CORE CONVERSION OF THE PORTUGUESE RESEARCH REACTOR TO LEU FUEL

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ABSTRACT

Core conversion of the Portuguese Research Reactor (RPI) to LEU fuel is being performed within IAEA's Technical Cooperation project POR/4/016, with financial support from the US and Portugal. CERCA was selected as manufacturer of the LEU assemblies by the IAEA after an international call for bids. CERCA provided a comprehensive package to the RPI which included the mechanical verification of the design of the assemblies, their manufacture and arrangements for a joint inspection of the finished assemblies. The LEU fuel assemblies were manufactured within 8 months upon final approval of the design. The safety analyses for the core conversion to LEU fuel were made with the assistance of the RERTR program and were submitted for review by the IAEA and by Portuguese authorities in January 2007. Revised documents were submitted in June 2007 addressing the issues raised during review. Regulatory approval was received in early August and core conversion was done in early September. All measured safety parameters are within the defined acceptance limits. Operation at full power is expected by the end of October.

INTRODUCTION

The Portuguese Research Reactor is a 1 MW, pool-type reactor, commissioned in 1961. It is owned and operated by "Instituto Tecnológico e Nuclear", which is the third generation of the main national organisation for nuclear activities in Portugal. It was built by AMF Atomics and its design follows closely the one of the Battelle Research Reactor.

The main end-users of RPI are research groups from ITN and Portuguese Universities. The activities currently underway cover a broad range from irradiation of electronic circuits [1] to calibration of detectors for dark matter search [2], passing by more classical subjects such as neutron activation analysis [3]. Education and training has always been an important activity. Although the RPI is not a University reactor, it supported experimental classes for graduate and post-graduate studies in Physics, Chemistry and Biology since its very beginning. An aspect of growing importance in a country without a nuclear power programme is public tours. The reactor had more than 20 000 visitors since the early nineties and the number of visitors per year is now over 2 000, mostly students.

The RPI was commissioned with LEU fuel, supplied with the reactor on a lease agreement. However it was later converted to HEU fuel for economic reasons. In 1999 Portugal declared its interest to participate in the Foreign Research Reactor Spent Nuclear Fuel Acceptance Program (FRRSNF). A commitment was made to stop using HEU after May 12, 2006 and return all HEU fuel until May 12, 2009.

Although the need to perform the core conversion to LEU was never questioned, the 2006 deadline prompted a discussion on the back-end solution for the new LEU fuel. The announcement in the end of 2004 of the 10 year extension on the FRRSNF policy opened a new window of opportunity for the operation of the RPI with LEU fuel. The core conversion to LEU is being performed within IAEA's Technical Cooperation project POR/4/016, approved in early 2005, with financial support of the US and Portuguese governments.

CONVERSION MILESTONES

The schedule for the conversion project was developed with the objective to have LEU fuel available as soon as possible after May 12, 2006, and return the HEU fuel before May 12, 2009. Table 1 summarizes the main milestones of the project.

Table 1. Milestones for the conversion project

MILESTONE	PLANNED	EFFECTIVE
Commitments for funding	Mid 2005	As planned
Feasibility study	End of 2005	As planned
Safety studies	Mid 2006	End of 2006
Project and Supply Agreement	Mid 2006	Early 2007
Regulatory Approval	End of 2006	August 2007
Fuel manufactured	End of 2006	As planned
Conversion	Early 2007	September 2007
Return of HEU fuel	Before May 12, 2009	In preparation

Ensuring funding for the conversion project was the first challenge. With the budgetary restrictions of the last years, ITN did not have enough funds to procure the new fuel. On the other hand, it was clear that ITN also did not have enough technical resources to perform the necessary safety studies by itself. This led to the submission of a project under the Technical Cooperation programme of the IAEA for the 2005-2006 cycle. Project POR/4/016, "Core Conversion of the Portuguese Research Reactor to LEU fuel" was approved in early 2005, but with funding covering only missions. Funds for fuel procurement were allocated under the "footnote a)" label, i.e., dependent on donors. Formal discussions were held just a few weeks after the approval of the project. The Global Threat Reduction Initiative (GTRI) agreed to provide partial funding for the conversion project if Portugal also made a significant financial commitment to the project. Diplomatic Notes were exchanged between the US and Portuguese governments agreeing to the main points on shared funding for the project.

