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**AUSTRALIAN ATOMIC ENERGY COMMISSION
RESEARCH ESTABLISHMENT
LUCAS HEIGHTS**

RESEARCH ESTABLISHMENT PROGRESS REPORT 1978

URANIUM FUEL CYCLE

December 1978

AUSTRALIAN ATOMIC ENERGY COMMISSION
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PREFACE

The Research Establishment Progress Report is a technical report dealing with work done in the twelve months period ending on September 30 each year.

It is issued in several volumes, each recording the technical effort within broad areas of responsibility. A change was made in the lines of responsibility for management of research programs on 3 July 1978 but this report describes the work under the former program headings as follows:

AAEC/PR45-P	Power and Energy Program
AAEC/PR45-U	Uranium Fuel Cycle Program
AAEC/PR45-N	Nuclear Science and Applications Program
AAEC/PR45-D	Divisional Research
AAEC/PR45-S	Site Management

The contributions to each report are made by Research Divisions, Research Sections and Site Management Departments where appropriate. Wherever possible the names of staff responsible for each project are indicated.

K.H. TATE
Controller, Site Information Services

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1. INTRODUCTION

Work at the AAEC Research Establishment relating to the use of uranium as a source of nuclear power generation was carried out under the auspices of the Uranium Fuel Cycle Program up to 3 July 1978. A reorganisation which took effect on that date placed the responsibility for all research and development work within the Research Establishment with the Deputy Director, Research. Since a major part of the period covered by this progress report preceded the reorganisation, the format of previous progress reports is retained.

International developments during the year in relation to the uranium fuel cycle included:

- . Increasing generation of electricity by nuclear reactors as power programs got under way, and correspondingly increased production and use of uranium and fuel cycle services.
- . Reductions in forward estimates for future installations of power reactors, with corresponding reductions (or delays) in fuel cycle requirements.
- . Substantially increased world reserves of uranium, partly as a result of an increase in the cost categories used for reporting.
- . The commencement in Japan of the construction of a centrifuge pilot plant.
- . The initial stages of the EURODIF diffusion plant in France became operational.
- . The demonstration centrifuge enrichment plants in the United Kingdom (UK) and the Netherlands owned by URENCO/CENTEC began operations.
- . The United States Department of Energy (DOE) introduced revised contracts for enrichment services, which could lead to some reduction in the rate of market growth over the next few years.
- . Following a major public inquiry (the 'Parker Inquiry'), approval was given by the British Government for the construction at Windscale of the proposed Thermal Oxide Reprocessing Plant (THORP).
- . Commercial-scale operations with highly active waste commenced at the Marcoule Vitrification Plant in France.
- . The International Fuel Cycle Evaluation (INFCE) study got under way, with meetings of eight working groups and a number of sub-groups (see Section 6.2).

In Australia, significant events during the year included the enactment by Parliament, subsequent to the Government's decisions on

uranium mining, of legislation relating to environmental protection, national parks and wildlife, Aboriginal land rights, and an amendment to the Atomic Energy Act.

2. MINING AND TREATMENT OF URANIUM ORES

2.1 Leaching of Uranium Ores [R.J. Ring, Chemical Technology Division]

Laboratory studies continued on Australian ores to investigate improved leaching processes which might increase uranium extraction and reduce milling costs.

Ferric sulphate leaching

The use of acidified ferric sulphate solutions has been shown to give increased extractions of uranium and lower acid consumptions for some South African and Canadian ores. Ferric ion is reduced during leaching, but it can be regenerated by chemical or bacterial oxidation and then recycled.

Experiments with Ranger and Nabarlek ores at 35-40°C showed that high ferric ion concentrations (5-15 g l⁻¹) reduced acid consumption by 20-40 per cent without any detrimental effect on uranium extraction. Above 40°C, the effect of an increase in temperature was the same as with conventional leaching; a slight increase in uranium extraction was obtained at the expense of a substantial rise in acid consumption. Optimal initial concentrations of ferric ion were 10 g l⁻¹ for Ranger ore and 15 g l⁻¹ for Nabarlek ore.

There was a gradual reduction in redox potential during leaching, due to reduction of ferric ion. Maintenance of the redox potential at -475 mV (relative to the calomel electrode) by addition of pyrolusite was also examined. A slight increase in uranium extraction was observed under these conditions but acid consumption also rose significantly. The use of ferric chloride as an alternative leachant was also examined but the resulting uranium extraction was lower than with ferric sulphate. Of the leaching variants studied, ferric sulphate leaching, without addition of other oxidants, appeared to offer the greatest potential for reducing reagent consumption.

