CORE CONVERSION OF THE PORTUGUESE RESEARCH REACTOR

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ABSTRACT
Core conversion of the Portuguese Research Reactor (RPI) to low enriched uranium (LEU) fuel is being performed within the International Atomic Energy Agency (IAEA) Technical Cooperation project POR/4/016, with financial support from the U.S. and Portugal. The RPI is a 1 MW pool-type reactor commissioned in 1961. It started up using LEU fuel but a decision to convert it to highly enriched uranium (HEU) fuel was taken in the early seventies for economic reasons. However, HEU fuel only started being used in 1990, after a refurbishment of the reactor, at a time when many research reactors were converting instead to LEU fuel. The announcement in the end of 2004 of the 10 year extension on the U.S. foreign research reactor spent fuel acceptance policy opened a new window of opportunity for the operation of the RPI with LEU fuel. The safety analyses for the core conversion were made with the assistance of the Global Threat Reduction Initiative (GTRI) Conversion program and were submitted for regulatory approval in January 2007. At the time of writing of this paper, the core conversion to LEU fuel is expected in the summer of 2007.

INTRODUCTION
The Portuguese Research Reactor (RPI) 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 during the period of 1959-61 in the then “Laboratory for Nuclear Physics and Engineering” (LFEN in Portuguese). 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 hundreds of experimental works for graduate and post-graduate studies in physics, chemistry and biology. 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 high school and university students.

The RPI was commissioned with low enriched uranium (LEU fuel), supplied with the reactor on a lease agreement. With the change of U.S. Atomic Energy Commission (AEC) policy on leasing special nuclear materials in 1973, LFEN initiated the process to buy new fuel, of the highly enriched uranium (HEU) type. At the same time, efforts were made to arrange for the reprocessing of the LEU fuel until the end of 1974, which ended up not being possible and led to the decision to buy this fuel. The new HEU fuel was received in August 1974. One should mention that the acquisition of HEU was then proposed to Portugal, as it would decrease the costs, compared with the LEU fuel acquisition that LFEN was initially considering.

Since the LEU fuel could continue to be used, there was no immediate need for the HEU fuel. In 1981 a leakage in the primary system forced operation at low power (100 kW) further decreasing the uranium consumption. The primary piping of the RPI was embedded in its structure. This meant it was impossible to perform what could have been a simple repair and made it necessary to replace the whole primary piping. However, the necessary funds could only be secured in the end of the eighties, with a significant assistance from the International Atomic Energy Agency (IAEA), under the Technical Cooperation programme. The RPI was stopped in 1987/89 for a major refurbishment in which the pool lining was also replaced and new control rods and mechanisms were mounted [4]. The operation with HEU was only started at the end of this period.

Through this conjunction of factors, the RPI started using HEU fuel in 1990, well after the establishment of the U.S. Reduced Enrichment for Research and Test Reactors (RERTR) program (now known as the GTRI Conversion program), at a time when the conversion to LEU fuel was already being addressed in many research reactors.

In 1999 ITN declared its interest to participate in the U.S. Foreign Research Reactor Spent Nuclear Fuel (FRRSNF) Acceptance Program (now known as the GTRI U.S. Remove program). A commitment was made to stop using HEU after May 12, 2006 and return all HEU fuel until May 12, 2009. The LEU assemblies used since 1961, which had by then up to 38 years in the reactor's pool, were returned to the U.S. in the summer of 1999 [5].

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, which delayed all actions. Reprocessing that fuel seemed to be the most viable option. However, since Portugal has no other reactors and a nuclear power programme is not foreseen, the storage of the high or intermediate level waste generated by the reprocessing would be a technical and political problem. The announcement of the closing down of several European reactors on or before 2006 also had a considerable negative impact.

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 will be performed within IAEA's Technical Cooperation project POR/4/016, approved in early 2005, with financial support of the U.S. 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.

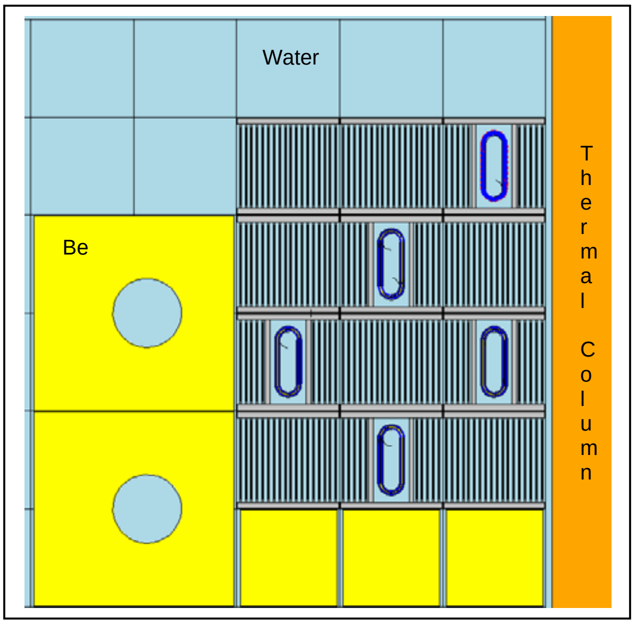
Table 1. Milestones for the conversion project

