PLAN FOR MOATA REACTOR DECOMMISSIONING, ANSTO

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ABSTRACT

‘Moata’ is an Argonaut type 100 kW reactor that was operated by Australian Nuclear Science and Technology Organisation for 34 years from 1961 to 1995. It was initially used as a reactor-physics research tool and a training reactor but the scope of operations was extended to include activation analysis and neutron radiography from the mid 1970s. In 1995, the Moata reactor was shutdown on the grounds that its continued operation could no longer be economically justified. All the fuel (HEU) was unloaded to temporary storage and secured in 1995, followed by drainage of the demineralised water (primary coolant) from the reactor in 1996 and complete removal of electrical cables in 1998. The Reactor Control Room has been renovated into a modern laboratory. The reactor structure is still intact and kept under safe storage.

Various options for decommissioning strategies have been considered and evaluated. So far, ‘Immediate Dismantling’ is considered to be the most desirable option, however, the timescale for actual dismantling needs to take account of the establishment of the national radioactive repository.

This paper describes the dismantling options and techniques considered along with examples of other dismantling projects overseas.

1. INTRODUCTION

Australia has two research reactors, HIFAR and Moata, both operated and maintained by ANSTO at its site located in a southern suburb of Sydney, approximately 35 km south-west of Sydney city. HIFAR is Australia's first reactor commissioned in 1958 and is still in safe operation at 10 MW. It is due to be replaced by a new and modern 20 MW reactor in 2005/6. Moata, the second reactor commissioned in 1961, was continually operated at 100 kW with a maximum flux of 1.2 x 10^{12} n cm $^{-2}$ s $^{-1}$ until it was finally shutdown in 1995 after 4519 separate start-ups generating 26.1 MWd burn-up. Moata is currently under safe storage or at 'Stage 1' decommissioning awaiting approval for final dismantling.

Moata is an aboriginal word meaning 'fire-stick' or 'gentle-fire'. Moata is classified within the ARGONAUT group reactors designed by the Argonne National Laboratory, USA. The ARGONAUT prototype was commissioned in 1956 (in USA) and, by the mid 1960s, about 17 derivative models had been built in 12 countries as well as eight in the USA itself. Several ARGONAUTs were built on university campuses and others, including Moata, were built on national Government laboratory sites. In 1961, the Australian Atomic Energy Commission (now ANSTO) acquired the Moata research reactor to train scientists in reactor control and neutron physics and to accumulate experimental nuclear data on the fuel/moderator systems.

To date, well over 650 research reactors have been built throughout the world and over 350 of these have been shutdown and decommissioned to various stages. Most of these reactors have not been designed or operated with decommissioning in mind. However, overseas experience has shown that research reactors can be safely decommissioned using current technologies and equipment soon after shutdown or after some decay period.

The purpose of this paper is to describe various decommissioning options ANSTO has considered before recommending the most appropriate strategies and methods available to facilitate the safe and cost effective decommissioning of Moata. It also illustrates how ANSTO arrived at those decisions.

2. DESCRIPTON OF MOATA REACTOR

The reactor core is contained within a monolithic concrete bioshield, approximately 5.8 m wide, 6.4 m long and 3.3 m high as shown in Figures 1 and 2. The bioshield contains seven major penetrations, four of which are on the sides and three on the top face. The side penetrations consist of concrete doors on rail with centrally located beam ports. The central top face penetration is fitted with three layers of massive shield blocks removable by the crane and containing beam and fuel element access ports. Other penetrations are cast in the bioshield to provide access for safety rod drives, primary water supply, neutron source movement control, irradiation target movement and electric cable. The eastern and western faces of the reactor and the inner 250 mm of the bioshield which surrounds the core cavity are composed of concrete impregnated with steel shots to provide an effective density of 5100 kg/m^3. The remainder of the Moata structure is cast in-situ in pours of standard concrete of 2300 kg/m^3 grade. In order to provide the extra radiation protection needed on the eastern side of the bioshield, a 25 mm thick lead slab is mounted across the entire inner face of the eastern side penetration.

The core cavity which measures approximately 1.2 m wide, 1.5 m long and 1.6 m high contains two parallel, open-top aluminium core tanks of rectangular section, joined and supported at the base by a common pipeline along which the primary light water moderator was circulated. Each core tank is divided by vertical aluminium spacer plates into six locations for fuel assemblies. The HEU (90% enriched) fuel assemblies consist of 12 aluminium clad fuel plates each of which contains about 22 g of U235 in an aluminium/uranium alloy. Almost the entire remainder of the core cavity volume is occupied by an assembly of reflector graphite blocks held in a tight array by restraint bars running around the perimeter. Each of the major bioshield side penetrations contains cavities filled with assemblies of graphite reflector blocks.