A joint feasibility study between ITN and the RERTR program at Argonne National Laboratory (ANL) was performed during 2005 to determine a suitable LEU fuel assembly design and perform the analyses necessary to establish the feasibility for conversion of the reactor [4]. An additional goal of this study was to minimize the number of assemblies required for the ten-year operation period until May 2016 during which the FRRSNF program is valid (estimated at 500 MWd, maintaining current operating levels).

Table 2. Summary of HEU and LEU Design Data

DESIGN DATA	HEU	LEU
Fuel Type	MTR Plate	MTR Plate
Fuel "Meat" Composition	U-Al alloy	U_3Si_2-Al
Uranium Enrichment (nominal)	93.2 %	19.75%
Fuel Plate Thickness (mm) Width (mm) Length (mm)	1.27 71.0 625.5	1.37 71.0 625.5
Fuel Meat Thickness (mm) Width (mm) Length (mm)	0.5 63.4 596.9	0.6 63.4 596.9
Uranium Density in Fuel Meat, g/cm^3	0.83	4.8
Cladding Material	1100 Al	AG3 NE
Cladding Thickness (mm)	0.38	0.38
Number of standard assemblies (Initial Core) Mass of ^{235}U per standard assembly Number of plates per standard assembly Coolant Channel Thickness (mm)	7 265 18 3.15	7 376 18 3.05
Number of control assemblies (Initial Core) Mass of ^{235}U per control assembly Number of plates per control assembly Coolant Channel Thickness (mm)	5 147 10 3.15	5 209 10 3.05

Uranium silicide (U_3Si_2-Al) dispersion fuel with a uranium density of 4.8 g/cm^3 was selected because of its widespread use in research reactors and for the relatively large number of manufacturers. From the onset it was decided to keep the same number of plates as the HEU standard and control assemblies to simplify the re-licensing procedure.

Table 2 provides a summary of the key design features of the HEU and LEU fuel assemblies and the initial HEU and LEU cores. The LEU fuel assembly design contains plates with a fuel meat thickness of 0.6 mm to replace the HEU fuel which had a fuel meat thickness of 0.5 mm. This results in a ^{235}U loading of 376 g per LEU standard assembly compared with 265 g per HEU standard assembly. No changes in the control rods, control rod mechanisms, or the reactor control and instrumentation were necessary.

The core size remains unchanged with the conversion to LEU fuel and no significant flux penalties are foreseen. The results of neutronic studies, steady-state thermal-hydraulic analyses, accident analyses, and revisions to the Operating Limits and Conditions demonstrate that the RPI can be operated safely with the new LEU fuel assemblies. These studies took longer than originally foreseen. While for the neutronic studies all information was readily available and a basic MCNP model existed [5], additional information was necessary on the reactor thermal-hydraulics parameters, taking into account the somewhat limited studies performed in the eighties for the conversion to HEU. The main results were presented in the RERTR 2006 meeting [6].

The original schedule was developed with the objective to have LEU fuel available as soon as possible after the deadline for use of HEU, May 12, 2006. It was clear from the start that the LEU fuel could not be delivered before the end of 2006. As the project progressed, DOE agreed to two postponements on the use of HEU, first until January 31, 2007 and later until May 31, 2007, to minimize any disruptions on the operation of the RPI. The RPI stopped using HEU in May 31, 2007, so as to guarantee a timely shipment of this fuel to the US.

The most challenging aspect of the conversion was the conclusion of a tripartite agreement between the IAEA and the US and Portuguese Governments. This involved several interactions with multiple governments, agencies, ministries and industrial partners. It also required a considerable time for ratification.

The submission of the safety documentation for approval, initially foreseen in mid 2006, was delayed by about 6 months. The IAEA initiated the review of the documents shortly after their reception. The expert's report was very positive and made a series of recommendations and suggestions. Revised documents were submitted in June 2007 addressing all the issues raised during review. Regulatory approval was received in early August and core conversion was done in early September.

FUEL ASSEMBLIES SUPPLY

CERCA was selected as manufacturer of the LEU assemblies by the IAEA as a result of an international call for bids. CERCA, a subsidiary of AREVA, has been in charge of manufacturing and supplying research and material test reactor fuel assemblies for more than forty years and is the world leader in its field. CERCA supply covers a large range of products, in terms of geometries (flat or rolled plates, tubular or ring-shaped elements) as well as enrichments (HEU, MEU, LEU), and fully satisfies the technical and scientific needs of customers demanding quality and safety.

