SAFARI-1: ADJUSTING PRIORITIES DURING THE LEU CONVERSION PROGRAM

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ABSTRACT

In July 2005, the South African Department of Minerals and Energy authorised the conversion to Low Enriched Uranium (LEU) of the South African Research Reactor (SAFARI-1) and the associated fuel manufacturing at Pelindaba. At that stage the proposed scheduling allowed approximately three years for the full conversion of the reactor, anticipating simultaneous manufacturing ability from the fuel production plant.

Initial priorities and regulatory agreements were allocated with the intention to manufacture and produce two Lead Test Assemblies (LTAs) from the Pelindaba plant (Phase I) and use these as qualification of manufacturer as well as initiation of the SAFARI-1 conversion (Phase II). Delays in the demonstration of sufficient confidence in the manufacturing ability to enable local fuel licensing and qualification have resulted in minor readjustments of these Phases.

Delays in the initial schedule that allowed for the insertion of the two South African LTAs during the 1st quarter of 2006 were pre-empted by the acquisition of 2 LEU silicide elements of SA design manufactured by AREVA-CERCA. These two LTAs are currently undergoing testing in SAFARI-1 and have to-date completed 5 cycles of irradiation each.

As a further precaution to the potential delays in the fuel-manufacturing Phase, a reload (760 plates) of LEU silicide element fuel plates were purchased and will be assembled locally to enable the SAFARI-1 conversion program to continue according to schedule.

This paper will trace the developments of the above in order to reflect the current status and the planned correlation of the Phase I and Phase II programs according to latest expectations.

1. Introduction

The development of the South African nuclear industry has been comprehensively reported at recent RERTR and other international conferences. In particular, the availability of large resources of natural uranium, the formation of the Atomic Energy Board (AEB) of South Africa, the establishment of the 1st South African Fundamental Atomic Research Installation (SAFARI-1) at the South African Nuclear Energy Corporation (Necsa) site at Pelindaba and the reactor's subsequent first criticality on 18 March 1965, have been well documented [1,2,3].

SAFARI-1, initially a 6.67 MW tank-in-pool type light water reactor, based on the Oak Ridge Reactor (ORR), was purchased from the USA but was soon modified to enable operation at 20 MW. The reactor is currently capable of functioning at 30 MW [5] but operational levels are maintained at a maximum of 20 MW, pending regulatory authorisation. The reactor was initially fuelled with Highly Enriched Uranium (HEU) sourced from the USA and elements manufactured either in the USA or the UK. In later years (post 1981), the reactor has been fuelled solely with HEU allocated from the South African HEU inventory (45 and/or 93%). At the same time, target plates required for a now well-established ^{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

SAFARI-1, which is owned and operated by Necsa on behalf of the Department of Minerals and Energy (DME) 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.

There are also pneumatic and fast pneumatic systems utilised for Neutron Activation Analysis (NAA). Utilisation of beam-ports for institutional (academic) purposes is encouraged and Neutron Diffraction and Neutron Radiography facilities are well utilised, whilst a Small Angle Neutron Scattering (SANS) facility, subsidised by the IAEA, is under development.

In support of safe operation and the commercial needs of NTP, SAFARI-1 applies an integrated management system, incorporating Quality, Health, Safety and Environment (QHSE). The reactor's Quality Management System (QMS) is fully certified according to ISO 9001 (2000) and it implements an incorporated Environmental Management System (EMS), fully certified according to ISO 14001 (2004) [4]. The current licence of SAFARI-1, as authorised by the National Nuclear Regulator (NNR) endorses operation of the reactor to 2020, but requires assurance that the proposed operational plan is justified, not only by the current safe operation of a well utilised RR but also by establishment of a longer term sustainability plan.

3. Conversion Strategy: HEU to LEU in View of Operation and Commercialisation

As reported earlier, the DME (July 2005) authorised the conversion to Low Enriched Uranium (LEU) of SAFARI-1 and the associated fuel manufacturing at Pelindaba over a period of approximately 3-4 years [3]

The original strategy to align SAFARI-1 as a multipurpose semi-commercial facility today provides the backbone of a strong medical isotope supply facility for SAFARI-1's major customer – NTP Radioisotopes (Pty) Ltd. This Necsa subsidiary is subsequently responsible for providing the major source of the reactors operational income by processing and distributing, amongst others, fission product isotopes (e.g. ^{99}Mo, ^{131}I) for medical applications. This successful marketing achievement currently positions SAFARI-1 as one of the top 5 reactors supplying services to producers of ^{99}Mo internationally. SAFARI-1 has a subsequent responsibility to ensure continuity of good quality supply of irradiated products and services.

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 3-4 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.