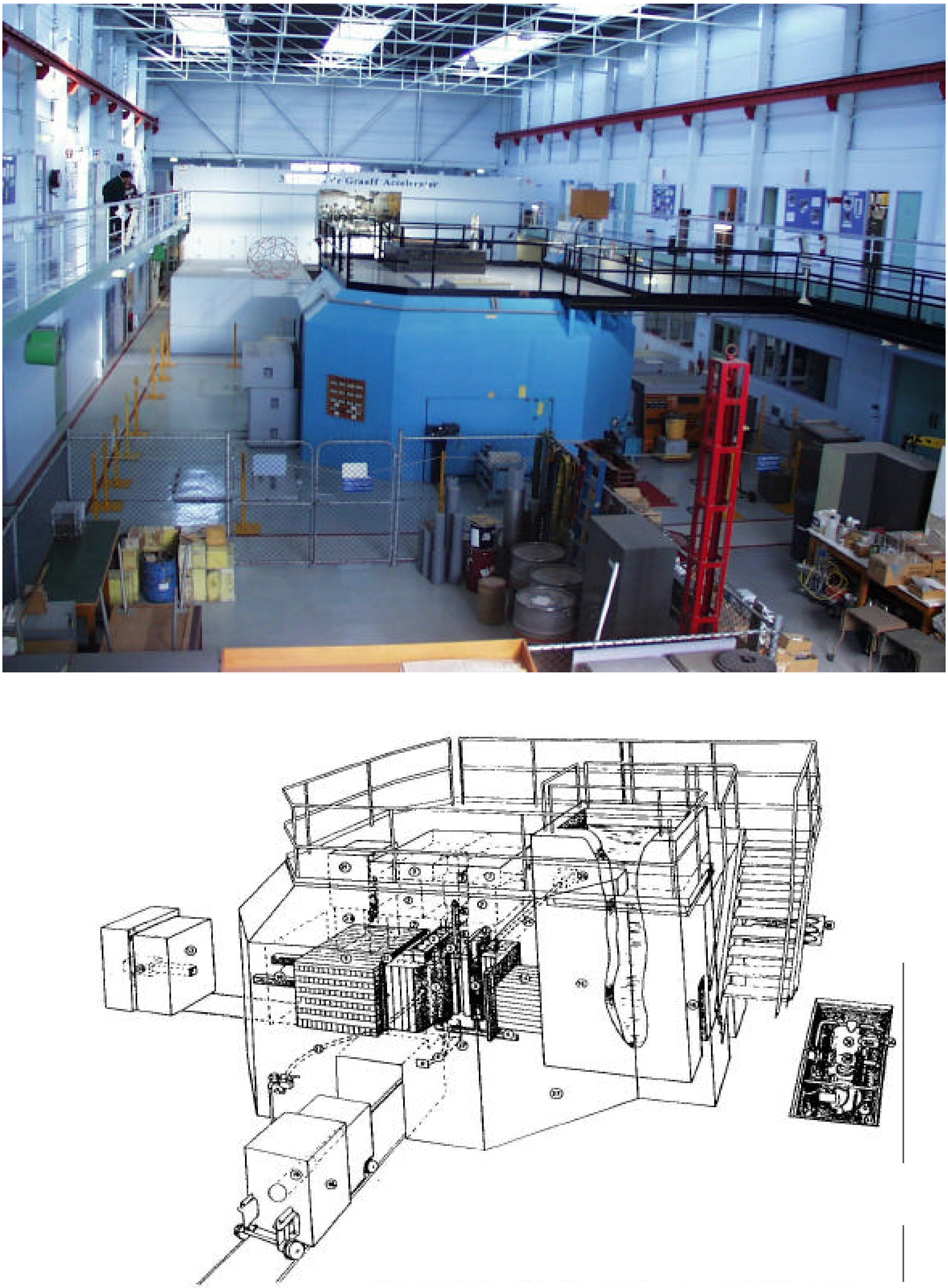
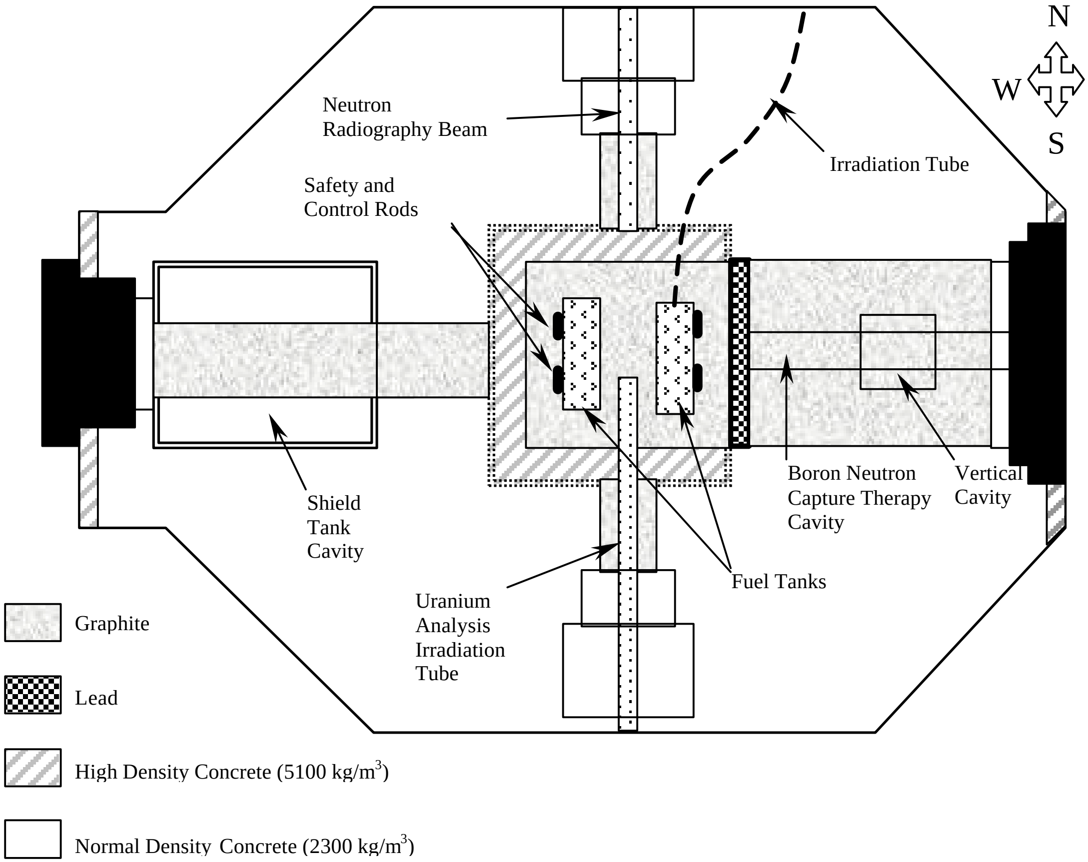