Hydrogen peroxide as an oxidant in sulphuric acid leaching

Hydrogen peroxide is a possible alternative oxidant to pyrolusite in sulphuric acid leaching of uranium ores. It is preferable on environmental grounds, forming water rather than manganous ions on reduction, and may increase the recovery of uranium from refractory ores, particularly if used in the form of Caro's acid (H₂SO₅). The major disadvantage of hydrogen peroxide is its high cost compared with that of the commonly used pyrolusite and sodium chlorate.

Leaching experiments on Ranger and Nabarlek ores showed that almost identical uranium extractions were obtained with hydrogen peroxide at the same oxidation potentials. The peroxide additions were 2.2 to 2.7 times less than for pyrolusite (compared to a theoretical factor of

3.2, assuming 79 per cent MnO_2) and the acid consumption was 10-20 per cent lower. These promising initial results are being explored further.

Leaching of Lake Way ore

The Lake Way deposit, situated about 60 km north of Yeelirrie in Western Australia, is a low grade carnotite ore (0.06% U) in a calcrete formation. As with Yeelirrie ore, leaching in sulphuric acid is not attractive because of the high acid consumption, and leaching at elevated temperatures in sodium carbonate-bicarbonate solutions is preferred. Whereas Yeelirrie ore required leaching in an autoclave at 105°C to achieve 98 per cent extraction of uranium, the same extraction was obtained with Lake Way ore at 95°C and atmospheric pressure. Slurries of Lake Way ore were found to be highly thixotropic; this could lead to problems in equipment design, particularly for leaching vessels and thickeners.

Leaching of Roxby Downs copper flotation residues

The flotation residues produced by preliminary tests on Western Mining Corporation's Roxby Downs copper deposit contain approximately 0.05% U which can be recovered as a by-product. Because of the completely different mineralogy of the ore compared with that in other Australian deposits, a series of exploratory leaching tests were undertaken to determine the leaching characteristics of the residue. The residues contain a high proportion of refractory uranium minerals and satisfactory leaching rates were only obtained by operating at elevated temperatures and strong oxidising conditions. The most suitable leaching conditions with sulphuric acid were 55°C, a redox potential of -650 mV, pH 1.5 and a leaching time of 24 h. These gave a uranium extraction of 87 per cent for 50 kg of acid and 8.3 kg of pyrolusite per tonne of ore. With ferric sulphate solutions at a redox potential of -650 mV, a slight improvement in extraction was achieved and acid consumption was decreased by 30 per cent.

Leaching of Nabarlek tailings

Since tailings from average Nabarlek ore grades could contain about 0.05% U, further leaching under more severe conditions was investigated to determine if some of this uranium could be recovered. Acid leaching experiments were carried out at 35°C, pH 0.9-1.8 and redox potentials of -475 and -650 mV. Under all conditions, a residue containing 0.034 per cent was obtained after 8 hours of leaching, and this did not improve in 24 hours. The minimum acid addition required to achieve this residue grade was 9 kg t^{-1} tailings. The overall increase of recovery of 96.6 to 97.5 per cent would not be sufficient to justify a second leaching stage.

2.2 Moisture in MKU Yellowcake [W.I. Stuart, Chemical Technology Division]

Six samples of Mary Kathleen Uranium Limited (MKU) yellowcake were examined using infrared spectroscopy, derivative thermogravimetry (DTG) and differential thermal analysis (DTA) to characterise water absorbed in yellowcake and the effectiveness of its removal by standard laboratory drying techniques.

Derivative thermogravimetric curves and infrared spectra showed that all samples were mixtures of UO_3 and U_3O_8 with some uranyl sulphate present in varying amounts.

Ammonium uranate samples absorb moisture when exposed to water vapour for prolonged periods of up to 40 days. Absorption of moisture arises from slow conversion of UO_3 to hydrated uranyl hydroxide and association of water with uranyl sulphate impurities.

Standard drying as used in the analysis of uranium content (*i.e.* isothermal heating at $110^\circ C$ for 18 hours) completely removes water associated with uranyl sulphate, but does not completely desorb water coordinated to uranyl hydroxide, nor does it lead to dehydroxylation. Thus care should be taken to prevent the absorption of water by yellow-cake samples before chemical analysis which may lead to low values for uranium concentration on a 'dry weight' basis.

