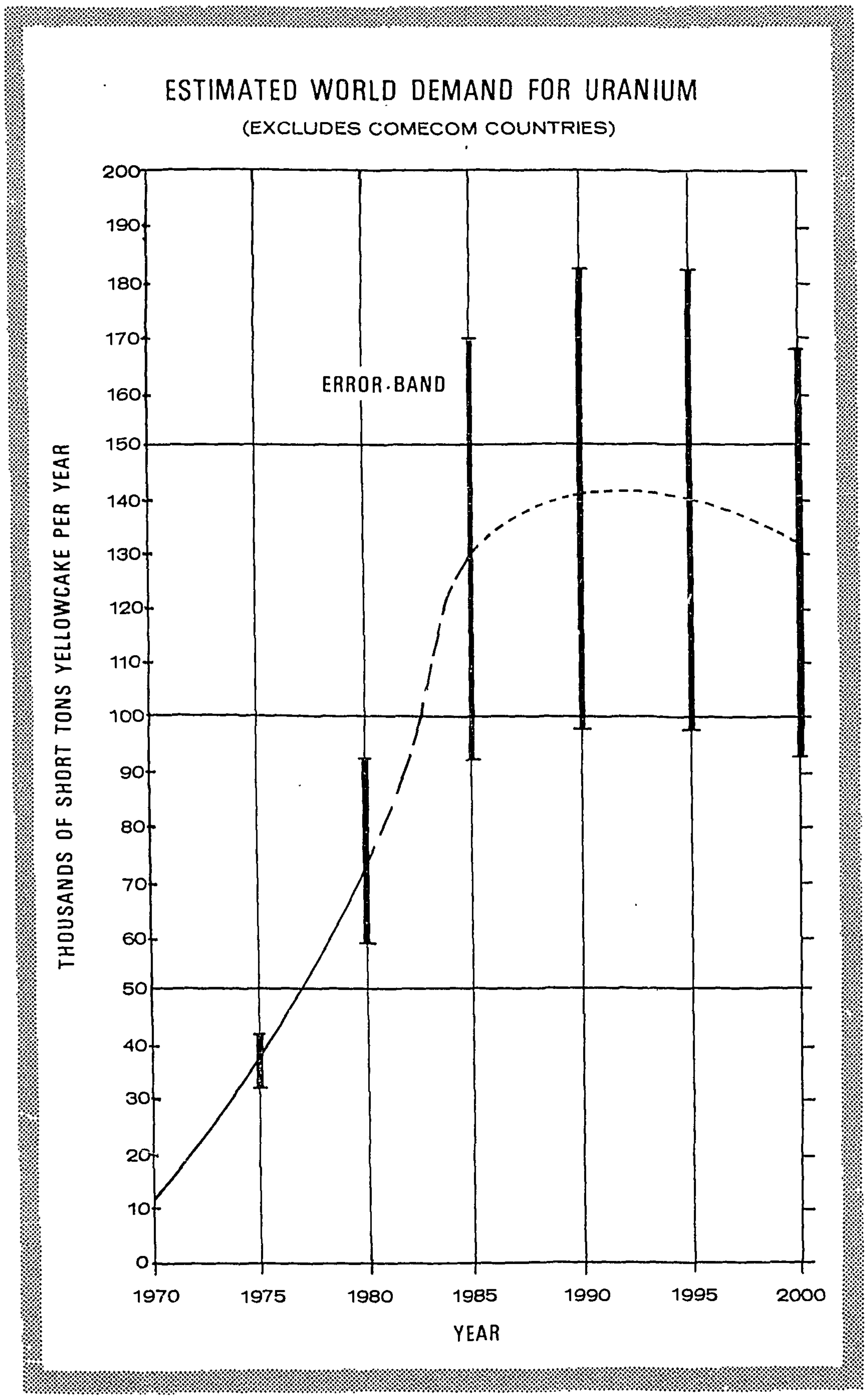
The second stage of upgrading involves the enrichment of uranium in the isotope uranium 235. The majority of the world's nuclear power stations currently operating or projected require uranium enriched in the isotope uranium 235 to a level of 2-3 percent, compared with 0.7 percent in natural uranium. The effort involved in concentrating the isotope is expressed in Separative Work Units (SWU-kilograms or tonnes) and the amount of separative work required to produce a given amount of fuel depends on the initial and final isotopic concentrations. The diagram below shows a material balance required to produce 100 tonnes of 3 percent enriched uranium. This quantity would be sufficient to provide about 22,000 million kilowatt-hours of electricity in a typical present-day nuclear power station.




Thus, about 5.5 kg of natural uranium is required for each 1 kg of 3 percent enriched product; the remaining 4.5 kg of "depleted" uranium is stored and ultimately would be used in fast breeder reactors.

The world demand for enrichment services is expected to reach 19,000 tonnes separative work a year in 1975, 43,000 tonnes a year in 1980 and 70,000-80,000 tonnes a year in 1985. Australian studies are being concentrated on plants of 5,000-10,000 tonnes a year capacity for initial operation in the period 1980-85.

At this output, the economics of enrichment by the established method of gaseous diffusion seem attractive. Costs depend upon cheap power supplies, which Australia might possess in certain locations, combined with a reliable source of uranium. These requirements place Australia in a favourable position to enter enrichment technology. Economic studies are continuing to define the value of this investment to Australia and to determine its technical and economic feasibility.

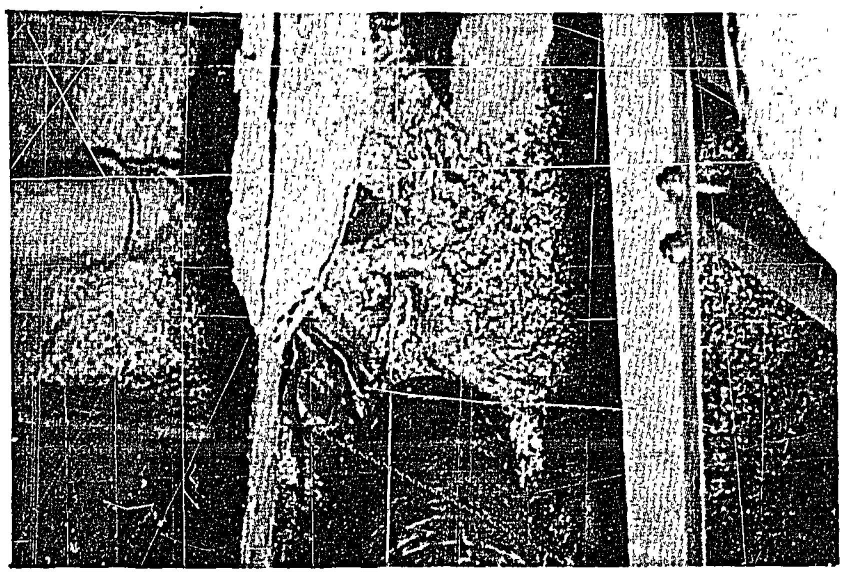

ESTIMATED WORLD DEMAND FOR URANIUM
(EXCLUDES COMECOM COUNTRIES)
ERROR-BAND
THOUSANDS OF SHORT TONS YELLOWCAKE PER YEAR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
1970
1975
1980
1985
1990
1995
2000
YEAR

As with hexafluoride, the advantages of enrichment are to broaden the market for sales, to increase overseas earnings, and to increase the level of technology and industry in this country. The cost of producing one kilogram of 3 percent enriched uranium is about $238, made up of $86 for feed uranium, $13 for conversion to uranium hexafluoride and $139 for the enrichment process. Expressed another way, the added value for each kilogram of uranium mined is about $27.50 ($10.60 per lb $U_3O_8$). The total value of Australia's export income from this industry, therefore, could be increased substantially by the conversion of yellowcake to enriched uranium.

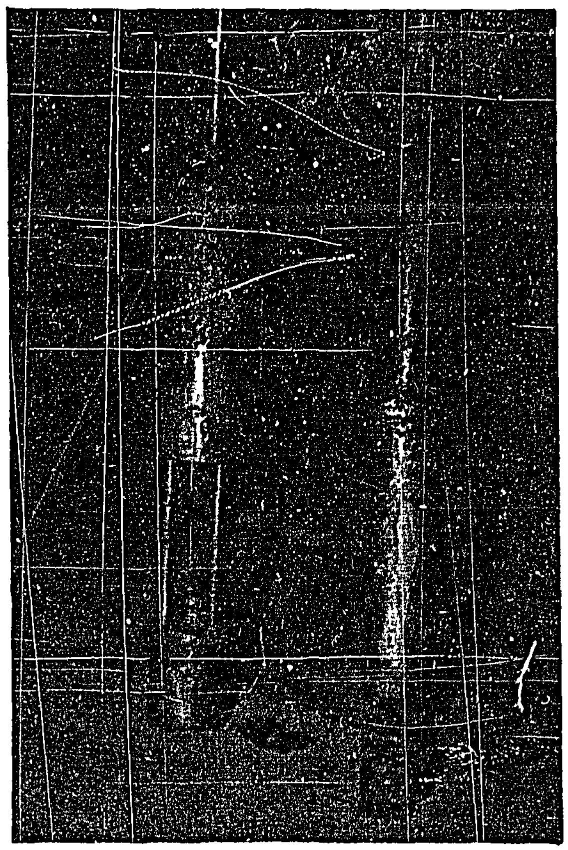
The final stage of upgrading uranium is the manufacture of finished fuel elements ready for use in the reactor. Studies have been completed on the engineering design and economic feasibility of plants for the manufacture of fuel elements for an Australian nuclear power program. These plants require a relatively low capital investment, and their operation is economic even at low outputs. This would be largely a domestic oriented industry. Whilst there are some opportunities for export, these might be small in the short term.

The technological and economic implications of Australia's move into the upgrading of uranium are being examined by the Commission in collaboration with other Government organisations and in consultation with interested overseas countries. These studies are being intensified with the objective of placing, as soon as possible, firm proposals before both the Government and industry on the desirable structure and growth of the industry as a whole.

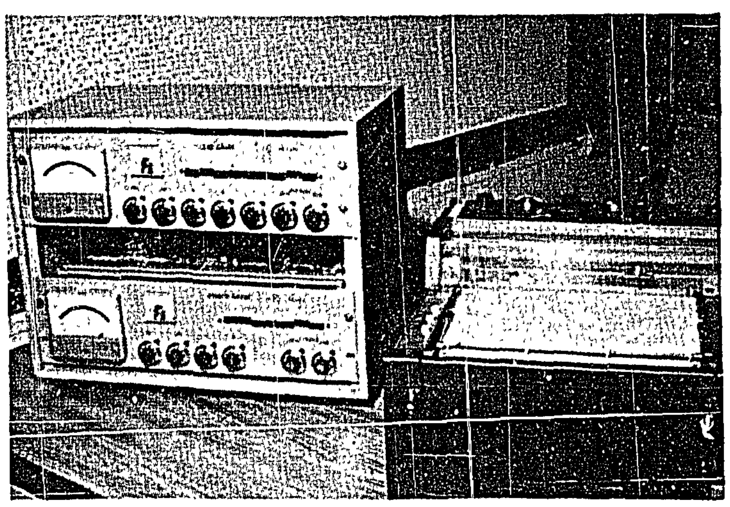
# RADIATION AND RADIOISOTOPE APPLICATIONS



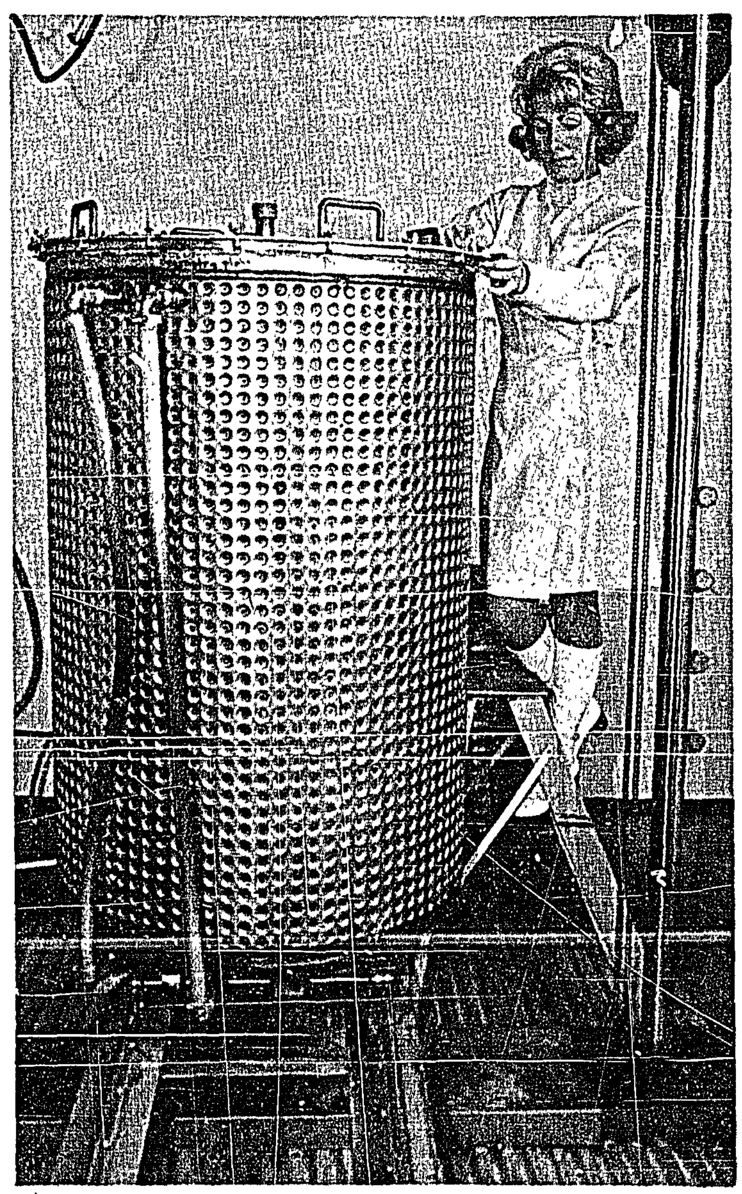
*Above: At Broken Hill, N.S.W., successful trials of immersion type analytical probes were carried out by The Zinc Corporation Ltd., New Broken Hill Consolidated Ltd. and Commission staff. Flotation feedflow at the head of one of the lead roughers at the New B.H. plant. A density probe (right) is supported from a cross-tank bracket. The sloping probe (left) is a fluorescence probe sensitive to zinc.*



*Right: Each probe contains a radioactive source and detector which sends signals to a computer. The left probe is used to measure density of the slurry by absorption of caesium 137 gamma-rays. The lead sensitive probe (right) depends on the absorption of gamma-rays from a gadolinium 153 source.*

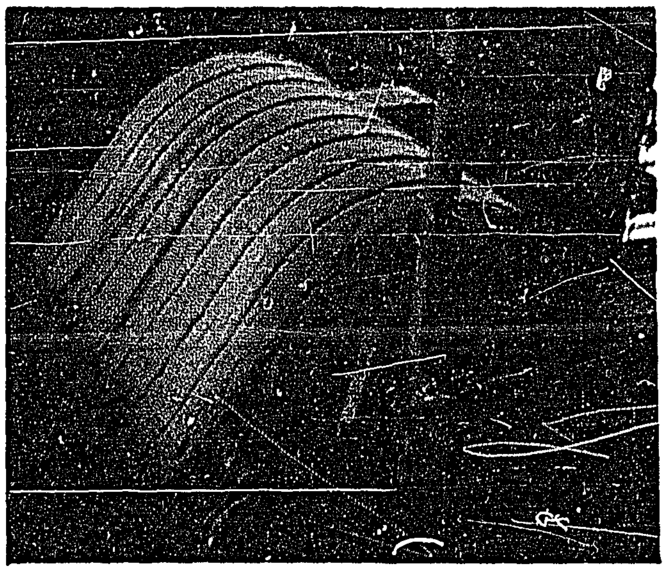


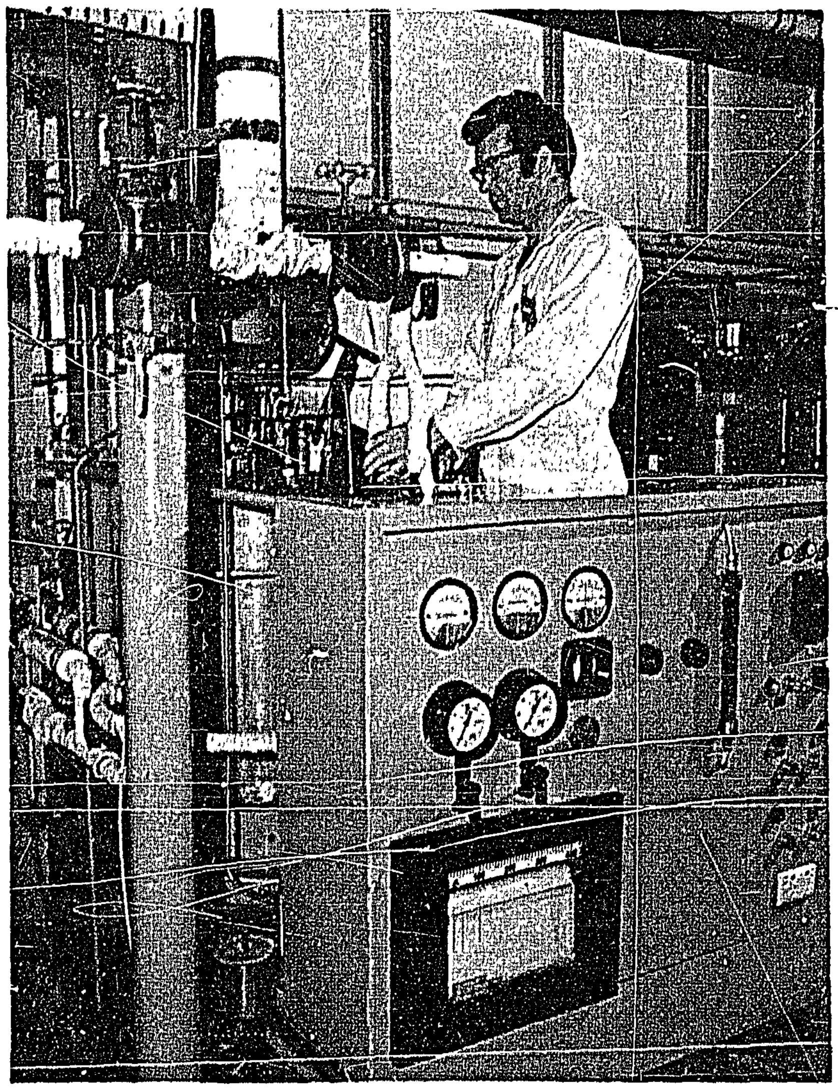
*Above: A Philips analogue computer used at the New B.H. plant to combine signals from the density and lead-sensitive probes to give a reading of percentage lead in the feed slurry.*



*Right: Research irradiator (GATRI) built at Lucas Heights by Imperial Chemical Industries of Australia and New Zealand Ltd., under an agreement between the AAEC and ICIANZ. Being set up is one type of reaction vessel used for research into radiation induced polymerisation of organic compounds. When in operation, the cobalt 60 source is lifted from the bottom of the shield pond into the centre of the reaction vessel.*

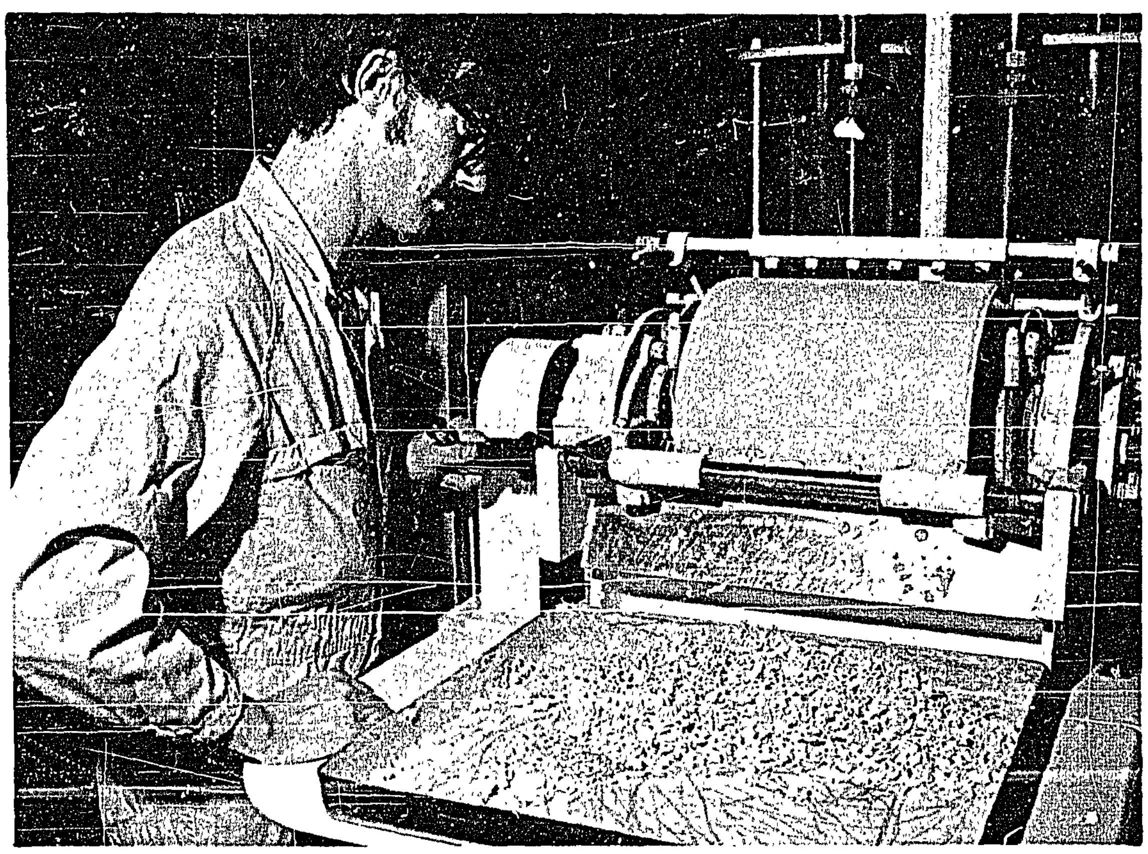
# FUEL STUDIES
## Fabrication





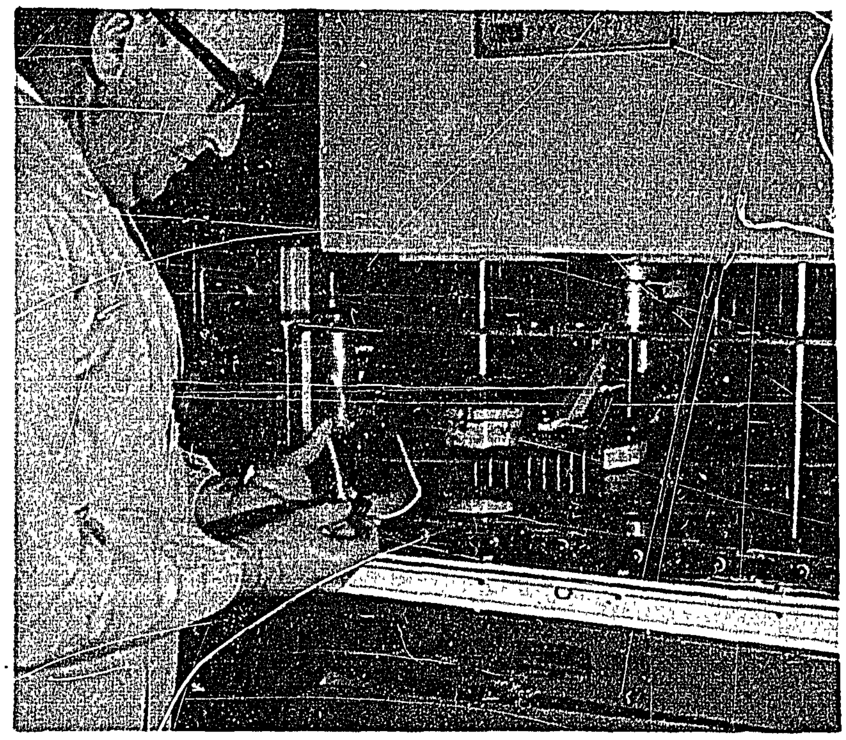
*Above: Uranium treatment plants at the mines produce uranium oxide ($U_3O_8$) yellow-cake as their final product, but the concentrate needs further processing before being used as a nuclear fuel material.*

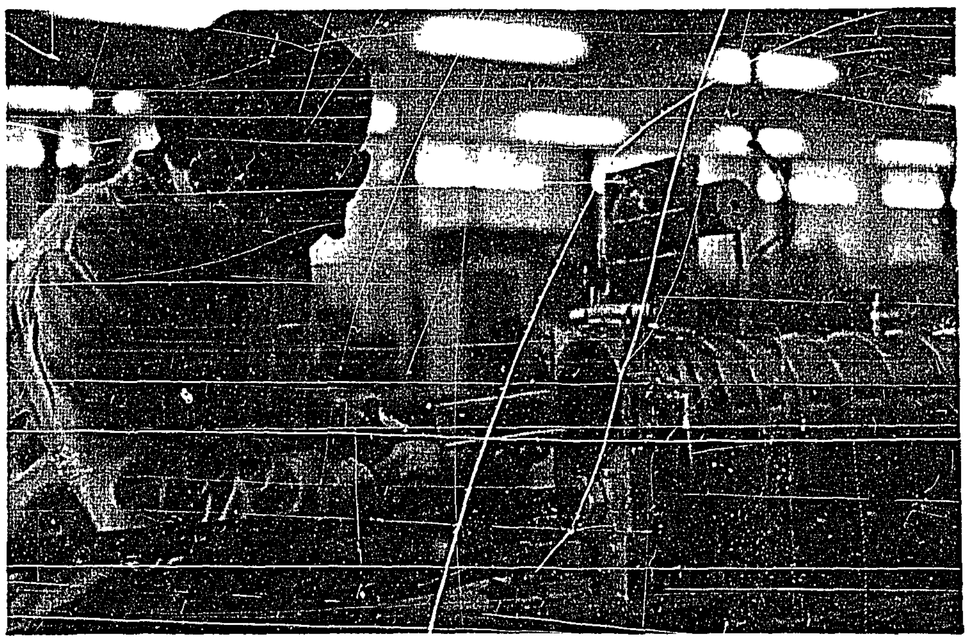
*Right: Plant used for the dissolution of Australian-produced yellowcake as the first stage in a study of the unit processes involved in the production of nuclear grade uranium dioxide ($UO_2$) for the manufacture of reactor fuel elements.*



*Filtration of ammonium diuranate (ADU) by means of a rotary drum vacuum filter, one phase in the conversion and purification of $U_3O_8$ to $UO_2$.*

*Right: Automatic cold pressing of $UO_2$ pellets. Pressed at 20 tons / sq.inch they measure approximately 0.7 inch diameter x 1.0 inch long. The capacity of the press is sufficient to meet the fuel make-up requirements of a 500 MW power reactor.*

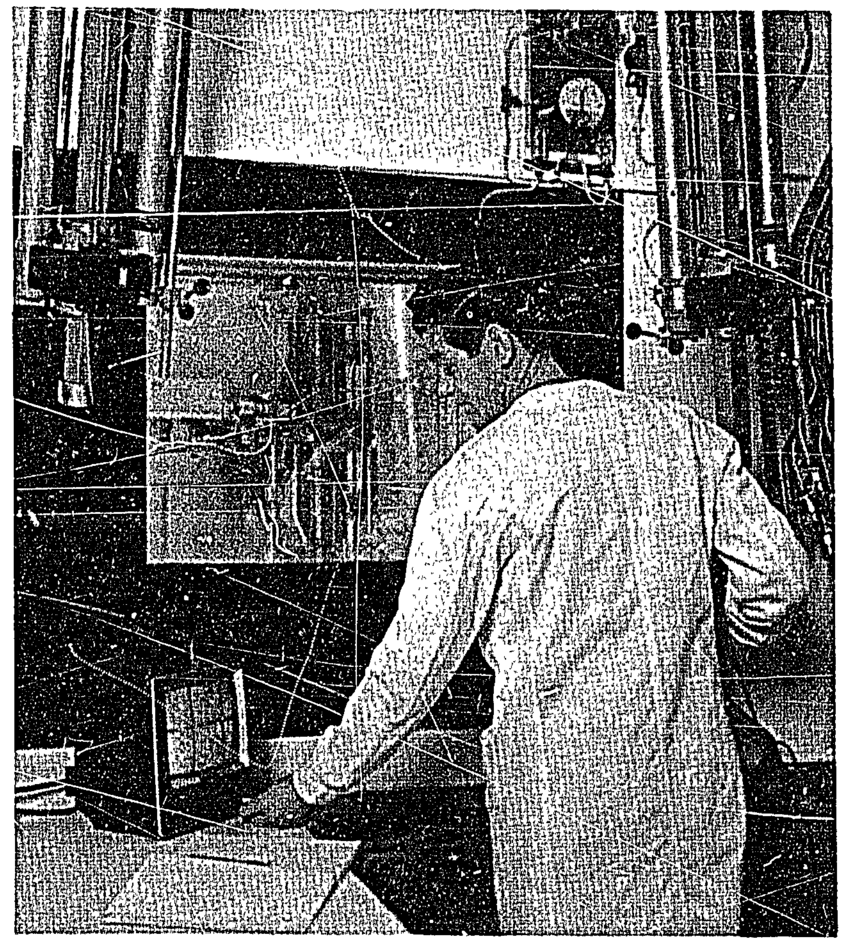




*Above: Loading pellets into a hydrogen-atmosphere, continuous sintering furnace. The pellets are maintained at a temperature of 1,500 degrees C for four hours during their 40-hour passage through the furnace. During sintering the pellets reach 96 percent of their theoretical density.*

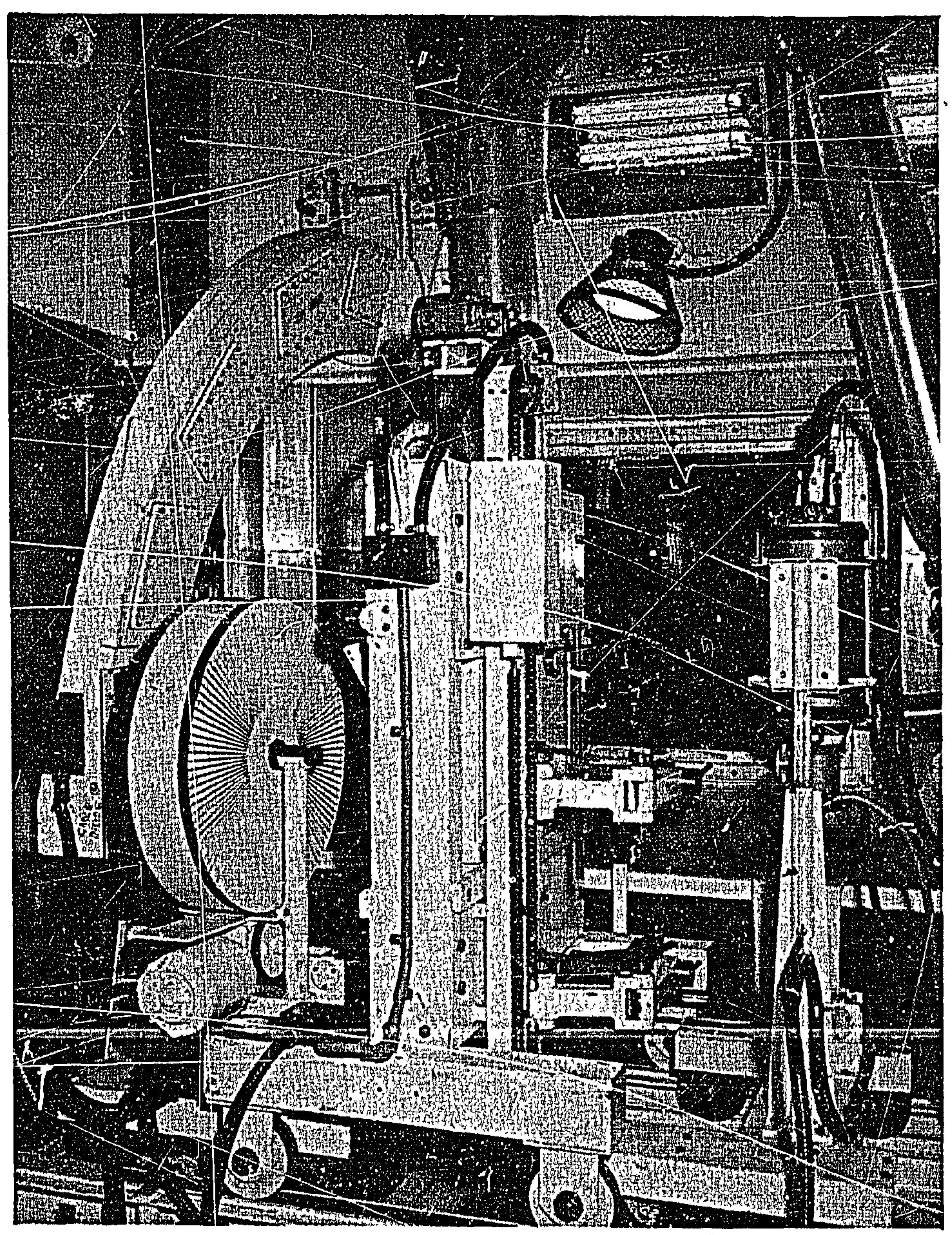
*Right: After sintering, the pellets are ground in a centreless grinder. They are then carefully washed, thoroughly dried, loaded and sealed in a zirconium alloy tube. This assembly constitutes a fuel pin.*

# Irradiation Performance



*Right: Equipment in a remote handling cell consisting of a microscope and closed circuit television camera which are used to view, display and magnify an etched grid on the surface of irradiated fuel cladding. Measurements of grid spacings on the irradiated material can be compared with measurements taken before irradiation to determine strain in the fuel cladding.*

*Below: In-cell equipment for radiographing irradiated, and therefore highly radioactive, fuel pins for non-destructive examination of the pellets and cladding material. This rear-of-cell photograph shows the fuel pin (centre) clamped vertically in front of a slotted lead shield. The lead prevents gamma radiation emitted by the pin fogging the film. The X-ray beam from the generator (far right) after passing through the pin, passes through a slit in the shielding and then through the slotted wheel (left) which rotates during exposure. The films and holder are transported remotely between the cell operating face and the in-cell position (left).*



# 8

# RESEARCH RELATED TO NUCLEAR POWER

The development of Australia's nuclear fuel resources, the introduction of nuclear power and the production of radioisotopes depend greatly on the sound research capability of the staff at the Research Establishment, Lucas Heights, New South Wales. The research support for radioisotope production and other projects is described in Chapters 9 and 10. Research support for nuclear fuel and nuclear power development is described here.

The intensive technical assessment of the tenders for the proposed Jervis Bay nuclear power station, in which many Research Establishment staff participated, was described in Chapter 2, but two major studies are of special interest — the comprehensive analysis of performance of the reactor core designs, and the continuing study of environmental aspects of the Jervis Bay site and surrounding area. The latter was referred to in Chapters 2 and 4.

## Tender Evaluation of Core Performance

In general, the reactor core designs tendered for Jervis Bay were developed from existing nuclear stations. These developments reflected the experience and growing confidence of the tenderer, but they also implied a change in the reactor operating conditions towards the basic design limits. It was necessary, therefore, to examine critically the designers' claims for improved performance, and to provide an independent evaluation of the operating margins in the various ratings and stability factors.

Because of the complexity of the neutronic processes, exact calculations are not possible with existing computers. The simplifying assumptions which can be made depend on the particular type of reactor. There is no universal method capable of dealing with all types of reactor on a common basis. Before receipt of tenders, Commission staff tested their methods of calculation against published data on systems for which tenders were expected. Improvements were made to computer programs to enlarge their range of validity.

Calculation of the neutronic interactions in the core provides important performance characteristics such as power distribution in the fuel, the effectiveness of the control systems, and the ability to maintain criticality throughout the stated fuel life. The calculated power distribution in conjunction with the coolant flow determines the heat fluxes and temperatures throughout the core.

When the Commission received the tenders, this approach was used to analyse carefully the claimed performance, taking into account the effects of uncertainties in the basic nuclear data and the evidence supplied on the performance of similar reactors.

Other aspects examined in detail included the thermal and hydraulic performance of each reactor design. In particular, critical aspects of heat removal from the reactor core were investigated.

An AAEC computer code, developed for predicting the onset of hydraulic instability under boiling flow conditions, was used to assess the margins to flow instability. This required information on the pressure distribution around the primary circuit and involved calculations of flow and pressure drop for steam-water mixtures.

Using information from a recently-established AAEC data bank of world information on dryout in rod cluster assemblies, in conjunction with a recently-developed AAEC computer program, suitable dryout correlations were selected to verify or establish the limits of thermal output for each design. Then, by applying statistical analysis techniques, and including all the relevant information such as power and flow distributions in the reactor core, it was possible to assess the adequacy of the margins, taking into account possible variations and transients.

These studies were extremely useful in determining the degree of confidence to be placed in each core design and in assessing the potential of the system for improvements in efficiency.

**Work at Jervis Bay**

During the past year, much work was carried out at Jervis Bay to provide data necessary to formulate discharge limits for radioactivity in the manner indicated earlier in this Report. The necessary work falls into the four principal categories of meteorology, hydrology, ecology and demography (the identification of communities needs to be considered in relation to possible exposure). Not infrequently there will be one or two groups of people whose diet, location or other characteristics are such that their potential exposure is clearly higher than for other people. Such groups are defined as critical groups and, when identified, limit the possibilities that need be considered.

The necessary meteorological work has been straightforward and amounted only to supplementing the limited local data already available with data obtained from equipment installed at the reactor site. Hydrology was more demanding, and a series of tests was made to obtain detailed knowledge of the circulation in the region of Murray's Beach, in Jervis Bay, and in the ocean near Governor Head. The methods used included multiple observations of surface currents with tethered drogue systems, and observations on the plumes formed by the release of a solution of a visible dye. In both methods aerial photography was the preferred method of observation. From these experiments it has been possible to form estimates of the distribution of currents in the region and of dilution factors.