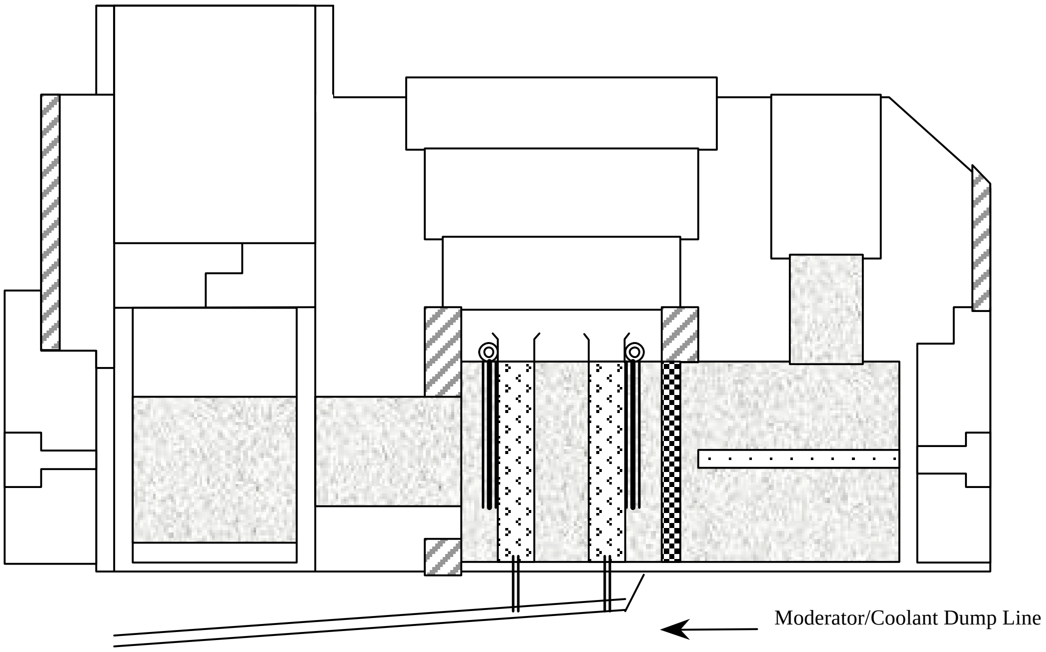