2.3 Review of Developments in Uranium Extraction Technology
[P.G. Alfredson, R.J. Ring (Chemical Technology Division)
R.E. Crawford (Production Division, Uranium Branch, now
employed by the Energy Authority of New South Wales)]

Developments in uranium extraction technology which have occurred since the AAEC Symposium on Uranium Processing in July 1972 were reviewed [Alfredson *et al.* forthcoming]. The main developments include:

- . autogenous or semi-autogenous grinding;
- . beneficiation techniques such as radiometric sorting, flotation, magnetic and gravity separation;
- . strong acid and ferric bacterial leaching processes;
- . horizontal belt filters for solid-liquid separation;
- . continuous ion exchange processes for use with solutions containing up to 8 wt % solids;
- . hydrogen peroxide and ammonia for the precipitation of uranium to improve product yield and purity; and
- . the recovery of by-product uranium from the manufacture of phosphoric acid and copper processing operations.

2.4 Publications

Report and journal paper

- Alfredson, P.G., Crawford, R.E. & Ring, R.J. [forthcoming] - Review of Recent Developments in Uranium Extraction Technology. AAEC/E466.
Costello, J.M. [1977] - Management of Wastes containing Radioactivity from Mining and Milling of Uranium Ores in Northern Australia. *At. Energy Aust.*, 20 (4) 2-9.

Conference paper

- Ring, R.J. & Rapisarda*, A. [1977] - Leaching of Uranium Ores with Hydrochloric Acid. Extractive Metallurgy Symposium, Sydney, 7-9 November. (*Vacation Student)

3. URANIUM ENRICHMENT

Japan/Australia study on uranium enrichment

A joint study on the feasibility of establishing a uranium enrichment plant in Australia was carried out as a result of an agreement between the governments of Japan and Australia. Meetings of teams of experts from both countries were held at Tokyo (29 November to 2 December 1976 and 16-18 November 1977) and at Sydney (5-7 April 1977 and 17-19 April 1978). Working papers prepared by both teams were presented and discussed at these meetings.

Agreement was reached at the fourth and last meeting on the text of the Final Report, which was based on draft chapters written by both teams. Editing and preparation for publication of the Final Report was carried out by staff of the Nuclear Fuel Cycle Unit; the report is scheduled to be distributed to both governments at the end of October 1978.

The study comprised five topics:

- (a) Future supply and demand for enriched uranium.
- (b) Availability of raw materials.
- (c) Siting and energy costs.
- (d) Capital requirements.
- (e) Availability of technology from third countries.

The Australian team, consisting of AEC officers from the Nuclear Science & Technology and the Regulatory & External Relations Branches led by the General Manager, Commissioner K.F. Alder, was as follows:

Mr K.F. Alder*	(General Manager)
Dr C.J. Hardy*	(Program Manager, Uranium Fuel Cycle)
Mr A.P. Marks*	(Assessment & Planning Unit, Uranium Fuel Cycle)
Mr D.J. Mercer*	(Centrifuge Enrichment Project Division)
Dr W.B. Rotsey	(Director, External Relations Office)
Dr J.L. Symonds	(Program Manager, Power & Energy)
Mr W.J. Wright*	(Director, Special Studies Unit)

**Denotes officers who took part in one or both of the meetings held at Tokyo, where they were assisted by officers from the Australian Embassy.*

4. WASTE TREATMENT IN THE NUCLEAR INDUSTRY

4.1 Treatment of Wastes from Uranium Mining and Milling [D.M. Levins, R.K. Ryan, K.P. Strong, Chemical Technology Division]

The wastes arising from the mining and milling of uranium ores include the tailings which contain about 75 per cent of the radioactivity and almost all the radium originally in the ore, the liquid process effluents that are discharged with the tailings, and radon gas which

emanates continuously from ore and tailings. Laboratory studies continued on improved methods of waste treatment and pollution control to reduce the environmental impact of these wastes.

Behaviour of radium and actinides in uranium milling

Little is known about the fate of radionuclides during the hydro-metallurgical operations involved in uranium milling and waste treatment. Chemical Engineering and Analytical Chemistry Sections undertook a joint study to determine the solubility of radium and actinides in acid leach liquors derived from Nabarlek and Ranger ores. The method involved the simultaneous determination of many radionuclides by γ -spectrometry over the range 0.06-1 MeV using a high resolution Ge(Li) detector. The leach liquors were counted over a period of four months to observe the growth and decay of short-lived radionuclides. A computer program was written to predict disintegration rates associated with all significant photopeaks arising from the uranium, actinium and thorium decay chains as a function of time.