Ecological studies were more extensive than necessary merely to define the possible pathways of exposure to man. The effects on the local ecosystem of site works, for example a possible breakwater, and of the several proposed inlet and outlet points for power station cooling water had to be considered. If radiological safety for man is assured, no radiological risk for lower species will exist since, for the most part, they are much more radio-resistant and have shorter life spans. But considerable changes in local ecosystems can be caused by changes in water flows and temperatures, and these have been predicted for the various alternative conditions. For radiation exposure to man, the most likely pathways are via the consumption of oysters, abalone and other local seafoods, but additional routes will be considered. Some localised environmental change will occur around the inlet and outlet canals, and this will include the growth of mussels in the outlet region.

The broad conclusion from these studies is that the reactor systems tendered are compatible with the site, irrespective of outfall location, but cost-benefit analysis may favour a particular location. No formal critical group has been defined at present, and more information on fish populations and consumption is needed to prepare a complete statement on discharge limits.

# REACTOR RESEARCH

## PRIMARY CIRCUIT MATERIALS

In water-cooled reactors, the fixed primary circuit materials (excluding fuel) which must withstand the most critical combination of neutron irradiation, temperature and stress, are the zirconium alloy pressure tubes (in pressure tube reactors) and the steel pressure vessel (in pressure vessel reactors). These components must contain the water or heavy water coolant under high pressures and must last for many years without deterioration. The mechanical properties of the materials used are critical in determining the performance of the component, and are being studied at a basic materials-research level.

Zirconium alloy pressure tubes gradually expand (or creep) at reactor pressures and temperatures, by a process known to be accelerated in a fast neutron flux, and this expansion may determine the service life of the pressure tubes. Part of the Commission's research program deals specifically with the in-reactor creep behaviour of the alloy known as cold-worked zirconium-2.5 percent niobium. This is part of a UKAEA-AAEC collaborative investigation of the effects of fabrication route and heat treatment on the in-reactor creep behaviour of zirconium-niobium pressure tubes. Zirconium-2.5 percent niobium was chosen because it holds promise of having a resistance to in-reactor creep which is superior to that of the hitherto more commonly used Zircaloy-2.

Other basic work on zirconium pressure tube alloys is aimed at improving understanding of the enhancement of in-reactor creep, the mechanism and stability of the strengthening produced by cold-work, and the effect of cold-work on creep and other mechanical properties.

In a pressure vessel reactor, the carbon or low alloy steel vessel must remain structurally reliable in spite of the effects of prolonged exposure to irradiation by fast neutrons and to a potentially corrosive environment under stress. The Commission's program in this area is concentrated on determining the extent to which Australian steels become embrittled by fast neutron irradiation.

The steels for study were chosen to be the equivalents of overseas steels used in pressure tube and pressure vessel reactors. Equipment to test irradiated samples of Australian steel has been installed in a high activity cell.

To assess the degree of embrittlement accurately, the various methods used to determine the ductile-brittle transition temperature have been evaluated. One promising technique has been chosen for intensive investigation and comparison with the more widely used but somewhat unsatisfactory Charpy V-notch test.

## CHEMICAL CONTROL OF REACTOR PRIMARY CIRCUITS

Research has been carried out on the chemical problems associated with the interaction of aluminium and steel with water in reactor coolant-moderator circuits. Even small amounts of corrosion products and impurities in the large quantities of water in a circuit can have serious effects on the efficient operation of the reactor over long periods.

Corrosion of steel in water results in the release of small quantities of corrosion products which deposit on fuel cladding and other parts of the circuit. Long-lived radioactive species are associated with the deposits, commonly referred to as "crud". An out-of-pile water loop to operate at temperatures up to 300°C and pressures up to 1,500 pounds per square inch gauge has been designed and is under construction. It will be used to study the effect of physical and chemical variables on the mass transport phenomena associated with crud.

The mass transport process has a stage in which the corroding surface releases metal ions, such as those of iron, cobalt, nickel and copper, to the water phase. The behaviour of these ions in water at temperatures close to 300°C is not well-known, and research is being conducted on hydrolysis equilibria and precipitation behaviour. A suitable spectrophotometer and high pressure cell is being built for this work.

In preliminary investigations at temperatures below 90°C, the precipitation from Fe (III) solutions has been found to be a complex and time-dependent process.

The corrosion of aluminium has been measured directly in out-of-pile water loops. The corrosion rate was increased by chloride ions in concentrations up to 15 parts per million and was not effected by changes in acidity or alkalinity. The work is being continued in-pile by exposing aluminium specimens in HIFAR in a simple immersion rig in a hollow fuel element position. Aluminium corrodes by pitting in the presence of halide ions. Electrochemical techniques have been used to study the effect of water conditions on the critical potential for pitting to occur and also to study the important adsorption behaviour of halide and other ions on the aluminium surface.

Water purity in reactor coolant-moderator circuits is invariably maintained by an ion exchange plant. In such a plant, resins remove impurities in the same way as they remove hardness from water in a water softening plant. The use of powdered resin held on a porous support is an alternative to the more conventional deep beds of resin beads. A small pilot plant has been constructed and used to investigate the capacity and efficiency of a powdered resin unit under a variety of conditions.

It is important that the level of copper impurity in a reactor coolant be kept very low. There was some doubt whether ion exchange resins could accomplish this in the presence of ammonia, which is added to control water degradation and tends to concentrate in the condenser of a direct-cycle reactor. Experiments have shown that copper at levels down to parts per billion ($10^9$) is removed by cation exchange resins in the presence of up to 500 parts per million of ammonia.

Chloride, even at very low concentrations, can cause serious corrosion of stainless steel components of steam generating systems. Sensitive methods are required, therefore, for determining trace levels of chloride in reactor feed water. Two such methods were developed recently in the Commission's laboratories.

Traces of cobalt (from alloys in the primary circuit materials) in high-purity reactor water can become activated to cobalt 60. This nuclide is intensely radioactive and, when spread throughout the reactor water circuit, complicates the routine maintenance of valves and other equipment. A sensitive catalytic method was developed which determines the ultra-low concentrations of cobalt present in reactor and other high-purity waters.

## FAST REACTORS

Systematic studies on the utilisation of uranium resources, undertaken by the European Nuclear Energy Agency, foreshadow in the 1980s the introduction of advanced thermal converter reactors and fast breeder reactors. These reactors initially will use stockpiled plutonium from existing thermal reactors, and later the plutonium from advanced thermal converter and fast reactor systems. All commercial reactors operating at present depend initially upon uranium 235 to provide the chain reaction. The nuclear fuel is either natural uranium (0.7 percent uranium 235) or enriched uranium (up to about 3 percent uranium 235). Even allowing that some of the plutonium produced in these reactors is also used as fuel, the energy produced is only about one percent of the energy potentially available from uranium ore. Greater energy utilisation is possible by re-using the plutonium produced during reactor operation (recycling) and by selecting a suitable reactor type.

At the neutron energies found in fast reactors, fission of plutonium produces more neutrons for continuation of the chain reaction than does the fission of uranium 233 (from thorium 232) or uranium 235. The neutron production rate is more than sufficient to maintain the chain reaction and, by careful design, the excess neutron production can be used for further plutonium production by neutron capture in uranium 238. The ratio of the new fuel produced to the fuel consumed is called the breeding ratio of the reactor. This breeding ratio may exceed unity in fast reactors, that is, more fuel is produced than is consumed.

With high power density per unit volume in the reactor core (500 kilowatts per kilogram) and a breeding ratio of 1.35, a fast reactor fuel inventory may be doubled in a decade, while at the same time raising the energy exploitation of the uranium to somewhat greater than 75 percent of its maximum. Although such performance may be achieved ultimately in plutonium fuelled systems, even at present it is possible to introduce a fast reactor system fuelled initially by uranium 235. Even though such a system may have a breeding ratio which is not much above unity, it is possible for this so-called fast converter to achieve a significant reduction in uranium supply requirements compared with present commercial light water systems by virtue of its superior plutonium production capacity. Furthermore, recycling of plutonium in advanced thermal systems, as proposed by Japan, also assists in reducing the overall uranium supply needed to support the industry.

With the increasing development of fast reactor systems in the United Kingdom, U.S.A., U.S.S.R., France and Germany up to the prototype stage, it now seems possible for fast reactors to begin to contribute significantly to power production in the 1980s, as is assumed in the ENEA studies. If fast reactors are likely to be introduced into Australia before the end of the century, the Commission must be able to assess the potential value of such systems in the intervening period, and to make a critical examination of designs offered by construction companies. As the Jervis Bay assessment has shown, the most appropriate way of achieving the necessary background data and expertise is through an Australian research and development program.

Although reactor physics information may not be the most critical in the final economic and technical evaluation of systems, it is the information which provides the basis for much of the preliminary evaluation and subsequent design of a system. It is usually more effective, therefore, to begin such reactor physics studies several years in advance of detailed engineering or metallurgical studies.

To this end, the Commission is building a large, low-power critical facility for reactor physics studies. With its designed flexibility in construction and use, the facility will allow investigation of a wide variety of reactor problems, including those associated with the use of plutonium in advanced thermal reactors and in fast reactors.

Since much of the basic information on plutonium and its isotopes, required for detailed design and assessment of fast reactors, is inadequately known or even unknown, remedy of this position is likely to be the theme of reactor physics research throughout the world over the next decade. By studying very simple designs of plutonium-fuelled reactors, it is hoped that scientific contributions of international value can be added to knowledge of the influence of the isotopic composition of plutonium on the behaviour of fast reactors. Allied with the present Commission studies on fission and neutron capture processes, the work will provide a sound basic understanding of reactor systems likely to be in use by the end of the century, as well as information which may be exchanged with other countries.

This research program would be given further emphasis by the installation of a thermal reactor system in Australia, resulting in the production of several hundred kilogrammes of plutonium a year. Subject to a decision on a national fuel policy, the plutonium from the first Australian reactors could be recycled in those reactors as a replacement for the uranium 235 consumed, used as fuel in advanced thermal converter reactors, or used ultimately in fast breeder reactors. The data and information obtained through the use of the new critical facility either directly or by exchange will assist in forming the most advantageous fuel policy.

## FUEL RESEARCH

### Fabrication of Zirconium Alloy-$UO_2$ Fuel Elements

Research and development into the fabrication of fuel elements has been concerned mainly with the basic unit process involved in fuel fabrication and inspection. The emphasis has been more on fuel pins than on complete fuel assemblies. Fuel pins differ little in basic design from one reactor concept to another, except in length, whereas the mechanical and geometrical design of assemblies differ widely. Some pilot-scale facilities also have been developed for such operations as processing Australian uranium ore concentrates to nuclear grade uranium dioxide powder and fabricating this powder into reactor-grade uranium dioxide pellets. The scale of these plants is sufficiently large to allow information to be obtained for the design of a fuel fabrication plant at the appropriate time.

Unit processes at all stages of fuel manufacture, from uranium ore concentrates to the finished fuel pin, are being studied to gain a better understanding of the potential and limitations of existing processes. The pulsed fluidised bed developed at Lucas Heights for the calcination-reduction of ammonium diuranate (ADU) to uranium dioxide has produced powders superior in quality to those from the normal tray reduction route.

Various problems with pellet fabrication have been studied. In particular, the importance of atmosphere control during sintering is now well understood. The potential advantages of various organic binders for automatic cold-pressing of pellets have been evaluated, and an alternative sintering process developed which operates at a much lower temperature than the usual process. More basic work is in progress on the effect of excess oxygen on the sintering kinetics and sintering mechanism in uranium dioxide.

The process being studied for fuel element cladding fabrication is hot extrusion followed by cold-drawing, since this technique is within the present capacity of Australian industry. Four-inch diameter Zircaloy-2 billets are extruded in two stages to $\frac{3}{4}$ inch diameter hollows. The main aim has been to produce a concentric hollow so that the concentricity of the cold-drawn fuel tubing will be satisfactory. Cold-drawing has also been evaluated by an industrial firm. The main area of study in this operation has been the effectiveness of various die lubricants and the control of crystallite orientation or "texture" (which affects corrosion and mechanical properties) during cold-drawing.

The Research Establishment has equipment for specialised welding processes to weld end caps to fuel tubes. These include inert gas arc welding and electron beam welding. Magnetic force welding equipment is to be installed shortly. Vacuum induction brazing and spot welding processes have been assessed and used for the attachment of wear pads to fuel pins.

Zircaloy tubes for fuel element cladding must meet rigid quality control inspection standards, particularly as to dimensions and freedom from flaws. Equipment for ultrasonic wall thickness gauging and flaw detection is being set up to gain experience in the assessment and testing of fuel tubing. Small batches of imported commercial tubing, industrially cold-drawn tubing and tubing produced at the Research Establishment are being assessed and compared.

### Fuel Performance

The evolution of efficient fuel element designs is critically dependent on an understanding of the factors which affect fuel element performance. For example, the zirconium alloy cladding, whose main function is to contain the fuel and highly radioactive fission gases, should be fairly thin to minimise parasitic absorption of neutrons. However, there should be a very small risk of the development of defects (e.g. pinholes) which would allow the escape of fission gases to the coolant. Defects can occur by many mechanisms which include corrosion, vibration-induced fatigue and thermal strains produced by the uranium dioxide fuel itself. Work in each of these areas is in progress at Lucas Heights to improve understanding of performance and its relationship to design.

### Corrosion

All zirconium alloys corrode to a certain extent in high-pressure water, but the oxide film is normally protective, so the reaction rate is slow. For fuel cladding applications, local high corrosion rate (which can occur under certain conditions) is more likely to result in defects than uniform corrosion. Even so, uniform corrosion rates should be known accurately so that the initial cladding thickness can be adjusted if necessary. On the other hand, for zirconium alloy pressure tubes, uniform corrosion is more important because of the required long residence time — at least ten times that of fuel. Unfortunately, the corrosion behaviour of zirconium alloys is neither well characterised nor well understood.

This applies particularly to corrosion in the presence of radiation, and to local corrosion which is often responsible for fuel defects.

Research on zirconium alloy corrosion at Lucas Heights is concerned both with measurement of corrosion rates under a variety of conditions and with improved understanding of mechanisms. The work has application to the behaviour of pressure tubes as well as fuel cladding.

Corrosion rate measurements have shown that high concentrations of oxygen can greatly accelerate the corrosion of Zircaloy-2 in high-pressure water, and that reactor irradiation further increases the rate. However, gamma radiation has relatively little effect. The electrochemical properties of oxide films on zirconium alloys have been shown to be sensitive to irradiation, and increased ionic conductivity can be correlated with enhanced in-reactor corrosion rates. The work is continuing.

Another area of study has been the development of non-porous crud layers, consisting of deposited corrosion products from other parts of the circuit. These can cause local overheating and high corrosion rates on the fuel cladding, particularly in direct-cycle reactors. It has been shown that non-porous crud can be produced on Zircaloy-2 in the presence of sea-water salts.

## In-Reactor Testing

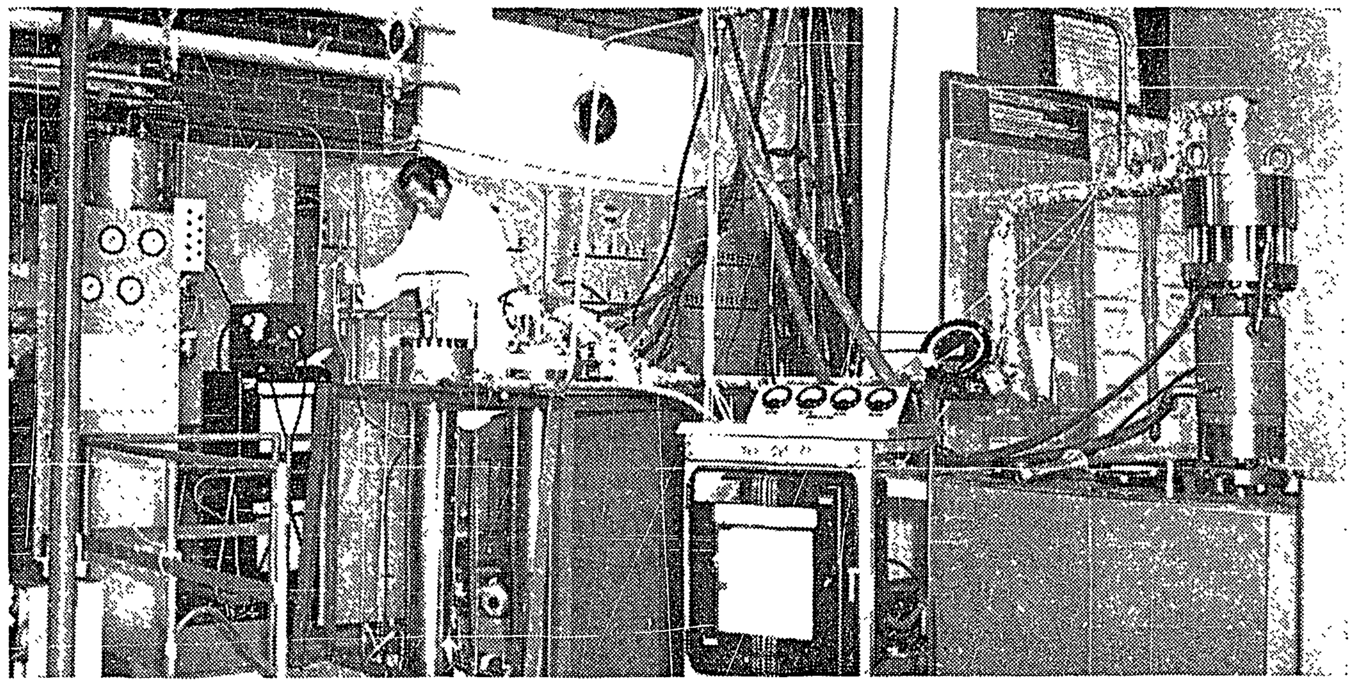
Many aspects of fuel performance will be studied in an in-reactor high-pressure water loop designed for irradiation testing of experimental fuel pins. The loop is nearing completion, and fabrication of fuel pins for the initial tests is well advanced. The pins will contain Australian uranium dioxide pellets fabricated in the pilot scale facilities at Lucas Heights. The fuel enrichments required to give the desired range of heat ratings have been determined by reactor physics experiments using prototype fuel pins irradiated at low reactor power levels. It appears that adequate heat ratings will be attained with the reactor HIFAR operating at its normal power level of ten megawatts.

A program has been established for irradiation testing of 20 inch long Zircaloy-uranium dioxide fuel pins. The series of irradiation experiments will become a focal point for all projects concerned with fuel development. Changes in uranium dioxide pellet fabrication techniques, new fuel pin designs, and the effectiveness of component inspection procedures, will be tested in conditions which closely simulate a power reactor environment.

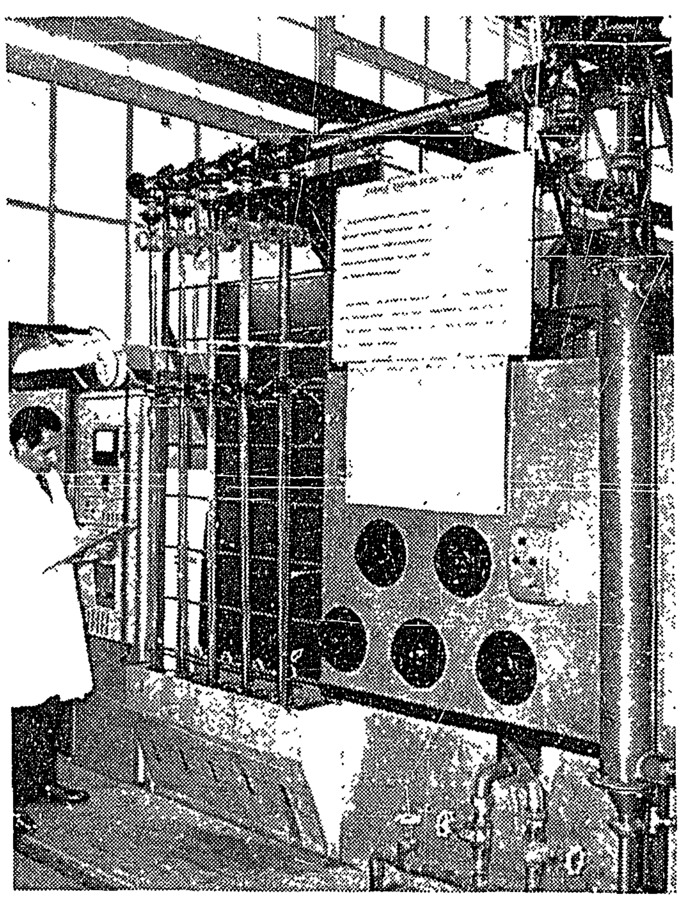
After exposure in the reactor, the fuel pins will be studied in high activity handling cells. Suitable equipment is being developed for these examinations. Dimensions of the irradiated fuel pins will be measured and other assessment techniques will be used such as leak testing, radiography, gamma scanning, metallography and mechanical testing. Uniform and local strains introduced into the fuel element cladding will be determined by measuring grid spacings on the cladding surface. The grid etching technique has been perfected, and closed circuit television is being set up in conjunction with an in-cell microscope to allow accurate measurement of changes in grid spacing.

## Vibration

The rapidly flowing coolant in the fuel channel is capable of causing intense vibration of fuel element components. This is particularly true in reactors having two-phase flow in the core. The fuel assembly must be designed and developed

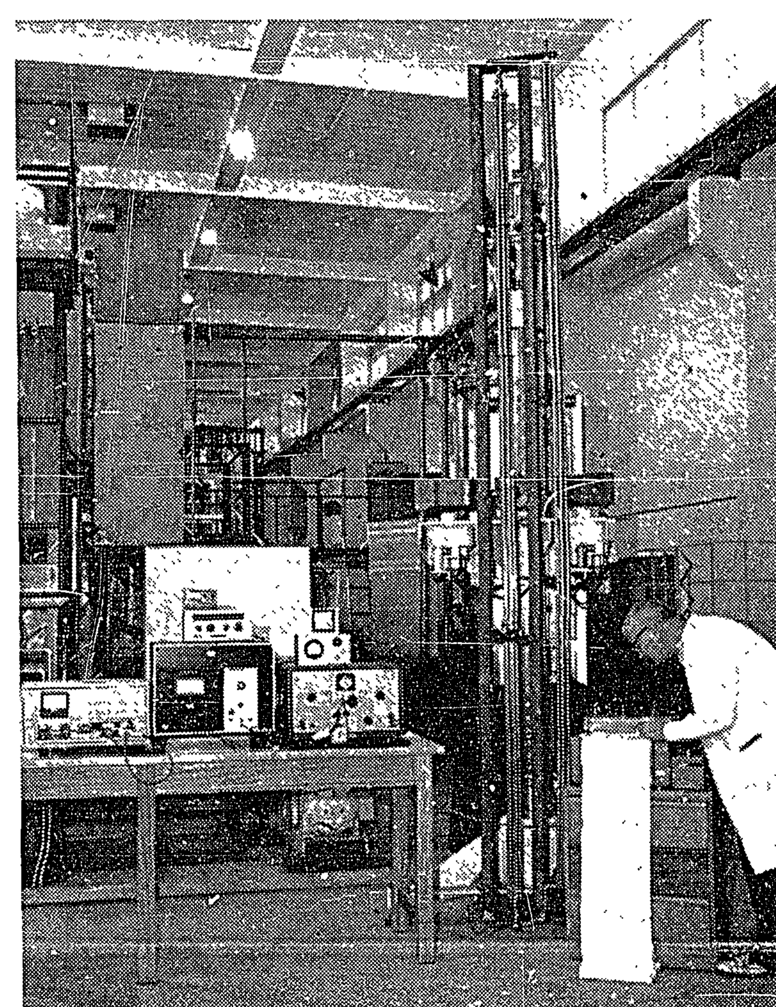


*Above: Out-of-pile commissioning tests of an in-pile high-pressure water loop which, when installed in HIFAR reactor, will closely simulate core conditions in a power reactor. The equipment will be used in studies on irradiated fuel pins.*



*Above: A parallel channel Freon rig (TOPSY*) used to investigate and visually demonstrate the phenomenon of unstable coolant flow oscillations which can occur in boiling water reactor systems. (*Two-phase oscillations in parallel channel systems.)*

*Below: Inspecting an automatic mechanical signature analysis system record which shows the response of a model nuclear fuel element to electromechanically induced vibration over a range of frequencies.*



to suppress vibration effects, as far as practicable, and to mitigate the damaging effects of any residual movements. Such damage would ultimately show itself as cladding failure resulting from fatigue failures or fretting wear produced by relative movement of components having some mechanical contact with each other.

Fuel element assemblies are complex structures having many components and many partial restraints on vibratory movements. The prediction of vibration modes and their consequences in such structures appears to be impracticable by calculation from first principles, although general design guide-lines are obtainable from empirical experiments. Developmental testing and pre-production proving of fuel element structures is therefore required. Furthermore, this testing program must be repeated before any modification is incorporated.

An investigation program is in progress at Lucas Heights into the vibration-causing effect using flowing water or air-water mixtures (to simulate steam-water), and into the response to applied vibratory forces of mechanical models of fuel element assemblies. The object is to develop laboratory techniques to aid in the evaluation of fuel element designs offered for use in Australia, and to provide direct support for local fuel element development. As this work requires extensive capacity for the analysis of complex electrical signals, the Commission has set up a well-equipped noise analysis laboratory.

### Fuel Reprocessing

The optimisation of a total fuel cycle for large power reactors usually requires reprocessing of the discharged radioactive nuclear fuel to recover valuable fissile materials. It seems unlikely that, in the near future, new processes will be introduced which will provide substantial cost savings in relation to the well-established solvent extraction processes now used in almost all plants overseas.

Commission staff, therefore, are examining the prospects for significant cost reduction in this type of plant by improving the design and layout of the chemical plant, and optimising such items as shielding and instrumentation. Overseas activities in the area of new and improved equipment are being watched and evaluated.

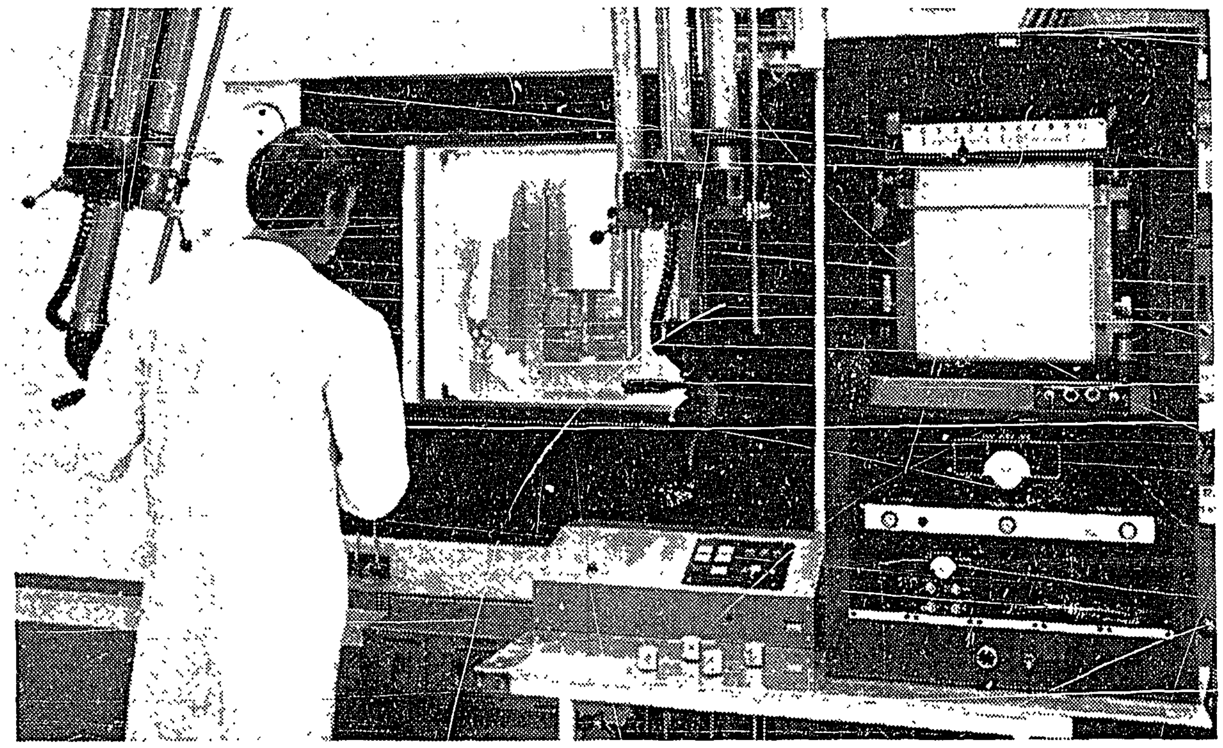
## REACTOR PHYSICS CALCULATIONS

Accurate prediction of the behaviour of neutrons is a most important part of studies of nuclear power reactors and reactor experiments. These predictions are achieved by computation from nuclear data for materials used in the reactor system. The data are extracted from a library of nuclear data and processed to suit the particular calculational methods to be used.

To analyse a reactor system, a selection has to be made of the computer programs best suited to the particular problem. Some programs use processed data directly, but others require the results from other computer programs as part of their input. If the whole sequence can be automated, the possibility of error from manual handling of data can be eliminated.

In many overseas laboratories, a modular coding scheme has been developed in which programs each produce files of information that can be automatically processed by any other program in the system.

Having limited manpower, the Research Establishment has used an alternative approach by writing separate routines to connect any chosen pair



*An in-cell tensile testing machine and its associated measuring and control equipment for determining the post-irradiation strength of reactor materials. These strength values are compared with pre-irradiation values to find the effect of neutron irradiation on the materials examined. The machine is controlled remotely from the cell operating face. A load is applied to the specimen and the resultant strain measured. The specimen can be heated to temperatures of up to 400°C and maintained in a vacuum or an inert atmosphere during the test.*

of programs. The present temporary technique is working satisfactorily and will allow the eventual change to the modular scheme to be made gradually.

## NUCLEAR DATA RESEARCH

The Commission's research program includes both theoretical and experimental studies to produce and correlate new nuclear data. No single country sensibly can bear the cost of operating a completely independent data gathering program, and the compilation and dissemination of nuclear data is now international.

The Commission participates in these activities through its membership of the International Atomic Energy Agency, and also exchanges data under bilateral agreements. The Commission now has access to the Evaluated Nuclear Data File (ENDF), a compilation of data evaluated in the U.S.A., to which the AAEC has contributed its evaluation of cross section data for fission product nuclides. These data complement those available from the United Kingdom Atomic Energy Authority files and from other sources.

The IAEA has assisted the Commission's theoretical research program by providing files of experimental measurements of neutron cross sections. Theories describing the energy variation of neutron cross sections can be checked against these measurements so that, where validated, the theories can be used to fill in gaps in the experimental measurements and to resolve discrepancies between different measurements.

## HEAT TRANSFER

The most stringent limitation to the power that can be extracted from water-cooled reactors is the effect of a natural phenomenon in which part of the heating surface suddenly becomes blanketed with vapour. Because the output of nuclear heat is not significantly affected by this process, and because steam is much inferior to water as a coolant, a dry-out condition occurs which results in local overheating of the fuel pins.

For materials normally employed in water-cooled reactors, the consequence will usually be some metallurgical deterioration of the fuel cladding, the amount of damage depending upon the duration of the dried-out condition, the power rating of the reactor and the coolant operating conditions. The main effect of such damage will be the development of leaks in the fuel cladding, leading to the release of fission products into the primary circuit.

The reactor power at which dry-out will occur cannot be predicted at present from theory and basic data, so tests are necessary. The only category of laboratory test entirely acceptable for reactor design is one where a full-size replica of the fuel element is heated electrically beyond its normal operating power to the actual dry-out rating, while being cooled by water at representative operating conditions.

Typically, the normal power output of a single fuel element assembly in a water-cooled reactor would be several megawatts of heat. Dry-out power would be about half as much again, operating pressure would be in the range of 800 to 2,300 $lb/in^2$ and the temperature would be in the 250°C to 350°C range. Test rigs for such experiments cost about a million dollars and require substantial operating and supporting staff.

About ten years ago much thought was given, particularly in England, to the use of a fluid to serve as a scale model for water. Less energy would be needed, lower operating pressures and temperatures would be required, and economies would be introduced. The choice settled on certain of the chlorine-fluorine substituted hydrocarbons which are used as refrigerants. Their basic attributes were low latent heat of evaporation and low boiling point compared with water, and their properties were excellent as regards flammability, toxicity, electrical insulation and corrosion. Early tests indicated a general similarity in the dry-out performance. General considerations indicated that the essential scaling condition was that the ratio of vapour density to liquid density in the test fluid be set at the same value in the test rig as the ratio of steam density to water density would be in the reactor.

Several years of tests have progressively confirmed the general applicability of this method for increasingly complex geometries tested at full size. Sufficient confirmatory work has not been done yet, but it is likely the method will supersede water testing. However, the technique is already adequate to facilitate useful comparative tests of the performance of detailed aspects of the dry-out process.

Extensive experimental work at Lucas Heights, in collaboration with the UKAEA laboratory at Winfrith, in which the work originated, has been in progress towards the establishment of a firm foundation for model fluid testing of reactor fuel element geometries. Dry-out tests of an extensive range of single rod test sections arranged in annular flow geometry have been made in the refrigerant Freon 12. This, in essence, is the simplest possible test of a module of a reactor fuel rod bundle or cluster.

Results of these tests in Freon are being compared with those from a smaller range of tests being carried out in England using high pressure water in corresponding geometries and operating conditions. In all, some 30 test sections, on loan from the UKAEA, are being subjected to dry-out tests over a suitable range of pressures, flow rates and entry sub-cooling temperatures. Results obtained so far give increasing confidence in the model fluid technique.

After experiments on annular test sections, attention will turn to representative rod cluster geometries and hydraulic details representative of actual reactor practice. The aim is to develop the method until it is practicable to provide, in Australia, direct answers on the thermal performance characteristics of any design of water-cooled reactor fuel element that may be offered or developed for use in Australia.

General techniques being developed look beyond water-cooled thermal reactors to future sodium-cooled fast reactors to which the model fluids techniques are thought to be applicable also.

# REACTOR MATERIALS

The principal materials used to fabricate the fuel elements for the present designs of water-cooled power reactors are uranium oxide for the fuel, and zirconium for the cladding. The usual raw material sources of the highly-purified products are uranium ores and zircon sands. These are in good supply in Australia.

Apart from its use for cladding the fuel, zirconium is used as a structural material in reactors. Another essential material in many designs of water-cooled power reactors is heavy water, but this is not produced in Australia.

## Extraction of Uranium

The ease with which conventional grinding and leaching processes can be applied to extraction of uranium from its ores varies considerably with the microstructure and distribution of uranium within the ore. Work therefore is continuing at Lucas Heights on the characterisation of uranium ores of a variety of grades by the techniques of optical microscopy, scanning electron microscopy and electron-microprobe analysis.

The usual concentrate produced at most uranium mine sites is called "yellowcake". The product is shipped to uranium refineries for conversion to very pure uranium compounds which can be fabricated into fuel elements. It would be an advantage to purify the uranium to a high degree at the mine treatment plant and thus save some of the costs of treatment at the refinery. Work continued at the Research Establishment to develop a suitable amine solvent extraction process. A method of analysing uranium solutions containing 0.01-1.0 g U/litre, using gamma-ray excited fluorescent X-rays, was developed to enable solutions from the solvent extraction equipment to be analysed rapidly.

Ultimately, most uranium concentrates are converted to uranium hexafluoride ($UF_6$) for supply to enrichment plants. Most types of power reactor in use or under construction use enriched uranium dioxide fuel. Since Australia is a potentially large producer and exporter of uranium, it would be in Australia's interest to sell uranium hexafluoride rather than yellowcake. Moreover, if enriched uranium dioxide power reactors were to be installed in Australia and fuel policy demanded an indigenous fuel supply, it would be necessary to have facilities for uranium hexafluoride production and conversion to uranium dioxide powder. Therefore, an assessment is being made of the requirements for the introduction of uranium hexafluoride production into the Australian uranium industry. Research and development work is in progress on the chemical and chemical engineering aspects of the handling of fluorine and uranium hexafluoride.

## Extraction of Zirconium

As Australia is one of the world's principal sources of zirconium ore, it may be considered desirable to extract and process the metal in Australia. There is a considerable difference in value between the crude zircon (9 cents per kilogramme of zirconium) and finished products such as highly-pure zirconium metal ($70/kg). The Commission and the Bureau of Mineral Resources have jointly completed an assessment of the reserves, annual production and prices for zircon; the Australian and world requirement for zirconium for nuclear power reactors; and future zirconium production and prices. In addition, the Research Establishment has made a detailed review of the available processes for the purification of zirconium.

## Heavy Water Production

The world supply and demand for heavy water is reviewed in Chapter 5. At Lucas Heights an assessment has been made of the current status of the most widely favoured processes — the hydrogen sulphide-water exchange process, the ammonia-hydrogen exchange process, and recently proposed variants of the latter using amines in place of ammonia, or a hydrogen-water exchange step to provide an unlimited supply of hydrogen. Research continued on possible new and cheaper methods for obtaining heavy water.

## Uranium Analysis in Ores

Due to the increasing importance of Australia's uranium deposits, a collaborative analysis program was initiated between several laboratories in an attempt to standardise methods for the determination of uranium in ores. Twelve mining companies are involved in the survey. The Canadian Department of Energy, Mines and Resources also has agreed to participate. Four uranium ore samples were issued to each laboratory with the request that they be analysed by as many different techniques as possible. The results will be examined statistically and compared with those obtained in the Commission's laboratories.

One interesting and potentially very sensitive method being evaluated by the Commission is the determination of uranium content of ore samples by delayed neutron measurement after neutron irradiation. The method is relatively simple and can be made selective as uranium has the unique property of thermal neutron induced fission. However, the method requires access to high neutron fluxes which are normally associated with reactors or particle accelerators.

Fissile material (uranium 235 in natural uranium) undergoes fission when bombarded with neutrons. During the fission process, further neutrons are emitted, the majority of them promptly. A small fraction of the neutron yield results from the decay of neutron-rich fission products and can be studied for several minutes after neutron irradiation.

Preliminary work has shown that relatively short irradiations of uranium ore samples in the low power reactor Moata will enable uranium ore concentrations of 0.2 lb per ton to be estimated with simple equipment, and that ten samples per hour can be examined.

# 9

# OTHER RESEARCH

Earlier chapters of this Report emphasise research conducted by the Commission which is of crucial importance in the assessment of nuclear power plants suitable for installation by Australia. While these studies were proceeding, the Commission's Research Establishment was engaged also in research projects which constitute a large part of the list of research activities listed in Appendix D.

The interaction of radiation with living tissue, establishment of national radiation standards, development of new radioisotope products, improvement of radiation detectors, computer research, new methods of fabricating ceramic nuclear materials, neutron diffraction studies, various physics studies and many more topics, are the subject of intensive research at Lucas Heights. Some of the developments in these fields are described below.