Figure 1. Moata Research Reactor, 100 kW



Horizontal Section at Mid Core Cavity Level



Vertical Section on Mid East-West Plane

Figure 2. Moata Reactor - Cross Sections

3. DECOMMISSIONING OPTIONS CONSIDERED

Currently available and feasible decommissioning options that have been recognized by the International Atomic Energy Agency and practiced by overseas organisations have been considered for Moata decommissioning and described below.

3.1 Immediate Dismantling

This is the option whereby the complete reactor assembly and ancillary systems are removed or decontaminated to a level that permits the property to be released for unrestricted use. This approach normally occurs shortly after the reactor is shutdown. If the facility or the reactor site is to be reused for future nuclear activities, restricted release may be prudent instead of unrestricted release.

Advantages	Disadvantages
☺ Personnel with first-hand knowledge of the reactor are still available; ☺ Immediate reuse of property is possible; ☺ There is no liability for the reactor after decommissioning.	☹ Little decay period is available; ☹ Potential for higher radiation doses to workers during dismantling is increased; ☹ Dismantling and waste management costs may be higher due to higher activity level; ☹ Funds must be provided immediately.

3.2 Long Term Storage

Long Term Storage is one of the most popular methods for large reactors in which the nuclear facility is stored and maintained in a safe condition allowing it to decay sufficiently before dismantling. The storage period may last from several years to 140 years depending on the results of characterisation of the radioactive inventories at the time of shutdown.

Advantages	Disadvantages
☺ More efficient and cost-effective dismantling techniques will be developed; ☺ Sufficient decay period would allow lower radiation exposure to operators during dismantling; ☺ Waste from dismantling can be handled safely due to the reduced activity levels; ☺ Active waste volume is low; ☺ Waste disposal cost is low.	☹ Staff with first-hand knowledge of the reactor will not be available; ☹ Maintenance and surveillance must be carried out on a regular basis to prevent deterioration; ☹ Costs for care and maintenance will accumulate to a large sum; ☹ The site cannot be re-used until dismantled; ☹ The reactor owner will be liable for the safety of the reactor for a long time.

3.3 Entombment

The entombment is the method whereby the reactor structure is encased in a structurally stable material, such as concrete. The entombed structure is to be maintained and surveyed until the radioactivity decays to a level that permits unrestricted site release. This method is limited to the facilities where the appropriate decay of the nuclides in the nuclide vector is shorter that the expected life of the structure.

Advantages	Disadvantages
☺ Initial waste disposal cost is low; ☺ Waste management is simplified; ☺ Overall decommissioning cost is low; ☺ Radiation hazards to operators during decommissioning are low; ☺ Special equipment or technology is not required.	☹ It is not appropriate for most research facilities due to the presence of long-lived nuclides requiring several centuries to decay to an acceptable free release level; ☹ Long term liability and maintenance cost may cause a serious problem ☹ The reactor site cannot be reused.

4. ASSESSMENT OF OPTIONS

The following factors have been used to determine the decommissioning strategy for Moata. It should be noted that the ‘Entombment’ option is not considered for Moata.

- Use of Reactor Site
- Physical Condition of Facilities
- Status of Radioactive Material
- Regulatory Requirements
- Waste Management Policy
- Availability of Moata Personnel
- Availability of Technology and Overseas Experience
- Socio-economic Considerations
- Risk Assessment
- Cost Estimate

4.1 Use of Reactor Site

Moata is located on the ground floor of Building 22. The demand for the floor space presently occupied by the reactor system is not high. However, it could be more cost effective to re-use the site to be released by decommissioning than constructing new office or laboratory buildings. The reactor control room has already been released for refurbishment as laboratory space. The ‘Immediate Dismantling’ option is favoured for this factor.

4.2 Physical Condition of Facilities

Building 22 has been and will continue to be used to accommodate offices and laboratories. The building will be maintained or refurbished to meet the on-going needs and commitment of the building users and will provide an adequate weather shield for the reactor. Under these conditions, Moata can be stored and maintained in good and safe conditions for many decades. The ‘Long Term Storage’ and ‘Immediate Dismantling’ options are both considered to be acceptable for this factor.

4.3 Status of Radioactive Materials

Overseas experience (mainly USA and Western Europe) in decommissioning research reactors has shown that most of the radioactivity results from neutron irradiation of structural, shielding, experiment-related, and core-related components. Therefore, the operational history and characterisation measurements were used to estimate the irradiation exposures and calculate the radionuclide content of principal materials and known impurities.

For Moata, the isotopes of Co^{60}, Eu^{152} and Eu^{154} in the reactor structure are dominant in the total radioactive inventory as reported in the Moata Radioactive Materials Inventory Assessment[1] which carried out a comprehensive analysis of the Moata reactor components. Total activities of the Moata components as of 1/1/1998 (2 ½ years after shutdown) are shown in Table 1 below and compared with the values after decay of 30 years or as of May 2025 (shown in parenthesis). NB, non-active components are not shown.