The percentage of each element dissolved by acid leaching is shown below:

	<u>Ranger Ore</u>	<u>Nabarlek Ore</u>
	%	%
Uranium	89	96
Protactinium	~ 15	~ 15
Thorium	58	62
Actinium	0.5	1
Radium	0.02	0.01

The slightly higher extractions from Nabarlek ore were probably due to the more severe leaching conditions. The most significant change in activity of the leach solutions with time was due to the decay of ^{227}Th (half-life = 18 d) and the consequent growth and decay of ^{223}Ra (half-life = 11.4 d). This occurs because a large fraction of the thorium is dissolved but only a little of the radium. There was no measurable change in the activities of ^{230}Th and ^{226}Ra because of their long half-lives. After three weeks, the ^{223}Ra activity reached its maximum value which was about eighty times that of ^{226}Ra . Failure to appreciate the high activity of ^{223}Ra in acidic mill liquors has frequently led to the misinterpretation, in the published literature, of radium analyses performed by radiochemical methods.

Neutralisation of tailings-raffinate slurries

All proposed uranium producers in the Northern Territory intend to neutralise their tailings-raffinate wastes with lime to reduce the concentrations of heavy metals and radioactivity in tailings dams. Neutralisation tests on tailings-raffinate slurries derived from Ranger, Koongarra and Nabarlek ores showed that, with the exception of radium, the final concentration of contaminants varied over a narrow range and was essentially independent of initial concentrations. When the slurries were neutralised to pH 8, the concentrations of contaminants were

SO ₄	= 5-8 g l ⁻¹	Mn	≅ 100 mg l ⁻¹
Pb	≅ 0.2 mg l ⁻¹	Zn	≅ 0.05 mg l ⁻¹
Cu	= 0.05-0.1 mg l ⁻¹	U	= 0.006-0.01 mg l ⁻¹ .

Unlike other heavy metals, the concentration of ²²⁶Ra actually increased during neutralisation, reaching a maximum concentration at pH 6. The maximum and final concentrations of ²²⁶Ra were dependent on the grade of the ore as shown below:

	<u>Radium-226 Concentration (Bq l⁻¹)</u>		
	<u>Untreated</u> <u>pH = 1.5-2</u>	<u>Maximum</u> <u>pH = 6</u>	<u>Final</u> <u>pH = 8</u>
Nabarlek (1.42% U)	24	285	126
Koongarra (0.37% U)	8.1	107	67
Ranger (0.20% U)	5.2	27	19

These results were unexpected since previous studies with raffinate alone had shown a steady decrease in ²²⁶Ra concentration. The observed results are now believed to be partly explained by the fall in sulphate concentration as calcium sulphate is precipitated; this leads to dissolution of radium from the tailings in accordance with the common ion effect. However, on a percentage basis, the rise in ²²⁶Ra activity was greater than the fall in sulphate concentration which suggests that other factors were contributing to the increased solubility. Precipitated calcium sulphate could be responsible because its incorporation into barium-radium sulphate precipitates has been shown to increase the solubility of radium.

To simulate long-term containment in a tailings dam, tailings from a number of Australian sources were slurried with either raffinate or demineralised water, neutralised to pH 7.5 with lime, and slowly agitated; the liquids above the tailings were then regularly sampled over a four month period. The ²²⁶Ra concentration decreased with time for the first two months indicating a slow ageing process that led to precipitation of radium. The final concentration of ²²⁶Ra varied from 0.5 Bq l⁻¹ (MKU) to 5 Bq l⁻¹ (Nabarlek).

Chemical extraction of radium from uranium tailings

Removal of radium from tailings would substantially lessen their environmental impact because it would eliminate, or greatly reduce, the hazards arising from radon emanation, leaching of radium, dust dispersal and gamma radiation. A number of salt solutions (e.g. NaNO₃, Ca(NO₃)₂, NaCl, KCl, CaCl₂, BaCl₂) were found to promote rapid leaching of radium. Sodium chloride was chosen for detailed study because of its low cost and availability. Although the extent of extraction was found to increase with the NaCl concentration, operation above 3 M NaCl does not appear to be warranted because the increase in radium solubility is relatively small. Lowering the pH from 7 to 3 by the addition of HCl increased the single-stage extraction by 25 per cent. Operation below pH 3 was considered undesirable because of the consumption of acid by the gangue.

The dissolution of radium in a single-stage batch extraction at a liquid/solid ratio of 5 l kg^{-1} was inadequate and below that measured with more dilute slurries. Increase in liquid/solid ratio and multi-stage contacting were found to favour dissolution because they effectively reduced the sulphate concentration in solution. The maximum extent of radium extraction from Ranger tailings was 92 per cent after five leaches at a liquid/solid ratio of 5 l kg^{-1} . This compares with 89 per cent extraction of uranium from the same ore by acid leaching. It appears likely that the radium that could not be extracted was associated with refractory uranium in the ore.