## INSTRUMENTS FOR NEUTRON DIFFRACTION

For many years, the Commission has provided equipment (in conjunction with the Australian Institute of Nuclear Science and Engineering) for research workers who wish to carry out diffraction experiments using the neutron beams from the reactor HIFAR. It is only the existence of this facility that makes it possible to do this work in Australia. The equipment is used by chemists to study molecular structures, by physicists to study magnetic moments and interatomic vibrations in liquids and solids, and by metallurgists to study alloys and phase transitions.

A comprehensive range of advanced instruments has been assembled during the past ten years. The main instruments operate under the control of small on-line computers and, as far as possible, have been designed and built locally.

The most important new instrument commissioned this year is a triple axis neutron spectrometer which is used by physicists to study interatomic vibrations and forces. This large instrument weighs more than 20 tons and was designed by the Weapons Research Establishment, Department of Supply, to an AAEC specification.

It was built by Vickers Ruwolt Pty. Ltd., Melbourne. The intricate system of on-line computer control for the various axes was designed and assembled within the Research Establishment. Commission scientists, in conjunction with research workers from the University of New South Wales, are conducting the first experiments with the instrument.

The installation supplements the range of modern instruments available to study the structure of materials by means of neutrons, and should meet the requirements of users for the foreseeable future.

## FABRICATION OF CERAMICS

During the early 1960s some work commenced on the production of ultra-high density fuel particles for dispersion fuels using sol-gel techniques. It appeared possible to use sol-gel techniques to produce larger bars or rods of a material such as thorium oxide, which would have much higher density and strength and a finer grain size than cold pressed and sintered material.

The results from a small research program, initiated several years ago with this aim, have been promising. Strength values have been increased by a factor of two to three over those normally expected. However, the fact that it was a batch process was a disadvantage, and alternative methods of forming gel bars from sol were explored.

An apparatus was then developed for the continuous concentration and extrusion of ceramic sols, with probable application also for slurries and precipitates. It is similar to a plastics extruder, but has a porous barrel within which concentration can be carried out, and has been tested successfully with ammonium diuranate slurries. The apparatus is believed to be versatile with potential application in many areas of ceramic technology.

## COMPUTING RESEARCH

### New Computer Language

Reactor research calls for major computing facilities, and the Research Establishment has a large central computer and numerous smaller computers. A Section engaged in research in applied mathematics and computing has made important advances in computer language studies.

A conversational computer language, ACL-NOVA, has been developed and implemented on the Commission's small NOVA computer. It is now providing Research Establishment staff with immediately accessible interactive computing facilities for many problems formerly needing the power of the larger central computer. Many users may converse with the NOVA computer at the same time. Five terminals are available. The development of ACL-NOVA has prompted many enquiries from outside organisations. The Commission hopes to make the language available commercially.

### New Computer Network

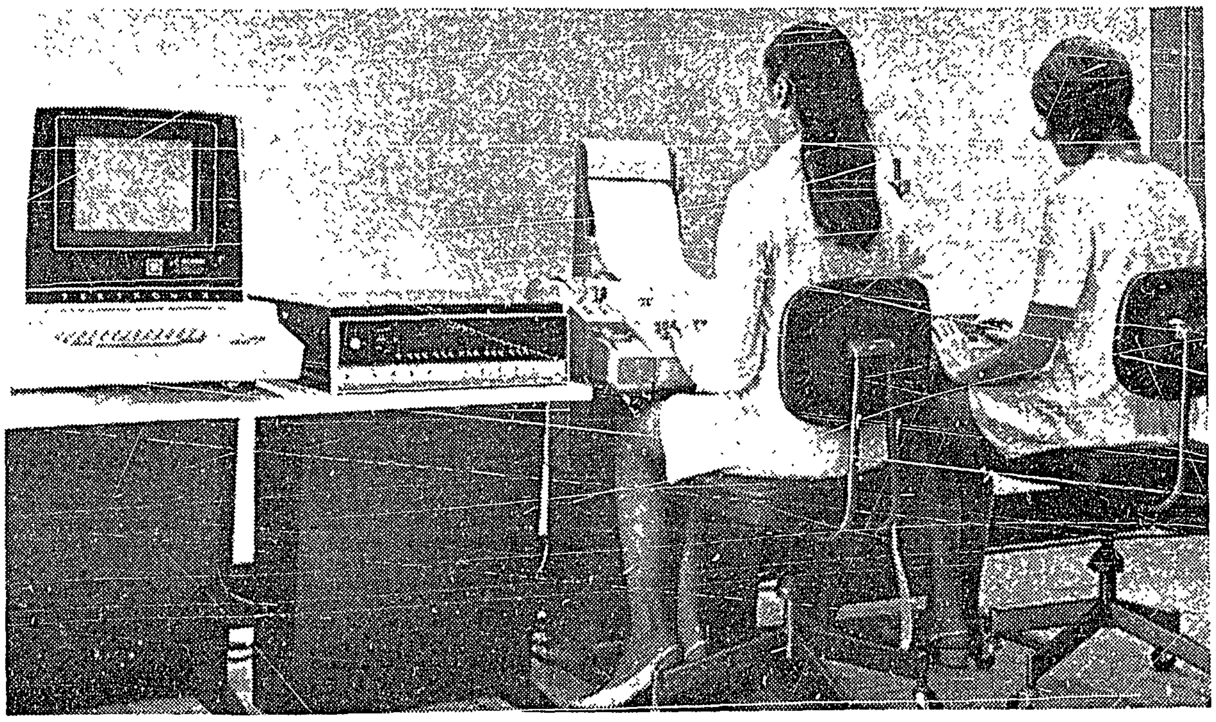
The linking together of the various Research Establishment computers into a computer network is well advanced, and will come into operation shortly. The high capacity and potential power of this network has also aroused considerable interest outside the Commission.

The link will allow the NOVA terminals to be placed at strategic locations to provide excellent computing facilities in Research Establishment offices and laboratories. However, its major function is to allow the small computers (used for control and monitoring of experiments) to call on the computing power of the large central computer (IBM360/50 I) and its associated disc storage when their own capacity is inadequate for the current task.

The computer link is achieved by means of a multi-wire cable having various entry points at appropriate locations. All stations have a standard control unit and an interface to translate the standard signals to the logic conventions and circuit techniques appropriate to the particular computer or peripheral device.

The network is operated on a party-line basis with any pair of stations able to communicate with each other. The two major uses of the network will be automatic and rapid evaluation of experimental results and provision of remote central computer program monitoring facilities for research staff.

Assemblers and simulators for various network computers have been designed and written for use on the central IBM 360 computer. This has enabled the speed of the central computer to assist in the preparation and testing of programs that will be run later on smaller computers.



*Two programmers working at the data input/output terminals attached to the ACL-NOVA computer system. This system is used for rapid solution of small scientific problems. When in full operation, the graphical display terminal (left) will be used to improve a user's interaction with his problem. In addition, graphic input can be entered from the screen of the graphic display terminal.*

## Compound Semiconductors for Nuclear Radiation Detectors

Research over the past few years has aimed at developing nuclear radiation detectors suitable for more precise nuclear measurements. As noted in previous Annual Reports, the work has concentrated on the elemental semiconductors silicon and germanium.

The choice of silicon and germanium was dictated by their availability in single crystals of reasonable size and good quality. However, the materials are not ideal. For example, their low band gap (the difference in energy level of bound and free electrons) requires that they be operated at very low temperatures — near that of boiling liquid nitrogen — otherwise the thermal vibrations of the crystal permit some electrons to acquire sufficient energy to jump the narrow band gap. The resulting currents of free electrons and holes can obscure those produced by the nuclear interaction that should be detected. Furthermore, their low atomic number reduces their efficiency for detection of gamma-rays, compared with that of, say, a sodium iodide scintillation counter.

Materials which could be used for detectors with high gamma-ray efficiency, yet could be operated at ordinary temperatures, need wide band gaps and high atomic number. These characteristics can be found in a number of compound semiconductors. However, one material, cadmium telluride, which has so far received most attention in this and other laboratories, has proved markedly inferior to silicon or germanium for such detectors.

The Commission recently evaluated high-purity, n-type gallium arsenide grown by a technique called "liquid phase epitaxy". Samples of the material, developed originally for Gunn effect solid-state microwave oscillators, were obtained from overseas laboratories. High resolution performance at room temperatures was found in radiation detectors made from this liquid-phase epitaxy gallium arsenide, demonstrating for the first time that an alternative, useful compound semiconductor is available. The one restriction is the relatively small size of the crystals grown by this technique. It has also been possible to measure several significant basic properties of gallium arsenide as a detection medium. The new work is held to be of considerable importance in the radiation detection field, indicating the potential application of gallium arsenide for detectors in areas such as nuclear physics, radiomedicine and radioassay. There are prospects for commercial exploitation of the discovery.

## PHYSICS RESEARCH

The well-known chain of events in which a neutron induces fission in a nuclear fuel and further neutrons are generated, is the basis of present-day nuclear reactors. The probability of neutrons interacting with a particular material is known as a "cross section". In the following examples of physics research, mention is made of the development of neutron sources for special purposes, studies of the emission of gamma-rays following the capture of neutrons of particular energies, theoretical calculation of neutron cross sections and some problems in nuclear analysis. These topics are representative of the work carried out in the theoretical and experimental branches of reactor physics research.

### Development of Neutron Sources

Investigations into the probabilities of neutron interaction with isotopes and studies of reactors in accident conditions require intense sources of neutrons. Such neutron sources vary in shape, size and intensity, and may be operated either continuously or as a series of pulses.

Neutron sources are used in mining exploration to activate materials. Subsequent analysis of the gamma-rays emitted is used to identify minerals present in rocks. The search continues for sources of smaller size but higher

*Assembly of a high resolution, semiconductor spectrometer for detecting X-rays. The detector is housed in a cryostat operating near liquid nitrogen temperature. The system is used for such applications as X-ray fluorescence analysis of minerals and in X-ray diffraction studies.*

intensity. One such device — the plasma focus source — is being investigated at the Research Establishment. In this device, magnetic energy stored in the gas plasma is converted rapidly into plasma energy (heat) at the same time as the plasma is condensed by its self-excited magnetic field.

Pulses of $10^{10}$ neutrons per second should be obtainable on a 0.1 microsecond time scale from deuterium interactions within the energetic deuterium plasma, and similarly $10^{12}$ neutrons per pulse from a deuterium-tritium mixture. Deuterium (D) and tritium (T) are isotopes of hydrogen.

The reactions are:

$D + D \rightarrow He^3 + n + 2.45$ MeV

$D + T \rightarrow He^4 + n + 14$ MeV, where MeV = million electron volts.

The dense plasma focus gun consists of two coaxial cylindrical electrodes separated at the breech end of the gun by a Pyrex glass insulator. The device is contained in a vacuum vessel, and is operated with a gas filling in the pressure range 0.1 to 10 Torr. When technical problems believed to be associated with cabling and induced inductances and possibly the polarity of the central electrode are resolved, operation of the gun with deuterium fillings will proceed, and then the neutron output will be developed.

## Theoretical Neutron Cross Sections

In the analysis of nuclear cross sections for energies below one million electron volts, the theory of resonance processes plays the dominant role. Early theories assumed that a cross section showing a series of resonances as a function of energy could be represented by a simple sum of contributions from individual resonances, the so-called single-level scheme. This was adequate for all nuclides except those which undergo fission. The resonances for fissile nuclides are so close together that complicated non-linear interference effects take place. Satisfactory agreement between theory and experiment demands the more complicated reaction matrix theory developed by Wigner and others. This is called the multi-level scheme.

The multi-level scheme involves a mathematical operation which normally cannot be done without using elaborate approximations, and it is never clear that the approximations do not introduce appreciable errors. It was discovered that an investigation into a model of the nucleus in which all processes are described by the scattering of waves with an equal change in phase in all processes, led to a full description of the compound nucleus process. In this mechanism, a neutron is absorbed by the nucleus, and the resulting compound nucleus lives for a very long time, so that there is no correlation between the final decay of the compound state and the initial neutron-nucleus state. Under such a condition, the cross section can be expressed as a product of probabilities.

It was found in Commission research work that the compound nucleus mechanism leads to the above equiphase condition, which in turn through mathematical operations leads to much more manageable expressions for cross sections. The fission cross sections of the nuclides uranium 233 and uranium 235 were fitted to an accuracy much better than the error expected from experiment, and thence the appropriate nuclear constants were derived. It was shown also that all nuclei have a certain proportion of direct processes present when reacting with neutrons. Direct processes are essentially non-compound nucleus reactions in which no long-lived intermediate compound state is formed, but the neutron reacts directly with a component of the nucleus in a very short time.

A program of fitting all the fissile nuclides to this theory is in progress, giving results which so far are superior to those of any multi-level scheme except that proposed by Adler and Adler, to which our formulae are equivalent. Unlike other multi-level theories, the theory allows Doppler broadening of resonances (an effect arising from heating of materials) to be carried out analytically. The parameters obtained are throwing new light on the nature of compound and direct processes, and their connection with reaction matrix theory.

### Neutron Capture Gamma-Rays

Gamma-rays emitted from nuclei, following the capture of neutrons, are important in the study and interpretation of neutron cross sections particularly when it is necessary to calculate unknown cross sections. The gamma-ray data are also valuable for direct use when considering secondary processes in neutron shields, where absorption of a neutron near the external face of a shield may present gamma-ray shielding problems which are of lesser significance, but are still economically important.

Precision measurements of the gamma-rays resulting from capture of neutrons in the energy range 10-100 thousand electron volts (keV) have been undertaken over the past four years at Lucas Heights, as equipment and techniques have been developed and improved. Using the Commission's 3MeV Van de Graaff accelerator, it has been found possible to make measurements for nuclei in the medium mass range. In studies of more than 20 different natural elements and separated isotopes, the precision of the measurements has led to the discovery of unexpected gamma-rays. These cannot be explained without postulating unusual resonance properties associated with neutrons of higher angular momentum or less probable transitions. The work has allowed also the resonances associated with keV neutron capture to be resolved in some target materials. The analysis of these results has required the development of new theoretical methods for deriving resonance parameters from the observed gamma-ray spectra, together with continued improvement in experimental equipment and techniques for handling data.

A thorough compilation has been made of the Commission's experimental data and those of the few overseas workers in this field, to make them available for world-wide publication. This time-consuming work greatly assists the establishment of a satisfactory understanding of neutron absorption in any energy range where accurate measurements are difficult, and for structural materials used in fast reactors.

Considerable effort is being expended to refine the experimental equipment to accept smaller samples and to improve energy resolution and source strength. It is hoped that by these means the energy range of the measurements may be widened and that elements of higher mass may be studied.

## NUCLEAR ANALYSIS

Nuclear analysis is sometimes called prompt activation analysis and makes use of radiation emitted during a nuclear reaction to determine the types of material present in a sample.

Any radiation which interacts with a nucleus may be used to initiate a reaction. Gamma-rays, protons and other charged particles have useful application. Several reactions have been studied in connection with the possible solution of practical problems, typical examples being the detection of heavy water concentrations and oxygen in metal surfaces.

### Photonuclear Reactions—Determination of Heavy Water

The stability of a nucleus is such that energy must be provided or work done to remove a particle from the target nucleus. The characteristic feature of photodisintegration (i.e. by gamma-rays) is the energy threshold below which no reaction can take place. Deuterium has the second-lowest threshold (2.2 million electron volts), and if material containing deuterium is bombarded with gamma-rays whose energy exceeds this threshold, it is relatively easy to detect any emitted neutrons. A common gamma-ray source for this purpose would be radioactive sodium.

The probability of this photoneutron reaction occurring is strongly dependent on the gamma-ray energy, and is greatest at gamma-ray energies in the region of 4 million electron volts. Small electron accelerators provide the most satisfactory and readily available source. It appears possible that with further development and high, but realistic source strengths, variations of 2-5 percent in the natural abundance of deuterium may be measured.

### Charged Particles—Determination of Oxygen in Metals

The problem of oxygen concentration in metal surfaces has provided an opportunity to demonstrate the speed and accuracy of charged particle reactions, even though further development is required. The reaction used is $^{18}0(p\alpha)^{15}N$. The method is restricted to the study of surface layers of the metal sample, because the penetration depth range of protons and deuterons at moderate energies (up to 5 million electron volts) is only 10-100 microns (for titanium, zirconium and iron). The limited range of the incident particles requires that analysis be done in a vacuum chamber. The particle detector is commonly a small solid-state detector suitably shielded from incident and scattered particles.

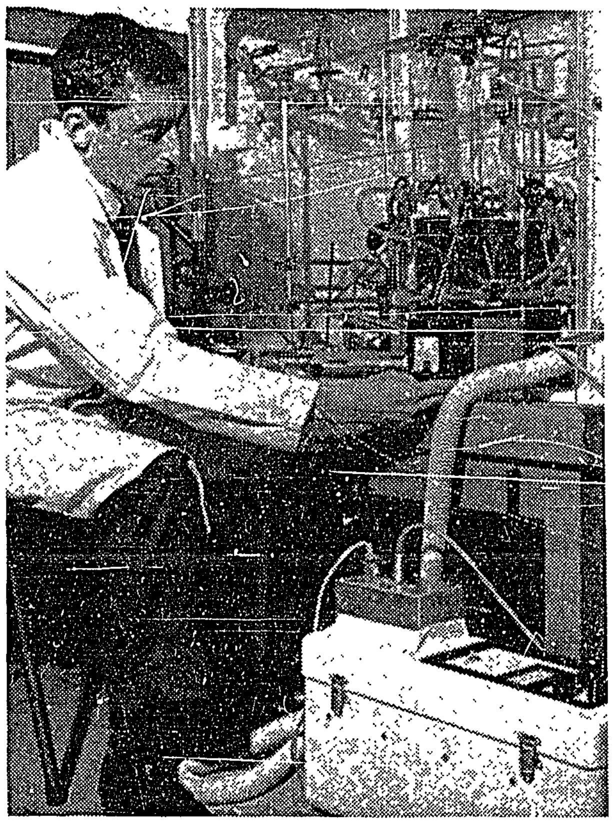
By counting the events recorded by the detector, relative values of oxygen concentration may be obtained and it has been shown that concentration is linear with the detected count rate. The technique has been used to measure the diffusion coefficients of oxygen in metals, and by scanning across a surface it is possible to obtain a micro-analysis of oxygen.

## ANALYTICAL CHEMISTRY

The chemical analysis of a wide range of materials is required in support of the Commission's research activities. Frequently only small amounts of samples are available for analysis and impurities must be determined quantitatively at ultra-trace levels, that is, parts per billion ($10^9$). This work necessitates a program to develop sensitive and precise methods of analysis and a number of instrumental methods have been developed recently within the Chemical Technology Division to enable precise analysis of the many materials of interest.

Hydrogen has been determined in the range 10 to 4,000 parts per million by an isotope equilibration method in metals such as titanium, zirconium, tantalum and vanadium. Deuterium gas is first exchanged with the hydrogen in the metal at 800°C, and the resulting change in the ratio of hydrogen and deuterium atoms in the gas phase is measured with a mass spectrometer.

An improved spectrographic method has been developed for the analysis of rare earths in uranium ores of Australian origin. Previously, large samples of the ores were required, but the present method requires samples of only five grammes, because interfering impurities are removed by either solvent extraction or carrier distillation before the spectra are measured.



*Part of the experimental rig used to measure the efficiency of semi-conductors to be used in a cardiac pacemaker nuclear battery. A National Heart Foundation Fellow is working in close co-operation with the Commission on the development of a long-life nuclear battery for use in an implantable cardiac pacemaker.*

Neutron activation analysis and radiochemical analysis have been applied successfully to a variety of problems. One of these was the determination of the composition of the paint of an old master painting whose authenticity was in doubt. The total determination was carried out on a sample which weighed less than half a millionth of a gramme. Samples of human hair have been analysed for the Forensic Science Department of the Commonwealth Police. This Department has a scientist attached to the Chemical Technology Division to exploit and develop advanced techniques of analysis in the forensic field. Assistance was given also to the CSIRO Division of Mineral Chemistry in the determination of the age of rocks.

## NUCLEAR CARDIAC PACEMAKERS

The Commission is supporting work on cardiac pacemakers by supervising a National Heart Foundation Fellow and providing laboratory facilities. The project began in January 1970 and has an initial duration of two years. The aim is to develop a long-life nuclear battery to be used in an implantable cardiac pacemaker.

The conventional pacemaker consists of a compact solid-state electronic unit driven by a small chemical battery. It is implanted in the patient's body by major surgery and provides a periodic electrical pulse to control heart beat. By this means a patient with a usually fatal condition can lead a near-normal life. The life of the chemical battery is limited to about two years, after which it must be replaced completely.

Pacemakers powered by radioisotope batteries with an estimated life of ten years are now in use in France and England, and five have been implanted in humans to date. Power is provided by the radioisotope plutonium 238 coupled to a thermoelectric converter. Other batteries being developed in the United States use the radioisotope promethium 147.

The Australian project is directed towards producing a nuclear cardiac pacemaker battery which uses tritium as the radioisotope fuel and the electron voltaic effect as the energy conversion principle. Use of tritium with its very soft beta radiation, in preference to either plutonium or promethium, should provide a lower radiation dose rate to the patient, lower toxicity of the radioisotope to both the patient and the environment in the event of battery rupture, and a much lower operating temperature for the battery.

The potential demand per annum is 40 to 50 units per million population. Achievement of a safe, inexpensive and long-life nuclear battery will be a major advance in the use of cardiac pacemakers. Present nuclear batteries made in Europe and U.S.A. cost about $2,000 to $4,000 each.

## INTENSIFICATION OF PHOTOGRAPHIC IMAGES

Recent Commission research has shown that underexposed or faded photographs can be improved greatly by autoradiography. The process involves making the silver grains of the image radioactive and then preparing an autoradiograph copy of any desired density by pressing the active photograph against an unexposed film for a predetermined time.

When applied to photographic negatives, the process provides a useful increase in apparent film speed by a factor of as much as 50. When applied to positive prints, the process can be used to renovate faded photographs of historic or sentimental value.

Methods which have been investigated to make the silver image radioactive include neutron irradiation, toning by chemical reaction with various appropriate radioisotopes, and exchange with radioactive silver isotopes in solution. Toning the silver image with sulphur 35 to produce radioactive silver sulphide is one of the most convenient methods.

Only small quantities of radioactivity, of the order of a microcurie, are required for a 24 hour autoradiographic exposure. The exposure time can be reduced proportionately by using larger quantities of the radioisotope.

The current level of under-exposure (about 1/50th of the optimum exposure) which can be intensified successfully is limited mainly by the general level of fog on the photograph. Any developments in photographic science which permit an increased image-fog ratio at low photographic densities will give a corresponding decrease in the level of exposure which can be successfully intensified.

The process could be of value in reducing radiation dose (or exposure time) in medical and industrial radiography. Photographic applications where light levels for image formation are unavoidably low (as in astronomy or the recording of high-speed phenomena) should also benefit from the process. To meet large routine demands as would arise from radiography, it is considered that a fully-enclosed and automatic unit could be developed, employing higher levels of radioactivity, to produce an intensified photograph in a short time. (See page 89.)

## EFFECTS OF RADIATION ON BACTERIA

Gamma radiation from the radioisotope cobalt 60 is increasingly being used to sterilize medical and veterinary supplies and dressings manufactured in Australia. A total of more than one million curies of cobalt 60 is now being used for radiation processing in this country.

The growth of this method, which is particularly suitable for heat-sensitive substances, increases the need to understand the effects of radiation on various bacteria, not only to establish the sterilizing dose, but also to obtain insight on factors such as environmental conditions which could increase or decrease their radiation resistance.

Research with this objective is being undertaken using bacterial spores, because they are among the more resistant micro-organisms. These organisms can exist for years in a dormant state, until suitable conditions occur which trigger metabolic activity and their multiplication by division into colonies of bacteria.

Extensive studies have been made of the radiation resistance of a species of bacterial spore *(Bacillus pumilus)* at the time of initiation of its metabolic activity. This research has revealed a fivefold increase in the lethal efficiency of gamma radiation on the spore as soon as its dormancy is lost. The initiation of activity can be achieved by hydrostatic pressure. The influence of environmental conditions such as temperature and the presence or absence of oxygen is being studied to assist in understanding the mechanism which causes the enhanced sensitivity, and to determine the site of the injury which kills the spore.

Apart from the potential value of this work in increasing the efficiency of gamma-ray sterilization methods, it has also revealed possibilities for increasing the effectiveness of heat and other conventional sterilization methods.

Patent applications for an invention arising from this work were lodged in France, Italy, U.K., Canada, U.S.A., Australia, Germany and Japan. So far, patents have been granted in the first five countries.

## RADIATION PROCESSING AND AUSTRALIAN INDUSTRY

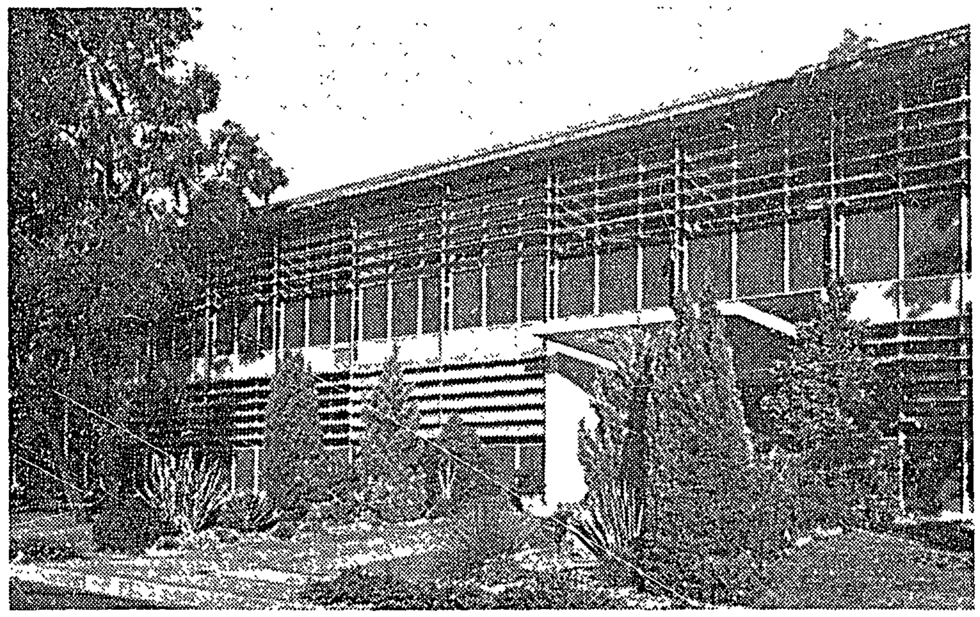
The most important industrial applications of radiation overseas have been in the sterilization of medical products and in the polymer field. In the past year there have been parallel developments in Australian industry.

Imperial Chemical Industries of Australia and New Zealand Ltd. continued to use the irradiator GATRI at Lucas Heights. Among the processes investigated are the pilot plant scale manufacture of specialty ion exchange resins. Radiation provides better control of the manufacturing conditions than is possible with conventional chemical methods for initiating polymerisation.

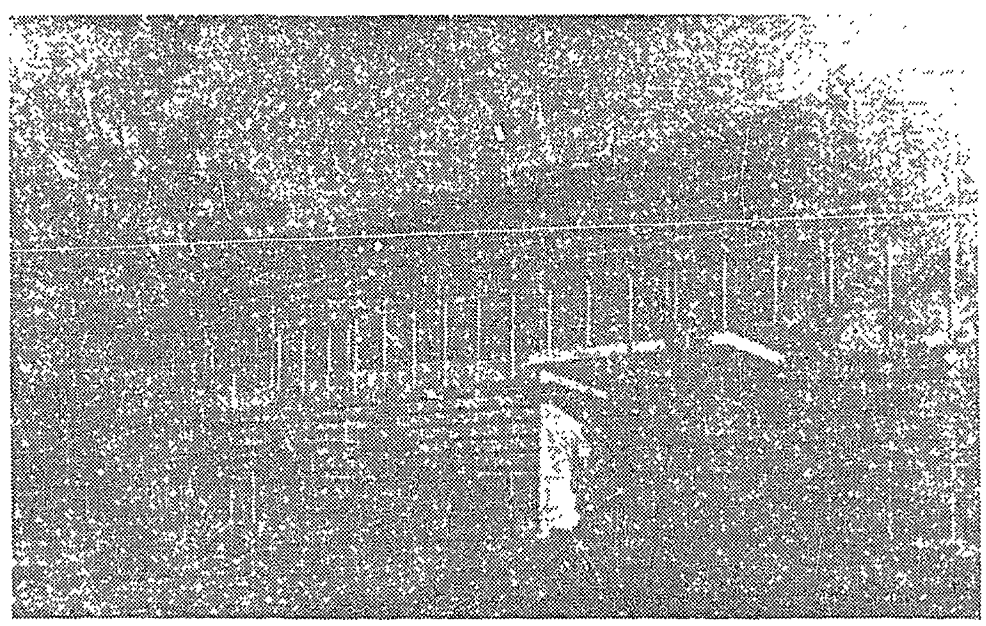
In the Westminster Carpets Pty. Ltd. irradiation plant at Dandenong, Victoria, the commercial manufacture of wood plastic composite floor tiles is being undertaken. Initial production is intended for parquet-type flooring, but a wide variety of uses is envisaged, from sporting goods to furniture. The process enhances the features of natural wood and provides many improvements, e.g., hardness increased up to fivefold. The tiles are being marketed in New South Wales by George Hudson Pty. Ltd.

Tasman Vaccine Ltd., who have operated a gamma-sterilization plant for some years at Upper Hutt near Wellington, New Zealand, have built a plant at Dandenong, Victoria. The company is marketing a range of gamma-sterilized medical products.

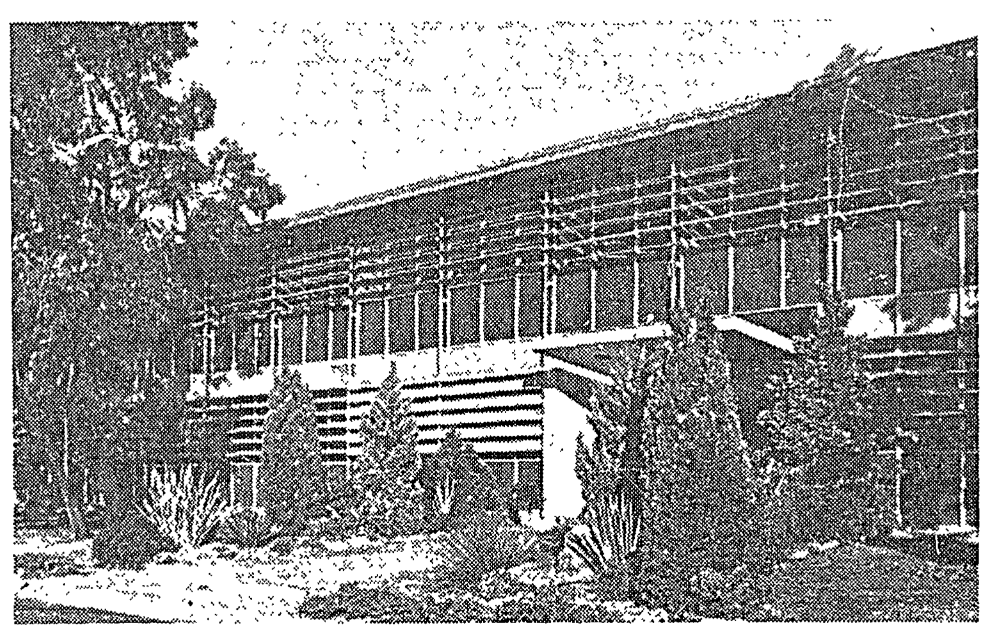
The Commission surveyed the potential for application of low-energy electron accelerators for the radiation-curing of thin films and coatings. Some Australian firms displayed considerable interest, but at this stage it is felt that the Commission's role should be to advise and inform industry of the possibilities of these radiation processes, rather than to undertake an active research and development program in this field.



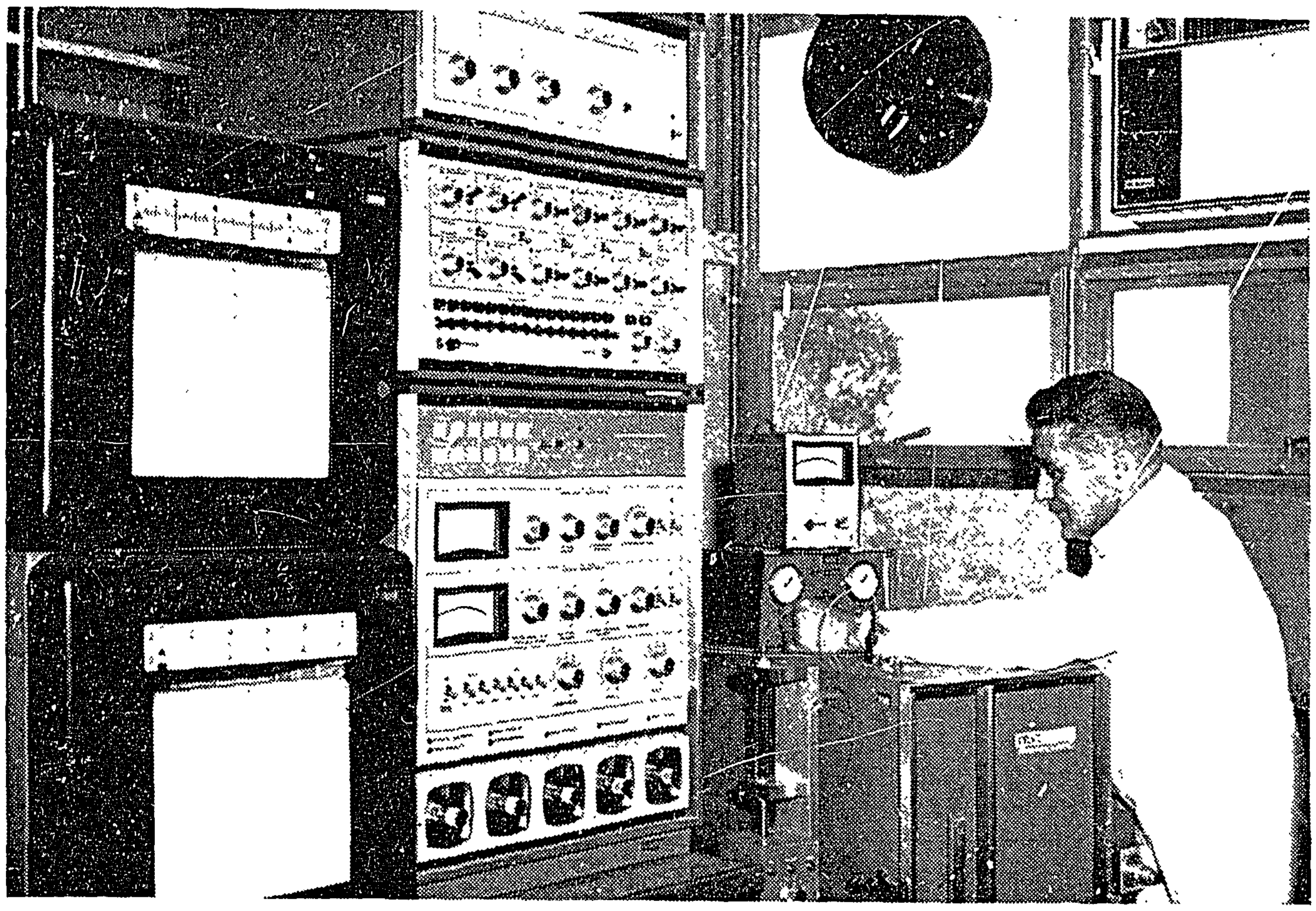
*Photograph prepared with optimum exposure (Ilford Ortho film and No. 2 Bromide paper).*



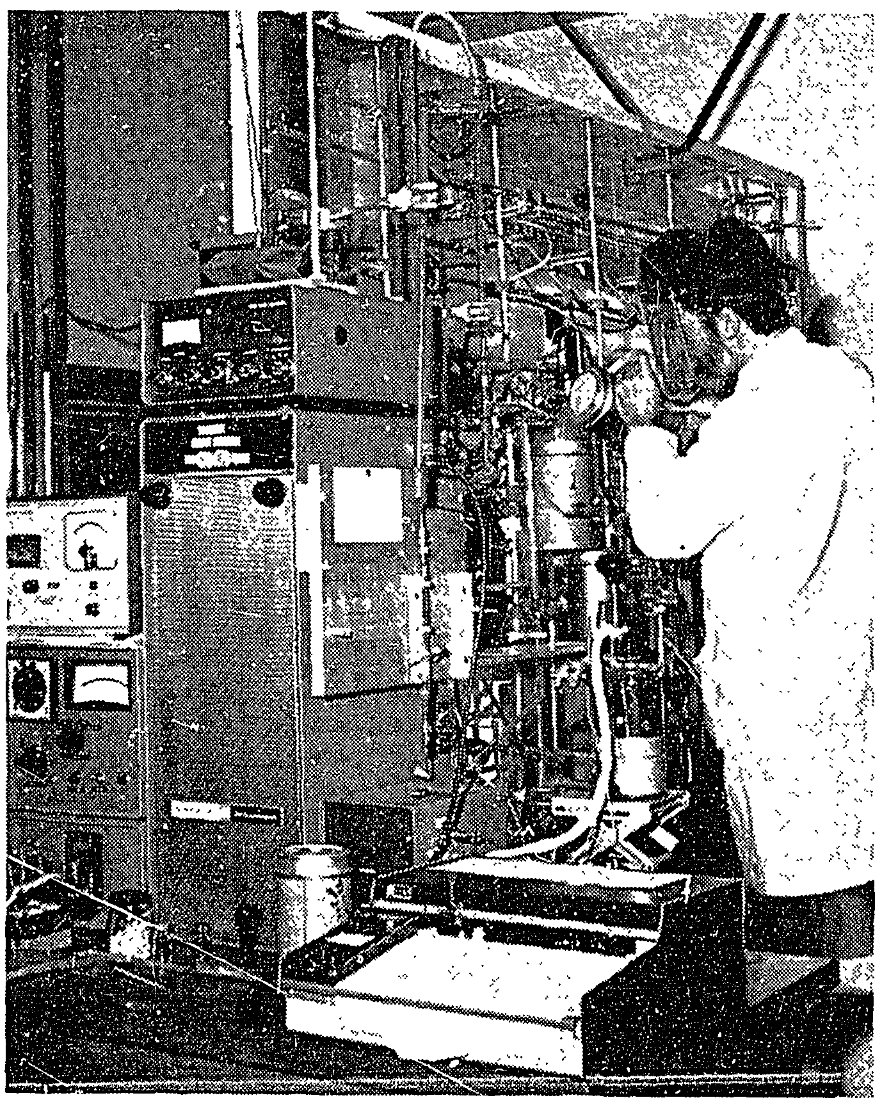
*Photograph prepared with 2% of optimum exposure (Ilford Ortho and No. 4 Bromide paper).*



*Photograph prepared from intensified negative (autoradiograph) of 2% optimum exposure (Ilford Ortho toned sulphur 35, transferred to Ilford F type X-ray film, No. 2 Bromide paper).*



*Above: Preparative gas chromatographic equipment used to separate quantities of the components of irradiated organic materials. Individual chemical species are then identified by other methods.*



*Left: A vacuum rig and gas chromatography apparatus separate, identify and measure the chemical species produced during irradiation of gases.*

Research was continued on the radiation curing of polymer in impregnated composites and on radiation grafting of polymer onto substrates. By these means some of the physical properties of the original materials can be improved considerably, and unusual combinations of desirable properties achieved in the one composite.