CERCA manufacturing plant, located in Romans in the south of France, has a global manufacturing capacity of 20 000 plates. The production is around 11 000 plates per year and more than 80% of the manufacturing is of the LEU type. Since 1960, CERCA has manufactured over 310 000 fuel plates, about 21 000 fuel assemblies of 70 designs, delivered to 40 research reactors in 20 countries. A part of this large experience concerns silicide U_3Si_2 fuel assemblies that CERCA manufactures on an industrial scale and routinely delivers worldwide. By mid-2007, CERCA has manufactured 3000 U_3Si_2 fuel assemblies (about 60 000 plates), for customers distributed in Australia, France, Germany, Greece, Netherlands, Japan, Canada, Portugal, Romania, South Africa, Sweden, Switzerland, Taiwan and Turkey.

Thanks to this broad supply, CERCA has gained a high quality experience feedback. It is employed to the benefit of reactor operators by providing them with high performance and high quality fuels, thanks to its proven and tested Q&A system, skill and trained teams, last technologies for the inspection, maintenance organization, transport process (casks and others). With all these processes, CERCA is considered as a qualified fuel manufacturer and is able to produce fuel on a reproducible manner which fulfils the requirements of Safety Authorities.

This has enabled CERCA to be assessed as fully qualified for the manufacturing of U_3Si_2 fuel assemblies for the RPI reactor. CERCA can also address specific needs of the operators. For the RPI reactor, CERCA has provided an integrated package including:

- Verification of the mechanical design of the standard and control fuel assemblies, including all the necessary final drawings and mechanical specifications.
- Manufacturing of standard and control fuel elements.
- Quality control inspection before shipment.
- Transportation to Portugal using licensed CERCA 01 packages.

The mechanical study was carried out in collaboration with NRG (The Netherlands) who performed the relevant calculations and verification.

The schedule for the completion of this project was very short, starting in January 2006 with the call for bids launched by IAEA and being achieved with the delivery at RPI reactor site in early 2007.

- January 12, 2006: issuing of the call for bids by the IAEA
- February 2006: submission of CERCA proposal
- March 2006: choice of CERCA as the supplier
- April 2006: completion of the mechanical design study and start of manufacturing
- December 2006: end of manufacturing
- January, 2007: inspection at Romans facility and assemblies ready for delivery to RPI.

CONVERSION

Fig. 1 shows the initial LEU core configuration. LS1 through LS7 are standard assemblies and LC1 through LC4 are control assemblies. The shim-safety rods are mounted in assemblies LC1 to LC4; the regulating rod in assembly LC5. In Fig. 1, NS is a Sb-Be neutron source, FC a fission chamber and the DA are dummy assemblies. Rows 7 to 9 of the core grid plate are not shown for simplification.

An approach to criticality was made in several steps, starting without fuel assemblies LS6 and LS7 and without the two large Be reflector blocks. One fuel assembly or reflector was added for each step. The shim-safety rods were slowly extracted for each of the steps. An extrapolation of the position of the rods at criticality was made using the standard inverse multiplication curve, which provided good guidance of the criticality positions.

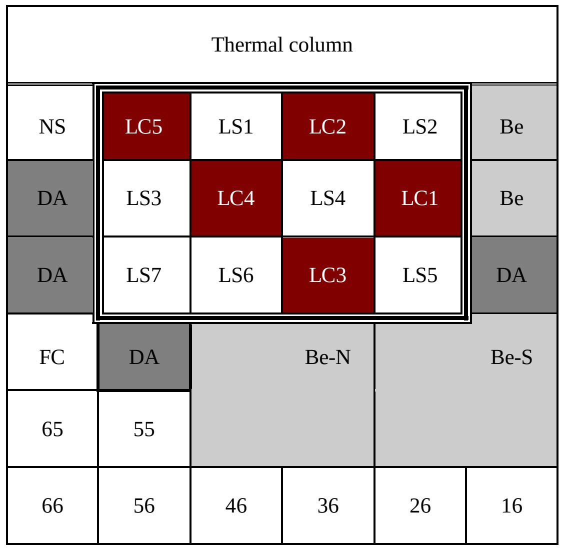

Figure 1. Initial LEU Core Configuration.
LS1 through LS7 are standard assemblies and LC1 through LC4 are control assemblies; NS is the neutron source, FC a fission chamber and DA a dummy assembly.

