SAFARI-1: ACHIEVING CONVERSION TO LEU
A LOCAL CHALLENGE

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ABSTRACT

Two years have passed since the South African Department of Minerals and Energy authorised the conversion from High Enriched Uranium (HEU) to Low Enriched Uranium (LEU) of the South African Research Reactor (SAFARI-1) and the associated fuel manufacturing at Pelindaba. The scheduling, as originally proposed, allowed approximately three years for the full conversion of the reactor, anticipating simultaneous manufacturing ability from the fuel production plant.

Due to technical difficulties experienced in the conversion of the local manufacturing plant from HEU (UAl alloy) to LEU (U Silicide) and the uncertainty as to costing and scheduling of such an achievement, the conversion of SAFARI-1 based on local supply has been allocated a lower priority.

The acquisition in mid-2006 of 2 LEU silicide elements of SA design, manufactured by AREVA-CERCA and irradiated as test elements in SAFARI-1 to burn-ups of ~65% each; was successfully accomplished within 9 cycles of irradiation each.

Furthermore, four “Hybrid” elements (AREVA-CERCA plates assembled locally at Pelindaba) are ready for irradiation and have received regulatory authorisation to load. This will enable the SAFARI-1 conversion program to continue systematically according to an agreed schedule.

This paper will trace the developments of the above and reflect the current status and the rescheduled conversion phases of the reactor according to latest expectations.

1. Introduction

The South African nuclear industry has recently evoked significant interest regarding the intent of the current government to establish a rapid development program for nuclear power alternatives. The status of this has selectively been reported in the media and at international conferences recently [9]. In particular, the availability of large resources of natural uranium, and the potential beneficiation of this for the country’s development as a value adding commodity, has been a responsibility allocated to the South African Nuclear Energy Corporation (Necsa) site at Pelindaba.

The 1st South African Fundamental Atomic Research Installation (SAFARI-1) established in 1965, is envisaged to play an important role in any subsequent nuclear fuel and technology development. The related role of SAFARI-1, the commitment to the conversion from Highly Enriched Uranium (HEU) and in forthcoming commercial and academic programmes, has been well documented [1,2,3,8].

SAFARI-1, a 20 MW tank-in-pool type light water reactor, based on the Oak Ridge Reactor (ORR), is capable of functioning at 30 MW [5] but operational levels are maintained at a maximum of 20 MW, pending regulatory authorisation. Since the mid 1980’s, the reactor has been fuelled solely with HEU allocated from the South African inventory (45 and/or 93%). Target plates required for the ^{99}Mo production programme at Necsa are also manufactured from this original SA HEU inventory (45%).

2. SAFARI-1: The Role in Necsa's Isotope Production and R&D Programmes

Necsa owns and operates SAFARI-1 on behalf of the Department of Minerals and Energy (DME). The reactor is currently utilised mainly as a client service to perform irradiations for NTP Radioisotopes (Pty) Ltd (NTP) for the production of radioisotopes for medical application (national and export) as well as for the production of Neutron Transmutation Doped (NTD) silicon.

Although the reactor is utilised mainly for the above commercial purposes (>70%), pneumatic and fast pneumatic systems are also utilised for Neutron Activation Analysis (NAA). Beam-port utilisation is virtually dedicated to institutional (academic) applications and Neutron Diffraction and Neutron Radiography facilities are well utilised. Major refurbishment of these latter facilities is foreseen in the near future. Development of a Small Angle Neutron Scattering (SANS) facility, a project supported by the IAEA, is progressing well.

SAFARI-1 implements an integrated Quality Management System (QMS), incorporating Quality, Health, Safety and Environment (QHSE). This QMS is fully certified according to ISO 9001 (2000) and the incorporated Environmental Management System (EMS) according to ISO 14001 (2004) [4]. Operation of SAFARI-1, as authorised by the National Nuclear Regulator (NNR) is endorsed to ~2020. The continued safe operation of SAFARI-1 as a well utilised RR is in turn based on the implementation of a longer term sustainability plan.

As a result of commercial requirements, the reactor currently operates on a cyclic programme of ~5 weeks full power operation at 20 MW and shuts down for essential maintenance and fuel reload/reallocation over a period of 3-5 days. The resultant ~312-317 FPD operation implies a demanding average availability in excess of 84%.

These high commercial expectations in terms of product supply and operational efficiency require a reliable continuity of provision of quality isotopes to the medical industry, both for the well-being of fellow humans as well as for the financial sustainability of the reactor.

3 Postulated Conversion of SAFARI-1

3.1 The Impact of LEU Conversion – Operational and Commercial

Theoretical models applied to the current HEU utilisation, indicate operational efficiency losses of ~8%, with slightly smaller penalties in the fast-to-thermal flux ratios for the LEU conversion. Impacts on the levels of utilisation for the irradiation services such as fission isotope production and NTD of silicon are thus expected to be minimal.

3.2 Phase I: Manufacturing Ability

The local inventory of HEU has been used for all fuel supplies for the operation of SAFARI-1 since the mid 80's. Assemblies (fuel elements and control rods) as well as ^{99}Mo target plates are fully manufactured at Pelindaba.