Multistage extraction of radium from tailings in stirred vessels requires the circulation of large quantities of NaCl solution. Another possibility would be to extract the radium by washing with brine solution on a filter cake. This should lead to a more rapid decrease in sulphate concentration and hence more efficient radium extraction. Two samples of Ranger tailings slurry were filtered on a Buchner funnel to give cake thicknesses of 14 and 25 mm. Each filter cake was then washed with 3 M NaCl and the filtrates were analysed to determine the cumulative leached radium. Extraction was greatest for the 14 mm cake and only 5 l kg^{-1} tailings was required to achieve 90 per cent extraction.

Unless there was a large source of salt water near the mill, the leach solution would have to be recycled for the process to be effective. Experiments confirmed that sodium chloride would not extract further radium unless the radium and sulphate were removed before each recycle. It was shown that sulphate could be held on De-Acidite FF anion resin and radium on Biorad AG 50W-X8 cation resin but the presence of high salt concentration greatly reduced radium retention. A chelating resin, Biorad Chelex-100, is being tested as a possible alternative to Biorad AG 50W-X8.

Thorium-230 was not leached to any significant extent in salt solutions and radium ultimately grew back into the tailings. However, about 60 per cent of the thorium was dissolved during acid leaching and could be removed from the raffinate.

Emanation of radon from ore and tailings

The emanation coefficient of a radium-bearing material is defined as the fraction of radon that escapes from its source. For uranium ores, the emanation coefficient has been found to vary over a wide range and depends on grain and particle size, mineralogy, ore grade and moisture content. Limited measurements on Australian crushed ore and tailings showed that the radon emanation coefficient in air varied from 0.05 (Koongarra ore) to 0.17 (Nabarlek secondary ore). For Ranger tailings, the emanation coefficient varied little with particle size.

The emanation coefficients in water were 1.4-3.8 times the values in air. This can be explained in terms of the generally accepted theory for the emanation of radon from solids. According to this theory, radon will only escape from a solid if the recoil resulting from its formation transports the radon atom out of the particle or into a pore or interstices. Most recoils effectively 'bury' the radon atom in other grains where the probability of escape is negligible. If the pores and fractures are filled with water, however, a recoil atom escaping from a

grain into a pore loses energy at a much higher rate. The radon atom is, therefore, more likely to end its recoil in a pore where diffusion proceeds at a rate many orders of magnitude faster than in a solid.

The role of water in increasing the emanation coefficient of radon from soils has been reported in the literature but has generally been ignored when estimating radon release rates from tailings dams. The effectiveness of water in suppressing radon release has, therefore, been overestimated.

Removal of radon from air streams

Activated carbon is the best known adsorbent for radon. Currently, activated carbon is used to collect radon for such analytical purposes as the measurement of ^{222}Rn concentration in air, ^{226}Ra concentration in water by the radon emanation method, and radon exhalation rate from the ground. A possible large scale use is the removal of radon from underground mine air. Activated carbon could also be used in gas masks for short-term exposure to atmospheres containing high radon concentrations and as part of a ventilation system for cabins of earth-moving equipment at uranium mines.

The adsorption of ^{222}Rn from air onto activated carbon was studied over the range 0-55°C. A sharp pulse of radon was injected into an air stream that flowed through a bed of activated carbon. The radon concentration in the exit from the column was continuously monitored using a zinc sulphide α -scintillation flow cell. Elution curves were analysed to determine the dynamic adsorption coefficient and the number of theoretical stages.

The dynamic adsorption coefficient was found to be independent of radon concentration, air velocity, bed height and column diameter. Within the temperature range 0-55°C, the dynamic adsorption coefficient followed the Arrhenius equation and the calculated heat of adsorption was 29 kJ mol⁻¹. A comparative study was made of five commercial grades of activated carbon under identical conditions. There was a wide variation in performance with the dynamic adsorption coefficient varying from 3.5-5.7 m³ (STP) kg⁻¹. The dynamic adsorption coefficient increased linearly with surface area and best results were obtained with Pittsburgh PCB coconut charcoal which has a surface area of 1300 m² g⁻¹ (N₂, BET method).