## RADIATION DOSIMETRY BY CHEMICAL METHODS

Until now there has been no simple, reliable method of measuring radiation doses at the levels used in sterilization and radiation processing. A marked improvement has been made at Lucas Heights in the performance of the ceric dosemeter by changing the chemical solution used. This extended its reliability and convenience.

However, a further improvement in convenience of use of the dosemeter was obtained recently through the development of a simple instrumental method for determining the radiation exposure of the dosemeter. The new method will be invaluable in both laboratory and industrial work where it can be made into a simple routine.

## RADIATION CHEMISTRY OF AQUEOUS SOLUTIONS

The rate of formation of radical species as impurities in the water in a nuclear reactor affects the decomposition of the water, the corrosion of reactor materials and the chemical reactions undergone by the impurity species. Yields of radicals in water irradiated at ambient temperature are fairly well known, but little is known of the variation in yield with water temperature.

Water in most water-cooled power reactors is at about 280°C, and a research project is in progress to study the effect at such temperatures. Results obtained from ferrous sulphate solutions suggest that at 200°C the yields have increased by less than ten percent of the yield at ambient temperature.

## CELLULAR BASIS OF RADIATION INJURY

Much of the Commission's biological research is based on the idea that an adequate understanding of the nature of radiation injury can come only from a study of the whole sequence of events, from the physical absorption of energy in an irradiated cell to the production of recognisable biological injury. In this respect, the submicroscopic or molecular distribution of the absorbed energy is important. A theoretical model, which locates radiation injury to specific molecular groupings, has been extended to cover the particular case of tritium incorporated into cellular DNA, and is reasonably consistent with the available experimental information.

Another facet of the model predicts that the biological effectiveness of neutrons will increase as neutron energy decreases below 1 MeV. This prediction has been further examined in tissue-culture studies, using various indicators of damage. The work has been extended down to neutron energies of 14 keV, and it is clear that efficiency does increase as energy decreases down to this figure. The actual values for relative biological efficiency (RBE) may be 50 or more, depending on the endpoint chosen. The values found for RBE also depend on the survival level selected. For example, the RBE for 80 percent survival of cells in culture is higher than that found when a lower survival is used as the index of injury. Other work in this field includes a theoretical study of the energy loss processes of charged and uncharged particles as they slow down in various media. When applied to the distribution of linear energy transfer values for charged and uncharged particles of various energies, this also leads to the conclusion that ICRP values for neutron RBEs at the lower energies are probably too low.

There have been several recent suggestions that cellular radiation injury should not be thought of as limited to some particular target, DNA for example. Further work has been done on the comparison of the effects of ultraviolet and ionising radiations in cultured cells, using either DNA synthesis or the production of chromosome aberrations as the marker. Differences in the effects of the two radiations are an indication that more than one target is involved.

## RADIOISOTOPE ANALYTICAL TECHNIQUES IN THE MINERAL INDUSTRY

Early in the 1960s, Commission research indicated that radioisotope X-ray techniques had considerable potential for rapid automatic element analysis in industry. The early applications of this research adopted by industry were to the accurate measurement of tin coating weight on steel (tinplate) and silver in photographic film emulsions. It was soon realised that the widest and most promising field for application was the continuous on-stream analysis of slurry streams in the mineral processing industry. On-stream trials were first undertaken by Commission staff at the North Broken Hill Ltd. plant in 1964, leading in 1968 to a permanent installation for continuous on-stream analysis for lead in flotation feed slurries. It is believed that this was the first permanent on-stream analysis installation in the world using radioisotopes in a mineral processing plant. It has worked successfully for three years.

Commission research on on-stream analysis was extended in 1966 to the development of techniques for a wide range of the higher atomic number elements, which include most metals of commercial value. This was followed by increasing interest and co-operation by the mineral industry, and by successful plant trials by the Zinc Corporation Ltd. on a second radioisotope technique suggested by the Commission for lead determination.

Closer contact with the mineral industry was essential and the Commission sought the assistance of the Australian Mineral Industries Research Association Ltd. (AMIRA). Beginning in 1967, AMIRA and the Commission jointly supported a training program for staff of the Australian Mineral Development Laboratories (AMDEL) to give them experience in this field of Commission research. Initially, AMDEL was to assist the Commission in plant trials. As its experience developed, AMDEL would take over complete feasibility studies for industry on a consulting basis.

Laboratory research by the Commission and the results of seven plant trials showed that on-stream analysis was possible for most Australian mineral processing plants which concentrate higher atomic number elements. With this widespread feasibility demonstrated, the Commission, AMIRA and AMDEL took the next logical step of placing the techniques on a commercial basis, by making an arrangement with a company widely experienced in the production and promotion of scientific and industrial instruments. After extensive negotiations during the past year, an Agreement was concluded between the Commission, AMIRA, AMDEL and Philips Industries Ltd., the Australian member of the world-wide Philips organisation. The Agreement provides that Philips be granted exclusive use of the technical information and patents on the subject owned by the other parties in exchange for royalties on sales. From Australia, Philips will promote the world-wide commercial sale of the instruments. AMDEL will act as consultant in the problems of calibrating and commissioning the equipment to ensure that it meets the requirements of the particular plant. Consultation and advice from the Commission will also be available as required.

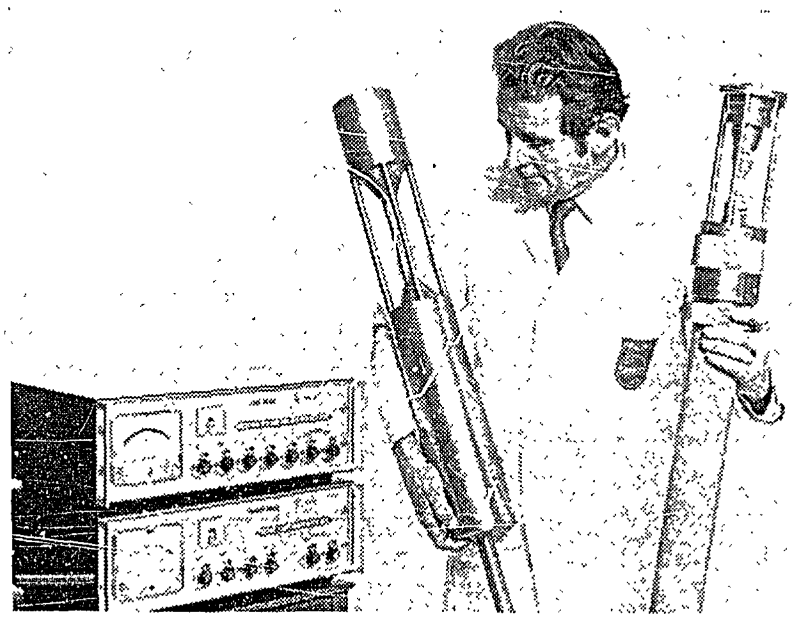
Philips has already begun vigorously to exploit the opportunities provided by the Agreement. Instruments are available for demonstration and sale, supported by promotional literature. The industry is most interested in the analytical techniques and many enquiries have already been received from overseas and from Australian organisations.

The entire development from the original research to the commercial exploitation is a wholly Australian co-operative venture which, apart from its direct commercial possibilities, will be of substantial national value in assisting the important Australian mineral industry. Rapid development in this industry favours the adoption of modern techniques. Although parallel developments have begun overseas, there is no evidence that they have yet approached the advanced stage reached in Australia.

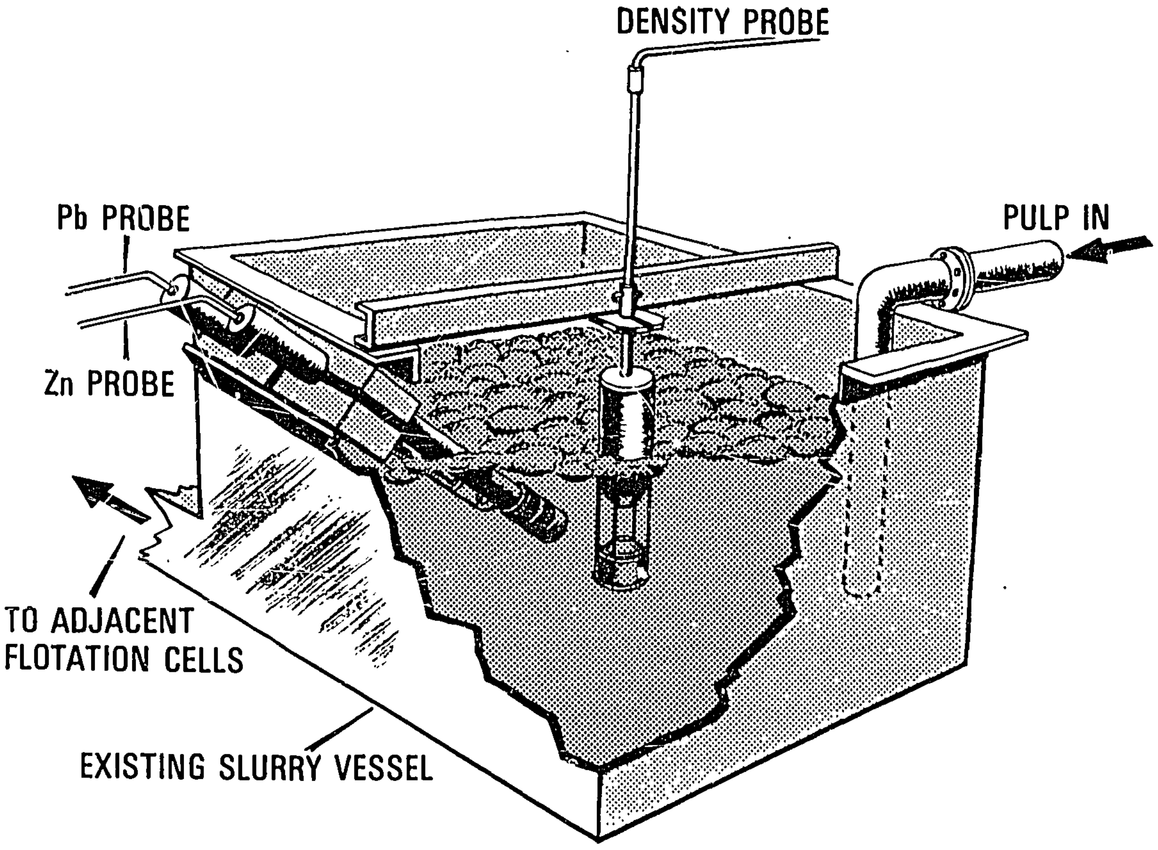
Papers describing the first six plant tests of radioisotope X-ray techniques were presented at the Symposium on Automatic Control Systems in Mineral Processing Plants organised by the Australasian Institute of Mining and Metallurgy (Brisbane, May, 1971). The general reaction of the participants, including overseas visitors, indicated that the radioisotope analytical techniques will find wide application throughout the world.

## Field of Application

In a mineral processing plant, the ore is usually finely ground and processed as a slurry, from which the minerals of interest are concentrated mainly by flotation or gravity methods. Variations in ore grade change the optimum control conditions in the plant so that, in the past, samples had to be taken regularly from the various slurry streams and analysed by conventional methods. Such analyses took at least 20 minutes, by which time the ore had passed through the plant. The need for continuous on-stream analysis has long been recognised by the mineral industry, and complex systems of analysis based on X-ray tubes have been developed. Their high cost (about $250,000) and technical problems have limited their use, and no overall plant analysis systems based on them are in use in Australia.



*Radioisotope on-stream analysis equipment designed and produced in Australia by Philips Industries Ltd. and based on Commission research. On the technician's right are analogue computers for density and lead concentration determinations. In his right hand is a density immersion probe; in his left, a probe to monitor lead.*




*Sketch showing the "analysis zone" in the flotation feed flow at the head of a lead rougher in a mineral processing plant.*

## Principles of the New Techniques

There are three basic methods of using radioisotopes for these analyses:

(1) Excitation of fluorescent X-rays by secondary radioisotope X-ray sources.

(2) Direct excitation of fluorescent X-rays by gamma-rays.

(3) X-ray or gamma-ray absorption.

The particular method used depends on the element, the concentration and the matrix composition.

In the system used in a mineral processing plant, simple probe units, containing a sensor comprising a radioisotope source in a specially designed mounting and an X-ray detector, are installed in the plant slurry streams to be monitored. Two to four probes per plant stream are required, each producing electrical signals which are processed in a central control room by a small computer to give the concentration of elements of interest. Although a large mill may require a total of 20 to 30 probes, an important advantage is that the radioisotope system can be built up from an initial two or three probes installed at a moderate outlay, and expanded later as the mill is progressively automated. Radioisotope systems are simple and far less expensive than X-ray tube methods, and overcome many of the latter's disadvantages.

Tests of the new methods at the seven Australian mineral plants convincingly demonstrated the suitability of the techniques for copper, zinc, tin and lead analyses. The precision of analysis, obtained for all streams including tailings, is within the limits necessary for plant control. A number of elements in samples from many other plants have been tested in the laboratory.

In an important technological breakthrough, suggested recently by the Zinc Corporation Ltd., probes are immersed directly in slurries in existing open channels or tanks. This avoids the complexities of continuous by-pass sampling and extensive slurry handling, which were used in the earlier radioisotope systems and were based on the methods characteristically required by X-ray tube systems. These immersion probes were recently tested in very successful trials undertaken at the New Broken Hill Consolidated Ltd. plant by the Zinc Corporation Ltd. and Commission staff.

## RADIOISOTOPE TECHNIQUES FOR MINERAL BOREHOLE ANALYSIS

The most usual method of examining boreholes for mineral content consists of diamond drill coring followed by laboratory analysis. This process is expensive and slow and there is considerable interest in the prospects of *in situ* logging of less costly percussion drilled holes by instrument probes lowered into the hole.

Some success has been achieved elsewhere with nuclear radiation methods, but a novel system is now being studied by the Commission which could be applicable to a borehole probe with potential for detection and measurement of a number of metals. The method depends on the enhanced scattering back of gamma radiation when it is in exact resonance with the nucleus of the element of interest. The system therefore depends on being able to match exactly the irradiation energy to the resonance.

Results to date show promise for measurement of copper and nickel, but considerably more laboratory development is necessary before field tests can be planned. A major advantage of the method is that it can be made completely specific for the element of interest. Full patent specifications covering this technique have been filed in Australia and overseas.

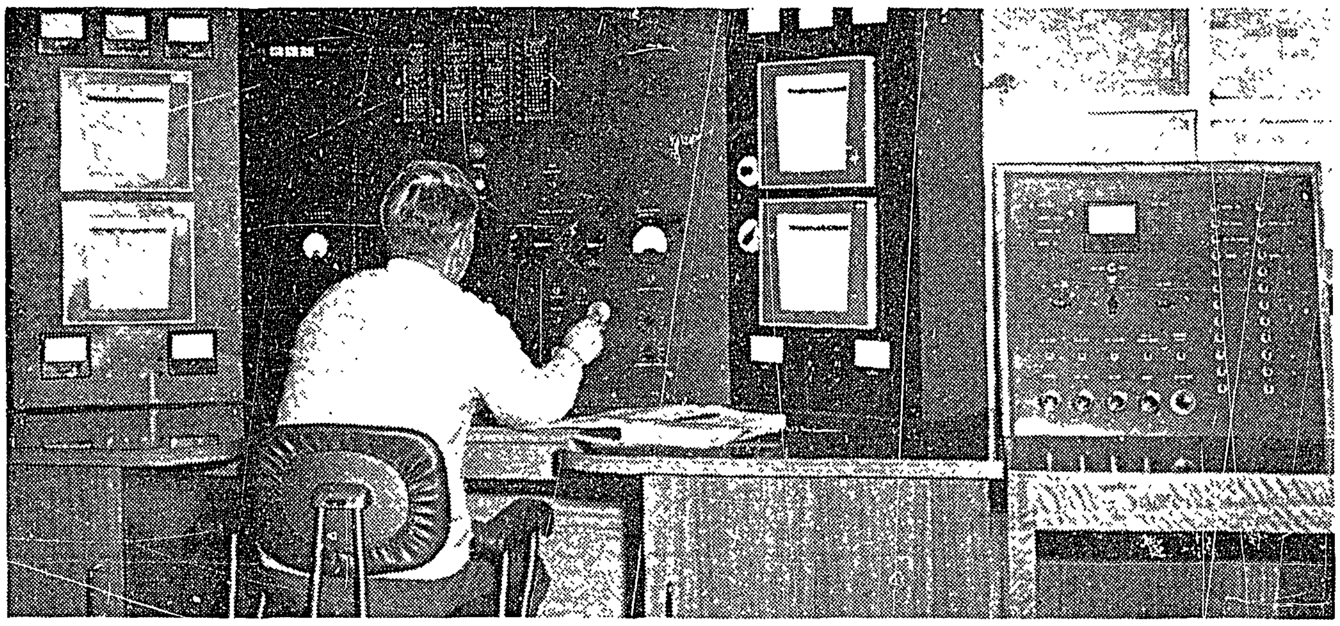
## RADIOISOTOPES IN HYDROLOGY

Natural isotopes can play an important role in hydrological studies, particularly for underground water. Facilities have been commissioned and tested for estimation of the natural isotopes tritium and carbon 14 at the low levels found in bore waters. These facilities are most complex and have required considerable research and development over a period of several years.

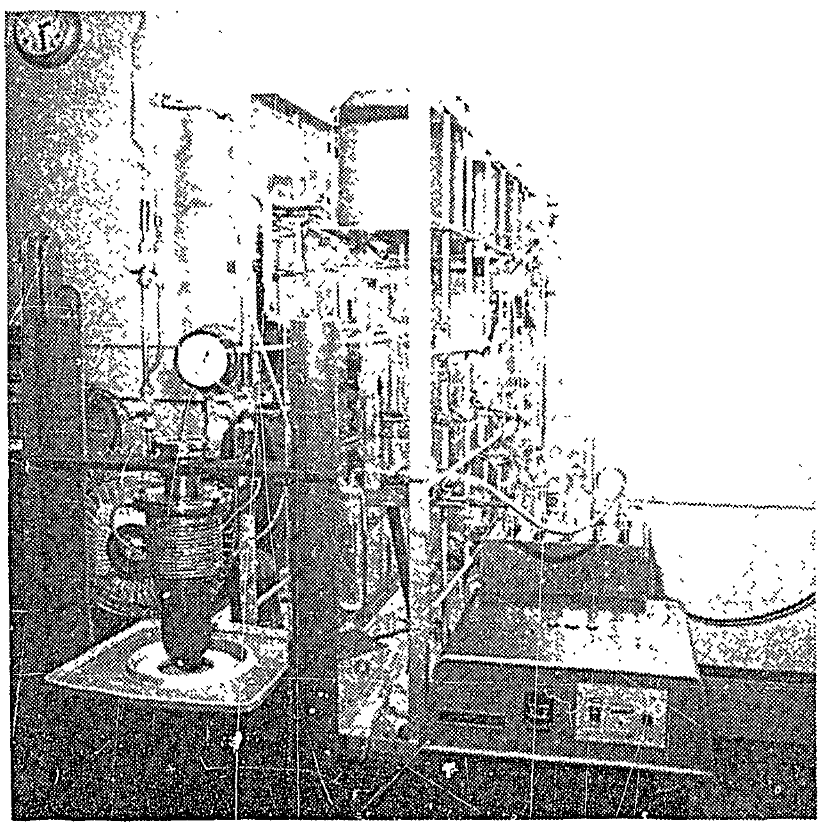
Application of these techniques to a hydrological investigation of underground water near Narrabri, New South Wales, has begun in conjunction with the Water Conservation and Irrigation Commission of New South Wales.

## MEASUREMENT OF GAS FLOW

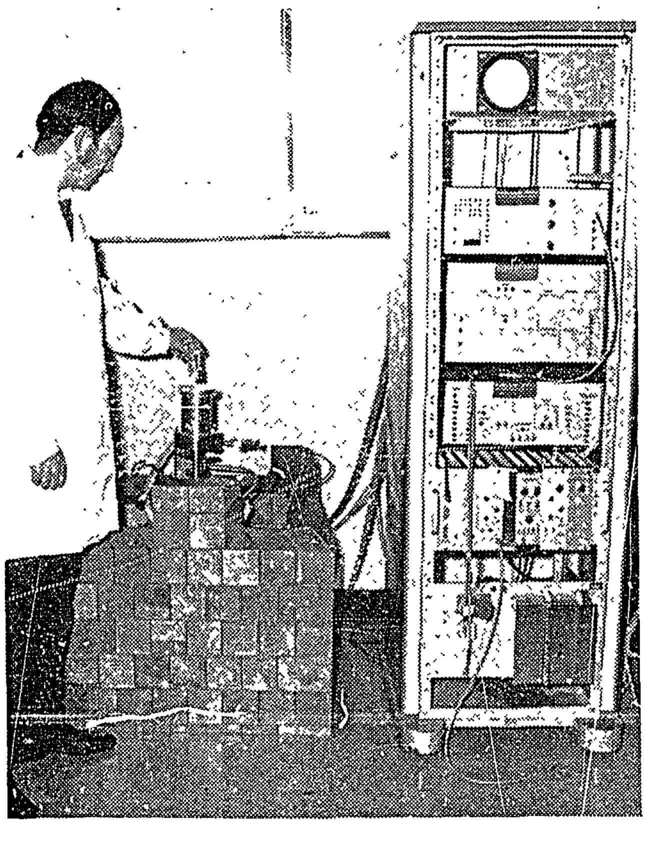
The previously reported method for measuring gas flow has now been proved in routine use in industry, including town gas mains, high pressure lines in the Imperial Chemical Industries of Australia and New Zealand Ltd. plant at Botany, N.S.W., and in a glass furnace at Australian Consolidated Industries Ltd. This technique, using the radioisotope krypton 85, is a highly accurate method for absolute gas flow determination. It is simple and highly versatile. Concentrations of krypton 85 used are well below levels associated with radiological health hazards.



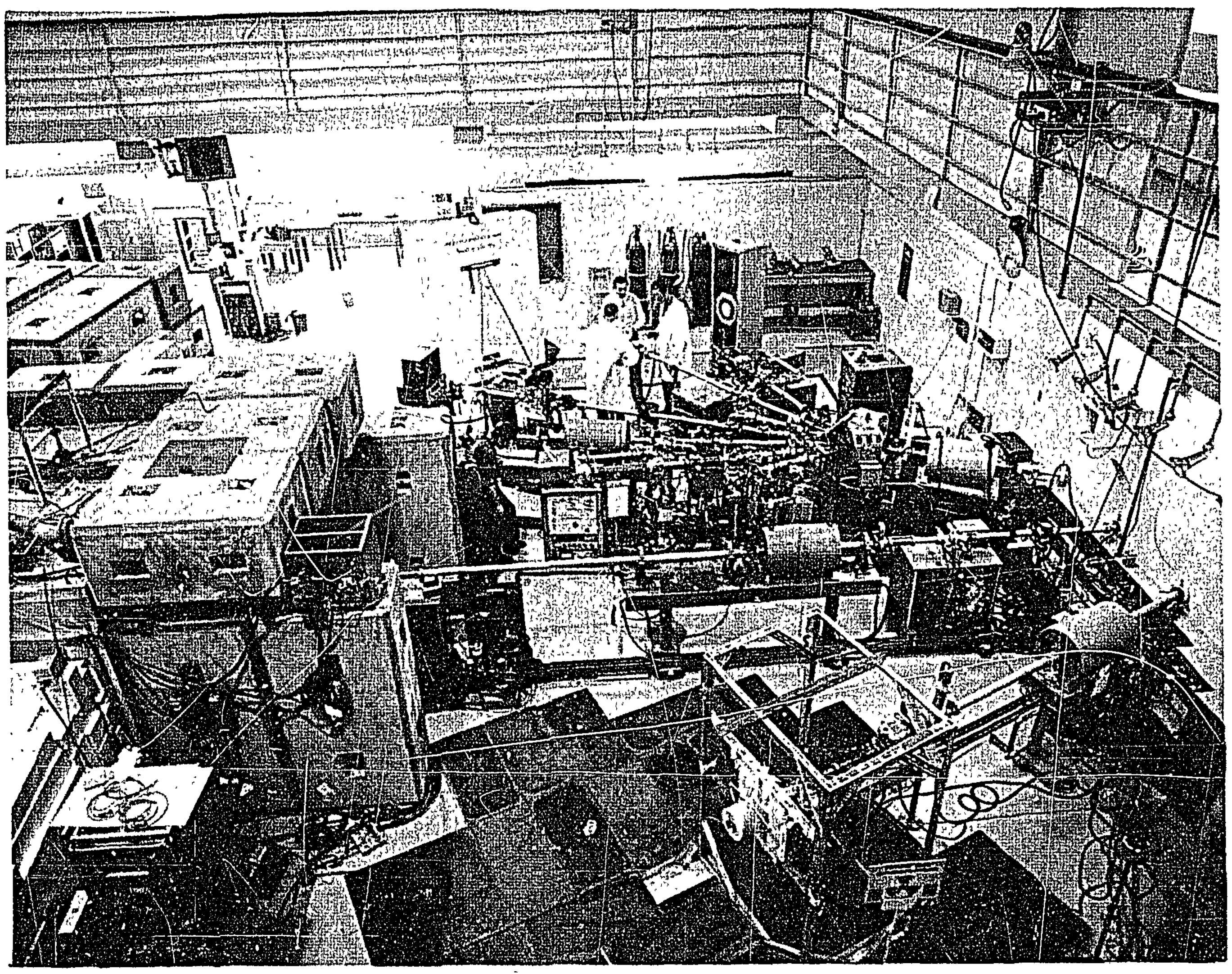
*Above: Control desk of the HIFAR simulator, under test in the Dynamic Analysis Group, receives its signal inputs from the 231R analogue computer. The simulator will be used to assist with the training of HIFAR operators.*



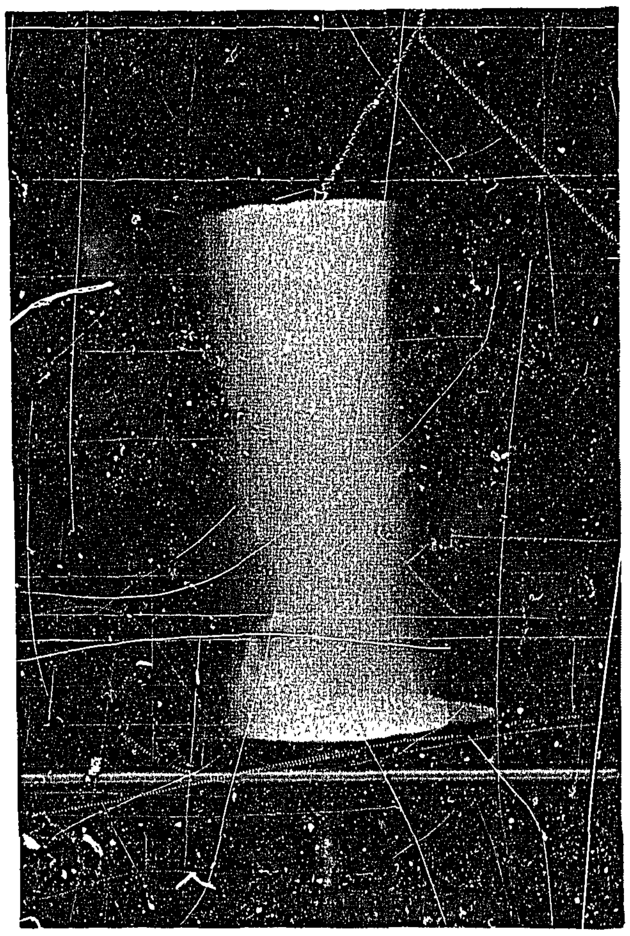
*Above: Experimental equipment used for determining carbon 14 in groundwater. The age of the water can be found from the carbon 14 content. Carbon dioxide is obtained from dissolved carbonates in the groundwater and this is converted to acetylene and then polymerised to benzene, which is counted in a liquid scintillation spectrometer.*



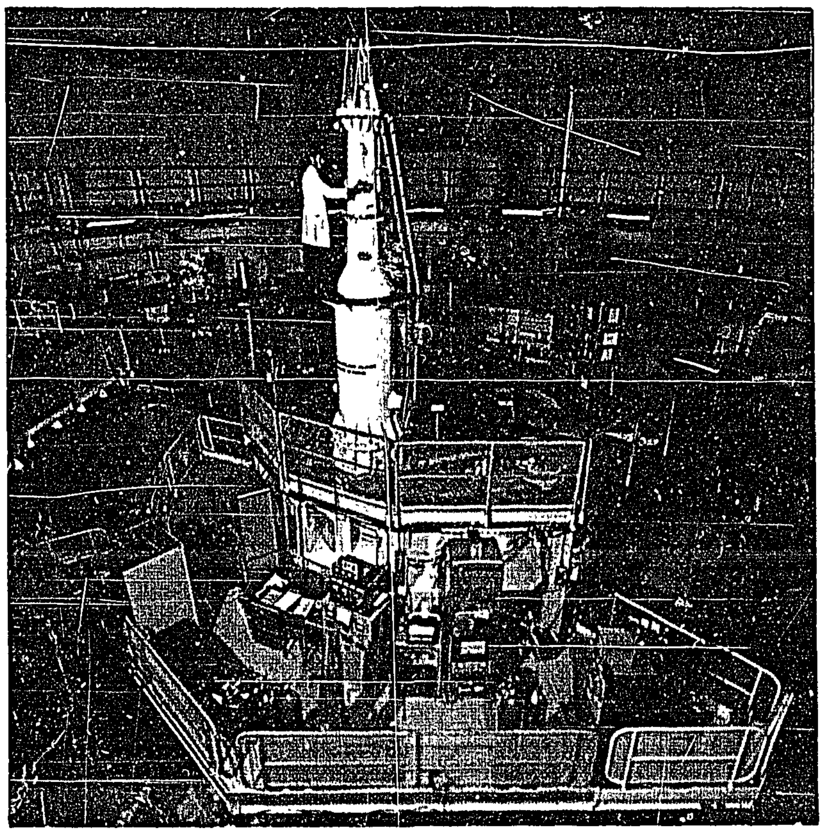
*Left: Neutron activation analysis is an ultra-sensitive technique of determining the minute amounts of trace elements in a forensic sample (e.g., hair, paint, etc.). This combination of elements is then used as a "chemical fingerprint" of this sample. Inspector J. Goulding, Commonwealth Police Force, places an irradiated forensic specimen in the detector of a gamma-ray spectrometer at Lucas Heights.*



*Above: Equipment used in conjunction with the Commission's 3 MeV positive ion Van de Graaff accelerator to study neutron processes in the intermediate and high energy ranges.*



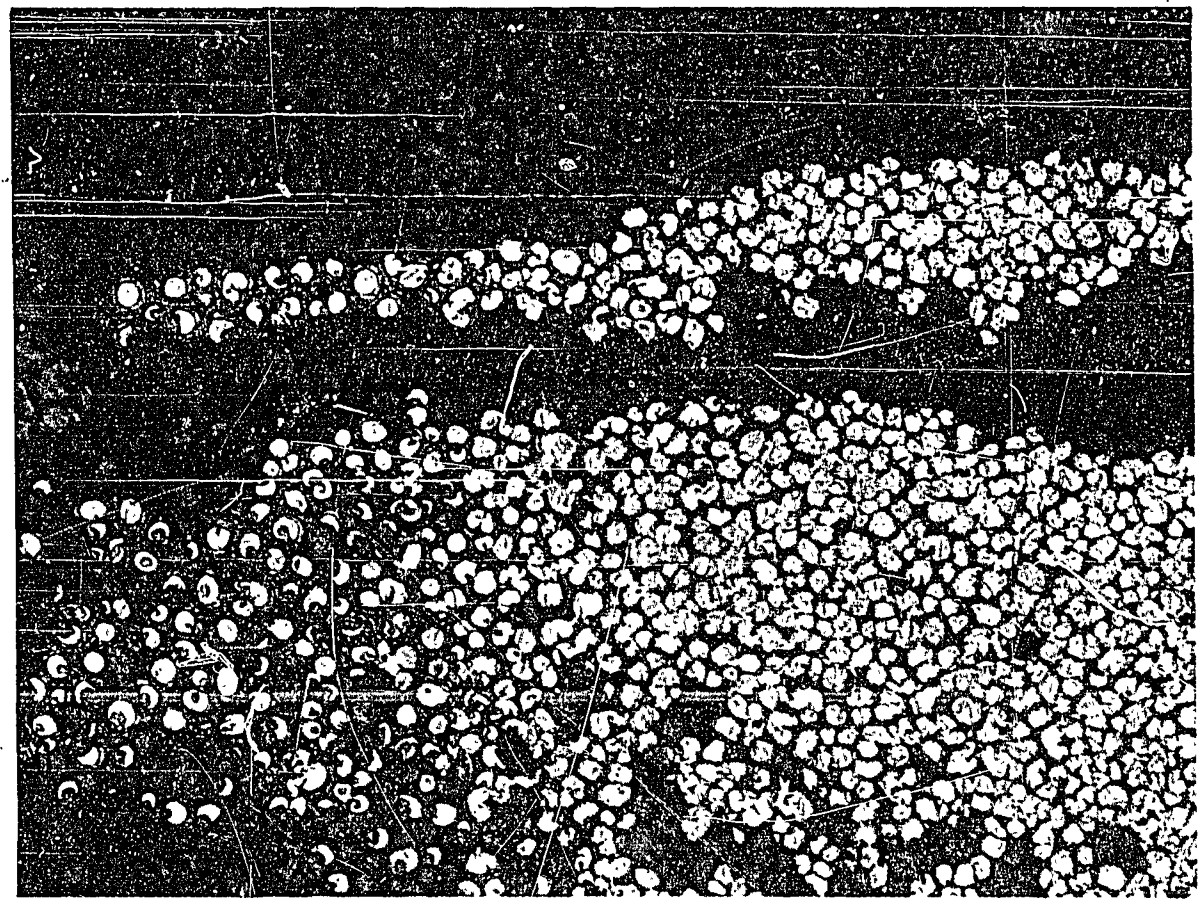
*Right: A propane gas burner developed at Lucas Heights to simulate, at full scale, the heat output of a small nuclear reactor. Novel design features of this burner could have application for industrial heating. A patent application has been filed.*

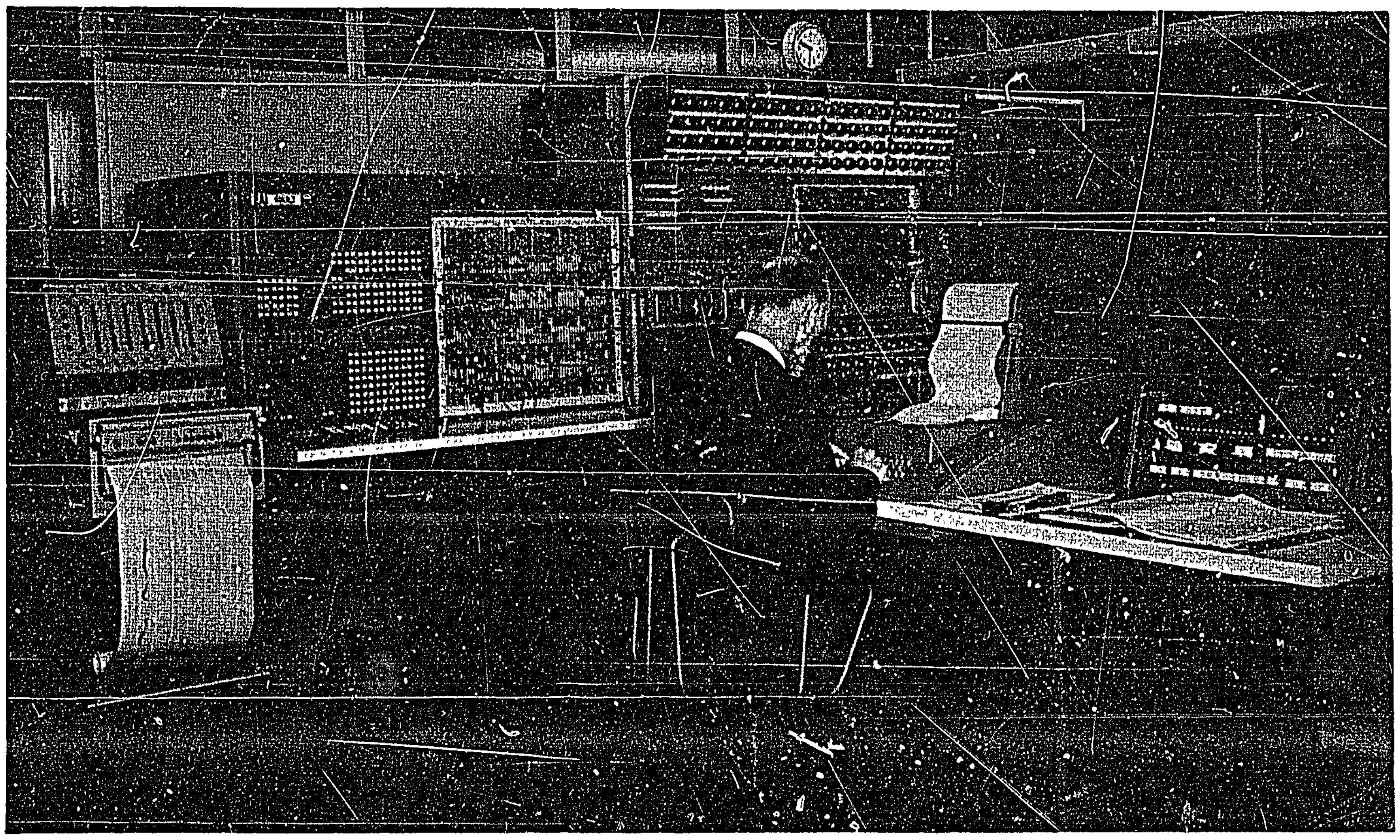


*Above: Interior of HIFAR reactor containment building at Lucas Heights. The 19½-ton flask shown on top of the reactor, is used to unload and handle highly radioactive materials from the reactor. The flask was designed by Commission engineers and built by local industry.*