4 Postulated Conversion of SAFARI-1

4.1 The Impact of LEU Conversion – Operational and Commercial

Earlier theoretical postulations modelled on the current HEU utilisation, indicated operational efficiency losses of ~8%, with slightly smaller penalties in the fast-to-thermal flux ratios for the LEU conversion. The latter could impact on the levels of utilisation for the irradiation services such as fission isotope production and NTD of silicon. In view of the DME's authorisation to progress with the conversion of SAFARI-1, together with provision of the necessary funding to ensure satisfactory conversion of both the reactor and the manufacturing process over a period of ~3-4 years, the conversion project was initiated during 2005.

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.

4.2 Phase I: Manufacturing Ability

As indicated above, all fuel supplies for the operation of SAFARI-1 after the mid 80's were sourced using local HEU and from assemblies (fuel elements and control rods) manufactured at Pelindaba.

The technology applied had been 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. In terms of this, 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 experienced during the local manufacturing development program resulting in minor delays in this phase of the conversion programme, are elaborated on at this conference [6].

The manufacturing test and qualification programs are currently scheduled for completion and supply of the 1st local Lead Test Assemblies (2 LTAs) by early 2007.

4.3 Phase II: Preparation for SAFARI-1 Conversion

Due to the delays experienced in the manufacturing conversion program and in view of the understood commitment to ensure that the conversion of the reactor takes place as postulated, it was agreed for regulatory purposes that two 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 (flux wires at each interim fuel cycle):
    - Two LTAs were imported from AREVA-CERCA and were installed, under conditional regulatory requirements from the NNR, into the SAFARI-1 core during January 2006.
    - The two LTAs have to-date each completed 5 cycles of irradiation and have achieved ~35% burnup on a predicted End-of Life (EOL) of ~70%.

  - The LTAs are being visually examined between cycles (during the shutdown period) and individually validated in terms of integrity of gap measurements for 12 of 18 channels.
  - Predetermined acceptance criteria (deviation of less than 0.1 mm from manufactured specifications) for unrestricted reinsertion of the LTAs into the next cycle have been established with the NNR - the required authorisation is provided by the SAFARI-1 Reactor Safety Committee, To-date all results have been in full compliance with the specifications.

- In view of the delay in the manufacturing program qualification, an annual supply of LEU silicide plates (760) has been acquired from AREVA-CERCA. Assembly qualification, using these plates and locally manufactured components, is proceeding. It is anticipated that the first fuel assemblies will be ready for insertion into SAFARI-1 early in 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. For this purpose, as mentioned, the first of the SA LTAs is expected to be loaded early in 2007, followed by successive local LTAs according to regulatory authorisation and as available.

In both cases, international and locally manufactured LTAs, the 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.

4.4 Regulatory Expectations Regarding SAFARI-1 Conversion

It is not expected that there will be any major operational deviations during the reactor conversion process – this is supported by communications with management of the sister reactor HFR at Petten and their experience as reported at this conference [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.

The following regulatory authorisations have been (or are being) negotiated:

- Initial irradiation of the two CERCA LTAs to demonstrate compatibility of the LEU with the current HEU core during conversion;
- Irradiation of successive additional LTAs either of South African origin after qualification of the local manufacturing process and/or of South African assemblies using CERCA manufactured plates;
- 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.

In general, the continuity of operation of the reactor should not be unnecessarily challenged, either by quality or financial efficiency. This implies that any inability to continuously supply the reactor with good quality locally or internationally manufactured fuel, due to possible fuel failure, must be matched according to schedule and finances of alternative supplies.

Furthermore, deviations from an operational schedule should not have significant negative impacts on supply of service to stakeholders.

Secondly, the fuel inventory should be utilised to optimise efficiency, i.e. ensure fuel discharge burn-up is in line with current HEU levels of utilisation (~60%). This requires selective matching of current HEU fuel inventories, local fuel manufacturing schedules for supply and the selective backup of international suppliers, which in this case, due to the efficiency of the current UAl manufacturing plant (Pelindaba) could impose a significant financial penalty.

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 imminent (early 2007). At the same time, in order to ensure that systematic conversion of the reactor is feasible, the purchase and irradiation of 2 Lead Test Assemblies from AREVA-CERCA proceeded during 2006. Currently each LTA has successfully completed 5 irradiation cycles and ~35% burnup. Further backup inventory has been acquired by the purchase of an annual supply of LEU plates for local assembly and utilisation in SAFARI-1 as may be required should further local manufacturing qualification delays be experienced. Regular utilisation of LEU in SAFARI-1 is expected over a transition period of ~3 years – under regulatory authorisation, which will require revision of the current Safety Analysis Report and review of the applicable risk assessment and transient applications.

6. References

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