Moata Components	Mass kg	Volume m^3	Co^{60} MBq	Eu^{152} MBq	Eu^{154} MBq	Total Activity MBq	Activity Bq/g
Graphite	12,068	7.1	350 (6.8)	3,800 (810)	330 (26)	4480 (843)	370 (70)
Stainless Steel	7	0.001	720 (14)	0.23 (0.048)	0.02 (0.00)	720 (14)	100,000 (2,000)
Mild Steel	232	0.03	730 (14)	15 (3.3)	1.3 (0.11)	746 (17)	3,200 (75)
Lead/Bismuth	1,506	0.13	25,000 (490)	25,000 (5,200)	2,200 (180)	52,200 (5,870)	35,000 (3,900)
Aluminium	371	0.14	870 (17)	19,000 (4,000)	1,600 (130)	21,470 (4,147)	58,000 (11,000)
Concrete	118,460	55.2	110,000 (2,100)	23,000 (4,900)	2,000 (160)	135,000 (7,160)	4,100 (220)
TOTAL	132,644	62.6	137,670 (2,642)	70,815 (14,913)	6,131 (496)	214,616 (18,051)	

TABLE 1. Activities of Moata Components in 1998 (and 2025)

It should be noted that after 130 years of decay the specific activity levels of the main reactor components (graphite, concrete and mild steel) will drop below 1 Bq/g and then most of them will no longer be classified as radioactive waste. However, some metallic waste, eg stainless steel and lead, will take a much longer period to decay and, therefore, will need to be transferred to an active storage or disposal facility regardless of the decommissioning time. The ‘Clearance Level’ recommended by the IAEA[8 and 9] is currently 2 Bq/g for Co^{60} and 5 Bq/g for Eu^{152}. In many countries, however, clearances have been granted on a case-by-case basis and no rationale is available.

For immediate dismantling of Moata, approximately 54% (by volume) of the waste will be free released as shown in Table 2 while the rest will be classified as Low Level Waste (46%, mostly concrete) and Intermediate Level Waste (0.1%, mostly lead).

Moata Components	Free Release Waste		Low Level Waste		Intermediate Level Waste		Total	
	kg	m^3	kg	m^3	kg	m^3	kg	m^3
Graphite	2,103	1.237	9,965	5.862	0	0	12,068	7.099
Stainless Steel	0	0	3	Negligible	4.5	0.001	7.5	0.001
Mild Steel	0	0	27	0.003	205	0.026	232	0.030
Lead/ Bismuth	154	0.0136	472	0.0416	880	0.078	1,506	0.133
Aluminium	0	0	260	0.096	111	0.041	371	0.137
Concrete	160,540	69.8	118,460	55.0	0	0	279,000	118.8
TOTAL	**162,797**	**71.1**	**129,187**	**61.0**	**1,200**	**0.146**	**293,184**	**132.2**
Percentage	**55.5%**	**53.8%**	**44.1%**	**46.1%**	**0.4%**	**0.1%**		

TABLE 2. Estimated Waste from Moata Decommissioning (Immediate Dismantling)

Figures 3 and 4 below show calculated activities and dose rates from Moata during long term storage. The rate of reduction in dose rate is significant in the first 30 years or so and then it tapers off because the decay of Eu^{152} (longer half-life than the others) becomes the dominant factor. Therefore, the accumulated dose to operators during dismantling can be significantly reduced if Moata were decommissioned after 30 years of shutdown.

‘Long Term Storage’ with dismantling taking place after 30 years is recommended for this factor because of the following reasons.

- Immediate Dismantling may require some degree of remote handling and temporary shielding around the working areas.
- Dismantling after 30 years of storage will allow safe handling of most of the reactor components without the need for remote handling or shielding, and facilitate waste handling.
- Dismantling after 130 years of storage will have the additional advantage of allowing the release of most of the reactor components as non-radioactive, but its advantage may be offset by the costs associated with long term maintenance and liability of the reactor.