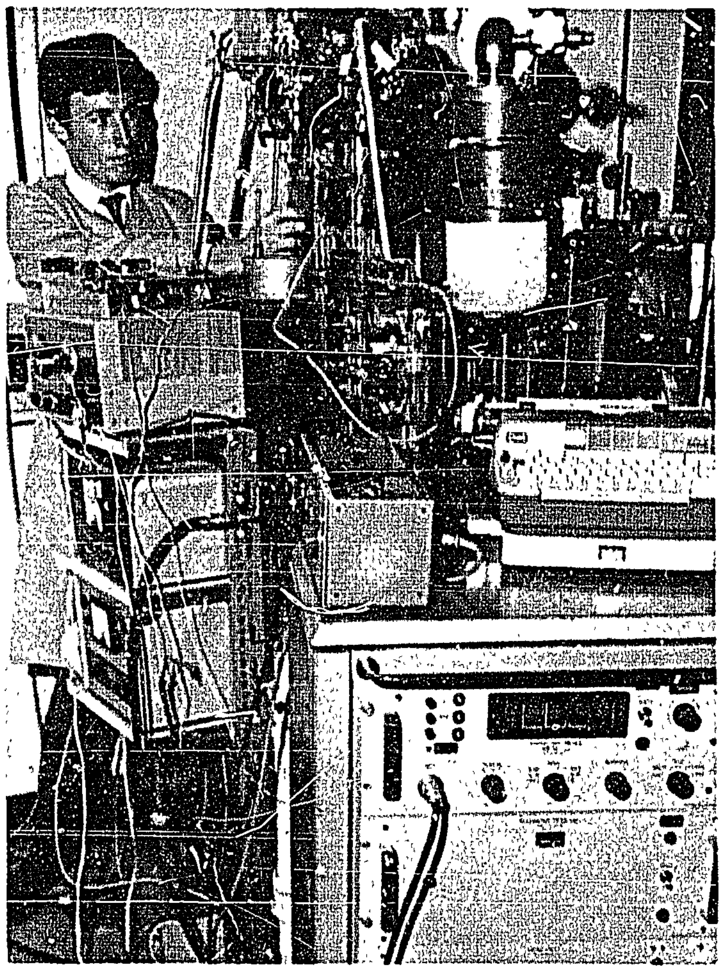
*Right: Part of the packaging section of the Isotope Division's radioisotope production and handling laboratories. Radioisotopes are despatched, packed and labelled to Australian and International regulations.*

*Below: Plan view of corrosion products (crud) deposited on the surface of Zircaloy-2 in a pressurised water environment contaminated by sea water. Adherent thermal layers such as this can contribute to the failure of reactor fuel elements. The formation and properties of crud are being studied as part of the reactor research program. The bright areas show where the crud has been removed from the surface of the specimen, whereas the dark green areas are crud. (Electron scanning micrograph; magnification 100x.)*



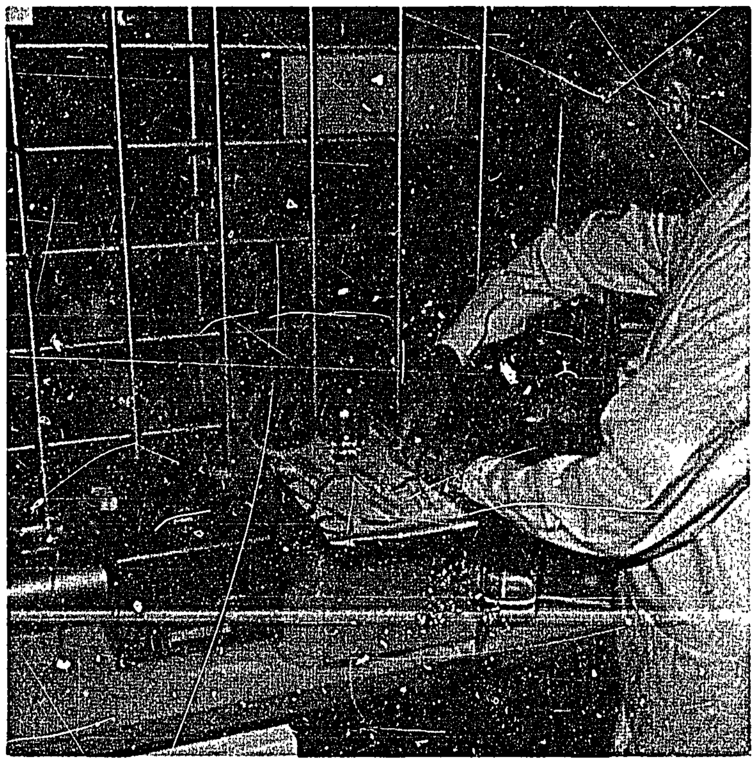


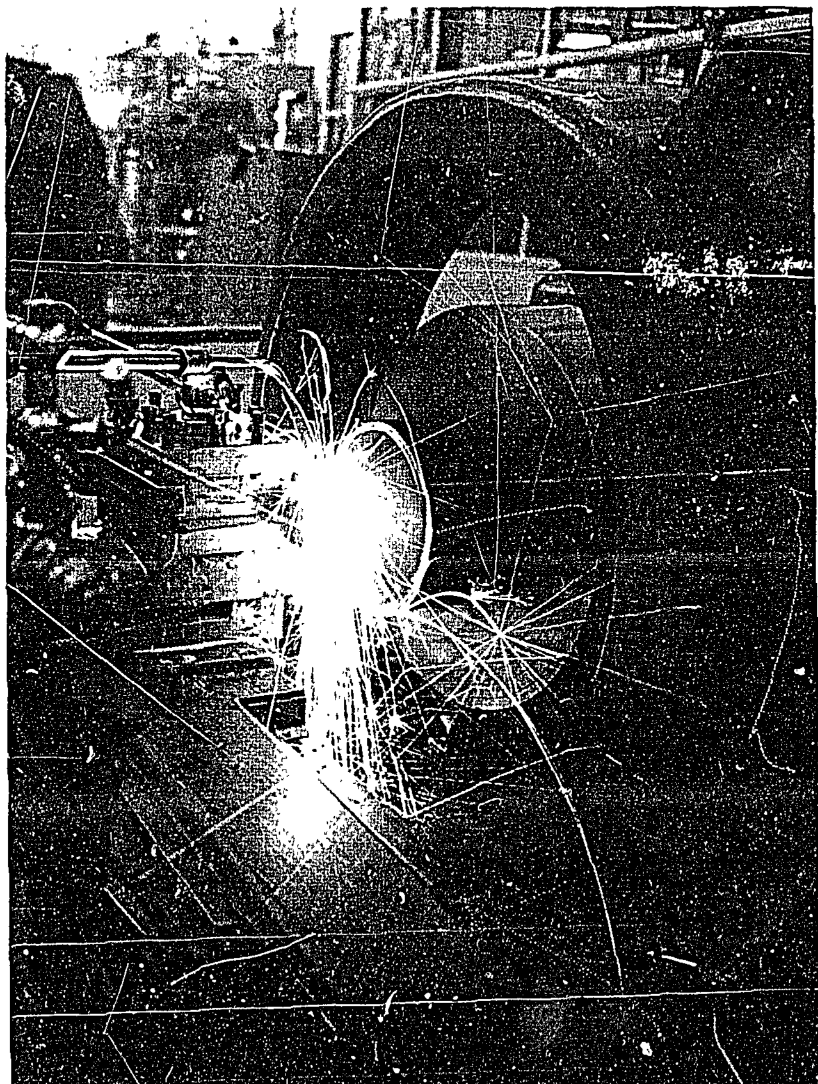
*Above: The recently extended hybrid computer system used for studies in reactor dynamics. The system consists of a high speed analogue computer (left), a general purpose digital computer (right), and an interface to connect the two. The hybrid system may be linked to the original analogue computer (centre).*



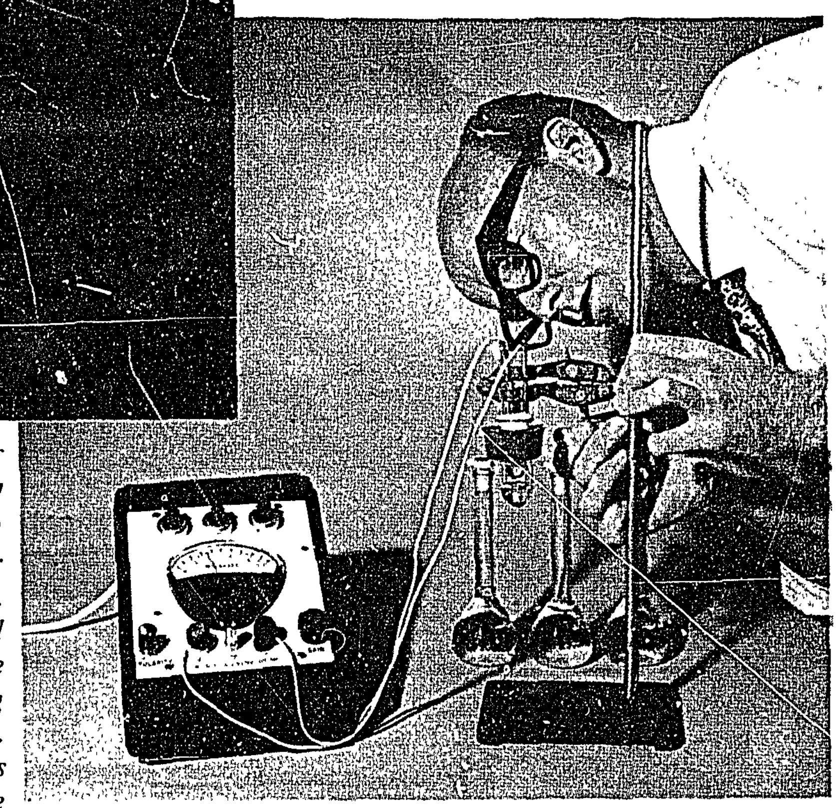
*Above: An electro-balance equipped with digital read-out for studying thermal decomposition of materials in vacuum or in a controlled atmosphere.*

*Below: Laboratory equipment for investigating the surface chemistry of uranium dioxide ($UO_2$). This technique is being used to develop a specification test for the $UO_2$ powders needed in the production of fuel pellets.*

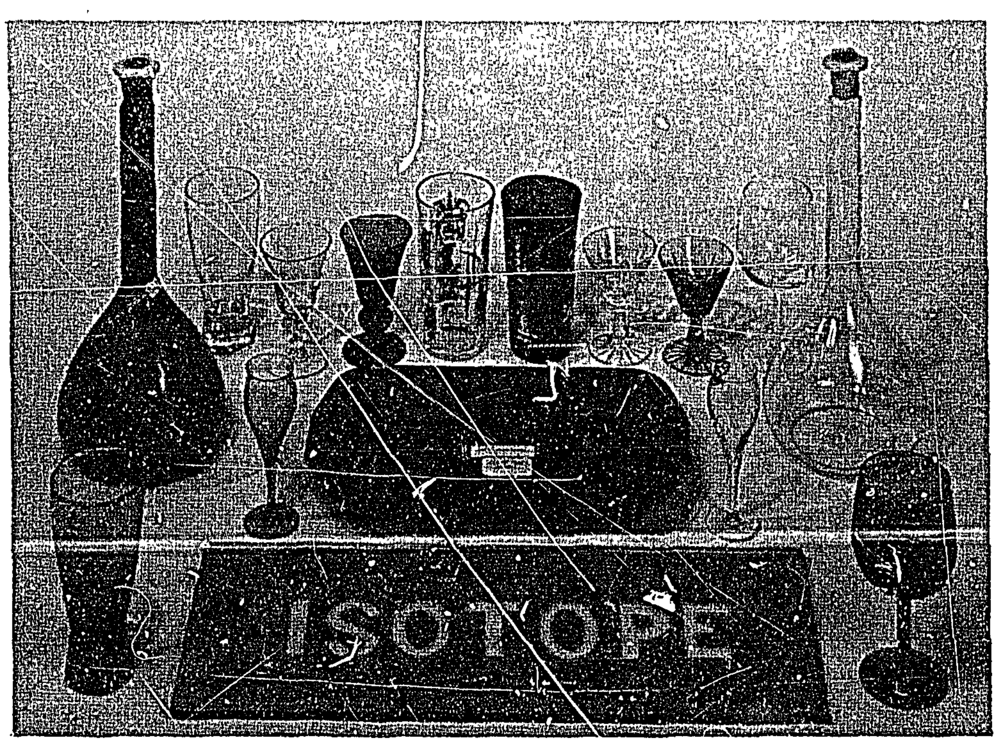




*Left: Machining a shielding component from a billet of depleted uranium in the Materials Division's Nuclear Fuel Development Laboratory. This component was required for the triple axis spectrometer which is used on HIFAR reactor for fundamental research into atomic vibrations in solids.*



*Right: Because of the increasing use of radiation for sterilizing medical and pharmaceutical supplies, it is important to have a reliable and uniform method for measuring absorbed radiation dose. Research on chemical reactions induced by gamma radiation resulted in the development of a direct reading dosemeter for the megarad range. Research equipment shown here is designed for accurate, routine measurement of radiation dose, and is suitable for commercial use.*




*Left: The coloured items of glassware shown here were irradiated in the high intensity gamma radiation pond at Lucas Heights. Colour centres develop during gamma irradiation and the different colours, occurring in the originally clear glass, depend on the nature of the trace elements present during manufacture. This effect may have limited specialised application. As with all processes using gamma radiation, the products themselves do not become radioactive. The clear items were not irradiated.*

# 10

# RADIOISOTOPES

## PRODUCTION AND SERVICES

The pattern of radioisotope production as described in previous Reports continued with an even greater increase in demand, particularly for radiopharmaceuticals. Some new radiopharmaceuticals were developed to meet requirements, but the emphasis remained on those based on technetium 99m, which has a short half-life and very suitable radiation characteristics for diagnostic use.

Close liaison is maintained in the supply of medical radioisotopes with the Commonwealth X-ray and Radium Laboratory which, when the products are for human use, approves all applications and arranges orders on behalf of the users. Close co-operation is also maintained with the Commonwealth X-ray and Radium Laboratory on the development of new radiopharmaceutical products to ensure co-ordination with the requirements of nuclear medicine in Australia.

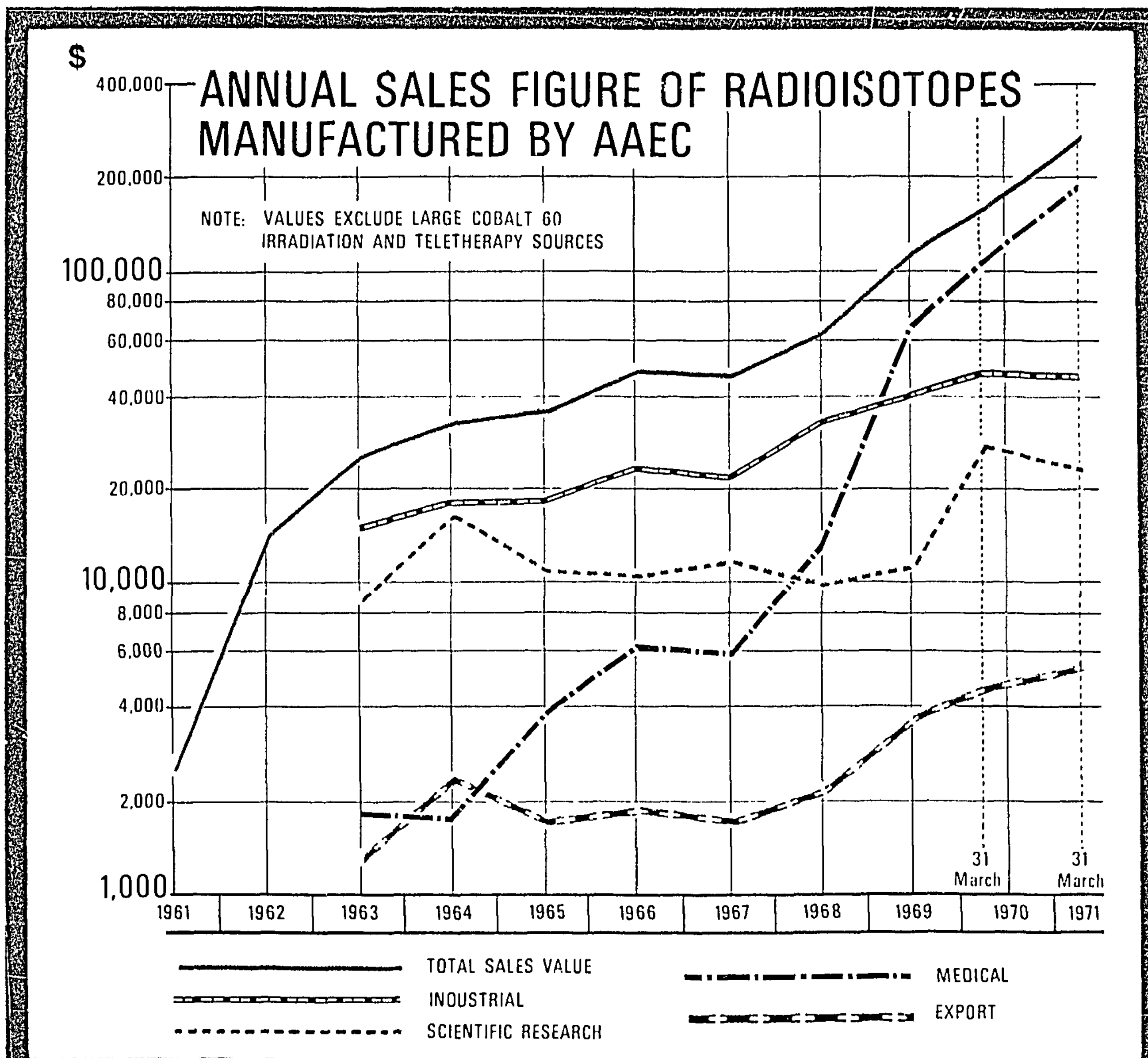
To help meet the increasing demand, the Commission has begun building an extension to its radiochemical processing laboratories.

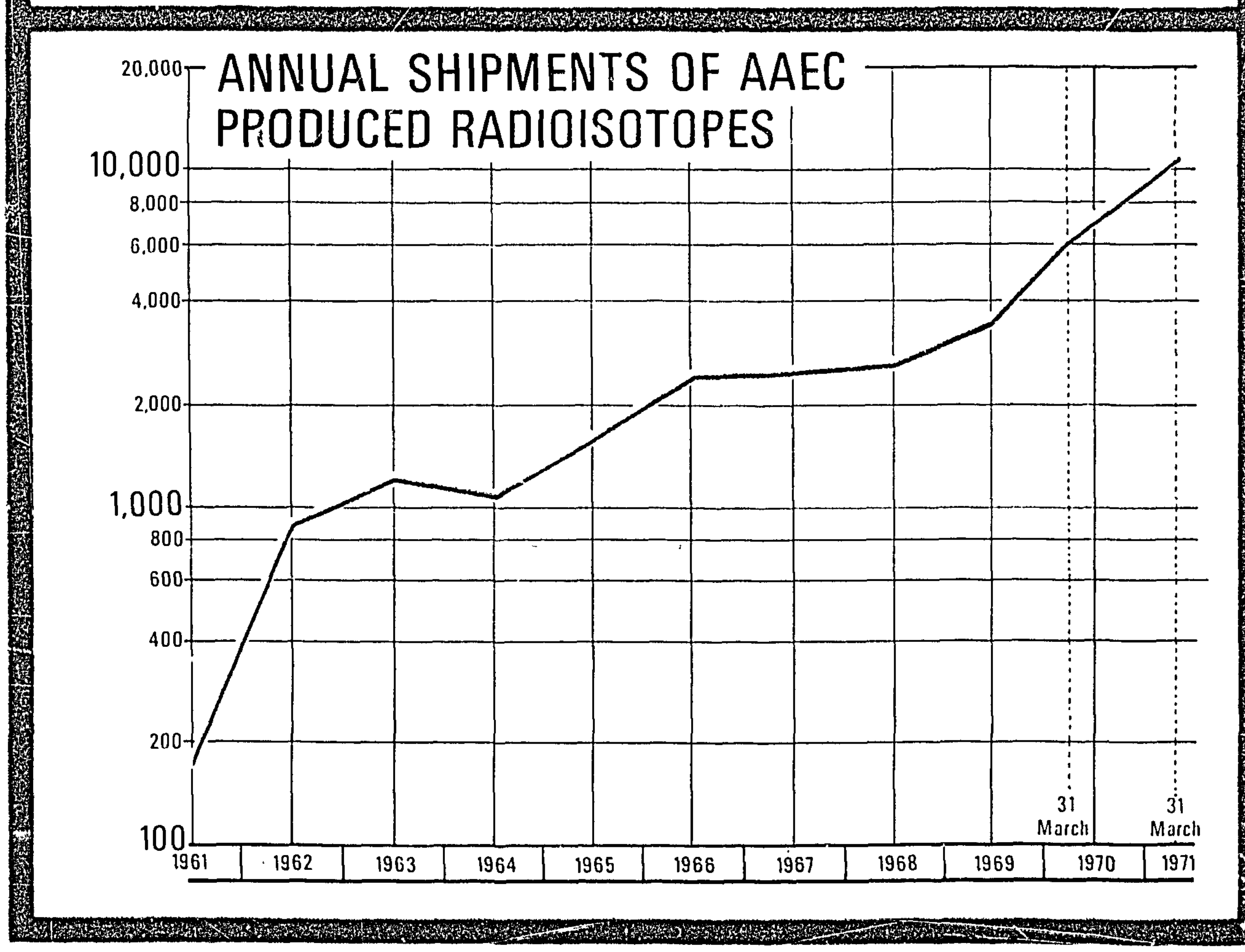
## SUPPLY AND DISTRIBUTION STATISTICS

The statistics reported in Table 1 and the graphs this year are for the period 1 April 1970 to 31 March 1971. This period will also be used as the base year for future Annual Reports. The total value of radioisotopes produced was $362,700. The corresponding figure for the previous year (1 July 1969-30 June 1970) was $257,200. Total shipments increased to 10,491 compared with 7,196 for the previous year. The increase is due mainly to the continuing expansion in the use of short-lived radioisotopes in diagnostic medical procedures. As a result of the introduction of new products described later in this chapter, a further increase in demand is expected. This activity of the Commission is meeting an essential local need in nuclear medicine.

Short-lived radiopharmaceuticals still constitute about 85 percent of total shipments. These are supplied to stringent standards of chemical, biological and radioisotopic purity. Products based on technetium 99m (half-life 6 hours) and fluorine 18 (half-life 110 minutes) are the most extensively used. Shipments of these products leave the Research Establishment three times daily for hospitals in all the State capital cities and Launceston, except that fluorine 18, because of its short life, is not delivered to Perth.

During the year the HIFAR reactor was shut down for overhaul for three months. A number of the short-lived products were not available during the shutdown, but arrangements were made with General Electric, U.S.A., and Bhabha Atomic Research Centre, India, for supply of certain bulk irradiated materials. By processing them at Lucas Heights into radiopharmaceuticals normally used in Australia, it was possible to maintain essential supplies of the more important products. *(Continued on page 102)*


ANNUAL SALES FIGURE OF RADIOISOTOPES MANUFACTURED BY AAEC
NOTE: VALUES EXCLUDE LARGE COBALT 60 IRRADIATION AND TELETHERAPY SOURCES
$
400,000
200,000
100,000
80,000
60,000
40,000
20,000
10,000
8,000
6,000
4,000
2,000
1,000
1961
1962
1963
1964
1965
1966
1967
1968
1969
31 March 1970
31 March 1971
TOTAL SALES VALUE
INDUSTRIAL
SCIENTIFIC RESEARCH
MEDICAL
EXPORT


ANNUAL SHIPMENTS OF AAEC PRODUCED RADIOISOTOPES
20,000
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
1961
1962
1963
1964
1965
1966
1967
1968
1969
31 March 1970
31 March 1971

## TABLE 1

### PRODUCTION OF RADIOISOTOPES BY THE AAEC, 1970-71
(FOR THE PERIOD 1 APRIL 1970 - 31 MARCH 1971)

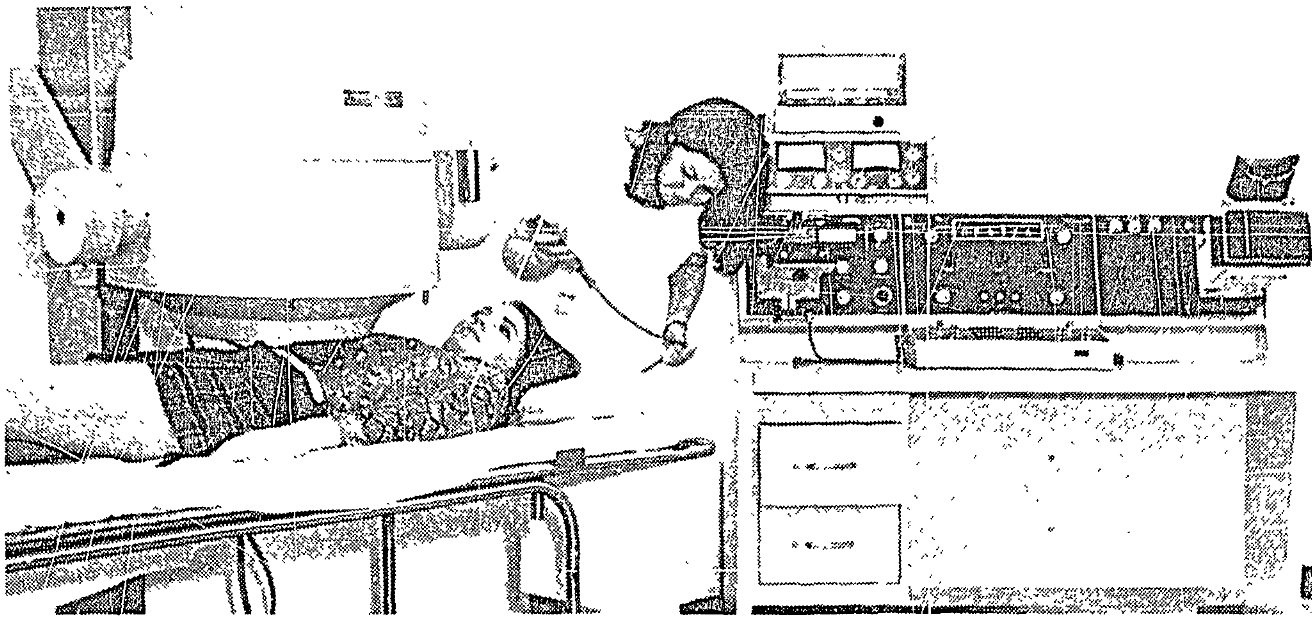
| USE | PRODUCT | DELIVERIES Total No. | DELIVERIES Value $* |
|---|---|---|---|
| **WITHIN AUSTRALIA** | Radiography sources | 237 | 40,500 |
| | Other encapsulated sources | 55 | 4,800 |
| | Miscellaneous | 31 | 1,500 |
| Total for industrial use | | 323 | 46,800 |
| Research | Cobalt 60 irradiation sources | 4 | 25,600 |
| | Miscellaneous | 1,099 | 17,500 |
| | Neutron irradiations | 189 | 5,300 |
| Total for research use | | 1,292 | 48,400 |
| Medical | Radioisotope implants | 51 | 2,000 |
| | Solutions for diagnosis and therapy | 8,668 | 197,500 |
| | Cobalt 60 teletherapy sources | 4 | 62,700 |
| Total for medical use | | 8,723 | 262,200 |
| Total for Australian use | | 10,338 | 357,400 |
| **EXPORTS** | Radiography | 11 | 2,100 |
| | Medical implants and solutions | 84 | 1,600 |
| | Miscellaneous | 58 | 1,600 |
| Total for export | | 153 | 5,300 |
| Total AAEC production | | 10,491 | 362,700 |

**Net catalogue values for Deliveries*

## TABLE 2

### TOTAL SALES VALUE OF AAEC PRODUCED RADIOISOTOPES

| Year | Cobalt 60 for Radiotherapy $ | Cobalt 60 for Industrial and Scientific Irradiation $ | Total of All Other Products $ | Grand Totals $ |
|---|---|---|---|---|
| Total 1 July 1960 to 30 June 1970 | 381,200 | 83,100 | 588,100 | 1,052,400 |
| Total 1 July 1970 to 31 March 1971 (9 months) | 34,100 | 21,800 | 249,700 | 305,600 |
| Total to 31 March 1971 | 415,300 | 104,900 | 837,800 | 1,358,000 |



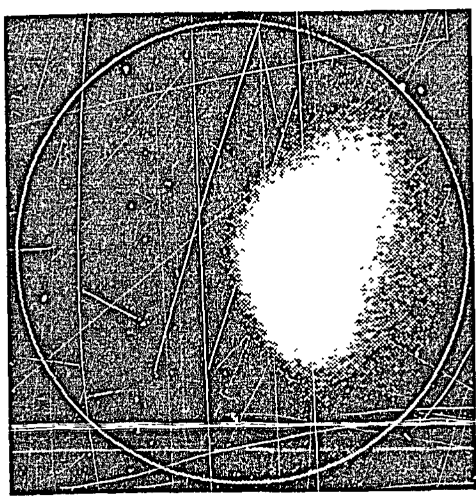
*Hospital staff demonstrate a gamma camera installed recently at the Prince of Wales Hospital, Sydney. The camera can display and allow a photographic record to be made of the distribution of a radioactive compound within a particular organ. The camera is used for diagnosis of disorders of the brain, thyroid, lungs, liver, kidney and bone.*

## KIDNEY TRANSPLANT STUDY USING NEW RADIOPHARMACEUTICAL

A single kidney was transplanted recently into the right groin of a 22-year-old woman.

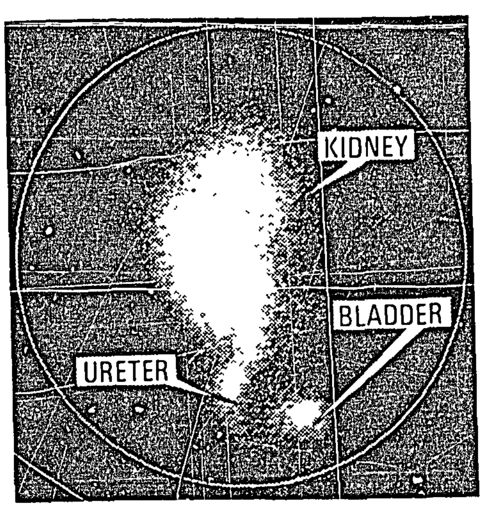
The method of investigation illustrated here allows a kidney transplant team to simply, quickly and accurately assess the success of the transplant. It provides information on all aspects of the transplanted kidney function. Prior to this technique much of the information would require anaesthesia and catheterisation, both of which are practically impossible in the early transplant period. (Scans, by courtesy of Department of Nuclear Medicine, Royal Prince Alfred Hospital, Sydney.)

1



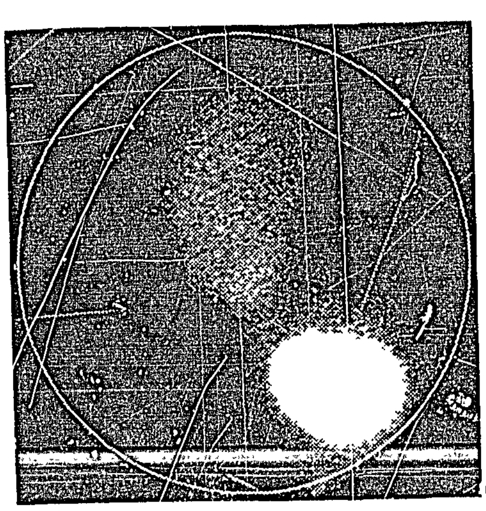
*1. Four seconds after intravenous injection of an AAEC radioactive technetium kidney-specific compound, the kidney is clearly seen, thus showing a potent blood supply (artery) to the kidney. This shows that the transplanted organ is functioning well and concentrating the radiopharmaceutical.*

2

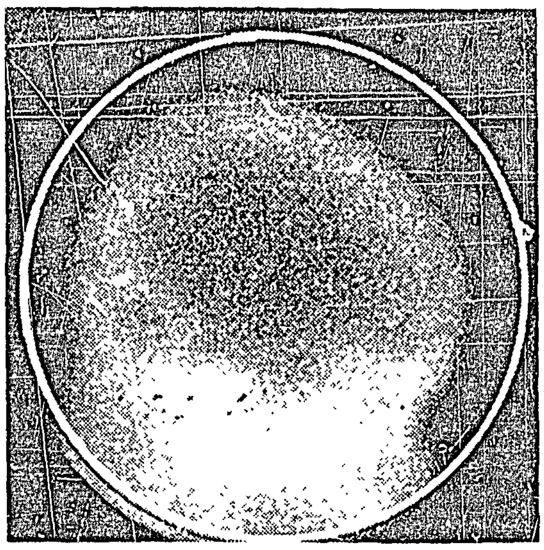



*2. Four minutes later the radiopharmaceutical is being passed by the kidney through its excretory pathway (ureter) to the bladder. This again confirms that the kidney is filtering well and the ureter is not blocked.*

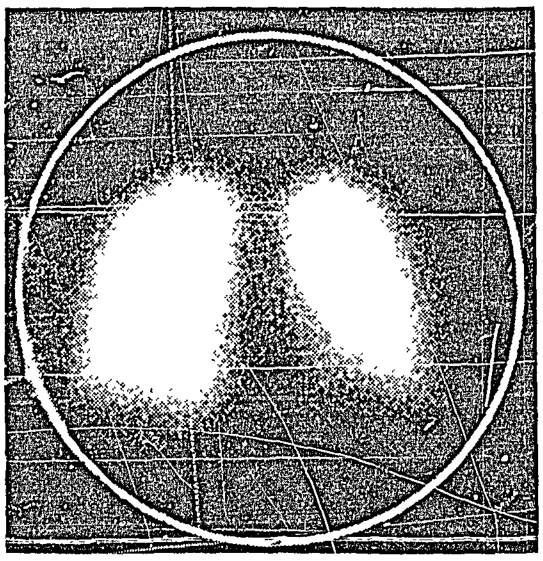
3



*3. After four hours, most of the radiopharmaceutical has been passed to the bladder. In the scans, the kidney is seen to be taking up the radiopharmaceutical uniformly.*

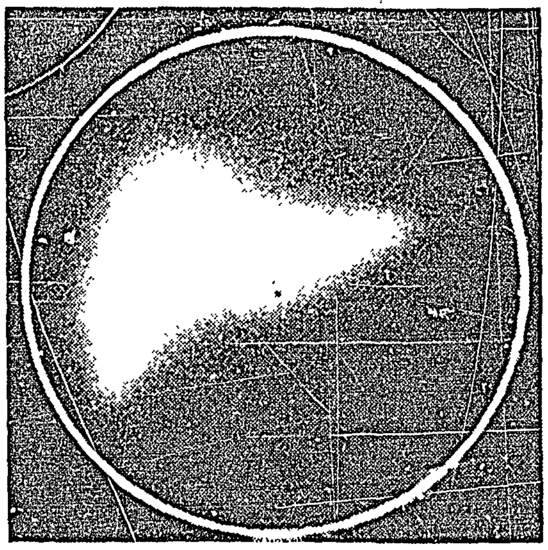


*Normal brain scan obtained with a gamma camera.*

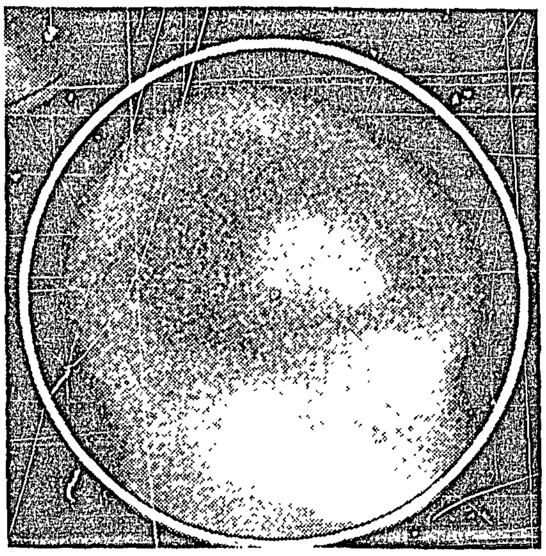


*Above: Normal lung scan.*

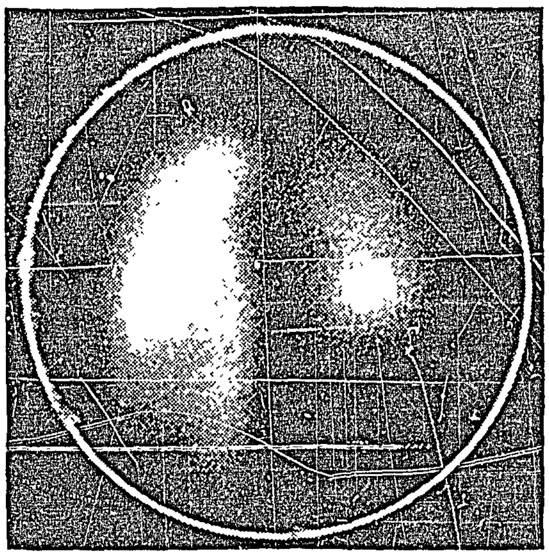
*Right centre: Abnormal lung scan showing areas of poor radiopharmaceutical delivery indicating abnormal perfusion, as occurs in pulmonary embolism.*

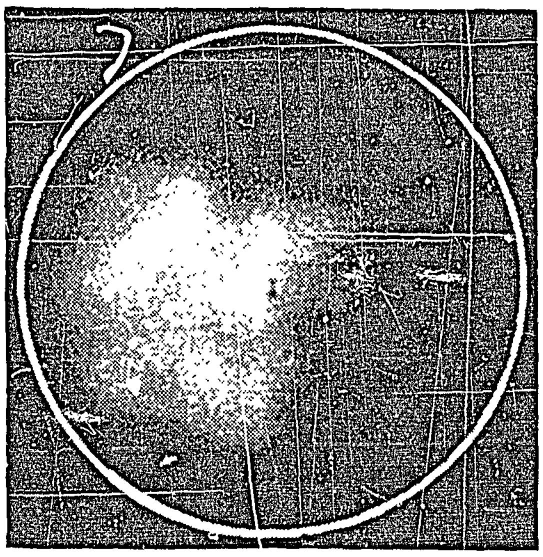


*Normal liver scan.*



*Abnormal brain scan showing large area of radiopharmaceutical uptake within the brain associated with a large tumour.*





*Abnormal liver scan showing multiple areas of absent radiocolloid uptake as the result of cancer deposits. (Scans by courtesy of Department of Nuclear Medicine, Prince of Wales Hospital, Sydney.)*

In addition to the delivery in June, 1970, of a 100 Rmm (Roentgen per minute at one metre between source and object) source for the Royal Perth Hospital (the sale was mentioned in last year's Report), three teletherapy sources have been sold for installation at Launceston (34 Rmm), Lae (Territory of Papua and New Guinea) (54 Rmm) and the St. John of God (Western Australia) (44 Rmm) Hospitals. A teletherapy source of 60 Rmm has been prepared for use by the Standardisation Group of the Commission's Health and Safety Division. A 25,000 curies cobalt 60 source was also supplied to the ICIANZ/AAEC Irradiation Research facility (GATRI) at the Commission's Research Establishment.

