CONVERSION OF AUSTRALIA'S HIFAR RESEARCH REACTOR TO LEU FUEL

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ABSTRACT

In May 2006 the HIFAR reactor was fully converted to Low Enriched Uranium fuel. The conversion commenced in October 2004. The LEU fuel was procured from RISO National Laboratory in Denmark, was originally made for use in the DR3 reactor, and was modified to be compatible with HIFAR. This type of fuel was used safely in DR3 before its closure. A safety analysis report for the approval and use of the LEU fuel which was prepared well in advance of loading the fuel into HIFAR, provides detailed analyses of issues important to reactor and general fuel safety, including, criticality safety outside the reactor, reactor physics, eversafe times, thermal hydraulics and accident analyses. Many of the issues that have been studied for LEU fuel reanalyse operational and accident conditions that have been previously analysed for HEU fuel. In most cases the conclusions provided in each analysis demonstrate there is little difference in behaviour between HEU fuel and LEU fuel in HIFAR under operational and accident conditions. However, there is one significant difference between HEU and LEU fuel as it is shown that in general eversafe times for LEU fuel are greater than for HEU fuel. Consequently, procedures were modified for some operations to ensure compliance with safe heat limits. The paper presents results from the measurement program undertaken during the conversion to show that the measured parameters were consistent with those calculated for the safety case. HIFAR is now operating safely with a full LEU core and is expected to do so until its final closure, planned for early 2007.

1. Introduction

The Australian Nuclear Science and Technology Organisation (ANSTO) began operating the High Flux Australian Reactor (HIFAR) in 1958, a DIDO-class research reactor operated at a thermal power of 10 MW. HIFAR is primarily used for neutron scattering science, service irradiations and isotope production. Over the nearly 50-year operating life of HIFAR a variety of fuel designs have been used. After the 1970s fuel enrichment was reduced in stages from over 90 percent to 19.75% in 2006.

The reactor core consists of 25 fuel elements with uranium fuel clad in aluminium alloy, arranged in concentric tubes. HIFAR is moderated and cooled by heavy water, and the coolant contained within an aluminium tank, which in turn is surrounded by a graphite reflector and concrete biological shielding. Reactor control and shutdown are achieved with six europium tipped cadmium control blades, which move as a bank between the rows of fuel elements. Two cadmium shutdown rods provide additional shutdown capacity.

The original uranium enrichment of the fuel used in HIFAR was 93% U235, and this reduced in stages until 60% enriched uranium fuel was introduced in 1983. For the 60% enriched fuel the nominal fresh ^{235}U mass was170g per fuel assembly. The enrichment remained at this level until 2004.

HIFAR operates continuously at nominal full power between refuelling periods, which are normally planned on the basis of five-week cycles and typically involve the replacement of three to four fuel elements. A plan view schematic of the HIFAR reactor is shown in Figure 1.

