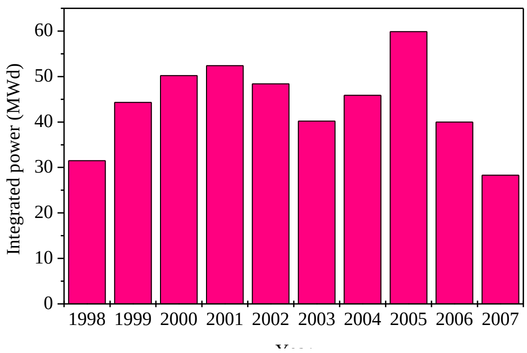
OPERATION AND EXPLOITATION OF THE REACTOR, DOSIMETRY (RPI) AND REACTOR CALCULATIONS

José Gonçalves Marques

The main objective of the Operation and Exploitation of the Portuguese Research Reactor (RPI) is to be able to satisfy the users' needs while conducting all tasks with the assurance that the reactor is operated in a safe and reliable manner by a highly competent and motivated staff. The implementation of such objectives demands a variety of activities, some of which are repetitive in objective and variable in content, while others address specific aspects of the same end situation.

The activities in 2007 were clearly dominated by the preparation for core conversion to low enriched uranium (LEU) fuel and its execution. Regulatory approval for conversion was granted in August and the actual core conversion was done in September and October, following a previously defined program. No loss of performance of the reactor was observed after conversion.



A new state-of-the-art setup for Perturbed Angular Correlation Experiments with short-lived isotopes was installed this year, as well as a setup for monochromatic neutron beams. A setup for neutron tomography suffered a significant delay and is now expected to become operational by the summer of 2008.

The main users of the reactor are described in the Table below.

User	Area	Time (%)
RPI	Dosimetry and Test of Detectors	35.4
	NAA	27.5
	Isotope Production	5.5
Chemistry	NAA	12.2
	Isotope Production	1.2
DPRSN	Isotope Production	4.8
Univ. Lisboa	Isotope Production	12.7
LIP/Lisboa	Isotope Production	0.1
IVIA	Radiation Effects	0.3
Univ. Coimbra	Isotope Production	0.4

The figure to the left indicates the integrated power produced by the RPI in the last 10 years. The decreases observed in 2006 and 2007 are related with the core conversion. In 2006 the reactor was stopped for 2 months, until an extension on the use of HEU was granted by the Department of Energy of the USA; in 2007 it was stopped for 5 months, from the agreed end of use of HEU on May 31, to resuming routine operation at 1 MW with the new LEU core

Research Team

Researchers

J.G. MARQUES, Princ.
A. KLING, Aux. (95%)
N. P. BARRADAS, Princ. (90%)
A. FALCÃO, Princ.
A.R. RAMOS, Aux. (90%)

Students

M.A.F. da COSTA, MSc Student, IST, ITN grant
A. RICO, MSc. Student, FCT, ITN grant

Reactor Operators

J. A. M. RIBEIRO
J. C. ROXO
N. SERROTE
R. SANTOS

Technical Personnel

R. POMBO
F. B. GOMES
A. RODRIGUES
J. S. SOUSA

Collaborators

T. GIRARD, CFNUL
T. MORLAT, Post-doc., CFNUL
F. GIULIANI, Post-doc., CFNUL
A.P. FERNANDES, HSM/CFNUL

Core Conversion of the RPI to LEU Fuel

J.G. Marques, N.P.Barradas, A. Kling, A.R. Ramos, J.P. Santos

Objectives

Core conversion of the RPI to Low Enriched Uranium (LEU) fuel was performed within IAEA's Technical Cooperation project POR/4/016. The core conversion took two years to complete, from the initial feasibility study to the actual core change, done in September 2007. The performance of the new LEU core is identical to that of previous cores built with High Enriched Uranium (HEU).

Results

A feasibility study was performed during 2005 with the assistance of the RERTR program at Argonne National Laboratory. Uranium silicide (U_3Si_2-Al) dispersion fuel with a 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. The new LEU standard assembly has a ^{235}U loading of 376 g vs. 265 g for an HEU standard assembly. With this design the core size remained unchanged, at 12 assemblies. The number of plates was kept the same as for the HEU fuel.

The results of neutronic studies, steady-state thermal-hydraulic analyses and accident analyses, made in 2006, demonstrated that the RPI could be operated safely with the new LEU fuel. The IAEA reviewed these studies, as required by the tripartite agreement between the IAEA, Portugal and the USA. Revised documents were submitted in May 2007 addressing the issues raised during review. The IAEA provided a letter of support for the conversion in late June and the licensing body of the RPI approved the conversion in August 2007.

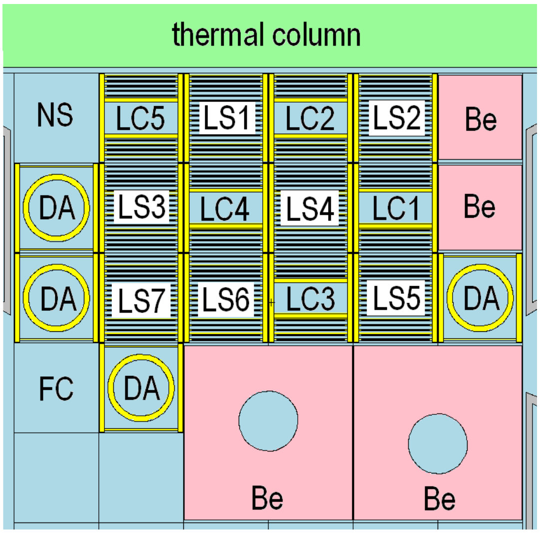


Fig 1. New LEU core, adapted from MCNP model output.