The overall demand for industrial radioisotopes has diminished slightly, but the requirement for radiography sources is still at a high level. Radiography sources have been exported to Singapore, New Guinea and New Zealand. There is a trend towards sources of greater activity, up to 100 curies, for special purposes such as inspection of jet engines and examination of large components of chemical plant.

Approvals were given for Customs entry of 1,608 items of radioactive materials imported by manufacturers and agents for scientific and industrial use compared with 1,465 last year.

# PRODUCT RESEARCH AND DEVELOPMENT

Nuclear medicine is in a state of rapid development with much of its diagnostic potential still to be realised. The Commission is contributing in this field by research on new radiopharmaceuticals with specific diagnostic functions. This work is usually carried out with the co-operation of nuclear medicine specialists and in consultation with the Commonwealth X-ray and Radium Laboratory. Research has also resulted in the improvement of radioisotope extraction processes, in the design of a more efficient technetium generator and in new techniques for interstitial radiotherapy.

## Technetium 99m Generators

Technetium 99m (half-life 6 hours), the most widely used diagnostic radioisotope in nuclear medicine is best supplied in the form of specific ready-to-inject radiopharmaceuticals. This is the method of supply preferred where transport is possible within the useful life-time of the material. Most medical centres in Australia are supplied in this way.

Technetium 99m is also supplied in the form of the longer-lived generator from which the user must prepare his own products for specific use. This is the most economic method for export sales. The generator carries molybdenum 99 (half-life 67 hours) which is separated at the Research Establishment in a highly purified form from fission products. Technetium 99m can be extracted easily from its parent molybdenum 99 as required by the user during a period of about seven days.

A detailed study of the purity and performance aspects of the portable technetium 99m generator has led to improvements in the fission product extraction process, and a proposal for a generator of new design. This work has coincided with the commissioning of a large-scale fission product extraction plant, and the Commission confidently expects that high-purity generators sufficient to meet Australian and export demands, operating at efficiencies approaching 100 percent, will be available during 1971.

## New Radiopharmaceuticals

Four new radiopharmaceutical preparations under development or introduced to the market are:

*Ytterbium 169-Diethylene triamine penta acetic acid complex (Yb169 DTPA)*

Yb169 DTPA is used as a tracer in flow studies of the cerebrospinal fluid. Since this material is injected directly into spinal fluid by means of a lumbar puncture, extraordinary demands on purity and sterility are placed upon its preparation and containment.

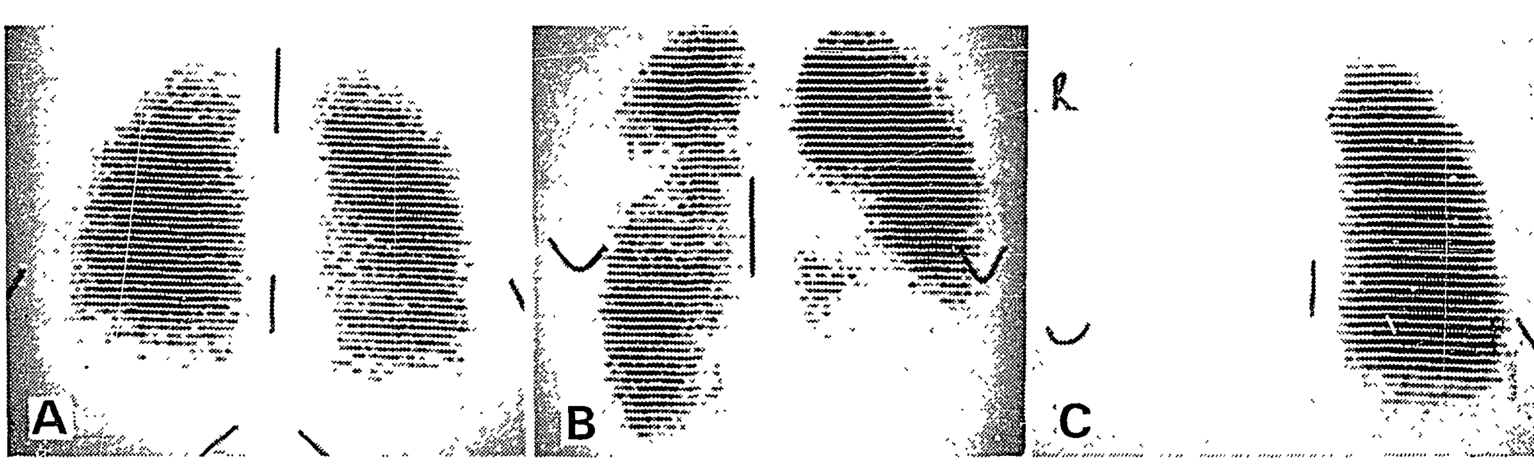
After undergoing a successful series of clinical trials in a number of hospitals throughout Australia, and being approved by the Commonwealth X-ray and Radium Laboratory, this diagnostic agent is now being used routinely.

*Technetium 99m:Tin:Diethylene triamine penta acetic acid complex (Tc-Pentastan)*

Tc-Pentastan is to be used for brain scanning, in which it is superior to other agents. It has a lower specificity for the non-target areas of the head such as salivary glands, choroid plexus and the thyroid gland. Hence, cerebral abnormalities in these areas are not masked, as is the case with Tc99m-pertechnetate. Problems of sterilizing Tc-Pentastan, which decomposes on heating, have been overcome by gamma irradiation at minus 70°C. The compound is undergoing clinical evaluation trials at a Sydney hospital.

*Technetium 99m:Gluconic acid complex*

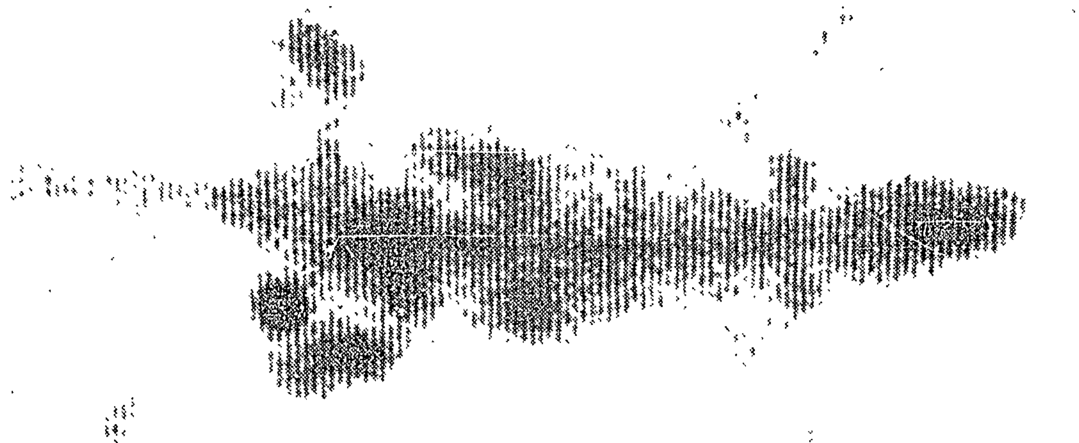
Investigation on animals has shown that technetium 99m:gluconic acid complex is selectively taken up by the kidneys, and should be a considerable clinical improvement over existing renal diagnostic agents. The chemical synthesis, stability and pharmacology of the compound have been studied in detail. Clinical evaluation trials are expected to start in the near future.




*A. Rectilinear scan of a normal lung using the radiopharmaceutical technetium 99m labelled macroaggregated ferrous hydroxide which was developed at Lucas Heights.*

*B. The same product after injection into another patient shows multiple defects in perfusion throughout both lungs caused by pulmonary embolism (clots in the lungs). This is the simplest and most accurate test for the diagnosis of this common condition and gives minimal discomfort to the patient.*

*C. A lung scan showing a congenital obstruction on the main pulmonary artery to the right lung. This was not indicated in a chest X-ray taken earlier. This radiopharmaceutical test is undertaken on outpatients without preparation or discomfort. (Scans, Department of Nuclear Medicine, Royal Prince Alfred Hospital, Sydney.)*



*Body scan of a young rat, four hours after injection with a technetium-based bone scanning agent now under development at Lucas Heights. If further laboratory and clinical tests prove this agent suitable, it could become an alternative to the much shorter-lived fluorine 18 for bone scanning and extend the range of distribution of a bone-scanning radiopharmaceutical as far as Perth and New Zealand.*

*Iodine 131 labelled quinoline derivatives*

Work continued on iodine 131 compounds proposed for use in locating malignant melanoma. Some difficulties have been encountered in the synthesis.

### Fluorine 18

A radiopharmaceutical preparation of fluorine 18 with a half-life of 110 minutes is a very valuable agent for bone scanning, and is being supplied daily to hospitals in Sydney, Melbourne, Brisbane, Adelaide, and occasionally to Hobart.

However, since the yield of this radioisotope in reactor production is very low, and chemical and decay losses occur during its processing into a pharmaceutical product and subsequent despatch to the user, there has never been sufficient to meet the still increasing Australian demands. A new chemical processing technique developed recently has increased the chemical yield and has reduced processing time from 60 to 40 minutes, resulting in a rise in output of at least 50 percent.

### Sources for Interstitial Therapy

The treatment of tumours by the surgical implantation of radioactive sources in and around the tumour is known as interstitial therapy. It is essential that the sources be placed accurately so that the required dose is delivered to the tumour, and that the dose to healthy tissue is minimised.

The accuracy of placement can be improved, and the dose to the surgeon reduced, if the patient is prepared by the insertion of inactive catheter tubes in the desired positions around the tumour and the radioactive sources inserted later. On completion of the treatment, which takes several days, the radioactive sources can be removed from the patient, and if a long-lived radioisotope is involved, the sources can be re-used.

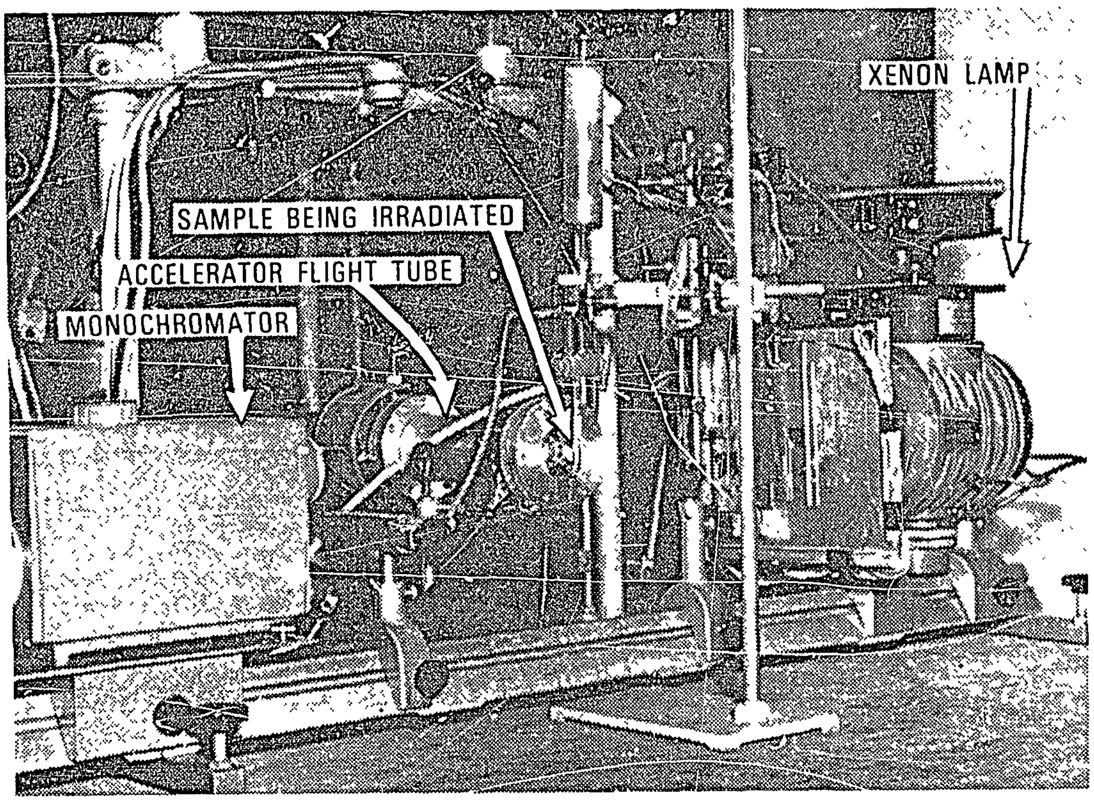
For this "after-loading" technique, the Commission's Radioisotope Production Section in co-operation with the Prince of Wales Hospital, Sydney, has developed radioactive sources in the form of flexible strings containing active components in a pre-arranged pattern. The active components are conventional platinum-sheathed gold grains (0.8 millimetre diameter x 2.5 millimetres long) separated by nylon spacers sealed in a flexible outer tube. The usual source string is six centimetres long and contains 13 gold grains, each with an activity of several millicuries of gold 198. At present the use of this radioisotope, which has a half-life of only 2.7 days, prevents re-use of the active strings. It is proposed to investigate re-usable strings with iridium 192 seeds (half-life 74 days).

## GAMMA-RAY AND ELECTRON BEAM IRRADIATION SERVICES

Demand has increased on the Commission's radiation facilities for radiosterilization. In particular, there has been a demand for the sterilization of peat as used in agriculture. Other work involved medical and pharmaceutical materials. For a number of materials and preparations, gamma sterilization is the only suitable method.

The demand for irradiations in research continued. The joint ICIANZ/AAEC research facility GATRI has been in constant use by both Commission and ICIANZ staff in research and development projects.

The Van de Graaff electron accelerator, used entirely for research, was fully utilised during the year by Commission staff and university research workers. Most of the electron beam irradiations have involved either the use of pulse radiolysis equipment or radiation polymerisation of thin films on various substrates.




*Pulse radiolysis apparatus installed at the target end of the Van de Graaff electron accelerator. A three microsecond pulse of electrons is injected into the glass vessel filled with the solution being studied. Light from the lamp on the right of the picture is partially absorbed by the radiolytic species and analysed by the monochromator on the left. In this way the chemical reactions of species existing for times as short as one millionth of a second can be followed.*

# 11

# OPERATIONS AND SERVICES

## OPERATIONS

### REACTOR HIFAR

The reactor HIFAR continued to operate on a 28-day cycle at an average power of 10 megawatts (thermal). A 93% full power utilisation, excluding time taken for fuel changing and scheduled maintenance, was achieved.

The scheduled three month major shutdown, which ended on 31 July 1970, was the longest of five completed during HIFAR's 13 years of operation. Notable aspects of the shutdown were the detailed examination of the primary heavy water circuit, successful repair of leaking thermal shield cooling coils, and the installation of two new main heat exchangers. The primary heavy water circuit shows no evidence of excessive corrosion. During the major shutdown inspection, additional leaks were found in the shield cooling coils. As another major shutdown would be necessary to repair these new leaks, and since the requirements of the research program can now be met by operating at 10 megawatts, it has been decided not to proceed with uprating HIFAR to 15 megawatts.

Standard Mark 4 fuel elements were introduced in HIFAR for the first time in the November full power operating period. In view of the use of these new Mark 4 concentric tube type fuel elements, the reactor sealed building air treatment system was modified to increase its operational reliability under abnormal conditions. Periodical checks of all elements are made in the reactor for vibration abnormalities, because such problems are known to occur with these elements under normal coolant flow conditions.

### ENGINEERING DESIGN AND MANUFACTURE

The demand for design, manufacture, inspection and testing services continued at a high level, with a large number of projects being undertaken for the major shutdown of HIFAR.

The Research Establishment completed manufacture and assembly of an in-pile high pressure water loop. This will be used for research on uranium dioxide fuel pins as mentioned elsewhere in this Report. A triple axis spectrometer was commissioned (see page 79).

A collaborative program on creep in materials was arranged between the United Kingdom Atomic Energy Authority and the Commission to enable such studies to be performed on zirconium alloys. In the first instance, under the terms of the agreement, the UKAEA will supply two in-pile rigs. The Commission will provide irradiation facilities in HIFAR and undertake intermediate and post-irradiation examination.

Other projects included:

### For Radioisotope Production

- Design and manufacture of an in-pile rig for radioisotope production in HIFAR. This rig can be removed for loading and unloading operations while the reactor remains at full power.
- Design and manufacture of shielded cells with remotely-operated handling facilities for the storage of radioisotopes.
- Design and manufacture of facilities and equipment for small caves and cells to allow remote handling of radioisotopes.
- Design and manufacture of a remote welding facility for sealing capsules containing radioisotopes.

### For the Research Program

- Engineering supervision of the design and construction of the critical facility.
- Design and manufacture of an experimental rig for investigation of the influence of fast neutron irradiation in the corrosion of zirconium alloys within a temperature range of 250°-800°C.
- Design and manufacture of in-pile collimators for neutron diffraction studies.
- Design and installation of a cooling circuit with sufficient capacity to allow removal of excess heat from the tips of all collimators in HIFAR.

A continuing requirement for the safe transport of radioactive materials is the design and manufacture of transport packages complying with International Atomic Energy Agency Regulations.

Contract services with local industry were maintained to supplement workshop effort at Lucas Heights. This allows industry to become familiar with nuclear work and guarantees a ready source of manufacture.

A 35 mm aperture microfilming system for the Drafting Office was introduced. Eventually this will enable the printing and record system to be automated.

## WORKS

Buildings completed or under construction were:

- Civil works for the critical facility (see page 108).
- A laboratory for fast access neutron activation.
- Extensions to several buildings.

Services provided included:

- Modifications to the space conditioner system in the reactor HIFAR.
- Cool air system for the canteen.
- Computer links from various buildings to the central computer.
- Storage for irradiated fuel.
- Extensions to electrical and other services and roadworks.

A technique, developed over several years, for drilling an 18 inch diameter hole 5 ft 3 in deep in the biological shield of HIFAR to permit repair of leaking cooling coils, proved very successful. The drilling operation and repair of the cooling coils was completed as scheduled during the three-month major shutdown.

## SITE OPERATIONS

Site services and plant were operated, maintained, and modified as necessary. Facilities and services were provided for the management of radioactive and toxic waste, for the ventilation of active areas and for contamination control.

Significant projects completed or commenced included:

- Survey and maintenance of boiler plant.
- Modifications to electrical installations.
- Major repairs to the air-conditioning system for the computer building.
- Manufacture of models of projected plant and equipment.

## WASTE DISPOSAL

The Commission's long-established policy of ensuring that no significant environmental damage results from its operations was maintained at the Research Establishment. Facilities and services associated with waste management operated satisfactorily. The amount of radioactivity discharged in liquid effluent to the Woronora River was below the limit allowed by the N.S.W. Government in the Lucas Heights discharge authorisation.

Commission policy also requires that effluent discharges be monitored independently of the operational controls and checks which ensure compliance with the authorisation. Thus check analyses made by an audit officer of the Research Establishment's Health and Safety Division provide an independent assessment of the amount of radioactivity discharged to the Woronora estuary. By means of a comprehensive, continuing and regular survey of the estuary environment, the Health and Safety Division ensures that no unexpected accumulations of radioactivity occur.

A similar system of authorisation and control applies to airborne discharges of radioactivity. An important part of this control system is the regular measurement of radioactivity concentrations in samples of milk produced in surrounding districts.

All solid radioactive waste produced at the Research Establishment is stored on the site. To reduce the volume requiring storage, very-low, low and intermediate-level wastes are compacted before storage. The now disused very-low-level solid waste burial ground is maintained as a secure area. Although the waste deposited there contains only a very small amount of radioactivity, a continuing survey is made of areas surrounding the burial ground.

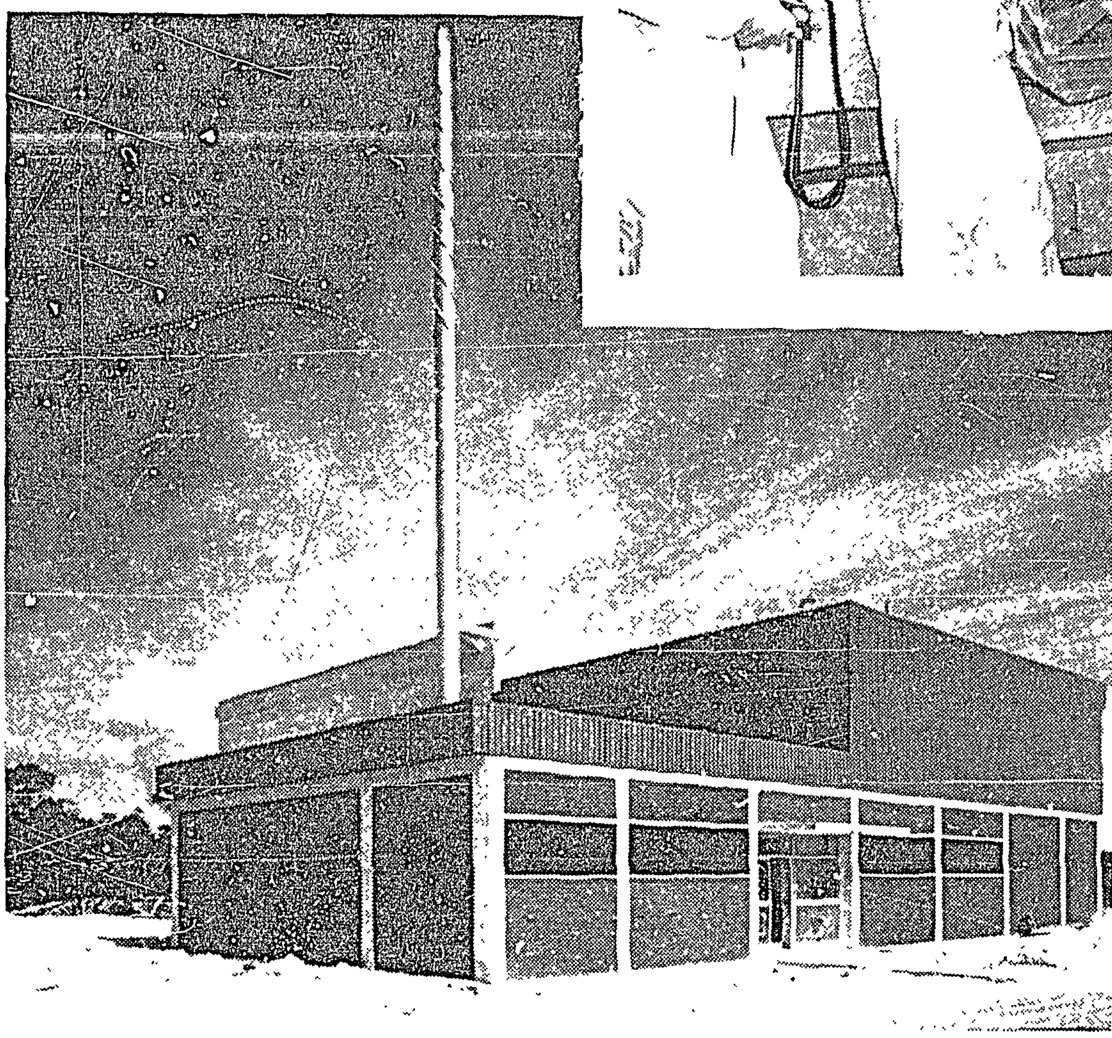
## CRITICAL FACILITY

The critical facility, a major installation for Physics Division, will make possible experimental studies of the physics of the utilisation of plutonium, reactor operating problems and advanced reactor concepts. Work on the facility continued throughout the year.

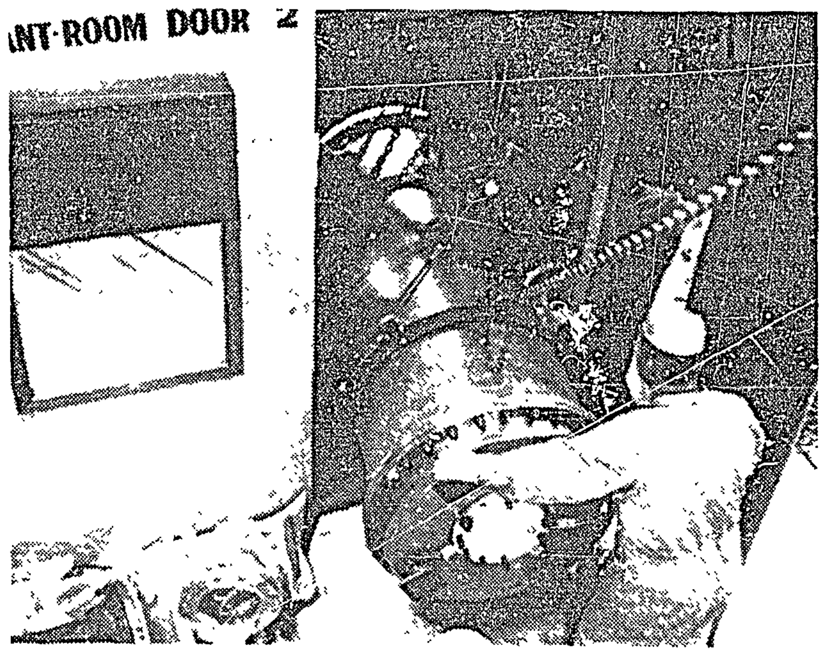
Construction work at Lucas Heights is being undertaken by the French organisation Groupement Atomique Alsacienne Atlantique, in association with Saint Gobain Techniques Nouvelles and M. R. Hornibrook (N.S.W.) Pty. Ltd. Construction of the control room, fuel storage and assembly complex, and the cell to house the split-table machine is now virtually complete.

The assembled split-table machine and its associated control electronics are being tested in France. Local foundation conditions at the plant prevented the carrying out of meaningful load tests on the split table. A full acceptance test program is being negotiated.

*Right: A contaminated high efficiency filter being removed from a laboratory exhaust ventilation system at Lucas Heights. The filter and ducting are completely sealed and contained at all times during the removal and replacement operation.*



*Above: General view of the critical facility building in final stages of construction.*




*Right: Heavy-water heat exchanger being removed from HIFAR reactor plant room during the 1970 major shutdown.*

# SERVICES

## HEALTH AND SAFETY SERVICES

The industrial and radiological health of all Research Establishment staff was closely supervised during the year. All staff are given initial medical examinations to determine their fitness for employment and for superannuation purposes. Subsequently they receive annual checks. The regulation and control of radiological and industrial safety throughout the year has been satisfactory and no serious accidents occurred.

## DISSEMINATION OF INFORMATION

The Research Establishment's library expanded its services to research staff by providing a current awareness service in the form of a semi-monthly Information Bulletin combined with a personal notification service. Retrospective searches of the nuclear literature for information on particular topics continued to be made on demand.

World-wide publication of literature falling within the Commission's fields of interest continues at an increased rate. This is reflected in the increase in the number of items acquired and processed by the library. Wherever possible, use was made of the centralised cataloguing facilities of the U.S. Library of Congress and the National Library of Australia to assist in handling the increased workload. Following the automation of periodicals records, a computerised loan recording system was introduced for technical report loans.

An increased number of abstracts of Australian sources of nuclear information was contributed to *Nuclear Science Abstracts* under the co-operation agreement with the USAEC's Division of Technical Information Extension. Through participation in the International Atomic Energy Agency's International Nuclear Information System (INIS), the library began to receive each month a computer tape containing references to nuclear literature. Work is proceeding on the preparation of computer programs to enable the library to use these tapes for selective dissemination of information and mechanised literature searching.

Publications by research staff of the Commission are listed in Appendix G. These range from scientific reports printed and issued by the Research Establishment, to papers included in learned journals and the proceedings of international conferences.

# 12

# INTERNATIONAL MATTERS

## FOURTH GENEVA CONFERENCE ON THE PEACEFUL USES OF ATOMIC ENERGY

The United Nations Organisation has invited Australia to participate in the Fourth Geneva Conference on the Peaceful Uses of Atomic Energy. This Conference will be held in Geneva from 6 to 16 September 1971, and will concentrate on experience in the application of nuclear energy. Five papers from authors in Australia have been accepted by the Conference organisers. The papers are as follows:

> "Some Recent Developments in Radioisotope Technology in Australia", by J. N. Gregory, B. D. Sowerby, W. T. Spragg, J. S. Watt.
>
> "The Production and Distribution of Radiopharmaceuticals in Australia", by R. E. Boyd, U. Engelbert, J. N. Gregory.
>
> "Survey of Australia's Energy Demand and Resources to Year 2,000", by F. L. McCay, R. D. Deas.
>
> "The Environmental Monitoring Program at the AAEC Research Establishment, Lucas Heights", by G. M. Watson.
>
> "The Projected Role of Nuclear Energy in Meeting the Future Energy Needs of Australia", by F. H. Carr.

In addition, Dr. A. R. W. Wilson, Deputy of the Executive Member, has been invited by the International Atomic Energy Agency to present on its behalf a paper reviewing the current status of civil engineering and mineral resources development applications of peaceful nuclear explosions. This will be the only paper presented at the Conference on this subject.

Dr. Wilson, an authority of international repute in this field, has chaired two IAEA panel meetings in Vienna on peaceful nuclear explosions. In 1966, at the request of the IAEA, the Australian Government made Dr. Wilson available to the Agency to assist the Government of Panama in its evaluation of the safety aspects of proposals for the nuclear excavation of a sea-level canal in Panama.

The Commission is co-operating with the Department of Foreign Affairs in arrangements for Australian participation at the Geneva Conference. It is expected that the Australian delegation will include representatives of the Commission, the Department of Foreign Affairs, the Department of National Development, and the Electricity Commission of New South Wales.

# SAFEGUARDS AND THE NON-PROLIFERATION TREATY

The Safeguards Committee set up by the International Atomic Energy Agency to formulate the structure and content of the agreements between States and the Agency, required in connection with the Treaty for the Non-Proliferation of Nuclear Weapons, completed its discussions on 1 February 1971. Its report was adopted by a special meeting of the Agency's Board of Governors on 20 April 1971.

The Committee held 75 meetings between June, 1970, and the date of completion. As many as 53 Member States took part. The Committee's report is in two parts — Part I containing the basic provisions for Safeguards Agreements, and Part II specifying the procedures to be applied to carry out the provisions of Part I.

The Agency is now in a position to attempt to negotiate with States which have ratified the Treaty the actual safeguards agreements required by the provisions of Article III of the Treaty. Each such agreement will be submitted to the Agency's Board of Governors for approval. Several States have already begun these negotiations.

Australia was represented at all meetings of the Safeguards Committee. Mr. T. F. B. MacAdie of the Commission's staff led the Australian Delegation for the greater part of the session of meetings of the Committee which produced Part I of the report. Subsequent Australian delegations were led by the Executive Member of the Commission, Mr. M. C. Timbs.

# IAEA PANEL ON PEACEFUL NUCLEAR EXPLOSIONS

A second panel meeting convened by the IAEA to foster the exchange of information on peaceful uses of nuclear explosions was held in January, 1971. More than 60 experts and observers from 25 countries and several international organisations participated in discussions on the practical applications of peaceful uses of contained nuclear explosions for industrial purposes. Dr. A. R. W. Wilson, Deputy of the Executive Member, chaired the meeting. Dr. R. K. Warner, Chief, Nuclear Technology Division, was the Australian panel member.

Considerable discussion took place on developments in the technology of fully-contained applications of nuclear explosions, since such applications have promise for stimulation of natural gas and oil held in low permeability rock strata, for the creation of underground cavities for natural gas storage, and for *in situ* leaching of mineral deposits. Progress in the U.S.A. and U.S.S.R. in studying these applications was noteworthy.

In its final session, the Panel recommended that the Agency be provided with technical data on proposed peaceful nuclear explosions. Also, that the Agency might facilitate exchange of relevant geological information and institute training programs for countries interested in applying this technology to the development of their natural resources.

## SYMPOSIUM ON THE BIOPHYSICAL ASPECTS OF RADIATION QUALITY

A Symposium on the Biophysical Aspects of Radiation Quality was held at Lucas Heights from 8 to 12 March 1971 under the auspices of the International Atomic Energy Agency, and as a follow-up to two Agency panels on the same subject held in 1965 and 1967 respectively. The subject concerns the actions of different types of ionising radiation on living organisms. Some 40 papers were presented covering all aspects of the field. A total of 66 persons participated from 16 countries and two international organisations were represented. The Symposium provided a thorough review of the state of current knowledge, and pointed to the conclusion that much more work needs to be done before radiation quality factors can be specified with precision.

## OVERSEAS VISITS

During the year Commissioners and Commission officers took part in a number of important meetings and discussions overseas.

The Chairman of the Commission, Sir Philip Baxter, as Chairman of the IAEA Board of Governors, attended meetings in Vienna in September 1970. He also visited Japan and New Zealand.

The Executive Commissioner, Mr. M. C. Timbs, visited Indonesia at the invitation of the Indonesian Atomic Energy Authority for discussions on regional co-operation. Later he visited Thailand where he attended the IAEA sponsored Conference on Regional Co-operation in South-East Asia.

Mr. Timbs made three visits to the United States as leader of the Australian group which, with Bechtel Pacific Corporation Ltd., performed the technical and economic assessment of power reactor systems in association with the Jervis Bay Nuclear Power Project. Subsequently, Mr. Timbs led the Australian delegation to the second session of the IAEA Safeguards Committee in Vienna.

During 1971, Mr. Timbs led Australian delegations to three meetings of the Board of Governors of the IAEA in Vienna and subsequently visited France, Germany, Italy and the U.S.A. He and Dr. A. R. W. Wilson were invited by the Commissariat à l'Energie Atomique to visit atomic energy research centres in France and, in particular, the gaseous diffusion enrichment plant at Pierrelatte.

Mr. Commissioner K. F. Alder visited the U.S.A. in November 1970, and attended *inter alia* a meeting of the Atomic Industrial Forum.

Dr. A. R. W. Wilson, Deputy of the Executive Member, was invited by the IAEA to participate in a panel charged with revising the Agency's transport regulations. He was also a member of the Australian delegation to the third session of the IAEA Safeguards Committee.

Mr. D. R. Griffiths, Chief, Nuclear Power Assessment Division, and a number of other officers travelled to the United States in connection with the assessment of tenders for the proposed Jervis Bay nuclear power station.

Mr. T. F. B. MacAdie and Mr. F. L. Bett attended respectively the first and second sessions of the IAEA Safeguards Committee in Vienna. Dr. W. B. Rotsey took part in a Japan Atomic Industrial Forum Conference in Tokyo. Dr. D. J. Higson attended a Symposium on Nuclear Ships held in West Germany.

As in past years a number of Commission officers travelled overseas to maintain liaison with atomic energy and other laboratories, and to attend conferences of value to the Commission. In particular, Mr. J. S. Watt made a short tour of Asia lecturing on radioisotope techniques, and the Research Establishment Chief Librarian, Mr. H. W. Groenewegen, took part in discussions in Vienna on the International Nuclear Information System.

## DISTINGUISHED VISITORS

Distinguished visitors included: The Hon. R. W. C. Swartz, M.P., Minister for National Development; The Hon. W. C. Wentworth, M.P., Minister for Social Services; Professor I. S. Zheludev, Deputy Director-General, Department of Technical Operations, IAEA, Vienna; Sir Lenox Hewitt, Secretary, Department of the Vice-President of the Executive Council; Sir Leonard Huxley, Australian National University, A.C.T.; The Hon. J. G. Beale, M.L.A., Minister for Environment Control, N.S.W.; The Hon. J. J. Greene, Canadian Minister for Energy, Mines and Resources; Mr. George F. Murphy Jnr., Deputy Director, and Congressman Wayne N. Aspinall, U.S. Joint Committee on Atomic Energy; Professor Sir Edward Ford and members of the National Radiation Advisory Committee; Major-General Sir Erskine Crum and members of the Imperial Defence College Seminar 1970; Dr. R. E. Robinson, Director, National Institute for Metallurgy, South Africa; Professor J. S. Anderson, Oxford University, United Kingdom; Mr. P. Scott Maxwell, Managing Director, Vickers (Australia) Ltd.; Mr. L. Corkery, Australian Ambassador to Austria; Professor V. P. Guinn, University of California, Irvine, U.S.A.; Mr. R. V. Moore, Managing Director, Reactor Group, UKAEA; Dr. Bertrand Goldschmidt, Director of International Relations, Commissariat à l'Energie Atomique, France; Professor G. Eldridge, Massachusetts Institute of Technology, U.S.A.; Mr. M. Diamante, Director of Field Operations and Acting Director for Managemen, Philippines National Science Development Board; Mr. Chester Norris Jnr., Director U.S. Trade Center, Sydney; Mr. M. I. Michaels, Under-Secretary, Department of Trade and Industry, U.K.; Dr. H. H. Eisenlohr, Scientific Secretary, IAEA Vienna; Dr. T. Alper, Director, Experimental Radiopathology Research Unit, Medical Research Council, Hammersmith Hospital, U.K.; Dr. V. I. Ivanov, Institute of Physical Engineering Dosimetry Laboratory, Moscow, U.S.S.R., and other delegates to the IAEA Conference on the Biophysical Aspects of Radiation Quality; Mr. C. Allday, Managing Director, and Mr. J. Waddams, Commercial Manager, British Nuclear Fuels Ltd., U.K.; Mr. W. Tajitsu, Chairman, Mitsubishi Bank, Tokyo; Dr. R. L. Straszacker, Chairman, South African Electricity Supply Commission; Dr. C. G. Bigotte, Manager for Overseas Mineral Exploration, Commissariat à l'Energie Atomique, France; Professor D. F. Parsons, Roswell Park Memorial Institute, Buffalo, U.S.A.; Mr. R. F. StG. Lethbridge, Mining Adviser to the UKAEA; Mr. H. D. V. Pakenham, British Deputy High Commissioner to Australia; Sir Roland Wilson, Chairman, Qantas Airways Limited; Mr. B. S. Sudarsono, Deputy Director-General and Secretary, Indonesian National Atomic Energy Agency; Mr. F. E. Stewart, M.H.R.; Dr. J. L. Gray, President, Atomic Energy of Canada Ltd.; Mr. S. A. Ghalib, Managing Director, and Mr. D. R. Smith, Commercial Manager, The Nuclear Power Group Ltd.; Mr. W. Altvater, Kraftwerk Union A.G.; and Mr. J. J. Kreuthmeier, Manager, Nuclear Plant Department, Westinghouse Electric Corporation; with specialist teams from Canada, the United Kingdom, the Federal Republic of Germany and the U.S.A. respectively for discussions in connection with the Jervis Bay Project.