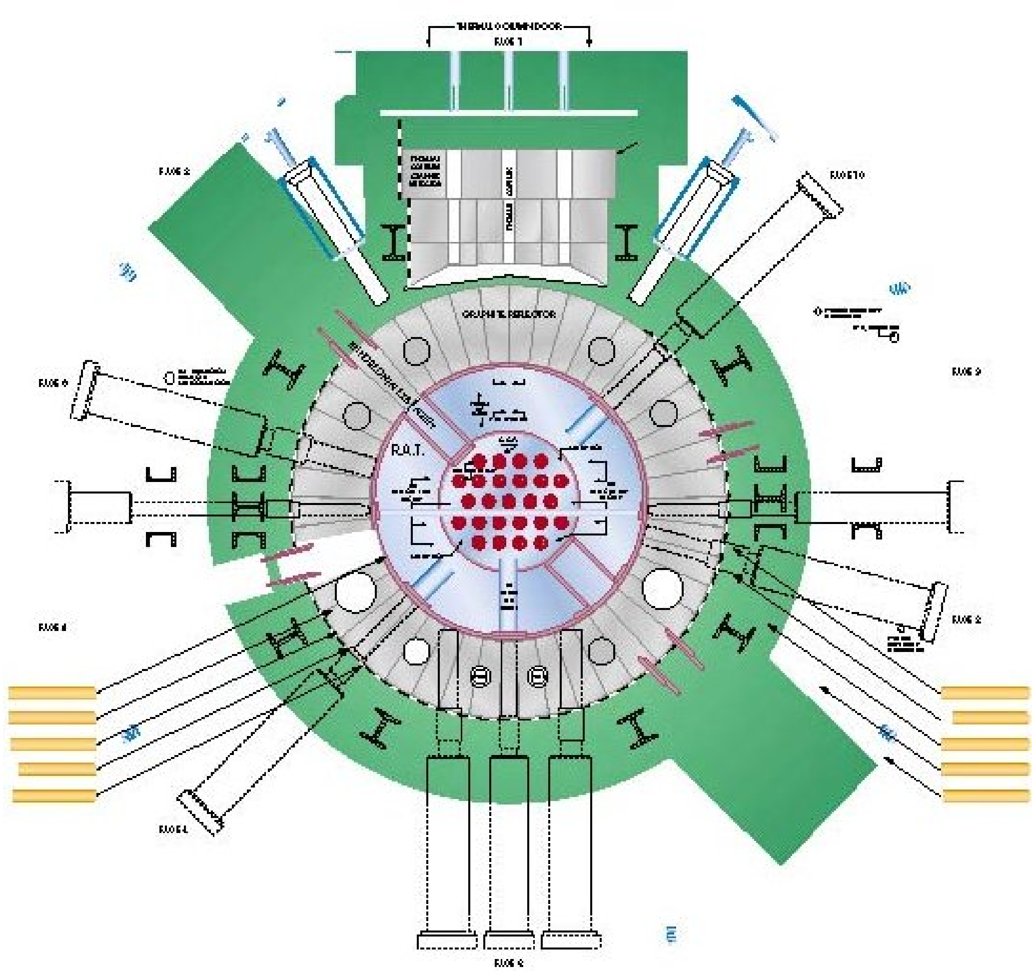

Figure1. Plan view of HIFAR showing position of the core, control blades, reactor aluminium tank and heavy water, and reflector and beam facilities.

2. Conversion Process

With the decision by the Australian Government to replace HIFAR with the OPAL research reactor, it became important for ANSTO to procure sufficient fuel to operate HIFAR until OPAL was fully commissioned. Based on the inventory of fuel at the time, ANSTO needed to procure new fuel elements to achieve operational objectives for about five years. At about this time, the RISO national laboratory in Denmark announced the closure of its PLUTO-type research reactor DR3, which was of similar design to DIDO reactors.

The unused LEU silicide fuel elements (type 18A with 180g U235 per fresh element) left after the closure of DR3 were eventually purchased by ANSTO, after it was concluded that the fuel was compatible with the HIFAR design, pending modifications to non-fuel portions of the fuel elements.

A project was initiated to manage the conversion of HIFAR to LEU fuel [1]. This project was managed under the ISO 9001:2000 accredited quality assurance system used in the HIFAR organisation. The project was broken down into the following major activities:

- Design review
- Design modifications
- Fuel shipment
- Safety case preparation and application
- Operational documentation modification
- Operational conversion
- Reporting

The project has spanned about 6 years, with a total resource allocation of approximately 12 person-years of effort.

3. Regulatory Approvals and Safety Case

An important part of the conversion process was the regulatory approvals required prior to the introduction and use of the new fuel type into HIFAR. The regulatory submissions were divided into four stages, and each submission undergoes rigorous internal review prior to submission to the regulator.

Stage 1 – Conceptual and preliminary design submission
Stage 2 – Detailed design and safety case submission
Stage 3 – Implementation submission
Stage 4 – Reporting and finalisation

Approvals have been obtained for Stages 1 (September 2001), 2 and 3 (June 2004). The Stage 4 submission is currently being prepared and essentially reports on practical completion of the project.

As part of the Stage 2 submission a rigorous safety analysis report was prepared to assess the safety aspects of operating HIFAR with the LEU fuel. The report included assessments of the following topics:

- Criticality safety outside the core
- Reactor Physics
- Fuel Handling and Ever-safe Times
- Mixed Core Operation
- Thermal Hydraulics
- Emergency Cooling
- Reactivity Insertion Accidents
- Thermocouple Position

- Anticipated Transient Without Scram
- HIFAR Reference Accident
- Steam Explosions
- Fuel Management Computer Code

In parallel with ARPANSA consideration of the Safety Case submission updates to operational documentation were undertaken including, Operational Limits & Conditions (OLCs), the HIFAR SAR, work procedures and instructions, reactor physics data, and the HIFAR Descriptive Manual. The fuel management computer code HIFAM [2] which directly uses the AUS modular neutronics code system [3], and which had been validated with HEU fuel was formally proposed to be used for core management of HIFAR in the future. These issues were incorporated into the Stage 3 submission along with responses to questions received during the ARPANSA review of Stage 2. Approval to use the LEU fuel in HIFAR was obtained from ARPANSA in June 2004.