The regulating rod was calibrated using the positive period method. The shim-safety rods were calibrated in pairs B1/B2 and B3/B4 by comparison with a known displacement of the regulating rod. At the end of these calibrations, the safety parameters of Table 3 were determined, where B1 through B4 represent the shim-safety rod worths.

Table 3. Compliance with Safety Parameters

Parameter		Value	Requirement	Measured
1	BOC Core Excess Reactivity, % Δk/k	E	< 4.80	4.11
2	Total Shutdown Subcriticality[1], % Δk/k	E – (B1+B2+B3+B4+BR)	< -3.00	-9.09
3	Minimum Shutdown Subcriticality[2], % Δk/k	E – (B1+B2+B3)	< -1.00	-4.73
4	Regulating rod worth, % Δk/k	BR	< 0.60	0.33

[1] With all shim-safety rods and the regulating rod inserted in the core with the core cold and xenon-free.

[2] With shim-safety rod of maximum worth (B4) and the regulating rod stuck out of the core with the core cold and xenon-free.

The OLC limit the excess reactivity (parameter 1) to 4.8% Δk/k. Thus the measured value is clearly below this requirement. The OLC specify that the total shutdown subcriticality (parameter 2) must be at least -3.00 % Δk/k. The measured value of -9.09 % Δk/k thus exceeds this by far. The same is applicable for the minimum shutdown criticality (parameter 3), which is required to be at least -1.00 % Δk/k and is -4.73 % Δk/k. The regulating rod worth is well below the limit of 0.6% Δk/k, at about half of this value. Thus all safety parameters, as shown in Table 3, are in full compliance with the limits as set by the OLC.

Table 4. Comparison between measured and calculated safety parameters

Parameter		Measured value	Calculated value	Difference measured – calculated
1	BOC Core Excess Reactivity, % Δk/k	4.11	3.03	+1.08
4	Regulating rod worth, % Δk/k	0.33	0.46	-0.13

Table 4 compares the measured with the calculated values for the most critical safety parameters. The measured excess reactivity was 1.08% Δk/k higher than calculated. Part of the observed difference is due to conservative assumptions on the clad composition. The chemical analysis of the AG3NE lot used for fabrication shows that it has about half the boron amount conservatively assumed in the calculations for the (equivalent) 6061 alloy. This alone accounts for an increase of the calculated excess reactivity of about 0.5% Δk/k [7], or about half the observed difference. The agreement for the regulating rod worth is good.

CONCLUSIONS

Core conversion of the Portuguese Research Reactor to LEU fuel is being performed within IAEA's Technical Cooperation project POR/4/016, with financial support from the US and Portugal. It has been a clear collaborative effort between the US, Portugal, the IAEA and CERCA.

CERCA has been involved for around thirty years in international cooperation with the RERTR Program, starting in 1978 with the development of U_3O_8 fuels, then U_3Si_2 fuels and now U-Mo fuel. This is why since 1985, CERCA has been chosen by its customers for reactor conversions for MTR and TRIGA reactors worldwide as in Japan, Germany (amongst which GKSS, the first to be converted), and France. With the new GTRI Program, the reactor conversion program has been significantly accelerated and these last three years CERCA has been a major key player by supplying in due time, the first and new LEU fuels in the Netherlands, South Africa, Japan, Australia, Romania and the US. The story is still going on as since 2007, CERCA has been involved in the reactor conversion of the MARIA Reactor in Poland and has recently signed a long term contract for the conversion of at least four TRIGA Reactors in the US.

For Portugal, CERCA provided a comprehensive package, which included the mechanical verification of the design of the assemblies, their manufacture and arrangements for a joint inspection of the finished assemblies. With this supply, successfully completed in a tight schedule, CERCA has gained additional competences as regards to reactor conversion and has developed new relationships with ITN. It has also strengthened the long-lasting relationships between the IAEA and CERCA and developed mutual benefit for the two entities.

The actual core conversion of the RPI to LEU fuel was done in early September 2007. All measured safety parameters are within the defined acceptance limits. A report was submitted to the local authorities and operation at full power is expected by the end of October, once permission is granted to the gradual approach to 1 MW.

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