# 13

# GENERAL

## SENIOR STAFF CHANGES

Pending decision by the Government on the Jervis Bay Nuclear Power Station and contingent on that decision a number of senior staff changes were made as follows:

Mr. K. F. Alder was seconded from duties as Director of the Research Establishment to become the Commissioner responsible for the Power Group.

Mr. A. D. Thomas was appointed Acting Deputy Head of the Power Group.

Dr. J. L. Symonds, Chief of the Physics Division, was appointed Acting Director of the Research Establishment during the attachment of Mr. Alder to the Power Group.

Dr. A. R. W. Wilson, Deputy Director of the Research Establishment, was appointed Acting Chief of the Technical Policy and International Relations Division and Deputy of the Executive Member.

Dr. R. Smith, Assistant Director of the Research Establishment, was appointed Acting Deputy Director of the Research Establishment, during the attachment of Dr. A. R. W. Wilson.

Mr. A. J. Moulding, formerly Director of Finance, was appointed Acting Associate Controller (Management) of the Jervis Bay Nuclear Power Project.

At the Commission's Research Establishment, Dr. C. J. Hardy, formerly on the research staff of the United Kingdom Atomic Energy Authority, was appointed Chief of the Chemical Technology Division.

## TERMS AND CONDITIONS OF EMPLOYMENT

During the year, the Commission made a number of Determinations which gave effect to variations in conditions of service and provided for increased salary rates for all designations employed in the Service of the Commission.

Apart from the normal increases in salary and wages accruing to various occupational groups following arbitral determinations or Consent Agreements, the Commission adopted the decision of the National Wage Case 1970 by increasing all salaries and wages by the overall six percent represented in the judgment.

### Industrial Matters

The Commission was involved in a number of industrial stoppages during the year which had a direct and at times unfortunate bearing on some of the Commission's activities. At one stage, as a result of industrial action, deliveries of diagnostic medical isotopes were disrupted for some time. The frequency of stoppages increased during the year up until the end of December, 1970. Similar stoppages apparently occurred in other areas of Commonwealth employment and private industry during the same period. Disputes relating to a Log of Claims lodged on the Commission by the craft unions resulted finally in an approach by the Commission to the Commonwealth Conciliation and Arbitration Commission. After this approach and further consultations with the unions involved, better relations were established during the latter half of the year, and a more favourable climate prevailed over the last five months, when work stoppages were reduced to a minimal amount. Overall, 6,080 manhours were lost by the stoppages in the period October 1970 to March 1971, of which 3,079 manhours were lost in December 1970 alone. Since 1 January 1971, only 32 manhours have been lost.

Arising from the decision to close down the Rum Jungle operation, it was necessary to devise a severance scheme for the staff employed at Rum Jungle. A suitable scheme was adopted in close collaboration with the operating company at Rum Jungle, Territory Enterprises Pty. Limited. The scheme was satisfactory to both the staff and the unions concerned, and has operated successfully during the final stages of the Rum Jungle operation.

After the decision of the Public Service Arbitrator on the salary of Research Scientists, an appeal was made on behalf of Senior Principal Research Scientists, Chiefs of Division and Chief Research Scientists. The Commonwealth Conciliation and Arbitration Commission revised upward the rates fixed for these classifications in the original Arbitrator's determination. The rates for other classes of Research Scientists were left unchanged.

## STAFF NUMBERS

The total staff employed by the Commission at 30 June 1971 was 1,256. Head Office staff (including Atomic Energy Attachés overseas) accounted for 101, the Research Establishment staff was 1,136 and 19 were committed to the Power Station Project.

The disposition of staff according to groups compared with the previous year is as follows:

| | *At 30.6.70* | *At 30.6.71* |
|---|---|---|
| Executive and Senior Staff | 8 | 9 |
| Research Grades | 112 | 121 |
| Experimental Grades | 134 | 138 |
| Other Professional Grades | 79 | 84 |
| Technical Grades | 395 | 410 |
| Trade Grades | 138 | 141 |
| Administrative and Clerical | 183 | 193 |
| Support Staff (Storemen, Drivers, etc.) | 174 | 160 |
| | 1,223 | 1,256 |

## NEW PREMISES

At the beginning of the year the Commission decided to purchase new premises at Gardener's Road, Mascot, to meet increased accommodation needs. The premises were in the form of a disused bowling centre, which was converted to office space, and now houses the staff of the Power Group and some others. It is likely to be also used by consultants and contractors, associated with the Jervis Bay Project.

## ACKNOWLEDGMENTS

The year under review was demanding on the Commission and its staff, particularly in relation to the additional effort required to complete the assessment and evaluation of the tenders for the Jervis Bay Power Station, in order to submit a considered recommendation to the Government within the time required.

The Commission wishes to acknowledge the very considerable effort by many of the staff who were called upon to work for extended periods, including many weekends, to complete the tasks before them.

The Commission also expresses its appreciation to the many other organisations which have assisted and co-operated with it during the year.


## ATOMIC ENERGY ADVISORY COMMITTEE

On 28 April 1971, a meeting of the Atomic Energy Advisory Committee was held in the Australian Institute of Nuclear Science and Engineering Conference Room at Lucas Heights. Commission officers presented papers on the Jervis Bay Nuclear Power Project, environmental studies in relation to nuclear power stations, the uranium industry, and research in radioisotope technology. The Commission wishes to record its appreciation of the very informative discussions with members of the Committee which followed the presentation of the papers.

## SAFETY REVIEW COMMITTEE

The Safety Review Committee held its eighth and ninth meetings in December, 1970, and April, 1971. The Committee inspected various laboratories and facilities at Lucas Heights and reviewed the Commission's safety procedures for the storage and disposal of solid waste, the modified environmental survey program, activities of the various Safety Committees, emergency procedures and safety assessments.

The Committee was satisfied with the safety standards and endorsed the safety procedures. However, it noted a state of overcrowding in the radioisotope production laboratories caused by the increase in production of radiopharmaceuticals. It is satisfied that the Commission's extension plans will relieve this situation.

A recommendation was also put to the Commission to seek the assistance of the National Health and Medical Research Council in establishing radiation protection guides with respect to radiation accidents. This and other recommendations made by the Committee have been adopted by the Commission.

## INFORMATION SERVICES

Much of the activity of the Information Section was devoted to the Jervis Bay Project, and particularly to informing the Press and public on the implications of nuclear power and the operation of the power station. There has naturally been great interest in the South Coast area, and it has been Commission policy to give as much detail as possible on its activities at Jervis Bay, and future plans.

To this end a public meeting was held at Nowra on 19 August, under the sponsorship of the South Coast Conservation Society. The Commission Chairman and senior officers described different aspects of the project and replied to a number of questions. During the period, talks were given to clubs and schools throughout the area from Wollongong to Bega. The Commission's display caravan made two tours in the area, in addition to participating in the Nowra Agricultural Show in February, 1971.

Several Press and television visits to the Jervis Bay site were arranged, resulting in newspaper feature articles and television items. Throughout the period, briefings and background material were given to the news media.

Of particular value was a film showing environmental surveys being carried out at Jervis Bay. This proved to be an interesting television feature and was shown widely on A.B.C. and other television stations. The film subsequently was expanded and includes marine surveys of tides and currents and of marine life, and land surveys of flora and fauna. It includes aerial and underwater sequences, and was completed during the period. The Commission's technical film, "Radioisotope Analytical Techniques in Mineral Processing", completed at the end of the previous period, was widely distributed in Australia and overseas, and attracted favourable attention for these economically important techniques. There was a marked increase overall in the number of requests made on the Commission's film library.

Assistance was given to the making of a feature film for television, covering all peaceful aspects of atomic energy. This involved briefings and arrangement of interviews, together with several visits to the Research Establishment and Jervis Bay. Similar help was given to a German television station making a feature film on Australia's development. Another German television network has included the Commission film, "Search for Uranium", in its educational program.

At the Lucas Heights Information Centre a new display was designed and installed to explain the work of the Research Establishment. The Centre is open to the public seven days a week, and representatives of tourist organisations expressed interest in including a visit to the Centre in organised tours.

The Commission's 34 ft long display caravan was employed for the first time during the period, and proved to be versatile and highly successful. It toured the South Coast in July/August, stopping at Kiama, Nowra, Huskisson and Milton. In August/September, it took part in the Royal Adelaide Show, returning by way of the Murray Valley, with stops at Renmark, Mildura, Swan Hill and Echuca. In April, it toured the further South Coast as far as Bega. Between these tours it was used on several occasions for schools and local agricultural shows.

A display on nuclear power was mounted at the exhibition held in conjunction with the CETIA (Control Electronics Telecommunication Instruments Automation) Symposium held in February. Several other minor displays were set up during the period.

Publications issued during the year included the Commission's quarterly journal, "Atomic Energy in Australia", a revised version of the colour book "Lucas Heights", a new booklet "Brief Description of the Work of the AAEC Research Establishment", describing in more technical detail the work of the Establishment, and a visitor's guide for Open Days. There was a pronounced increase in the demand for booklets and reprints, especially those dealing with nuclear power. Several large internal reports were produced, also the printing requirements of the Australian School of Nuclear Technology.

Articles were written for newspapers and periodicals, including two educational broadsheets for a major daily newspaper. Many black-and-white and colour photographs were distributed. More than 50 talks were given to clubs and professional groups.

# EXTRAMURAL RESEARCH

The Commission arranges contracts with universities and other bodies to carry out research on topics of a fundamental nature directly related to the Commission's interests. Thus, the Commission is able to benefit from expert knowledge in the universities and to co-operate with them.

During the year, seven new contracts were awarded and support was continued for five earlier contracts. The total sum granted for the year was $102,611. A complete list of research contracts with relevant details is given in Appendix E.

# OVERSEAS ATTACHMENTS

## Special Experience Attachments

As in the past, the Commission arranged for selected officers to be attached to national laboratories, governmental organisations and universities overseas to gain experience and training which cannot be obtained in Australia. Overseas postings are usually of two years' duration, during which time the officers are encouraged to attend courses and conferences relevant to their particular field of work, and to visit other establishments engaged in similar fields of research.

During the year, the following officers were on attachment to establishments in the U.S.A., Canada, the United Kingdom and France:

| *Establishment* | *Officer* | *Field of Work* |
|---|---|---|
| USAEC Oak Ridge National Laboratory, U.S.A. | Mr. B. J. Allen | Time-of-Flight and Nuclear Physics Group. |
| USAEC Oak Ridge National Laboratory, U.S.A. | Dr. A. Jostsons | Radiation Metallography Group. |
| USAEC Oak Ridge National Laboratory, U.S.A. | Mr. B. J. McGregor | Study of shielding problems. |
| Cavendish Laboratory, Cambridge, U.K. | Dr. R. F. Mitchell | Medical Research Council, Research Group. |
| Commissariat à l'Energie Atomique Research Centre, Cadarache, France. | Mr. A. P. Marks | Physics. |
| AECL Power Projects, Sheridan Park, Toronto. | Mr. B. R. Lawrence | Reactor control and instrumentation. |

# RESEARCH ESTABLISHMENT OPEN DAYS

Open Days at Lucas Heights are now a regular feature of the Commission's public relations program and are attracting widespread interest. During the last week of April, a series of Open Days was held at the Research Establishment. Many of the laboratories, including some which are not normally available, were open for inspection. Special exhibits portrayed the work of the Research Establishment. Staff explained the work and answered many questions.

On the first day a number of special guests were invited by the Commission. On the second day members of professional and technical bodies, students and staff of universities and technical colleges, and staffs of government departments, CSIRO and industrial firms were invited. A total of 850 attended. On the following two days 7,000 fifth and sixth form high school science students and their teachers attended. The students came from as far away as Albury, Orange and Singleton. The last day, attended by 3,000, was for Commission staff with their families and friends.

## AUSTRALIAN INSTITUTE OF NUCLEAR SCIENCE AND ENGINEERING

The 15 Australian universities and the Commission composed the membership of the Australian Institute of Nuclear Science and Enginering for the year 1970-71, and all were involved in the Institute's continuing program supporting university research and training activities in the nuclear field. The major activities included AINSE Conferences in Radiation Chemistry and Plasma Physics, the provision of AINSE Post-Graduate Studentships and Research Fellowships, the award of AINSE Research and Training Grants, and arrangements for university groups to use the nuclear reactors and other specialised equipment at Lucas Heights.

The Institute completed in 1971 its eleventh year of active operation both within the universities and at Lucas Heights, where the AINSE Building occupies a site close to the AAEC Research Establishment. The AINSE Council, on which the Commission and each university was represented, exercised overall control. Office bearers were Professor D. E. Caro (University of Melbourne), President, 1970; Professor M. H. Brennan (Flinders University), President, 1971; Sir Ernest Titterton (Australian National University), Vice-President, 1970 and 1971; and Professor E. O. Hall (University of Newcastle), Vice-President, 1971.

The Council met twice at Lucas Heights and also at two member universities. The opportunity was taken on the university visits to present the following public lectures and discussions:

> "The Role of Nuclear Technology in Australia". A joint presentation by Sir Philip Baxter, AAEC; Mr. K. F. Alder, AAEC; and Mr. R. Stanton, Royal Perth Hospital. (University of Western Australia, August, 1970.)

> "The Role of Nuclear Science in Rural Industry". Presented by Professor L. E. Smythe, University of N.S.W. (University of New England, February, 1971.)

The Institute's financial records refer to the year ended 31 December 1971. At the beginning of the year increased membership subscriptions became effective, and the year concluded with the receipt from the AAEC in December 1970 of an increase in the "Contribution for Research and Training". This resulted in the Institute's annual income exceeding its expenditure for only the second time in eight years, and enabled sufficient funds to be carried forward at

31 December 1970 to permit operations planned for 1971 to be commenced with confidence. The 1970 (year ended 31 December 1970) income totalled $315,499 and expenditure amounted to $267,744. Planned commitments for 1971 exceed the estimated income for 1971 by $42,000 and this is expected to reduce reserves to a minimum safety level below $6,000 by 31 December 1971.

Continuing operations were conducted by the AINSE staff at Lucas Heights which consists of the Executive Officer (Mr. E. A. Palmer) and eight other members (including five scientists and technicians). The number of university staff members and research students visiting Lucas Heights or attached to the Institute during 1970-71, exceeded 300, involving a total of more than 3,000 man-days. The Institute made all necessary arrangements for these university visitors, including assistance with travel costs, organising the use of AAEC and AINSE equipment, discussions with AAEC scientists and engineers, and accommodation at Stevens Hall, Lucas Heights.

## AINSE Conferences

The organisation of specialist working conferences involving research groups from the AAEC, universities and other organisations continued to be an important AINSE activity. In August, 1971, the 5th AINSE Radiation Chemistry Conference at Lucas Heights was attended by 68 participants (including four overseas visitors) from 16 different organisations, to hear a total of 40 papers dealing with radiation effects in chemical systems. In February, 1971, 115 physicists and engineers (including 54 research students) attended the 8th AINSE Plasma Physics Conference to hear 50 papers dealing with various aspects of this subject, particularly those relating to the eventual achievement of controlled thermonuclear fusion. These were essentially working conferences at which research in progress was reported. They also provided a forum for discussion between AAEC staff members and research workers from universities and other organisations active in related fields. Early in 1971, work was begun on the organisation of the 5th AINSE Heat Transfer and Fluid Flow Conference (August, 1971), the 4th AINSE Nuclear Physics Conference (February, 1972), and the 3rd AINSE Radiation Biology Conference (October, 1971).

## AINSE Studentships

Two new AINSE Post-Graduate Research Studentships were begun early in 1971, five existing awards were extended, and two studentships completed. Candidates for these awards are nominated by the Australian universities and the students receiving awards are granted a basic stipend of $2,600 for about three years, while undertaking research leading to a Ph.D. degree. The student's project must be in the Institute's fields of interest, and must require the use of Lucas Heights' facilities to the extent that a quarter of the student's time is necessarily spent at Lucas Heights. Of the nine awards current in 1970-71, two were in the field of nuclear materials, three in neutron physics, two in neutron diffraction (crystallography), one in mechanical engineering (heat transfer problems), and one involved in the development of neutron detectors. The studentships are primarily a training activity to help provide engineers and scientists of high ability for the future. The operation of the scheme is a fruitful field of co-operation between the AAEC and the universities. (Studentship projects are included in Appendix F.)

## AINSE Fellowships

One AINSE Research Fellow completed his work in the year 1970-71, three Fellowships extended through the period, two new Fellows commenced work, and three awards were offered for tenure in the second part of 1971. AINSE Research Fellowships are post-doctoral awards tenable at a university in Australia, or directly at Lucas Heights, for two or three years. The six Fellows working in 1970-71 included one each from France, U.S.A., Canada and Britain and two Australians. The fields of research covered solid state physics, metallurgy, nuclear physics and radiation biology. Each project involved some use of facilities at Lucas Heights. The Fellowships continued to be highly competitive awards, and only two Fellows were appointed in response to more than 30 nominations considered in 1970-71. The work of AINSE Fellows continued to make a positive contribution to research in Australia in various branches of nuclear science. (Fellowship projects are included in Appendix F.)

## AINSE Research and Training Grants

The titles of the 87 projects supported by AINSE Research and Training Grants in the 1971 Series are included in the 1970-71 projects listed in Appendix F. These grants (totalling approximately $150,000) were awarded in response to proposals received from the universities, and provided support for a wide range of projects in radiation chemistry, plasma physics, radiation biology, nuclear physics, nuclear engineering, materials technology, and many other areas of research relevant to the nuclear field or requiring the use of facilities at Lucas Heights. Many of the projects involved close co-operation between staff members at Lucas Heights and the university staff and research students concerned. Major research tools, such as the reactor HIFAR and the 3 MeV accelerator at Lucas Heights, were made available by the Commission for some of these co-operative projects, several of which involved a number of university groups. The grants assisted with the provision of essential equipment, as well as contributing to other costs associated with the project, including travel costs to Lucas Heights from centres distant from Sydney. The results obtained in these investigations were available to the Institute's member organisations in the form of progress reports or published papers. A total of 160 such communications were listed for circulation early in 1971, arising from work carried out in 1970. This total does not include the 110 papers presented at AINSE Conferences in 1970.

## Neutron Diffraction

The Institute continued the development at Lucas Heights of AINSE research facilities using beams of neutrons generated in HIFAR, and provided substantial assistance to enable university research groups to make the most effective use of this equipment. Four AINSE staff members led by Dr. F. H. Moore are involved in this work. During the year, with the assistance of AAEC staff members, the group completed the commissioning of a computer-controlled neutron diffractometer for single crystal work, and proceeded with the construction of a polarised neutron unit (also computer-controlled). The Institute's other neutron diffraction facilities, including a powder diffractometer, a small angle unit and a second single crystal diffractometer, were used extensively by members of university groups, as were the AINSE facilities for collecting diffraction data at very low temperatures (-269°C) and in high magnetic fields. Information from these experiments was used in the study of molecular structure (crystallography) and also in the elucidation of magnetic structure problems in solid state physics. These experiments and the subsequent analytical work required the further development, jointly by AINSE, AAEC and university scientists, of a specialised computer program for use on the IBM 360/50 I machine at Lucas Heights, and other computers.

### AINSE Facilities

The Institute also increased its investment in equipment for use at Lucas Heights in connection with university work employing the Commission's 3 MeV proton accelerator. A member of AINSE staff was attached to the Physics Division of the Research Establishment throughout the year, to assist all university staff and research students using this accelerator and other equipment used in nuclear physics investigations. The co-operation received from Lucas Heights staff was again a major factor in the success of this work, as it was also in other fields, including radiation biology and radiation chemistry. Several projects in these areas involved the use of the AAEC 1.3 MeV electron accelerator and the AINSE equipment which has been added to it for work in the field of pulse radiolysis. To further extend facilities in Australia for this work, the Institute has decided to install at Lucas Heights a high intensity pulsed radiation source. This will be used by research groups from several universities and from the Commission.

### Other Activities

The Institute continued a variety of other activities as a normal part of its operations to assist research and training in its areas of interest. These again included the award of grants to assist university staff members attending courses at the Australian School of Nuclear Technology, and making arrangements for members of AAEC and AINSE staff to give lectures and courses at universities on specialised topics. The Institute's theatre and conference facilities were made available to the Commission for the International Atomic Energy Agency (IAEA) Symposium in March 1971 ("Biophysical Aspects of Radiation Quality"), and the Institute also acted as a liaison channel between the Commission and the universities on IAEA business and other matters. Overall, in the year 1970-71, the Institute's staff, facilities and financial resources continued to be fully extended in attempting to satisfy part of the demand.

## AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

The School operated throughout 1970-71. Radioisotope Courses for Graduates were held from 22 June to 17 July, from 14 September to 9 October, from 9 November to 4 December, and from 21 June to 16 July. The total number of participants was 53. Radioisotope Courses for Non-Graduates were held from 27 July to 14 August, and from 18 January to 8 February, with a total of 25 participants. A Nuclear Technology Course was held from 15 February to 4 June, with 15 participants.

The 93 participants at courses during the year included 19 Colombo Plan Fellows and one IAEA Fellow. Three free places were awarded to staff of institutes of technology to attend the November Radioisotope Course for Graduates, one free place was awarded at the June course, and two of the participants in the Nuclear Technology course were sponsored by the Institute of Nuclear Energy Research, Atomic Energy Council, Republic of China (Taiwan).

For the first time, a course is being organised in Radiological Protection, to be held in September 1971.

The First Quinquennial Report of the School covering the period 1 July 1965 to 30 June 1970 was published during the year. This pointed out that the number of participants at the 26 regular courses held totalled 435. In addition, 100 had attended the short specialised courses given for the State Electricity Commission of Victoria and the universities. Those attending the radioisotope courses for graduates and the nuclear technology courses included 35 and 19 overseas participants respectively. These included 38 Colombo Plan Fellows, two IAEA Fellows, and an AIAS (Australian International Award Scheme) Fellow. There were four overseas participants (including three Colombo Plan Fellows) at the Nuclear Facilities — Siting and Safety Assessment Course, and one Colombo Plan Fellow at the first course in Neutron Activation Analysis.

The School is operated by the Commission in co-operation with the University of N.S.W. It is located at Lucas Heights, where advantage is taken of laboratory and service facilities provided by the Research Establishment. Most of the lectures at the School are given by Commission staff, some by University of N.S.W. staff, and the remainder on a visiting basis by staff from other universities, industrial firms and Government laboratories.

## FINANCE

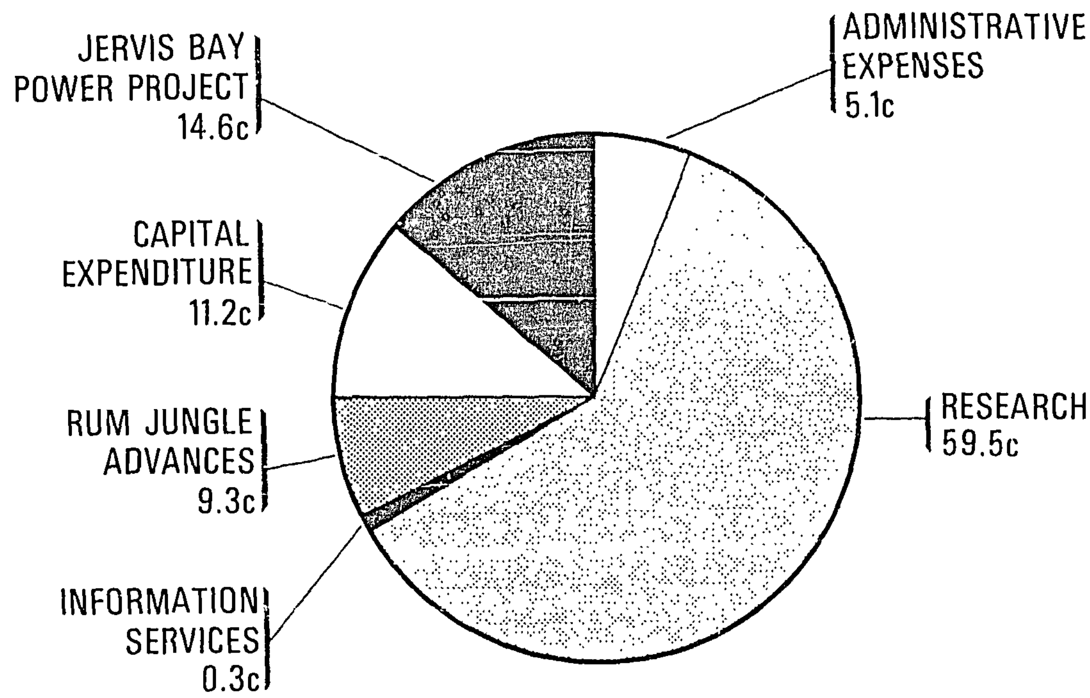
As required by Section 31 of the Atomic Energy Act 1953-66, financial accounts for the year ended 30 June 1971 are annexed as Appendix A and the report of the Auditor-General is included as Appendix B.

The Commission initially estimated total cash requirement from Commonwealth Appropriations at $16,166,000 ($12,882,000 in 1969-70). This consisted of a gross $12,446,000 for Operating expenditure ($11,152,000) offset by $457,778 of estimated revenue ($330,000) and cash on hand of $40,222. Included was a sum of $1,840,054 for buildings, works, plant and equipment ($2,060,000) and $2,378,000 for the Jervis Bay Nuclear Power Project. A $54 cash carry over in this division was also offset.

During the year, the Commission was able to reduce the requirement for Operating expenditure by $380,000 ($206,000 increase in 1969-70) and the Buildings, Works, Plant and Equipment estimate by $60,000. Expenditure on Jervis Bay was re-estimated at $2,448,000 ($712,000). Total final drawing from the Commonwealth, taking into consideration opening cash balances, therefore totalled $15,796,000 ($13,800,000).

The Rum Jungle plant ceased operation during April, 1971. After that date, expenses were incurred in the severance scheme adopted by the Commission, in making good certain sections of the area and in advertising the treatment plant for public tender. The township of Batchelor, comprising furnished houses, communal and ancillary services, was transferred at no cost to Northern Territory Administration. Certain buildings and equipment located at Rum Jungle were sold to Northern Territory Administration at an agreed valuation. Tenders were called for the purchase of the treatment plant building and equipment but response failed to reach realistic levels. It was decided therefore to auction these assets during July 1971.

An amount of $2,287,911 was expended on the Nuclear Power Project ($711,969 in 1969-70). Salaries totalled $195,073 ($52,454) while administration



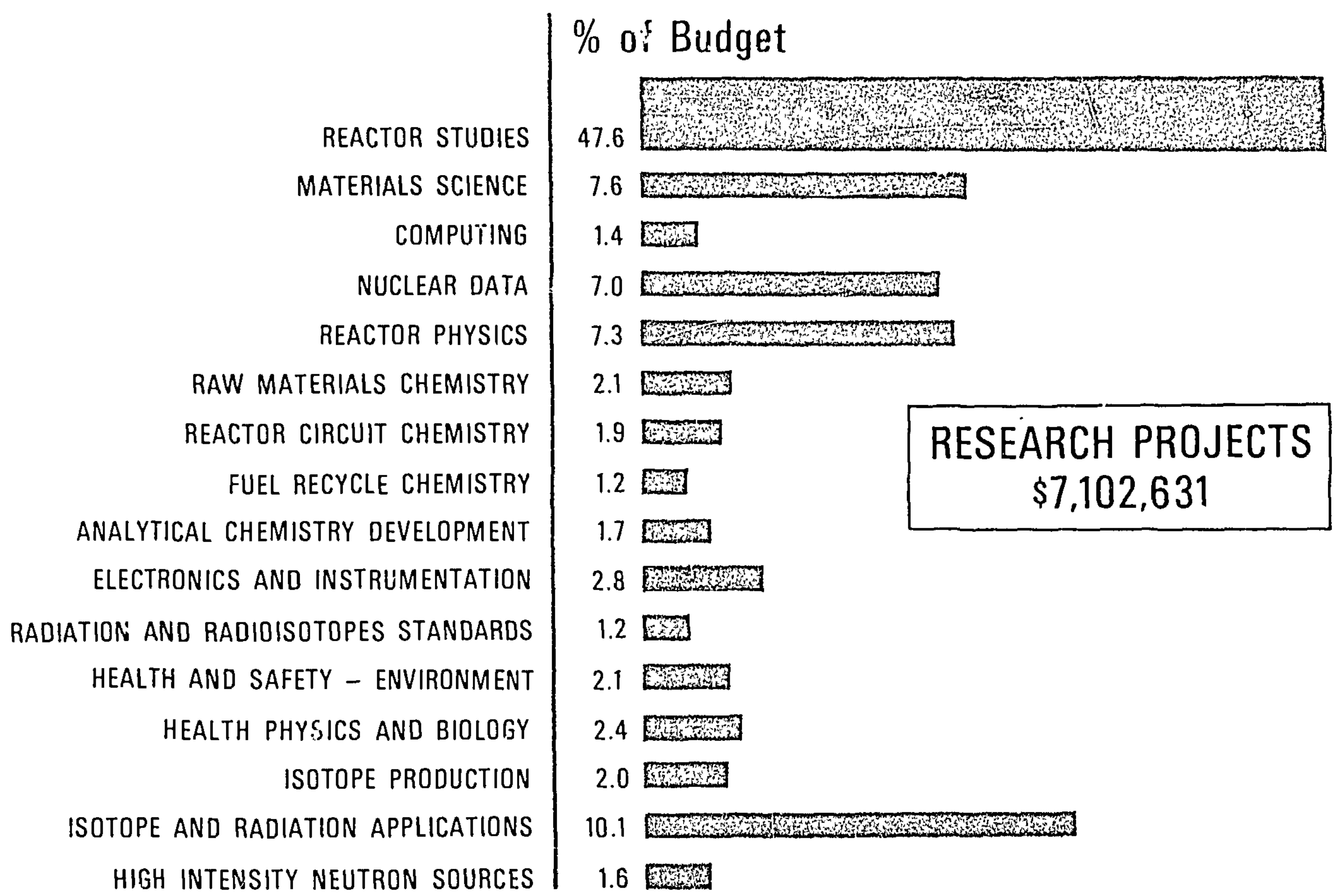

*Distribution of each dollar of expenditure.*

expenses covering fares, advertising, postages, electricity, etc., accounted for $110,223 ($51,581). A sum of $6,542 was provided for exhibitions and publications ($2,530). An amount of $366,033 ($112,531) was paid towards consultancy services for assistance with tender assessment and evaluation while $375,624 of Research Establishment effort was directed to tender analysis. A total of $115,433 ($163,835) was spent on site investigations and environmental studies, $609,244 ($26,205) for access roads, $274,364 for bulk excavation and $86,675 on water, sewerage, electricity services and landscaping. Equipment to the value of $17,048 ($6,098) was purchased and $131,652 ($296,733) was expended on suitable premises. Due to excessively wet weather, the contract for the access road and bulk excavation did not keep to schedule and the Commission under-expended drawings by $160,089.

Within the standard activities of the Commission, Administrative expenditure increased by $175,685 or 28%. Of this variation, $117,466 or 66.9% is attributable to increased salary costs stemming in the main from award variations and determinations. The balance of the increase is attributable to rising costs for general office services.

Research expenditure increased by 14% from $8,155,810 to $9,328,140. Salaries increased by $966,201 of which $40,500 is attributable to research staff increases of ten, while the balance of $925,701 relates to determination and award variations. Purchases of stores and materials absorbed $1,255,957 (13.4%) and of the $536,742 expended on power, water and supplies, $281,113 represents the purchase of fuel elements for the reactor HIFAR. The policy of aiding universities and other research organisations was continued during the year, the Commission contributing $114,000 to research contracts and $331,000 to the Australian Institute of Nuclear Science and Engineering. This latter sum is an increase of $149,000 over the previous year's expenditure and includes a retrospective adjustment of contributions and subscriptions. General administrative costs representing travel expenses, postages, telephone, transport, etc., amounted to $436,325 of the incidental expenses, the remaining $873,211 being expended on building maintenance, computer hire, cleaning charges and the hire of outside consultants.

The following illustrates the deployment of monies spent on research. The total allocation has been adjusted to exclude grants, isotope production costs and certain reactor operating expenditures.




Revenue increased by $283,613 to $780,959. Of this sum, $461,141 represents studies made for the Jervis Bay Nuclear Power Station ($116,811 during 1969-70). Sundry debtor recoveries from sales of radioisotopes decreased from the previous year's figure of $298,694 by $11,086 to $287,608.

Building construction expenditure amounted to $680,063 compared to $799,679 for the previous year. Of this, $19,498 was expended on alterations to the Administrative buildings at Head Office whilst $660,565 was expended on Research Establishment buildings, a decrease of $13,130 against 1969-70 expenditure. Main expenditures during the year were for the critical facility $366,000, mechanical development laboratory $73,000, and site services $111,000. Work in progress at the beginning of the year and minor buildings accounted for the balance of expenditure.

The cost of replacing superseded and obsolete equipment and the purchase of additional scientific apparatus decreased in 1970-71 to $1,074,866 in comparison with expenditure of $1,117,298 the previous year.

The cost of maintaining a scientist together with adequate technical support staff, equipment and Operating and Administrative services increased. During the two-year period 1968-70, these costs were approximately $29,130 per annum. In the year under review, the figure increased to $32,214 due primarily to higher salaries.

# APPENDICES

| | |
|---|---|
| A | Financial Accounts |
| B | Auditor-General's Report |
| C | Senior Staff of Commission |
| D | AAEC Research Projects |
| E | AAEC Research Contracts |
| F | AINSE Research and Training Projects |
| G | Technical Papers by Commission Staff |

## AUSTRALIAN ATOMIC ENERGY COMMISSION

### STATEMENT OF NET EXPENDITURE FOR THE YEAR ENDED 30 JUNE 1971

| | 1970-71 | | Comparative Figures 1969-70 |
|---|---|---|---|
| | $ | $ | $ |
| **Administrative Expenditure:** | | | |
| Salaries and payments in the nature of salary | 564,233 | | 438,930 |
| General Expenses | 250,516 | | 192,297 |
| | 814,749 | | 631,227 |
| **Less** Amount charged to Jervis Bay Nuclear Power Project | 15,000 | | 7,163 |
| | | **799,749** | 624,064 |
| **Research:** | | | |
| Salaries and payments in the nature of salary | 6,591,864 | | 5,625,663 |
| Stores and Materials | 1,255,957 | | 1,088,585 |
| Power, Water and Supplies | 536,742 | | 447,235 |
| Grants in aid of Research | 445,000 | | 285,993 |
| Incidental Expenses | 1,309,536 | | 1,226,430 |
| | 10,139,099 | | 8,673,906 |
| **Less** Amount charged to Jervis Bay Nuclear Power Project | 30,000 | | 20,750 |
| | 10,109,099 | | 8,653,156 |
| **Less** Proceeds of sales | 780,959 | | 497,346 |
| | | **9,328,140** | 8,155,810 |
| **Information Services:** | | | |
| Exhibitions, Publications and Publicity | 39,871 | **39,871** | 37,848 |
| **Exploration and Development** | | — | 90,057 |
| **Net Operating Expenditure** | | **10,167,760** | 8,907,779 |

| | 1970-71 | | Comparative Figures 1969-70 |
|---|---|---|---|
| | $ | $ | $ |
| **Capital Expenditure:** | | | |
| Administrative Buildings and Equipment | 19,498 | | 125,984 |
| Research Sites and Establishments | 660,566 | | 673,695 |
| Research Plant and Equipment | 1,074,866 | | 1,117,298 |
| | | **1,754,930** | 1,916,977 |
| **Net Operating and Capital Expenditure** | | **11,922,690** | 10,824,756 |
| Advances to Rum Jungle Project | | **1,468,000** | 2,350,000 |
| Advances to Jervis Bay Nuclear Power Project | | **2,287,911** | 711,969 |

## STATEMENT OF CAPITAL ASSETS AS AT 30 JUNE 1971

| | 1971 | 1970 |
|---|---|---|
| Administrative Buildings and Equipment | 465,854 | 446,356 |
| Research Sites and Establishments | 20,297,894 | 19,674,597 |
| Reactor HIFAR | 2,982,203 | 2,944,933 |
| Scientific Plant and Equipment | 9,483,356 | 8,436,421 |
| | 33,229,307 | 31,502,307 |

M. C. TIMBS,
Executive Member,
Australian Atomic Energy Commission.

C. A. WALTERS,
Acting Director of Finance,
Australian Atomic Energy Commission.

COMMONWEALTH OF AUSTRALIA

Commonwealth Auditor-General's Office,
Canberra, A.C.T.
3 September 1971

The Honourable the Minister for
National Development,
Parliament House,
Canberra, A.C.T.

Dear Sir,

**AUSTRALIAN ATOMIC ENERGY COMMISSION**

In compliance with section 31(2.) of the Atomic Energy Act 1953-1966, the Commission has submitted the following financial statements for my report—

Statement of Net Expenditure for the year ended 30 June 1971; and

Statement of Capital Assets as at 30 June 1971.

The statements are in the form approved by the Treasurer under section 31(1.) of the Act. Copies are attached for your information.

I now report that, in my opinion—

(a) the accompanying financial statements are based on proper accounts and records;

(b) the statements are in agreement with the accounts and records and show fairly the financial operations of the Commission for the year ended 30 June 1971; and

(c) the receipt, expenditure and investment of moneys and the acquisition and disposal of assets by the Commission during the year have been in accordance with the Act.