The technology applied was developed and established locally but was based on the ORR fuel design criteria, using initially 45% and then later 90% ^{235}UAl alloy. The first assemblies (19 flat-plate) had HEU loadings maintained at 200g - ^{235}U but were later modified to 300g - ^{235}U per assembly. The equivalent loading of 340 g ^{235}U per LEU assembly - corresponding to a uranium density of 4.8 gm/cm^3, maintaining the same geometric profile - was confirmed as feasible.

Typical challenges regarding the physical requirements were experienced by the local manufacturing development program during this phase of the conversion programme. These were reported at an earlier conference [6]. Technical evaluations by an international manufacturer have recently cautioned the continuation of a development program to produce Lead Test Assemblies (LTAs) and a possible technology exchange to enable a conversion of the HEU facility to a fully qualified LEU production manufacturing facility was advocated. The risk associated with potential fuel failure problems in SAFARI-1 was deemed as unacceptable. The concerns were based on variations experienced regarding the cladding thickness in the dog bone area, confidence regarding efficient clad adherence, as well as occasional homogeneity of uranium distribution. The development of the local LEU manufacturing capability as essential for the conversion of SAFARI-1 has subsequently been allocated a lower priority, with current expectations that the first South African qualified LTAs will be available by ~2010/11.

3.3 Phase II: Preparation for SAFARI-1 Conversion

Based on the delays in the manufacturing conversion program and in respect of the commitment to ensure that the conversion of the reactor takes place as postulated, it was agreed that the following approaches would be used:

- Demonstration of the ability of the core management processes to predict the impact of LEU addition to the core in terms of both operational and commercial efficiency by gradual transition, i.e. selectively starting with one and gradually adding more LEU assemblies. This is a combination of benchmarking the existing core management software (SAFI-2000 and OSCAR-3) against experimental measurement (temperature postulations and flux wire confirmations at each interim fuel cycle):
    - Two LTAs, imported from AREVA-CERCA, were installed into the SAFARI-1 core during January 2006, under conditional regulatory requirements from the NNR and have successfully completed 9 cycles of irradiation each, achieving an averaged ~65% burnup.
    - The LTAs were visually examined between cycles (during the shutdown period) and individually validated in terms of integrity of gap measurements for 12 of 18 channels.
    - The predetermined acceptance criteria (deviation of less than 0.1 mm from original manufactured specifications) were satisfactorily met throughout the irradiation lifetime of both LTAs. The approval of routine import of these elements is now merely a question of final qualification of the manufacturing procedures.

- Qualification of assemblies, using LEU silicide plates (760) imported from AREVA-CERCA and locally manufactured components has been successfully completed. The first of these "Hybrid" fuel assemblies have been authorised for insertion into SAFARI-1 during September 2007.

- The final approach remains unchanged to that reported earlier, viz. the demonstration, using the imported fuels as benchmark, of the suitability of the locally manufactured fuel. The first of the SA LTAs, however, is not expected to be loaded before ~ 2010/11, followed by successive local LTAs according to regulatory authorisation and as available.

In all cases, international and locally manufactured LTAs, benchmarking will consist mainly of inter-cycle monitoring of the fuel condition, i.e. visual and gap-measurement verification of the cooling channels as set out above.

4. Conversion Strategy and Regulatory Requirements

4.1 Initial Conversion Scheduling

The conversion to Low Enriched Uranium (LEU) of SAFARI-1 and the associated fuel manufacturing at Pelindaba was authorised by the DME (July 2005) [3]. The original scheduling, allowed approximately three to four years for the full conversion of the reactor, anticipating simultaneous manufacturing ability from the fuel production plant.

As indicate d above, the project was split into two major phases for regulatory purposes:

Phase I Establishment of a qualified local fuel (LEU) manufacturing ability; and
Phase II: Transition of SAFARI-1 core from HEU to LEU Fuel.

In view of the explanations offered above, the conversion of SAFARI-1 (i.e. Phase II) will receive priority as indicated below.

4.2 Regulatory Expectations Regarding SAFARI-1 Conversion

Experiences reported by various research reactors that have undergone similar conversion to LEU indicate that there will not be any major operational deviations during the conversion process [7]. As previously discussed, however, the conversion must be done systematically in a controlled manner that ensures optimum utilisation of the South African HEU inventory and at the same time guarantees the continuity of quality service to clients, particularly in the field of isotope supply. This requires good coordination of the systematic conversion of the reactor together with an acceptable licensing approach.

In summary, the following regulatory authorisations have been (or are being) negotiated:

- Initial irradiation of the two imported (CERCA) LTAs to demonstrate compatibility of the LEU with the current HEU core during conversion was completed for 9 cycles each to an approximate burn up of 65%. These elements were systematically inspected both visually and by gap measurement control after each irradiation cycle. The results to-date were very acceptable and include a worst case condition of ~0.1 mm gap closure;
- Irradiation of “Hybrid” elements – defined as elements assembled in South Africa using local components but imported (CERCA) LEU fuel plates. The irradiations of these elements received regulatory authorisation to commence at the end of August 2007.
- Additional LTAs of South African origin after qualification of the local manufacturing process will be loaded when these are ready; i.e. completion of Phase I, expected by ~2010/11.
- Systematic conversion of SAFARI-1 to LEU Fuel assemblies over a period of the next 3 years – this will require a significant revision of the current Safety Analysis Report [5] to incorporate thorough reapplication of the relevant risk analyses and transient and accident conditions analyses using e.g. the thermal-hydraulic code RELAP.