4. Core Conversion Strategy and Implementation

Following regulatory approval for use of LEU fuel a loading plan was developed based on a series of core conversion simulations conducted with HIFAM. The loading plan was to firstly load one type 18A LEU fuel element in an intermediate core position, and operate the reactor with one type 18A LEU fuel element and twenty-four MkIV HEU fuel elements for a minimum of one operating program to enable agreed measurements to be performed. Conversion of the core was then planned sequentially following approved procedures and various measurements undertaken to monitor the fuel and core safety and performance.

Training and information sessions were held for operational staff, with the training being tailored for specific job requirements. An emphasis was placed on the operational changes to occur using LEU fuel. The most obvious of these was the extension in eversafe times of the fuel, which was caused principally by the increased energy absorption in the larger U238 inventory. The eversafe times were calculated conservatively using a fuel element power higher than allowed by the OLCs, which was determined by applying a conservative total uncertainty in fuel element limiting decay power of 18%. In operational terms the net result was increased times for removal of fuel from the reactor and the irradiated fuel element storage block.

Action limits and limiting acceptance criteria were determined for most of the activities or measurements performed during the conversion of HIFAR to LEU. Table 1 provides a summary of the activity or measurement, the reactor states that pertain to the activity, limiting acceptance criteria and an action limit for various measured reactor parameters.

Activity / Measurements	Reactor State	Frequency	Action Limit	Limiting Acceptance Criteria
Fuel element loading / unloading	Shutdown	Each scheduled shutdown	NA	NA
Fuel element temperature	Shutdown, Low power, Raising power, Full power	Continually monitored on DAS	Nominal maximum 58C	OLC limit of 65C. CFE trip set at 62C.
Safety rod – reactivity assessment	Shutdown	Series of SR drop data each shutdown	<7.6% and 10% average before FC <15.0% and 17.0% average after FC	SR reactivity worths as stated in Section 4 of HSD
Fuel element reactivity worth	Low power	Selection of central, intermediate and outer positions	Reactivity accounting error to within ± 0.5%ρ.	Reactivity accounting error to within ±1%p
Control Arm sensitivity – Inverse kinetics	Low power	Once per shutdown or as advised by the Reactor Physicist	Refer to established HEU reference data	Reactivity accounting error to within ±1%p
CCA sensitivity – D2O temperature variation	Full Power	Weekly intervals	Refer to established HEU reference data	Reactivity accounting error to within ±1%p
Approach to critical and reactivity balance	Low power	Prior to and following fuel change	Reactivity accounting error to within ± 0.5%ρ.	Reactivity accounting error to within ±1%p

Table 1: Activities, acceptance criteria and action limits for LEU measurement program

5. Results

A selected set of results from the measurement program are given below.

First loaded fuel element

After the first LEU fuel element was loaded, particular attention was given to monitoring the fuel element temperature using the Data Acquisition System at low power, whilst raising power and then again at full power. The fuel element temperature was within the normal operating range and was similar to that of the HEU fuel elements in the core. The measured reactivity gain of the LEU fuel element was found to have a difference of 12% to the estimate calculated using HIFAM.

Fuel Element coolant outlet temperature

The maximum coolant outlet temperature recorded for the LEU fuel elements during the first 6 months of the conversion was about 56°C measured in an inner core position. All recorded temperatures of the LEU fuel elements were similar to those of the HEU fuel elements in the core.

Fuel Element Change Reactivity Gain

Table 2 shows a comparison between the measured and estimated reactivity gain of the fresh LEU fuel elements loaded into the core. As can be seen, the values are less than the limiting acceptance criteria of ±1 %ρ and the action limit of ±0.5 %ρ. The estimated and measured reactivity gain values are comparable indicating that the HIFAM fuel management code is good at predicting the fuel element change reactivity gain.

Operating Program	LEU Fuel Element ID No.	Measured Reactivity Gain (%ρ)	HIFAM Reactivity Gain Est. (%ρ)	Reactivity Gain Difference (%ρ)
571	18A-380	0.970	1.094	-0.124
572	18A-381	1.064	1.046	0.018
573	18A-382	1.431	1.329	0.102

Table 2. Comparison between the measured and estimated reactivity gain for the fresh LEU fuel elements.

Control Arm Sensitivity – Inverse Kinetics

Table 3 shows a comparison of the measured Coarse Control Arm (CCA) sensitivity using the Inverse Kinetics (IK) Method compared to the standard CCA differential reactivity worth calibration for mixed core operation.

For the CCA angles where IK measurements were performed, the measured CCA sensitivity is comparable to the standard differential CCA sensitivity calibration. The results were found to meet the action limits.