Yours faithfully,

(V. J. W. SKERMER)
AUDITOR-GENERAL FOR THE COMMONWEALTH

# Appendix C — Senior Staff of Commission at 30 June 1971

## HEAD OFFICE

*Secretary:* W. B. Lynch, B.A.

*Acting Chief, Technical Policy and International Relations Division:*
A. R. W. Wilson, M.Sc., Ph.D.

*Head, International Relations:* T. F. B. MacAdie, C.B.E., D.S.O.

*Head, Technical Policy Section:* F. L. Bett, B.Met.E. (Hons.), M.Eng.Sc. (Hons.), M.A.I.W., M.Aus.I.M.Met.

*Chief, Nuclear Technology Division:*
R. K. Warner, Ph.D., A.R.A.C.I., A.M.I.Chem.E.

*Head, Nuclear Materials Section:*
S. A. E. South, B.Sc., Grad.Dip. (Min.Proc.), A.M.Aust.I.M.M.

*Director, Information Services:* R. L. Crivelli, B.A., B.Com.

*Acting Director of Finance:* C. A. Walters, A.A.S.A.

### Power Group

*Head, Power Group:*
K. F. Alder, M.Sc., F.I.M., M.I.R.E.E. (Aust.), A.M.Aust.I.M.M.

*Deputy Head:* A. D. Thomas, M.Sc., A.Inst.P., A.A.I.P.

*Chief, Nuclear Power Assessment Division:* D. R. Griffiths, B.E.

*Head, Safety Assessment Section:* D. W. Crancher, M.Sc., M.I.Mech.E.

*Head, Reactor Assessment Section:* F. H. Carr, M.E., M.I.E.Aust.

*Controller, Nuclear Power Project Jervis Bay:*
W. E. T. Cawsey, B.E., D.C.Ae., A.M.I.E.Aust., A.F.A.I.M.

*Acting Associate Controller (Management) Nuclear Power Project:*
A. J. Moulding, A.A.S.A., A.C.I.S.

*Chief, Nuclear Development Division:*
G. L. Miles, B.A., M.Sc., Ph.D., F.R.I.C., F.R.A.C.I., A.Inst.P., A.A.I.P.

*Leader, Fuel Projects:* W. J. Wright, M.Sc., F.I.M.

### Overseas Representatives

*Atomic Energy Attaché, Washington:* P. V. Crooks, B.Sc., A.F.A.I.M.

*Atomic Energy Adviser, London:* R. M. Fry, B.Sc. (Hons.)

*Attaché (Atomic Energy), Vienna:* G. L. Hanna, M.Sc.

## RESEARCH ESTABLISHMENT

*Acting Director:* J. L. Symonds, B.Sc. (Hons.), Ph.D., F.Inst.P., F.A.I.P.

*Acting Deputy Director:* R. Smith, B.Met.E. (Hons.), M.Eng.Sc., Ph.D.

## Isotope Division

*Chief of Division:* J. N. Gregory, D.Sc., F.R.A.C.I.

*Head, Irradiation Research Section:*
J. G. Clouston, M.Sc., Ph.D., A.S.T.C., D.I.C., F.A.I.P.

*Head, Isotope Applications Research Section:* J. S. Watt, M.Sc., A.A.I.P.

*Head, Radioisotope Production Section:*
U. Engelbert, Dr. Ing., F.I.M.(Lond.), V.D.Eh.

*Technical Sales Manager:* W. A. Wiblin, B.Sc.

## Chemical Technology Division

*Chief of Division:* C. J. Hardy, B.Sc.(Hons.), Ph.D., D.Sc., F.R.I.C.

*Acting Head, Reactor Chemistry & Chemical Physics Branch:*
R. N. Whittem, B.Sc.(Hons.), A.R.A.C.I.

*Acting Head, Reactor Chemistry Section:*
J. V. Evans, B.Sc.(Hons.), Ph.D., A.R.I.C.

*Acting Head, Chemical Physics Section:* J. W. Kelly, M.Sc., Ph.D., A.A.I.P.

*Head, Inorganic Chemistry Section:* T. M. Florence, M.Sc., A.S.T.C., A.R.A.C.I.

*Head, Chemical Engineering Section:*
P. G. Alfredson, B.Sc.App.(Hons.), B.E.(Hons.), M.Sc., C.Eng., A.M.I.Chem.E.

## Engineering Research Division

*Chief of Division:* G. W. K. Ford, M.B.E., M.A.(Cantab.), M.I.Mech.E.

*Head, Reactor Performance Section:*
A. Bicevskis, M.Eng.Sc., Dipl.Ing., M.A.N.S., M.B.N.E.S.

*Head, Heat Transfer Section:*
K. R. Lawther, B.Sc., B.E., Ph.D., C.Eng., A.M.I.Chem.E.

*Head, Engineering Physics Section:*
T. J. Ledwidge, B.Sc., Ph.D., C.Eng., M.I.E.E., M.Inst.P.

## Instrumentation and Control Division

*Chief of Division:* J. K. Parry, M.Sc., Ph.D.

*Head, Applied Physics Section:* A. J. Tavendale, M.Sc., Ph.D.

*Head, Control and Systems Studies Section:* C. P. Gilbert, M.Sc., M.I.E.E.

## Materials Division

*Chief of Division:* D. G. Walker, M.Sc., Ph.D., A.R.A.C.I., A.M.Aust.I.M.M.

*Head, Fuels Branch and Head, Ceramics Section:*
K. D. Reeve, M.Sc., Ph.D., A.I.Ceram.

*Head, Metallurgy and Assessment Section:* R. J. Hilditch, B.Tech., A.S.A.S.M.

*Head, Physical Metallurgy and Corrosion Section:*
P. M. Kelly, M.A.(Cantab.), Ph.D., A.Inst.P.

*Head, Reactor Materials Section:* K. U. Snowden, B.Sc., Ph.D., A.Inst.P., A.A.I.P.

*Head, Solid State Physics Section:*
A. W. Pryor, B.E., B.Sc., Ph.D., F.A.I.P., M.I.R.E.Aust.

## Physics Division

*Acting Chief of Division:* W. Gemmell, B.Sc.(Hons.), A.Inst.P., A.A.I.P.

*Acting Head, Experimental Physics Section:* D. B. McCulloch, B.Sc.(Hons.)

*Head, Neutron Physics Section:* J. R. Bird, M.Sc., Ph.D., F.A.I.P.

*Head, Theoretical Physics Section:* B. E. Clancy, M.Sc.

## Health and Safety Division

*Chief of Division and Head of Radiation Biology Section:*
G. M. Watson, M.B., B.S., D.Phil., M.R.C.P., M.R.A.C.P., M.R.C.P.A.

*Head, Safety Section:* J. C. E. Button, B.Sc.(Hons.), F.Inst.P., F.A.I.P.

*Head, Radiation Medicine Section:* A. D. Tucker, M.B., B.S.

*Head, Health Physics Research Section:* D. R. Davy, B.Sc.(Hons.)

## Operations Division

*Associate Director (Operations):*
R. C. P. Cairns, B.Sc.(Hons.), Ph.D., D.Sc., A.S.T.C., C.Eng., M.I.Chem.E., F.I.E.Aust.

*Acting Head, Reactor (HIFAR) Operations Section:*
G. A. Creef, A.S.T.C.(Mech.E.)

*Head, Engineering Services Section:* A. C. Higgins, C.Eng., M.I.Mech.E.

*Head, Works Section:* S. M. Burke, B.Sc.(Eng.) (Hons.), C.Eng., M.I.C.E.

*Head, Site Operations Section:* E. D. Hespe, A.S.T.C.

## Mechanical Development Section

*Head of Section:* D. R. Ebeling, B.Mech.E., M.I.Mech.E., M.I.E.Aust.

## Applied Mathematics and Computing Section

*Head of Section:* D. J. Richardson, B.A.(Hons.), B.Sc., Ph.D., F.A.C.S.

## Administration Division

*Associate Director (Management):* H. W. J. Bowen, B.Ec.

*Acting Senior Administrative Officer:* C. H. Bebb, A.A.S.A.

## Technical Secretariat

*Scientific Secretary:* K. H. Tate, B.Sc., M.Aust.I.M.M.

*Librarian:* H. W. Groenewegen, B.A., Dip.Lib., A.L.A.A.

## AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

*Principal:*
C. L. W. Berglin, B.E., C.Eng., M.I.Chem.E., M.Aust.I.M.M., M.I.E.Aust.

# Appendix D — AAEC Research Projects

**Apart from work carried out directly in support of the Jervis Bay Nuclear Power Project, the following list gives the main research projects in progress at the Research Establishment at 30 June 1971.**

## Chemical Technology Division

Uranium — preparation, structure and kinetic studies of solid phases associated with $UO_2$ production.
Zirconium chemistry.
Diffusion studies related to zirconium-heavy water reactors.
Isotopic separation of nuclear materials by physicochemical processes.
Chemical separation of uranium isotopes.
High temperature aqueous chemistry.
Chemical control of reactor circuits.
Behaviour of solid corrosion product oxides.
Effect of water chemistry on corrosion.
Aqueous chemistry of the actinides.
Non-aqueous chemistry of actinide halide compounds.
Chemical analysis research.
Analytical chemistry development — spectrometry and radiochemistry.
Development of solvent extraction processes for the purification of uranium leach liquors.
Surface properties of $UO_2$ and $ThO_2$ and their relation to fabrication.
Production of nuclear grade $UO_2$ powder from Australian uranium concentrates.
Production of uranium dioxide by thermal denitration.
Development of pulsed fluidised bed reactor for $UO_2$ production.
Fluorine production.
Isotopic effects in crystalline hydrates.

## Engineering Research Division

Reactor performance evaluation.
Reactor safety investigations.
Fuel element mechanical durability.
Heat transfer.
Multi-megawatt loop.
Fuel and cladding interactions.
Perturbations in coolant and core components.

## Health and Safety Division

Study of the generation, assessment and control of hazardous aerosols.
Development and provision of radiation standards.
Acute cellular radiation injuries and repair processes.
Stopping power studies.
Studies on the effects of neutrons and X-rays on mammalian systems.
Monitoring of radon in relation to mining of uranium.
Ionic relations of *Dunaliella tertiolecta*.
Studies on lymphocytes.
Pressure-induced changes in radiation response.
Acoustic meteorological sounding.

## Instrumentation and Control Division

Electronic circuit development.
Development of low noise amplifiers and their use in the evaluation and application of new compound semi-conductor detectors.
Physics of semi-conductors.
Nuclear detector development and application.

Radioisotope standards development.
Utilisation of computers in control applications.
Dynamic studies.
Effects of radiation damage in semi-conductor devices.

## Isotope Division

Development of high purity, short-lived radioactive products.
Radioactive labelling methods.
Development of irradiation and activity measurement techniques related to the production of high-grade radiochemicals.
Study of radiation spectra and energy distribution from medical and industrial radiation sources.
Production of radioisotopes, not producible by common activation techniques in reactors.
Containment of irradiation targets and irradiation sources.
The influence of pressure, temperature and substrates on the radiation susceptibility of viable cells.
The effect of high pressure on radiation initiated polymerisation.
Chemistry of irradiated aqueous systems.
Radiolytic labelling.
Irradiation chemistry of organic systems.
Radiation chemistry of corrosion and electrode processes.
Radiation polymerisation.
Megarad and submegarad dosimetry.
Radioisotope X-ray studies.
Nuclear techniques of analysis.
Chemical aspects of application of radioisotopes.
Radioisotopes in hydrology.
Radioisotope techniques in industry.

## Materials Division

Pre- and post-irradiation examination of $UO_2$-Zircaloy fuel elements.
Fabrication studies on $UO_2$.
Sintering studies on $UO_2$.
Structure and thermal decomposition of ammonium diuranate and related compounds.
Development and testing of zirconium-sheathed $UO_2$ fuel elements and their components.
Thermal conductivity of high temperature materials.
Effect of irradiation on Australian steels.
Strain ageing in Zircaloy-2 and zirconium-2½% niobium alloy.
Basic deformation mechanisms in zirconium.
Effect of interstitial elements on the mechanical properties of zirconium.
Non-destructive testing.
Physical metallurgy of zirconium alloys before and after irradiation.
Electrochemical properties of metal oxide films.
In-pile corrosion of zirconium alloys.
Fracture behaviour of zirconium alloys.
The characterisation of the micro-structure of Australian uranium ores.
Lattice dynamics of solids.
Growth of germanium single crystals.
Defect configurations by diffraction methods.
Neutron diffraction physics.
Study of the sol-gel process to produce high strength thoria.
Fabrication of ceramics by continuous concentration and extrusion.
Mechanical behaviour of fibre reinforced plastics.
Fabrication of carbon fibre-resin composites.
Physics of ceramic fuel materials.

## Physics Division

Nuclear data — theoretical studies.
Experimental nuclear data project — fission physics.
Neutron capture studies.
Neutron emission as a function of fission product mass and charge distribution (Indian AEC/AAEC collaborative experiment).
Theoretical reactor physics.
Critical facility — Part I: Design assessment, commissioning and safety assessment.
Pulsed neutron research.
Reactor dynamics.
Neutron spectra.
Anisotropy of neutron transport.
Computer code development.
Initial conversion ratios.
HIFAR support.
Relative $^{140}Ba/^{140}La$ yield in fission.
Design and development of high intensity pulsed neutron sources — (1) A coaxial plasma gun.

## Applied Mathematics and Computing Section

Computer software techniques and their application to atomic energy.
Application and adaptation of computer hardware to problem solving in atomic energy.

# Appendix E — AAEC Research Contracts

**In 1970-71, the Commission awarded research contracts for the projects listed below**

## NEW CONTRACTS

| *University or Organisation* | *Research Project* |
|---|---|
| **La Trobe University**<br>Department of Physical Chemistry | 1. The development of quadrupole mass spectrometers. ($10,150) |
| **University of Melbourne**<br>Department of Physics | 1. Development of nuclear analysis methods for light elements. ($10,900) |
| **University of New South Wales**<br>School of Chemistry | 1. Catalysis of isotopic exchange between water and hydrogen. ($9,650) |
| School of Textile Technology | 2. Study of carbon fibres. ($32,500) |
| Department of Ceramic Engineering | 3. Fission product effects in $ThO_2$. ($18,000) |
| Department of Analytical Chemistry | 4. Determination of trace metals by gas chromatography. ($6,100) |
| **University of Sydney**<br>Department of Surgery | 1. Control of graft versus host reaction, with special reference to bone marrow grafts. ($4,982) |

## EXTENDED CONTRACTS AND SUPPLEMENTARY GRANTS

| | |
|---|---|
| **Flinders University of South Australia**<br>School of Physical Sciences | 1. Study of single particle wave functions and comparison with AAEC Physics Division experimental results. ($3,000) |
| **University of Adelaide**<br>Department of Chemical Engineering | 1. Internal friction studies of interstitial atoms in zirconium. ($2,010) |
| **University of Melbourne**<br>Department of Chemistry | 1. Oxidation of metals and the effect of irradiation. ($2,030) |
| **University of Queensland**<br>Department of Mining and Metallurgy | 1. The nucleation and growth of gas bubbles in irradiated solids. ($1,289) |
| **Australian Mineral Development Laboratories** | 1. Application of radioisotope X-ray sources to on-stream analysis. ($2,000) |

# Appendix F — AINSE Research and Training Projects

The Australian Institute of Nuclear Science and Engineering supported the following projects during 1970-71.

## JAMES COOK UNIVERSITY OF NORTH QUEENSLAND

1. Investigation into the use of finite element methods for the solution of nonlinear problems in stress analysis and fluid dynamics. (Engineering, Associate Professor K. P. Stark and Mr. B. Best. $700)
2. Neutron-capture gamma-ray studies. (Physics, Dr. R. B. Taylor. $6,050)
3. Metal exchange studies on metal complexes of macrocyclic liquids. (Chemistry, Dr. L. F. Lindoy. $400)
4. Structural studies on coordination compounds. (Chemistry, Dr. L. F. Power. $1,284)
5. Structural studies of metal complexes of Vitamin $B_6$ and model systems. (Chemistry, Mr. K. E. Turner, AINSE Studentship)

## UNIVERSITY OF QUEENSLAND

1. Study of simultaneous flow of gas and liquid. (Chemical Engineering, Professor D. J. Nicklin. $2,850)
2. The modification of turbulence structure for optimum heat transfer in circular ducts. (Mechanical Engineering, Dr. K. J. Bullock. $2,780)
3. De-excitation gamma-rays from states of $^{48}V$ produced by reaction of $^{47}Ti$ nuclei with 950-1,300 keV protons. (Physics, Dr. W. B. Lasich. $600)
4. Radiation initiated polymerisation. (Chemistry, Dr. J. H. O'Donnell. $2,000)
5. Structure analysis using neutron diffraction. (Chemistry, Dr. C. H. L. Kennard. $2,000)
6. Neutron and X-ray scattering studies of crystalline solids near transition temperatures. (Physics, Dr. B. W. Lucas. $1,930)
7. Creep deformation processes in metals containing inert gas bubbles. (Mining and Metallurgical Engineering, Dr. I. O. Smith. $200)
8. Radiation damage in $\alpha$ and $\beta$ tin. (Physics, Drs. S. Myhra and R. B. Gardiner. $7,700)
9. $^{40}Ar/^{39}Ar$ age determinations. (Geology and Mineralogy, Dr. D. C. Green. $400)

## UNIVERSITY OF NEW ENGLAND

1. An investigation of the glow-arc transition. (Physics, Dr. G. A. Woolsey. $804)
2. Neutron scattering studies of disordered and statistical solids. (Physics, Professor N. H. Fletcher. $300)

## UNIVERSITY OF NEWCASTLE

1. Generation of unsteady oscillatory two phase flow by steady state interaction of a liquid jet and a free liquid surface. (Metallurgy, Mr. M. A. Molloy. $700)
2. Radiation induced polymerisation by siloxanes. (Chemistry, Mr. E. B. Jacobs and Associate Professor W. R. Walker. $400)
3. Neutron and X-ray structure determination of disilver-hydrogen orthophosphate. (Chemistry, Mr H. R. Tietze. $400)
4. Distribution and vibration of hydrogen in metals. (Metallurgy, Dr J. D. Browne and Mr. W. A. Oates. $550)
5. Ordering in intermetallic compounds. (Metallurgy, Dr. J. D. Browne. $250)
6. Interactions between interstitial solute atoms in $\alpha$-iron. (Metallurgy, Professor E. O. Hall and Dr. J. D. Browne. $650)
7. Structure of niobium-based alloys. (Metallurgy, Professor E. O. Hall. $2,100)
8. Impact properties of radiation damaged and strain-aged mild steel. (Metallurgy, Professor E. O. Hall. $1,200)
9. Solute-vacancy interaction in metals. (Metallurgy, Mr. J. E. McLennan. $200)

## UNIVERSITY OF SYDNEY

1. Simulation of diffusion processes in the turbulent boundary layer. (Mechanical Engineering, Dr. J. Atkinson. $900)
2. Basic study of convective heat transfer processes. (Mechanical Engineering, Dr. R. E. Luxton. $2,000)
3. Magnetohydrodynamic converter (closed cycle working media). (Electrical Engineering, Professor H. K. Messerle, Professor D. H. George and Dr. A. D. Stokes. $1,595)
4. Far-infrared wave interactions in plasmas. (Physics, Dr. L. C. Robinson. $1,330)
5. PIG discharge for cyclotron harmonic wave studies. (Plasma Physics, Dr. G. F. Brand. $2,555).
6. Interferometric determination of plasma electron densities. (Plasma Physics, Drs. W. I. B. Smith and I. S. Falconer. $960)
7. Measurement of the plasma electron temperature behind shock fronts. (Plasma Physics, Drs. W. I. B. Smith and I. S. Falconer. $6,195)
8. Neutron and X-ray diffraction studies of complexes of metals with amino acids and peptides. (Chemistry, Miss M. L. Golomb, AINSE Studentship)

## UNIVERSITY OF NEW SOUTH WALES

1. Quantitative measurements of unsteady temperature gradients using a modified Schlieren system. (Fluid Mechanics and Thermodynamics, Dr. M. R. Davis. $2,961)
2. Measurement of unsteady voidage in two-phase flow. (Fluid Mechanics and Thermodynamics, Dr. M. R. David. $850)
3. A study of mist flows. (Fluid Mechanics and Thermodynamics, Mr. K. Kjorrefjord. $1,346)
4. Thermo-mechanical analysis of nuclear fuel elements. (Nuclear Engineering, Associate Professor Z. J. Holy. $2,000)
5. Fluctuation and propagation phenomena in reactor systems and associated system components. (Nuclear Engineering, Mr. L. G. Kemeny. $5,102)
6. Prompt neutron emission by spontaneous-fission modes of $^{252}$Cf. (Physics, Wollongong University College, Dr. J. N. Mathur. $200)
7. The bremsstrahlung spectra of fast electrons through single crystals. (Physics, Associate Professor J. C. Kelly. $1,400)
8. Proton and ion channelling through crystal lattices. (Physics, Associate Professor J. C. Kelly. $2,700)
9. The study of transient species produced in organic liquids by pulsed radiolysis. (Nuclear and Radiation Chemistry, Dr. N. T. Barker. $2,000)
10. Radiation induced reactions of tritium with hydrocarbons. (Nuclear and Radiation Chemistry, Dr. M. A. Long. $1,400)
11. Radiation catalysis and studies in mass spectrometry. (Physical Chemistry, Associate Professor J. L. Garnett. $4,300)
12. Energy distribution of methyl radicals produced by gamma irradiation of acetone, di-tertbutyl peroxide, methyl halides and azomethane. (Physical Chemistry, Dr. R. Solly. $1,050)
13. Structure and lattice dynamics of ammonium halides. (Physics, Associate Professor J. F. McConnell and Mr. R. Seymour. $300)
14. Ferroelectricity in thiourea. (Associate Professor J. F. McConnell and Mr. D. McKenzie. $200)
15. A neutron diffraction study of short range order. (Physics, Associate Professor J. F. McConnell and Mr. R. C. Warren. $300)
16. Combined scattering of phonons by point defects and crystal boundaries. (Physics, Professor H. J. Goldsmid. $300)
17. Electrostatic collection of fission products. (Nuclear Engineering, Mr. R. Rosen. $500)
18. Effect of gamma and neutron irradiation on the mechanical properties of alkali halides. (Physics, Dr. H. F. Pollard. $640)
19. Investigation of the effects of neutron irradiation on chemically strengthened glass. (Ceramic Engineering, Professor E. R. McCartney. $300)
20. Statistical evaluation of properties of two phase flows. (Mechanical Engineering, Mr. P. M. Ong, AINSE Studentship)

## MACQUARIE UNIVERSITY

1. Structure and function of mammalian tissues. (Mathematics and Physics, Professor P. Mason and Mr. J. Unsworth. $440)
2. An investigation of the movement of sugars, ions and water in phloem. (Biological Sciences, Dr. J. Moorby. $600)
3. Collisional decomposition of molecules formed by recoil from nuclear reactions. (Chemistry, Dr. J. G. Hawke. $2,600)
4. Radiolysis of polyunsaturated acids and esters. (Biological Sciences, Dr. J. M. Gebicki. $450)

## AUSTRALIAN NATIONAL UNIVERSITY

1. $^{58}Ni$ (p, $\gamma$) $^{59}Cu$ reaction. (Nuclear Physics, Dr. G. U. Din. $500)
2. $^{40}Ar/^{39}Ar$ dating of rocks. (Geophysics and Geochemistry, Dr. I. McDougall. $350)
3. Studies of nuclear reactions in aluminium and beryllium. (Nuclear Physics, Dr. L. E. Carlson, AINSE Research Fellowship)

## UNIVERSITY OF MELBOURNE

1. Turbulent boundary layers and heat transfer. (Mechanical Engineering, Mr. P. N. Joubert and Dr. A. E. Perry. $4,770)
2. (p, $\gamma$) studies. (Physics, Dr. D. G. Sargood. $1,050)
3. Neutron capture gamma-ray studies. (Physics, Professor B. M. Spicer. $2,600)
4. Pulse and steady state radiolysis of aromatic systems. (Chemistry, Dr. R. Cooper. $1,650)
5. Activity coefficients of the hydrated electron in electrolyte solutions. (Chemistry, Dr. R. Cooper and P. T. McTigue. $1,700)
6. Radiation Chemistry of Freons. (Chemistry, Dr. R. Cooper. $2,850)
7. Radiation modification of adsorption properties of inorganic surfaces. (Chemistry, Drs. T. W. Healy and R. Cooper. $4,112)
8. Genes controlling radiation response in *Pseudomonas aeruginosa*. (Genetics, Dr B. T. O. Lee. $1,350)
9. Activation studies in meteorites, rocks and lunar materials. (Geology, Professor J. F. Lovering. $2,620)
10. Deformation and fracture of reactor materials at elevated temperatures. (Metallurgy, Mr. I. J. Spark, AINSE Studentship)
11. The study of (n, $\gamma$) and ($\gamma$, n) reactions for various elements in the keV region. (Physics, Mr. G. J. Broomhall, AINSE Studentship)
12. Studies of (p, $\gamma$) and (p, $\alpha$) reactions of astro-physical interest, in particular $^{23}Na$ (p, $\gamma$) and $^{23}Na$ (p, $\alpha$). (Physics, Mr. S. G. Boydell, AINSE Studentship)
13. Measurement of neutron capture and scattering cross sections at low and intermediate energies. (Physics, Mr. D. B. Stroud, AINSE Studentship)
14. Effect of irradiation on precipitation reactions. (Metallurgy, Dr. M. Dupuy, AINSE Research Fellowship)

## MONASH UNIVERSITY

1. Radiation sensitivity and radiation repair mechanisms in *Pseudomonas aeruginosa* and its bacteriophages. (Genetics, Professor B. W. Holloway. $2,050)
2. Radiation effects in polymers studied at the electronic level. (Physics, Dr. R. J. Fleming. $1,685)
3. Magnetic structure of transition metal olivines. (Physics, Mr. G. J. F. Troup. $900)
4. Short-range order in transition metal materials. (Physics, Associate Professor J. H. Smith. $600)
5. Giant moments in iron doped $Ni_3Al$ and $Ni_3Ga$. (Physics, Dr. T. J. Hicks. $1,500)
6. Distribution of magnetic moment in transition metals and alloys. (Physics, Dr. T. J. Hicks. $1,100)
7. Hyperfine interactions and nuclear orientation. (Physics, Drs. G. V. H. Wilson, J. A. Barclay and J. D. Cashion. $660)
8. Orientation of radioactive nuclei in solids at low temperatures. (Physics, Dr. J. A. Barclay, AINSE Research Fellowship)
9. Neutron diffraction studies of Mn-Au alloys. (Physics, Dr. J. S. Plant, AINSE Research Fellowship)

## LA TROBE UNIVERSITY

1. The genetic analysis of radiation resistance and sensitivity in wild Australian populations of *Drosophila*. (Genetics, Professor P. A. Parsons. $1,750)
2. The influence of repair mechanisms on radiation resistance and induction of mutations in *Salmonella typhirmurium*. (Genetics, Dr. D. G. MacPhee. $1,540)
3. Fission track dating Australian minerals and tektites. (Chemistry, Dr. D. H. Dale. $500)
4. The genetic analysis of radiation sensitive strains in *Drosophila*. (Genetics, Dr. J. M. Westerman, AINSE Research Fellowship)

## UNIVERSITY OF TASMANIA

1. Fast neutron transport in thorium. (Physics, Drs. K. B. and A. G. Fenton. $2,100)
2. Semi-conductor neutron detectors. (Physics, Mr. R. N. Williams, AINSE Studentship)
3. Radiosensitivity of marsupial chromosomes. (Zoology, Dr. Y. A. E. Bick, AINSE Research Fellowship)

## UNIVERSITY OF ADELAIDE

1. Development of laminar natural-convective flow in a vertical duct heated in a prescribed manner. (Mechanical Engineering, Mr. J. R. Dyer. $1,198)
2. Metabolism of copper in health and disease with particular reference to patients with Wilson's disease and their relatives. (Medicine, Dr. J. L. Gollan. $450)
3. Reactions of inorganic radicals in solution; flash photolysis and pulse radiolysis. (Physical and Inorganic Chemistry, Dr. G. S. Laurence. $1,185)
4. The use of radioactive nitrogen ($^{13}N$) in studies with bacterial enzymes. (Agricultural Biochemistry, Professor D. J. D. Nicholas and Mr. H. R. Lovelock. $1,600)

## FLINDERS UNIVERSITY OF SOUTH AUSTRALIA

1. A study of binary and ternary systems of the rare earths with carbon and nitrogen. (Physical Sciences, Dr. N. J. Clark. $350)
2. Solid state diffusion in ceramics. (Physical Sciences, Mr. H. J. de Bruin. $2,250)
3. Microwave interferometer for plasma density measurements on FPS-2. (Physical Sciences, Dr. A. L. McCarthy. $3,303)
4. Electron collision ionisation cross section in gases. (Physical Sciences, Dr. J. Fletcher. $975)
5. Electric arc driven shock tube for plasma studies. (Physical Sciences, Dr. M. G. R. Phillips. $3,110)
6. The anomalous skin effect in plasmas. (Physical Sciences, Dr. H. Blevin. $3,430)
7. Diffusion in $UO_{2+x}$. (Chemistry, Mr. G. E. Murch, AINSE Studentship)

## UNIVERSITY OF WESTERN AUSTRALIA

1. Absolute measurement of neutron production. (Physics, Dr. H. H. Thies. $600)
2. Crystal structure analysis by neutron diffraction. (Physics, Dr. E. N. Maslen. $1,700)

# Appendix G — Technical Papers by Commission Staff

The following research publications of the Commission consist of contributions accepted by scientific journals and a selection of unclassified scientific reports published in the official AAEC report series. The two groups of publications are listed separately and the latter is subdivided into the AAEC/E Series, the AAEC/TM Series and the AAEC/M Series. In addition, a large number of unclassified memoranda are distributed externally.

## PUBLISHED PAPERS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*ANASTASIA, L. J., ALFREDSON, P. G., *STEINDLER, M. J. (1971). Reaction model for the fluorination of uranium and plutonium compounds in fluidised bed reactors. *Ind. Eng. Chem. Process Design Develop.*, 10(2):150-157. (*Argonne National Laboratory, Argonne, Ill., U.S.A.)

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## PATENT APPLICATIONS

The following patent applications were lodged during 1970-71:

### Australia — Provisional

J. S. WATT. X-ray analysis employing a radioisotope source — PA 2118. Dated 10 August 1970.

J. E. EBERHARDT, R. D. RYAN and A. J. TAVENDALE. Improvements in gallium arsenide detectors for nuclear radiations — PA 3628. Dated 31 December 1970.

C. R. WALTERS. Improvements in gas burners — PA 5106. Dated 4 June 1971.

### Australia and Overseas — Complete

D. F. SANGSTER and A. DAVISON. Improved synthesis of C14 carboxylamino acids. (Prov. 58979 of 4 August 1969.) Aust. 18099 of 27 July 1970. U.K. 36493 of 28 July 1970. U.S.A. 60947 of 4 August 1970.

J. BARDSLEY and G. C. WALL. Method of sintering ceramic gel shapes. (Prov. 60893 of 16 September 1969.) Aust. 19638 of 7 September 1970. U.K. 43027 of 8 September 1970. Canada 092539 of 8 September 1970. U.S.A. 71934 of 14 September 1970. France 7033591 of 16 September 1970. W. Germany P2045210.2, G7033993.4 of 12 September 1970. Italy 29607 A/70 of 11 September 1970. Japan 80624/1970 of 16 September 1970.

R. B. ADAMS. Improved sintering process for production of $UO_2$ pellets. (Prov. PA 0858 of 9 April 1970.) Aust. 25651 of 18 February 1971. U.K. 25145 (Dated about February, 1971.) Canada 107879 of 16 March 1971.

B. D. SOWERBY. Applications of nuclear resonance fluorescence of X-rays to elemental analysis. (Prov. PA 1105 of 6 May 1970.) Australia, United Kingdom, Canada, U.S.A., France, Holland, Germany, Sweden, Japan. Complete specifications lodged, but dates of filing have not yet been advised.

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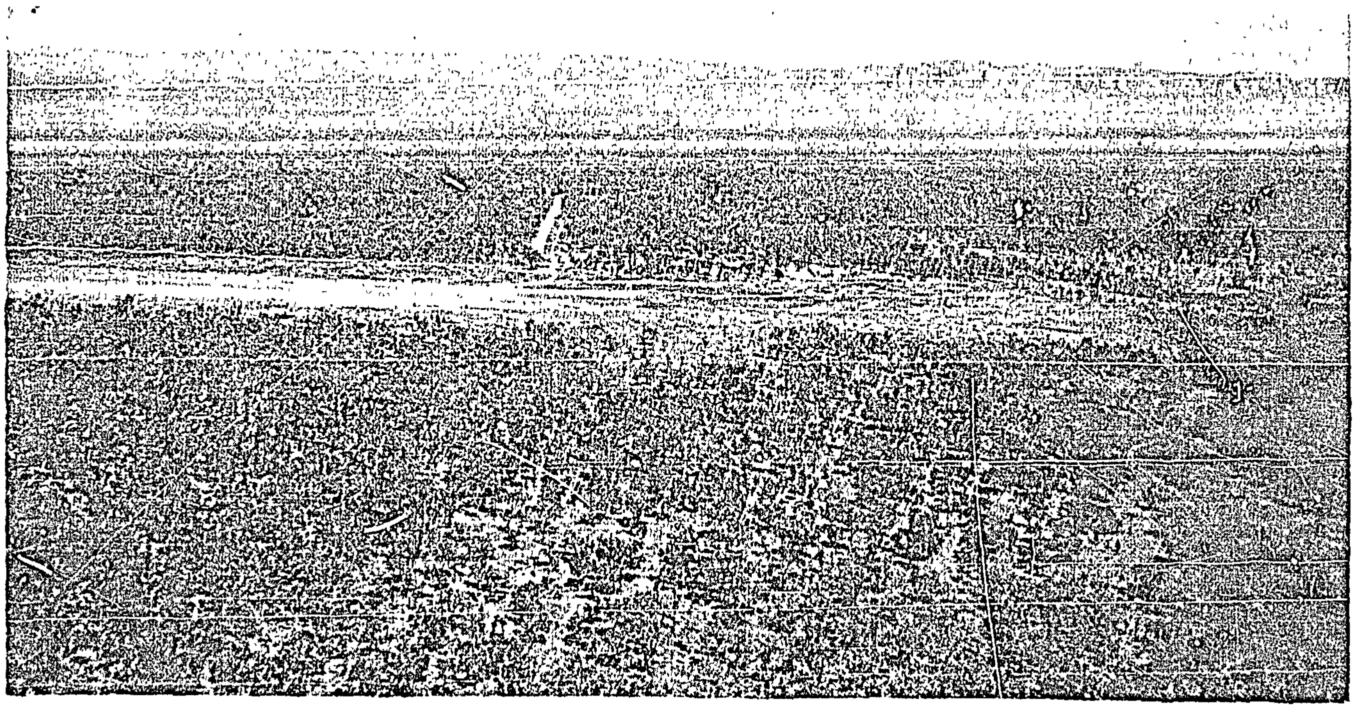
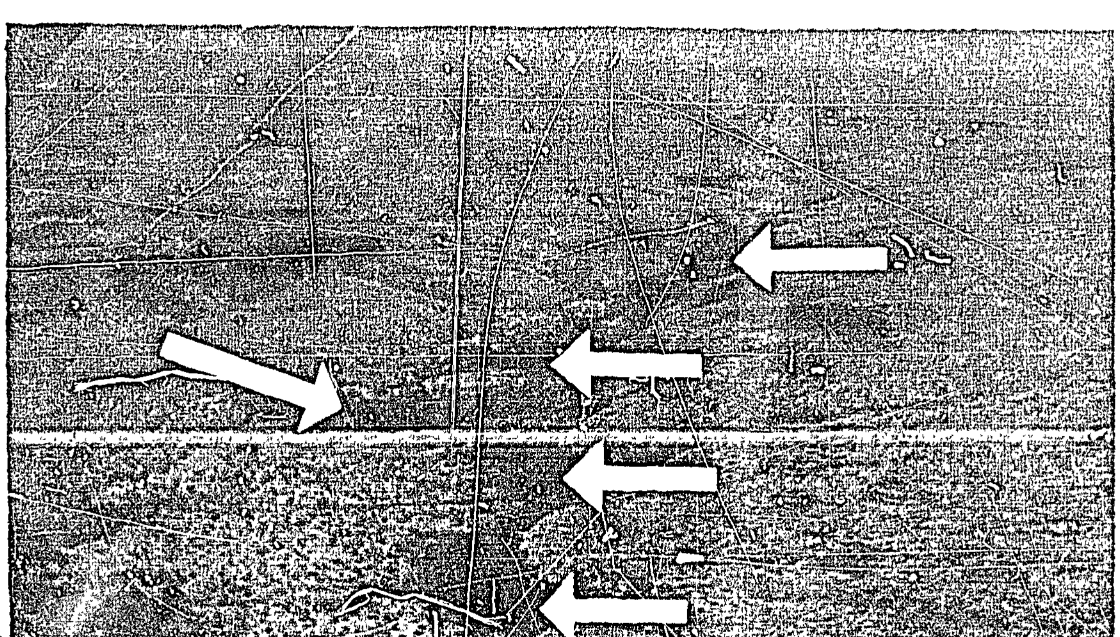


Above: An aerial view, from the north, of the Ranger exploration camp and showing in the background cliffs of the overlying Kombolgie Sandstone Formation. The Ranger prospect is held jointly by Peko Mines N.L. and Electrolytic Zinc Co. of (A/asia) Ltd. The area is about 30 miles southwest of the Nabarlek deposit in the Northern Territory. (Photo: Peko Mines N.L.)

Right: Ghen Ant Hill (Gabo), an aboriginal sacred rock, and prominent landmark in the Nabarlek hills, Arnhem Land, Northern Territory. Although close to the Queensland Mines Ltd. Nabarlek uranium deposit, exploration and mining activities will be excluded from this area. (Photo: Queensland Mines Ltd.)

Below: United Uranium N.L. located by airborne radiometric survey an extensive and complex anomaly on its prospect near the Fish River Gorge, Northern Territory. Arrows show the location of anomalies now under investigation. (Photo: United Uranium N.L.)



FRONT COVER

Uranium ore specimens at the Queensland Mines Ltd. Nabarlek prospect, Northern Territory. This ore consists of pitchblende surrounded by gummite. Nabarlek is one of several recent uranium discoveries in the Northern Territory. (Photo: Queensland Mines Ltd.)