A proposed schedule for the above applications for the systematic conversion of SAFARI-1 based first on imported and then on locally manufactured elements, is given in Figure 1.

The basic strategy must ensure the continuity of operation of the reactor as well as sustained quality and financial efficiency. The supply of the reactor with good quality, of either locally or internationally manufactured fuel, must be guaranteed according to schedule and feasible financing of alternative supplies. Deviations from an operational schedule should not have significant negative impacts on supply of service to stakeholders. In addition, efficient utilisation of the fuel inventory, i.e. ensuring a fuel discharge burn-up in line with current HEU levels of utilisation (~60%) requires selective matching of current HEU fuel inventories. In addition, local fuel manufacturing schedules for supply versus the selective backup of international suppliers, could impose a significant financial penalty, due to the efficiency of the current UAl manufacturing plant (Pelindaba).

5. Conclusion

The conversion of the South African research reactor SAFARI-1 and the related local fuel manufacture to LEU utilisation was authorised by the Department of Minerals and Energy (DME) in July 2005. The conversion has proceeded to the stage where the manufacturing qualification of the local facilities, although delayed somewhat due to technical complications, is still being pursued for completion by ~2010/11.

At the same time, in order to ensure that systematic conversion of the reactor is feasible, the successful purchase and irradiation of 2 Lead Test Assemblies from AREVA-CERCA proceeded during 2006 and 2007. These LTAs have successfully completed 9 irradiation cycles and ~65% burnup without any negative indications.

Further backup inventory has been acquired by the purchase of a reload of LEU plates and local assembly has been qualified for the manufacture of these “Hybrid” elements. Irradiation of the first LTAs of these has commenced in September 2007. Utilisation of these hybrids in SAFARI-1 will proceed as may be required until local manufacturing qualification is achieved. A schedule for the regular utilisation of LEU in SAFARI-1 is expected over a transition period of ~3 years – under regulatory authorisation. The required revision of the current Safety Analysis Report and review of the applicable risk assessment and transient applications is expected to be complete by December 2007.

6. References

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[3] CSB Piani, “South Africa and the SAFARI–1 Scenario: On the Road to Conversion – From HEU to LEU”, 2005 Meeting on RERTR, Boston, USA, November 2005.

[4] JF du Bruyn, CSB Piani, “ISO 9001 and ISO 14001: An Integrated QMS for an MTR Facility: SAFARI-1 Research Reactor”, Conference on RR Utilisation, Safety, Decommissioning, Fuel and Waste Management, Santiago, Chile, 10-14 November 2003.

[5] The SAFARI-1 Research Reactor Safety Analysis Report, RR-SAR-01 through 21 reflecting Chapters 01 to 21 of Licensing submissions to the National Nuclear Regulator.

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[7] F Wijtsma, “High Flux Reactor Petten – 6 months after Conversion”, RERTR 2006, Cape Town, South Africa, October 2006.

[8] CSB Piani, “SAFARI-1: Adjusting Priorities during the LEU Conversion Program”, RERTR 2006, Cape Town, South Africa, October 2006.

[9] Statement by the South African Minister of Minerals and Energy, 51st session of the IAEA General Conference, Vienna, Austria, September 2007.

ACTIVITY	Status	QUARTERS													
		06/1	06/2	06/3	06/4	07/1	07/2	07/3	07/4	08/1	08/2	08/3	08/4	09/1	09/2
LEU assemblies under irradiation in core		0 1 1	2 2 2	2 2 2	2 2 2	2 2 2	2 1 1	0 0 2	4 6 7	8 9 10	11 11 11	13 16 19	21 23 26	26 26 26	26 26 26
Stage-1: **Qualification of 2 French LTAs**	100%														
Stage-2: **Qualification of 4 Hybrid LTAs**	Fresh														
Stage-3: **Extended Qualification programme for a further >20 Hybrid LTAs** Local LTA/Cerca plates	Qualified delivery by Oct 07														
LEU Conversion Documentation and SAR Safety & Risk assessment	40%														
Licence submission for conversion	-														
NNR assessment of conversion LCR	-														
NNR approval of conversion LCR	-														
Routine loading of LEU fuel	-														>>

Notes: 1. The Status column gives the status at the vertical line indicating time "Now" > > > > > > > > >
2. The Stage-1 and 2 LTAs are subject to gap measurements throughout irradiation.
Stage-3 LTAs will be measured before and at the end of irradiations.
3. The heavy vertical line in mid-2008 indicates the postulated commencement of full conversion – i.e. Regulatory approval for routine loading.

Figure 1: LEU QUALIFICATION / CONVERSION SCHEDULE