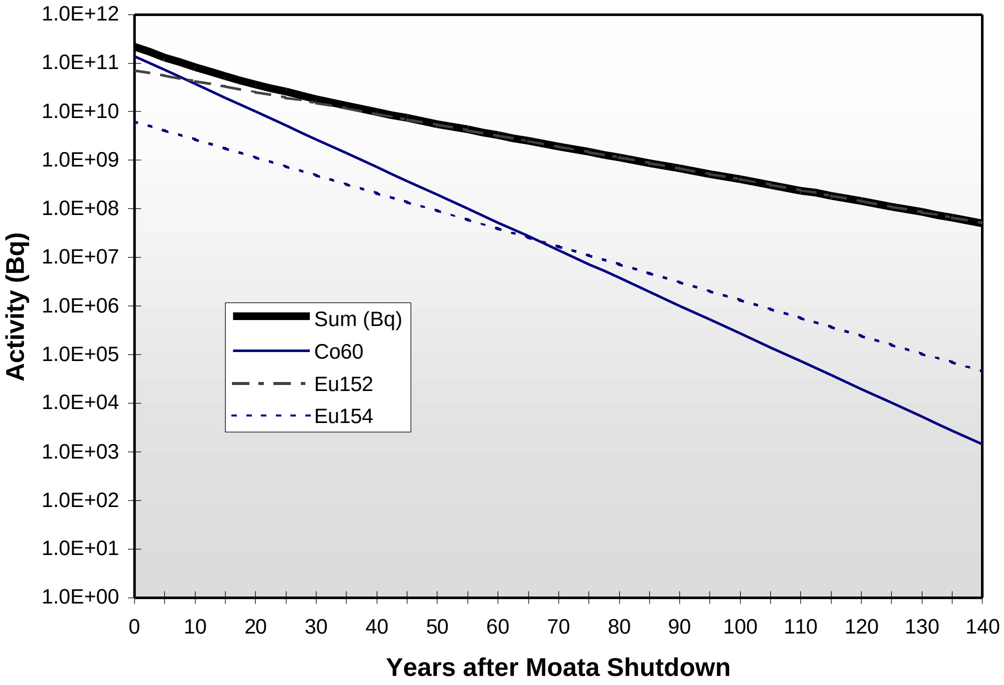


Figure 3. Decay of Main Nuclides of Moata

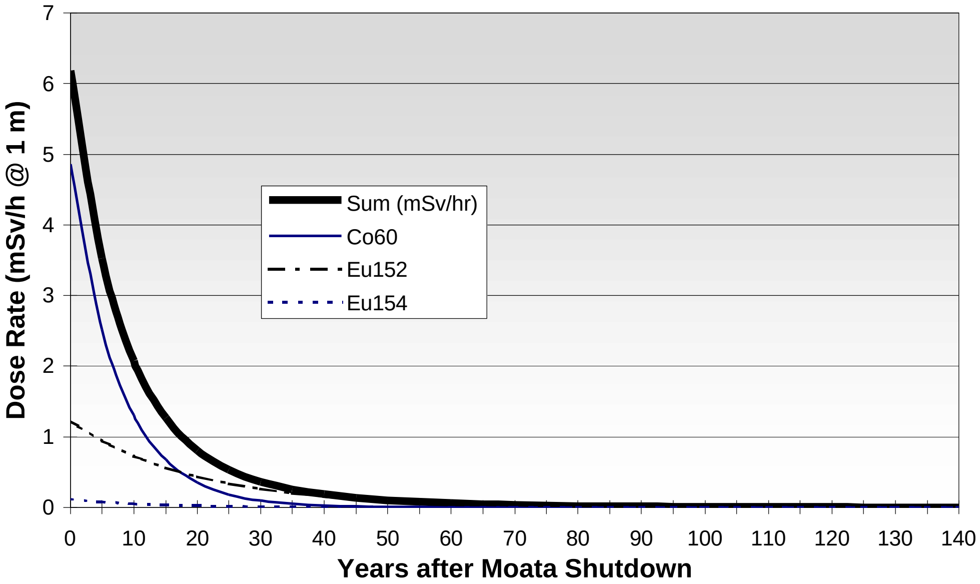


Figure 4. Dose Rate from Main Nuclides of Moata

4.4 Regulatory Requirements

'Safety Guidelines For Decommissioning Australian Nuclear Facilities' was prepared by the regulator, Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and covers general aspects of decommissioning. However, it is difficult to predict the future development of regulatory acts and requirements applicable to Moata during long term storage (if this option is taken) and how they will differ from the current ARPANSA Guidelines. Therefore, 'Immediate Dismantling' is best met in this factor because Moata can be dismantled according to the procedures currently in place.

4.5 Waste Management Policy

There is no national radioactive waste repository currently available in Australia. However an area in South Australia, approximately 2000 km west of Sydney, has been selected as the site for the proposed 2.5 hectare National Radioactive Waste Repository for *low level* and *short-lived intermediate level* wastes and it is planned that the repository will be operational in the near future. Until such a repository becomes available, 'Immediate Dismantling' will require that active waste from Moata dismantling be temporarily stored on-site in appropriate containers. 'Long Term Storage' is considered more appropriate for this factor.

4.6 Availability of Moata Personnel

ANSTO staff with relevant experience with the Moata reactor are still available (in 2002), some on site and some retired. The last Moata Supervisor retired in 1996 but has worked as a consultant to retrieve and place in safe storage all of the critical information on Moata including reactor operation history and radioactive inventory lists that are essential to carry out the Moata decommissioning project. It is useful to have Moata experienced staff assist decommissioning but this will not be possible unless the 'Immediate Dismantling' option is taken and carried out without delay. Nevertheless, with careful planning based on the existing records filed in ANSTO Engineering (ISO9001-1994 Quality System certified) and overseas experience, Moata can be dismantled safely with no restriction on time or the Moata staff. 'Immediate Dismantling' is considered to be the preferred option for this factor.

4.7 Availability of Technology and Overseas Experience

Many ARGONAUT type reactors around the world have been successfully decommissioned and some are shutdown waiting for dismantling. Lessons learned from the overseas projects[3] are:

(a) reactors of the equivalent size and irradiation history to those of Moata can be dismantled safely to Greenfield status within 5 to 8 years of final shutdown;
(b) use of conventional technologies currently available and in-house improvisations are sufficient to control on-site engineering safety and dosimetry problems; and
(c) movement and storage of waste do not present abnormal problems.