Inverse Kinetics	Minimum	Average	Maximum
Deviation from Calibration (%) Absolute	-6.9	2.0	4.9
Deviation from Calibration (%) < Calibration	-6.9	-2.4	-
Deviation from Calibration (%) > Calibration	-	1.4	4.9
Deviation from Calibration (%) < 20° CCA angle	-6.9	-1.3	2.1
Deviation from Calibration (%) > 20° CCA angle	-3.4	-0.5	4.9

Table 3. Comparison between the measured and standard CCA differential reactivity between operating programs 571 and 576.

Approach to Critical and Reactivity Balances

Table 4 shows a comparison between the measured and estimated core excess reactivities for the first reactivity balance after shutdown of the previous operating program as well as the post fuel change balance (i.e., last balance before start-up to full power). As can be seen in table 4, the action limit was exceeded during the first reactivity balance after shutdown in operating program 576. On this occasion, the reactor physicist was consulted, and the likely cause of the deviation was determined to be the accuracy of the poisons data used in the reactivity calculation. Subsequent reactivity balances were found to be accurate.

Heavy Water and Helium Chemistry

Dose rates monitored by installed radiation detectors were found to be comparable to those when operating with a full HEU core.

Health Physics Survey

The results from Health Physics surveys performed whilst the reactor power was raised and routinely during full power operation were similar to those performed for full HEU cores.

Neutron Flux Measurements

Table 5 shows the percentage difference between the HIFAM predicted thermal neutron flux compared to the measured thermal neutron flux at different axial heights in facilities that contained LEU fuel elements. A comprehensive set of neutron flux measurements has been performed for the LEU fuel element in HFE facility E4 starting from when the fuel element was first loaded into the core with a low U235 burn up in operating program 571 to when the fuel element had a high U235 burn up in operating program 576.

Operating Program	Difference from Measured (%ρ)	
	First Balance after Shutdown	Post Fuel Change Balance
571	-0.375	0.045
572	-0.312	0.251
573	-0.319	-0.01
574	-0.452	-0.01
575	-0.353	-0.027
576	-0.603	0.11

Table 4. Difference between the measured and estimated reactivity for the first reactivity balance after shutdown of the previous operating program and the post fuel change balance.

Operating Program	HFE facility	Axial Position	% diff. from measured
571 start of program (low burn up)	E4	B	-1.4
		C	9.8
		D	5.1
571 end of program	E4	B	0.3
		C	1.8
		D	0.5
572 (low burn up)	C1	B	-7.0
		C	-0.6
		D	2.1
573	E4	B	0.3
		C	4.2
		D	-0.8
574	E4	B	-0.4
		C	4.6
		D	3.0
576 end of program (high burn up)	E4	B	-1.1
		C	3.4
		D	-1.4

Table 5. Percentage difference between the measured and calculated thermal neutron flux in facilities containing LEU fuel elements measured between operating programs 571 and 576.

Even though the action limit is exceeded in some instances, the flux data presented in table 5 still shows a good comparison between the HIFAM predicted flux and measured flux. Further flux measurements have been performed and the results are being analysed.

6. Continued Operation with LEU fuel

Early in the construction period of OPAL, several geological features were exposed during excavations which indicated that geological faults had occurred in the past through the site where the facility was being constructed. A four month delay to the construction schedule resulted. By early 2005 it was increasingly likely that OPAL commissioning would not be completed before the last quarter of 2006, and ANSTO began considering in what ways HIFAR operation could be extended.

In 2005 a contract was signed with a fuel supplier for a limited number of new LEU fuel elements for HIFAR. The elements were a hybrid of the Mk IV HEU and 18A LEU designs. The uranium loading, enrichment, U density and silicide type are the same as the 18A type. The second supply of LEU fuel for HIFAR arrived at ANSTO in July 2006, and approval to use the fuel was obtained from ARPANSA in August 2006. The first of these fuel elements was loaded into HIFAR in October 2006 and is performing well.

7. Conclusion

The HIFAR reactor has been successfully converted to LEU fuel.

8. References

[1] D. Vittorio & G. Durance, "The Proposed Use of Low Enriched Uranium Fuel in the High Flux Australian reactor (HIFAR)", Proceedings of the International Meeting on Reduced Enrichment for Research and Test Reactors, Bariloche, Rio Negro, Argentina, November, 2002.

[2] G. Robinson, "HIFAM – A computational model for HIFAR fuel management using models of the AUS code system", ANSTO internal report, NTP-TN192, October, 1994.

[3] G. Robinson, "A guide to the AUS modular neutronics code system". AAEC/E645, 1987.