The effect of water vapour on radon adsorption was studied in two series of experiments. In the first series, the activated carbon bed was initially equilibrated with humidified air at the test conditions. The performance of the bed was satisfactory at relative humidities of less than 15 per cent, but deteriorated rapidly at high humidities. The dynamic adsorption coefficient was reduced to 50 per cent of its initial value at 30 per cent relative humidity. A few experiments were carried out at 100 per cent humidity, but the retention time was too low to be of practical use.

In the second series of experiments, humidified air was passed into a bed which was initially dry. The dynamic adsorption coefficient decreased by 30 per cent for an increase in the relative humidity from 0 to 100 per cent. This relatively small effect was explained by the

observation that the radon penetrated the bed at a faster rate than water vapour. Hence, for most of its travel, the radon passed through a dry bed.

The major factors affecting the height equivalent to a theoretical stage (HETS) were the particle diameter and air velocity. The minimum HETS was about four times the particle diameter and occurred at superficial velocities within the range $0.002-0.02 \text{ m s}^{-1}$. For superficial velocities above 0.05 m s^{-1} , the HETS was governed by the rate of intraparticle diffusion.

An ambient temperature adsorption system for large scale radon removal would require about one tonne of activated carbon for every $1 \text{ m}^3 \text{ s}^{-1}$ of air treated. Two adsorbers would be required so that one could be regenerated while the other was adsorbing. The quantity of carbon could be reduced by cooling the bed but the refrigeration requirements would make this approach less attractive than ambient temperature adsorption.

4.2 Waste Water Treatment [J.V. Evans, R.M. Wechsler, F.D. Nicholson, J.J. Foy, Chemical Technology Division]

This project is aimed at the investigation of advanced waste water treatment techniques, with an emphasis on pressure-driven separation methods such as reverse osmosis (RO). The pilot-plant evaluation of the use of commercial RO membranes for the concentration of low levels of radioactivity present in waste waters has been completed. Investigation of dynamic membranes and liquid membranes has commenced.

Treatment with commercial RO units

The use of commercial RO membranes to remove radioactivity from waste waters was studied in a $5 \text{ m}^3 \text{ d}^{-1}$ pilot plant. Water discharged from the AAEC Site Effluent Treatment Plant was used as a typical waste water and spiked with various radionuclides. Two different grades of cellulose acetate membranes were evaluated; one was a low flux membrane nominally rejecting 93 per cent, and the other a high flux membrane rejecting 80 per cent of a 0.5 per cent sodium chloride solution at an operating pressure of 4 MPa.

Individual rejections were measured for a variety of commonly occurring radionuclides, including ^{144}Ce , ^{141}Ce , ^{131}I , ^{134}Cs , ^{137}Cs , $^{129\text{m}}\text{Te}$, ^{239}Np , ^{95}Zr , ^{95}Nb , ^{140}La , ^{140}Ba , ^{51}Cr , ^{103}Ru , ^{106}Ru , ^{65}Zn , ^{60}Co and ^{59}Fe . The low flux membrane rejected more than 99 per cent of most of the nuclides while the high flux membrane usually rejected more than 85 per cent. However, the rejections of iodine and caesium were significantly less than those of the other nuclides, being 90 and 50 per cent with the two membranes for iodine, and 98 and 64 per cent for caesium. Between 25 and 90 per cent of the effluent was recovered as product and the remainder contained the rejected radionuclides.

The decline in flux for long periods of operation was logarithmic, but the fouling indices varied widely with the period of uninterrupted operation and the concentration of algae. However, in practice, low fouling indices would be expected with the low flux membranes requiring cleaning about once a week and the high flux membranes twice a week.

Cleaning with sponge balls was superficially effective but did not prevent a slow decline in the initial fluxes, especially for the high flux membranes.

The high flux membranes had such large fouling indices and initial flux declines that they had only marginally greater average fluxes than the low flux membranes. Overall, the low flux membranes were superior with their much higher rejections.

Dynamic membranes

A rig to evaluate dynamic membranes (laid down *in situ* from the circulating solution) and several small cells having a flat membrane configuration and circular water flow were constructed.

Initial work concentrated on producing a standard membrane on various Millipore 0.45 μm filter papers using a hydrolysed solution of zirconium oxychloride. Membranes giving rejections between 75 and 85 per cent were prepared but the results were inconsistent. It is thought that this may have been caused by the water flow pattern in the cell. A range of commercially available materials is being evaluated for service as membrane supports.

Liquid membranes

Stable membranes were prepared using di-2-ethylhexyl phosphoric acid/kerosene supported in a porous polyethylene film (0.1 μm pores). Using the chemical potential of processes at the membrane interfaces, it was possible to transport uranium across the membrane against a concentration gradient, *i.e.* to extract and concentrate the uranium.