Either 'Immediate Dismantling' or 'Long Term Storage' is considered acceptable for this factor.

4.8 Socio-economic Considerations

A modern 20MW reactor is scheduled to replace HIFAR in 2005. The experience gained in demonstrating that decommissioning obsolete nuclear facilities such as Moata is not a major issue will contribute to ensuring ongoing public support for the construction and operation of the replacement reactor. It would be possible to use the experience gained in dismantling Moata in both drafting and implementing some aspects of HIFAR decommissioning. Adopting the 'Immediate Dismantling' option for Moata would provide ANSTO with the opportunity to assure the public that:

- reactor decommissioning is not a major issue;
- ANSTO has the know-how to characterise and minimise active waste generated from the decommissioning of nuclear facilities; and
- HIFAR and its replacement reactor can also be safely decommissioned.

4.9 Risk Assessment

The following aspects of decommissioning have been considered in assessment of the risks associated with decommissioning: radioactive decay and dose to operators; material deterioration; earthquake; confinement building deterioration; fire; flood; crane operations; human errors; explosion; power blackout; and plane crash. A comprehensive safety assessment[2] (not described in this paper) of these factors indicates that *'Immediate Dismantling'* is considered the preferred option for this factor.

4.10 Cost Estimate

Cost estimates (indicative only) based on the timing of dismantling have been prepared by ANSTO Engineering[2]. For Moata, there would be little difference in the overall decommissioning cost between the 'Immediate Dismantling' and 'Dismantling after 30 years'. Actual dismantling costs will be reduced with time because the dismantling and waste handling procedures become less complicated as the radioactive inventory decays to lower levels, however, off-set by the yearly maintenance cost accumulating to a significant amount after several decades of storage.

Decommissioning costs of other ARGONAUT reactors overseas are shown in Table 3. All of these reactors were dismantled within several years from shutdown, ie 'immediate dismantling' options were taken.

Note:
1. The cost figures were reported by IAEA[7] and/or the reactor owners[10, 11, 12 and 13].
2. The cost figures are nominal in local currencies at the time of dismantling.
3. ILW = Intermediate Level Waste, LLW = Low Level Waste

Reactor	Power	Dismantled	Contractor	Cost (Approx.)	Active Waste	Dose (mSv)
Virginia P, USA	100 kW	1988		US$0.6M	481GBq, 62 m^3	79
UCLA R1, USA	100 kW	1992	NES Inc.* USA	US$1.7M	651 GBq, 143 m^3	38.7
THAR, Taiwan	10 kW	1993	NTHU (Taiwan)	US$0.5M		0.14
The Universities Research Reactor, Risley, UK	300 kW	1996	BNFL UK	£4M comprising; – £2M (dismantling) – £1M (waste) – £1M (fuel removal)	4662 GBq, 192 m^3	64
JASON Reactor*, Greenwich, UK	10 kW	6/1999	AEA Tech.* UK	£7M comprising; – £2M (management) – £2M (dismantling) – £1M (waste) – £2M (fuel removal)	60 kg ILW 116T LLW (approx. 50 m^3)	1.25
University of Washington*, USA	100 kW	Delayed	NES Inc.* USA	US$1.7M ('94 value) plus US$0.5M for decontaminating spills	*Estimated* 49 m^3	*Estimated* 60
Iowa State University*, USA	10 kW	2000	Duke Eng. & Services* USA	US$1M comprising; – US$0.2M – Planning – US$0.6M– Dismantling – US$0.2M–Final survey	28 m^3 LLW	*Negligible*
Moata, ANSTO, Australia	100 kW	Proposed 2006+		*Estimated* A$2M (approx.)	*Estimated* 1.2T ILW (0.146 m^3) 129T LLW (61 m^3)	*Estimated* less than 40