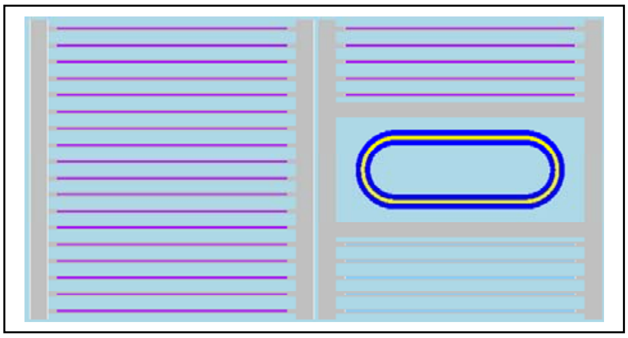
Milestone	Planned	Effective
Commitments for funding	Mid 2005	As planned
Feasibility study	End of 2005	As planned
Safety studies	Mid 2006	End of 2006
Project and Supply Agreement	Mid 2006	Early 2007
Fuel delivery	End of 2006	Early 2007
Regulatory Approval	Early 2007	Pending
Conversion	Early 2007	Pending
Return of HEU fuel	Before May 12, 2009	--

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. 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 core funding covering only expert 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 U.S. and Portuguese governments agreeing to the main points on shared funding for the project.

A joint feasibility study between ITN and the GTRI Conversion 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. 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 GTRI U.S. Remove (formerly FRRSNF) program is valid (estimated at 500 MWd, maintaining current operating levels).

Figure 1 shows the model for the HEU core configuration P1/2 using the MCNP Monte Carlo code [6]. Technically this was the second HEU core, but its predecessor was only used for tests and the commissioning process was done with this core.





Standard Fuel Assembly   Control Fuel Assembly

Above: Enlarged view of a standard fuel assembly with 18 fuel plates (left) adjacent to a control fuel assembly with 10 fuel plates and an oval-shaped shim-safety control rod (right) used in the MCNP model.

Figure 1. MCNP model of RPI’s core configuration P1/2 selected as reference.

Uranium silicide (U_3Si_2-Al) dispersion fuel [7] 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. The feasibility study has shown that an increase of 0.1 mm in the meat thickness (to 0.6 mm) would decrease the number of assemblies required for operation until 2016. With the increase in the meat thickness, the ^{235}U loading per LEU standard assembly is 376 g compared with 265 g per HEU standard assembly. The 500 MWd goal was achieved with a total of 14 LEU fuel assemblies in four core configurations. The results were presented in the RERTR conference in 2005 [8].

The detailed safety analyses were performed by ANL and ITN during 2006. They were preceded by two expert missions organized by the IAEA to examine the status of the safety documentation and make recommendations on the studies to be performed for the core conversion.

No changes in the control rods, control rod mechanisms, or the reactor control and instrumentation are necessary. The core size remains unchanged with the conversion to LEU fuel and no significant flux penalties are foreseen. Neutron fluxes in key experiment positions were compared for the HEU and LEU cores. Calculated thermal fluxes in the beryllium experiment blocks of the LEU core ranged from 1% - 9% lower than in the HEU core, with one position lower by about 16% in the fresh core, largely due to differences in the initial core configurations. The thermal flux at a selected beam tube entry was 0 – 2% larger in three of the four LEU cores. In the fresh LEU core, this loss is about 17%, again largely due to differences in the initial HEU and LEU core configurations.

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. The main results were presented in the RERTR conference in 2006 [9]. The detailed safety studies took longer than originally foreseen. While for the neutronic studies all information was readily available and a very basic MCNP model existed [10], additional information was needed on the reactor thermal-hydraulics parameters, taking into account the somewhat limited studies performed in the eighties for the conversion to HEU.

The most challenging aspect of the conversion (thus far) was the conclusion of a tripartite agreement between the IAEA and the US and Portuguese Governments. This is a necessary step before special nuclear material is supplied through the IAEA. The agreement was approved by the Board of Governors of the IAEA in June 2006. However, it took about 10 months for its entry into force. This significant delay contributed the need to get a “nihil obstat” from the European Commission, as well as a rather complicated ratification process in Portugal, imposed by the Constitution.

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, GTRI 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. May 31, 2007 is the final deadline, so as to guarantee the timely shipment of the HEU, expected in 2008.

The submission of the safety documentation for approval, initially foreseen in mid 2006, was delayed by about 6 months. As per the text of the tripartite agreement, Portugal is committed to ensure safety conditions as recommended in the Safety of Research Reactors, Safety Requirements edition of 2005 [11] and the IAEA must give its consent for the start of the conversion. 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. A revised report was finished in the end of May 2007.

As stated in the preamble of Decree 5/2007, publishing the tripartite agreement, Portugal recognizes the need to reduce the use of HEU in civilian applications and to replace it by LEU. With the return of its HEU, Portugal will cease to be a member of the 40+ non-nuclear-weapons states which still had this type of material, as of the end of 2003 [12]. Although HEU is the "leitmotif" of the current policies, one must emphasise that take-back programmes or a regional or international repository for research reactor fuel are of extreme importance for countries with no nuclear power programmes, as the construction of geological repositories for small amounts of spent fuel or waste from reprocessing is obviously not practicable.

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. No changes in the control rods, control rod mechanisms, or the reactor control and instrumentation system are necessary for the conversion. The core size remains unchanged and no significant flux penalties are foreseen after conversion. The safety analyses for the core conversion were made with the assistance of the GTRI Conversion (formerly RERTR) program and were submitted for regulatory approval in January 2007. The core conversion to LEU fuel is expected in the summer of 2007 and the shipment of the HEU fuel is expected in 2008.

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