Solutions of uranium (0.005-0.05 mol l^{-1}) in nitrate (0.1 mol l^{-1} , pH 1) were used as 'feed' and a solution of sodium sulphate (0.1 mol l^{-1} , pH 1) as the 'strip'. These were held in a cell separated by the membrane. Essentially all the uranium was transported from the feed and concentrated in the strip solution. The initial uranium flux was between 550 and 1000 $\mu\text{g cm}^{-1} \text{h}^{-1}$ and varied with the concentration of the feed. The effect of the pH and ionic strength of the neutral salt in the feed water were evaluated.

In addition to extraction, it should be possible to achieve a range of metal separations using these highly specific membranes. These aspects will be examined, together with methods for improving their practicability in terms of increasing the flux.

4.3 Publications

Conference papers

- Levins, D.M., Ryan, R.K. & Strong, K.P. [1978] - Leaching of Radium from Uranium Tailings. OECD/NEA Seminar on Management, Stabilisation and Environmental Impact of Uranium Mill Tailings, Albuquerque, New Mexico, 24-28 July.
- Strong, K.P. & Levins, D.M. [1978] - Dynamic Adsorption of Radon on Activated Carbon. 15th DOE Nuclear Air Cleaning Conference, Boston, Massachusetts, 7-10 August.

5. FUEL REPROCESSING AND MANAGEMENT OF HIGH LEVEL WASTES

5.1 OECD/NEA Radioactive Waste Management Committee [J.M. Costello, Assessment & Planning Unit, Australian delegate]

The promotion of collaborative programs of research and development by OECD/NEA member countries into management of high level wastes contained in spent fuel from nuclear power generation has continued to be the major role of the Radioactive Waste Management Committee (RWMC). Collaborative programs have been carried out in close consultation with the Committee on Radiation Protection and Public Health and the Committee on the Safety of Nuclear Installations.

Under the auspices of the Coordinating Group for Geologic Disposal, which met in September 1978 in Sweden, priority has continued to be given to encouragement of international collaboration in assessment of the technology and safety of burial of highly radioactive and long-lived wastes in deep stable geologic formations. Almost every member country with a nuclear program is involved in this work. Significant collaboration between the USA and Sweden is taking place at Stripa, where a program on the ultimate disposal of high level wastes into deep granite formations is under way; a seminar on *in situ* experiments was held at Stripa in September 1978.

The KBS Nuclear Fuel Safety project in Sweden has assessed a proposal for the disposal of vitrified high level wastes from 330 GWe y of nuclear power. Corrosion resistant canister materials were designed to restrict the access of water to the waste for over 1000 years after its burial at a depth of 500 m in granite. Radioactivity contained in the wastes was assumed to be leached by groundwater over a further period of 30 000 years. Estimates of the rate of transfer of radioactivity to the biosphere were used in pathway analyses to calculate radiological dosages to hypothetical populations living near the repository. The calculated upper limit dose to an individual (0.13 mSv) was a small fraction of background radiation in Sweden and considerably below the limit recommended by the International Commission on Radiological Protection (ICRP). An assessment with similar conclusions has been conducted by the UK National Radiological Protection Board.

A program on the disposal of high level wastes into or onto the deep ocean floor being carried out by the UK, USA, Japan and France, is being coordinated by the Sea-bed Working Group (SWG) which, with its seven Task Groups, met at Albuquerque, New Mexico, in February 1978. AAEC studies on mathematical modelling of oceanographic currents were submitted to the RWMC in support of this work.

Collaboration on the conversion of radioactive wastes into a practically insoluble glass, ceramic, or composite waste form has continued to be given high priority by the RWMC. A complementary symposium on Science Underlying Radioactive Waste Management, sponsored by the Materials Research Society, is to be held at Boston in November 1978.

In Paris, a seminar sponsored jointly by the NEA and IAEA on the Treatment, Conditioning and Storage of Alpha-bearing Wastes and Cladding Hulls was held in December 1977 and a workshop on the Processing of Combustible Radioactive Waste was held in September 1978.

A report by an NEA Group of Experts - 'Objectives, Concepts and Strategies for the Management of Radioactive Waste Arising from Nuclear Power Programs' was issued in November 1977 as a source of reference for informed scientific and public discussion on the issues relating to radioactive waste management. Mr I.G.K. Williams, the Director-General of OECD/NEA, addressed the International Conference on the Nuclear Fuel Cycle in London in September 1978 on the topic 'Nuclear Wastes - A Problem of Perspective'.