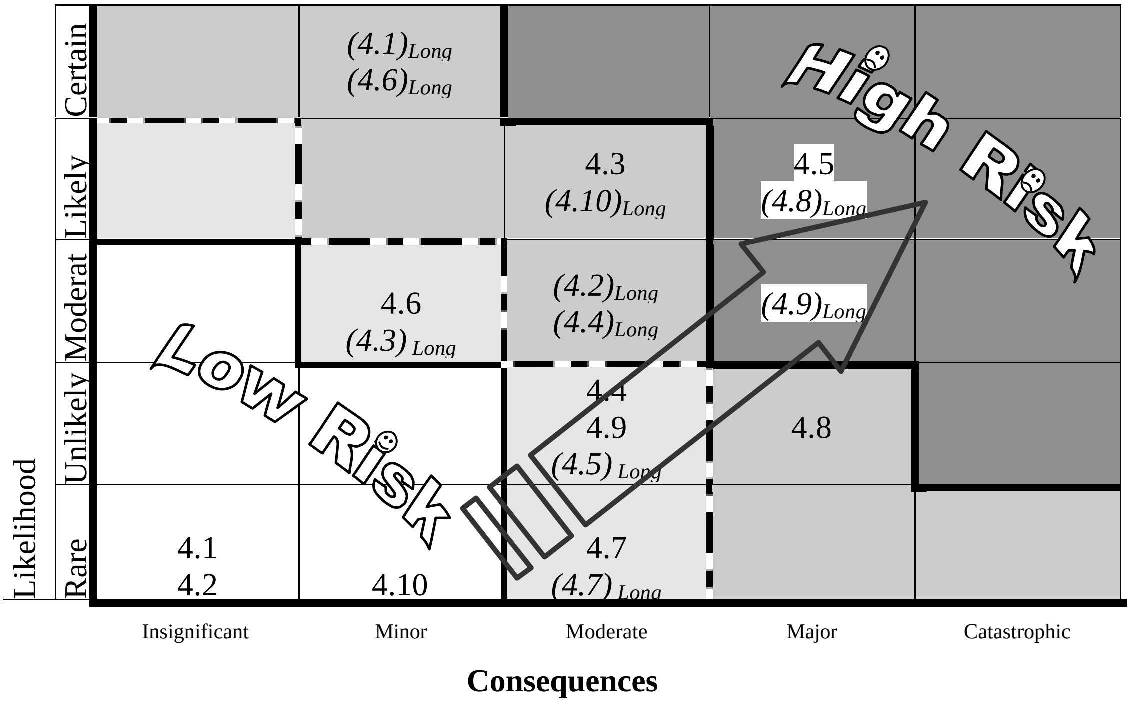
* These organisations were visited by ANSTO[3] in June 1999.

TABLE 3. Decommissioning Costs of Other ARGONAUT Reactors

5. RECOMMENDATION OF APPROPRIATE OPTION

It is difficult to rank the importance of the factors considered above. If they were assumed to be of equal importance for simplicity, 'Immediate Dismantling' is the logical option that should be implemented for Moata. The same conclusion can be reached when a more systematic method of analysing risks is employed as per the Australian / New Zealand Standard for Risk Management[4], AS/NZS 4360:1995. Qualitative risk analysis, Tables 4 below, shows that 'Long Term Storage' is more prone to higher risks than 'Immediate Dismantling'.

Section No.	Risk	Likelihood		Impact	
		Immediate Dismantling	Long Term Storage	Immediate Dismantling	Long Term Storage
4.1	Unable to re-use reactor site	Rare	Certain	Insignificant	Minor
4.2	Physical condition / Deterioration	Rare	Moderate	Insignificant	Moderate
4.3	Radioactivity (Dose to operators)	Likely	Moderate	Moderate	Minor
4.4	Regulatory requirement changes	Unlikely	Moderate	Moderate	Moderate
4.5	Waste management problems	Likely	Unlikely	Major	Moderate
4.6	Non-availability of Moata staff	Moderate	Certain	Minor	Minor
4.7	Technical difficulties	Rare	Rare	Moderate	Moderate
4.8	Socio-economic problems	Unlikely	Likely	Major	Major
4.9	Hazards (accidents/incidents)	Unlikely	Moderate	Moderate	Major
4.10	Cost increase	Rare	Likely	Minor	Moderate



LEGEND: (Risk definitions as per AS4360:1995[4], Table D3)

- 4.1 to 4.10: Factors considered for 'Immediate Dismantling' in Clauses 4.1 to 4.10 in this paper.
- *(4.1)*$_{Long}$ to *(4.10)*$_{Long}$: Factors considered for 'Long Term Storage' in Clauses 4.1 to 4.10.

▓	High Risk:	Detailed research and management planning required at senior levels.
▒	Significant Risk:	Senior management attention needed.
░	Moderate Risk:	Management responsibility must be specified.
□	Low Risk:	Management by routine procedures.

TABLE 4. Risk Register and Risk Analysis Matrix

6. CONCLUSION

It is concluded that the Moata reactor can be safely dismantled to 'Greenfield' status at any time using existing technology. Several overseas examples confirmed that the operation can be carried out immediately after shutdown with reasonably low accumulated dose levels. Alternatively, the reactor may be stored safely and maintained in safe condition for several decades or longer before dismantling.

A majority of factors considered in this document show that the preferred and safer option is dismantling in the short term rather than long term. 'Long Term Storage' would be more prone to high risks such as hazards (Clause 4.9) and socio-economic problems (Clause 4.8) as indicated by the qualitative analysis shown in Table 4. 'Immediate Dismantling' would have less risks; the only current problem is the non-availability of an off-site waste repository (Clause 4.5) which may place an over-riding constraint on the implementation of immediate dismantling unless temporary storage on site is allowed. The outcome is a long term storage regime which should be terminated and followed by immediate dismantling when a national waste repository becomes available.

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