5.2 Publications

Journal paper

Hardy, C.J. & Costello, J.M. [1977] - The Status of Technology and Management of High Level Waste Arising from Spent Nuclear Fuel. *At. Energy Aust.*, 20 (3) 2-7.

6. FUEL CYCLE PROGRAM UNIT ACTIVITIES

6.1 Calculation of Fuel Cycle Requirements [W.W. Plotnikoff, J.L. Dowdell, Assessment & Planning Unit]

Modifications have been made to an existing computer program which produces a reactor list for a given nuclear power projection. The changes facilitate projections for small nuclear power programs which have reactors sparsely distributed over a long period of time.

Nuclear power projections for 45 individual countries and three groups of countries have been produced jointly with the Power and Energy Assessment Unit. These projections are made periodically as information on significant changes to nuclear power programs and plans becomes available. Projected reactor lists are then produced and estimates of fuel cycle requirements, with either zero or full uranium recycle, are calculated and stored on computer files. An abridged single page output for individual countries and seven groupings of countries is produced by a computer program which reads the file and lists the requirements for uranium, uranium hexafluoride and uranium enrichment.

The fuel cycle requirements file is also used as the input to a computer program which calculates fuel cycle requirements, given assumptions on the amount of uranium to be recycled in low enriched reactor fuel cycles, on the basis of plans for the reprocessing of reactor fuel. Data files have been established for each country for estimated unprocessed fuel in storage and for future reprocessing rates. Assumptions are made with respect to the time when excess reprocessing capacity may become available to allow the processing and recycling of uranium contained in the backlog of unprocessed fuel. Items may be selected for each output page to include unprocessed fuel backlog and the excess reprocessing capacity required to process it, as well as the other fuel cycle quantities stored on the fuel cycle requirements file. Countries may be grouped or treated individually.

6.2 INFCE (International Nuclear Fuel Cycle Evaluation) [C.J. Hardy, A.P. Marks, Assessment & Planning Unit]

In June 1977, the AAEC was requested by the Deputy Prime Minister

and Minister for National Resources, the Rt. Hon. J.D. Anthony, to act as the designated INFCE agency for Australia. Australian participation in the study is based on the conviction that effective measures can and should be taken at the national level and through international agreements to minimise the danger of the proliferation of nuclear weapons without jeopardising energy supplies or the development of nuclear energy for peaceful purposes. Eight working groups, covering the whole range of the nuclear fuel cycle, were convened and have held a number of meetings.

The AAEC role in INFCE was subsequently clarified by the Prime Minister; it is concerned solely with aspects of a purely technical nature, and matters of policy are the province of other Departments, including the Department of Foreign Affairs.

AAEC officers nominated to participate in six of the eight INFCE working groups included Mr A.P. Marks (Working Group 2, Enrichment Availability) and Dr C.J. Hardy (Working Group 4, Reprocessing, Plutonium Handling & Working Group 7, Waste Management & Disposal). Restrictions on the availability of funds for overseas visits subsequently prevented these officers from attending all meetings of their designated working groups. On the occasions when approvals were given, a series of meetings were combined in the one visit. The following is a list of meetings actually attended:

Mr A.P. Marks	
WG 1A/2A	31 May (Vienna)
WG 2	5-6 June (Vienna)
Dr C.J. Hardy	
WG 1A/2A	10-11 July (London)
WG 2/2B	23-24 Feb, 4-15 Sept (Vienna)
WG 4	30 Mar-3 Apr, 15-19 May, 18-21 Sept (Vienna)
WG 5B	28-29 Mar (Vienna)
WG 7	22-23 Nov, 15-17 Feb, 20-23 Mar, 8-11 May (Vienna)
	11-12 July (Helsinki)
WG 8	11-13 Sept (Vienna)

Dr Hardy was a principal author of Australian working papers for Working Groups 4 and 7, and took part in drafting the Working Group reports.

6.3 Briefs and Public Relations Material [Assessment & Planning Unit]

All officers of the Assessment & Planning Unit were involved in the preparation of briefing material on various aspects of the fuel cycle for Commonwealth Government Departments, State Governments and industrial organisations. Material was also prepared for visitors to the AAEC Research Establishment Private Invitation Days, and for Commission exhibitions dealing in part with the ultimate disposal of radioactive waste. Draft replies to a number of parliamentary questions were provided.

Numerous talks and lectures on aspects of the nuclear fuel cycle were given to community and education bodies, both in the Sydney area and elsewhere.