Fig. 1 shows the initial LEU core configuration. LS1 through LS7 are standard assemblies and LC1 through LC5 are control assemblies, NS is a Sb-Be neutron source, FC a fission chamber and the DA are hollow dummy assemblies. The dummy assemblies were introduced in the core in order to improve the thermal hydraulic safety margins

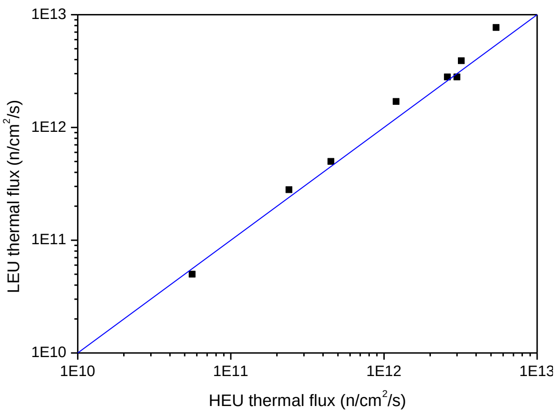


Fig. 2. Thermal neutron flux in pool irradiation positions for the new LEU core vs. a comparable HEU core.

Figure 2 shows a comparison of measured thermal fluxes for the new LEU core and a comparable HEU core. The average ratio between the thermal fluxes measured in the HEU and LEU cores is 0.9 ± 0.3, covering two orders of magnitude of the flux values. From the available data there is no clear loss or gain of thermal neutron flux with the conversion to LEU. Furthermore, the LEU core has 2 additional irradiation positions, inside the hollow dummy assemblies in positions 13 and 54, which have thermal neutron fluxes of 1.9×10^{13} and 1.8×10^{13} n/cm^2/s, respectively.

Gamma dose rates were also measured in all free grid positions, at mid-height of the core, using an ionization chamber. The ratio of HEU to LEU values is 1.1 ± 0.2, in agreement with the expected – as the LEU core has significantly more ^{238}U a higher attenuation should occur.

Work in progress includes the measurement of neutron fluxes and gamma dose rates in the beam tubes and improvements in the as-built MCNP model of the core.

New Spectrometer for Perturbed Angular Correlation Experiments
J.G. Marques, C. Cruz

Perturbed Angular Correlation (PAC) is a well known nuclear technique used in the characterization of materials at a microscopic scale. A state-of-the-art spectrometer for PAC studies using short-lived isotopes produced in the reactor was installed during 2007. The thermal neutron flux available for this application is 2E13 n/cm^2/s, which makes it possible to produce in just a few minutes enough activity. No long and bureaucratic transports of radioactive isotopes are necessary, since the analyzing facility is at the reactor. LSO scintillators were used for the detectors. These have higher detection efficiency than the commonly used BaF_2 scintillators, as well as a better energy resolution, although a slightly worse time resolution. Photomultiplier bases, able to handle count rates in excess of 100 kcps, as well as signal processing units, which are not commercially available, were developed locally, which allowed a significant reduction in the number of units and interconnections. The whole electronics for the spectrometer only required two standard NIM bins – which is half of the usually required.

Photon Dosimetry Using Red 4034 Harwell Dosemeters
J.P. Santos, J.G. Marques

The performance of Red 4034 Perspex dosemeters from Harwell Technologies in routine photon dosimetry in mixed fields was evaluated. The dosemeters were irradiated in core grid positions of the RPI under a photon dose rate of the order of 1E4 Gy/h, a thermal neutron flux in the range of 0.2-1.1E11 n/cm^2/s and temperatures below 40 ºC. Red 4034 visibly darkens upon irradiation and this effect, accurately measurable by spectrophotometry, is related to absorbed dose. Thermoluminescence dosemeters and a calibrated ionization chamber were used as comparison. The results show that Red 4034 performs relatively well in mixed fields, having determined photon doses with good linearity up to 50 kGy. A comparison of the three methods applied to determine the photon dose shows an agreement within 10%, which is acceptable for the intended application. Experiments at powers above a few tenths of MW cannot be directly monitored by Red 4034, but the characterization of the irradiation position at full power can be done at a lower power, e.g., 100 kW, and the results extrapolated. We recommend the use of a ^{16}N linear channel to minimize errors in the scaling of the values.

Neutron Tomography at the RPI
A. Rico, J.G. Marques

Neutron radiography is a well established non-destructive analysis method. Compared with X-rays, neutrons have as specific advantages a high interaction probability with hydrogen and a lower attenuation in several heavy elements which are "black" for X-rays. Tomography requires a reasonably high number of 2D images in digital form of the observed object rotated over 180 degrees related to its central axis. With modern CCD cameras it is possible to obtain 2D images in less than one minute, even for modest neutron fluxes of the order of 1E5 n/cm^2/s. A setup for neutron tomography will be implemented in beam line E4, through the installation of a removable divergent collimator in the irradiation cavity. The setup includes a ZnS:Ag scintillator screen, a FingerLakes CCD camera with fast readout and a rotary table where the object is placed in front of the beam. The beam will have 20 cm diameter, which is enough for a significant number of applications. Procurement of the major components could only be finished this year. A MATLAB interface for the CCD camera had to be developed, given the instability of the software provided by the manufacturer. This unexpected time-consuming task together with the unavailability of the reactor for 5 months delayed significantly the project, which is now expected to be complete by the summer of 2008.

Stability and Criticality Safety of the RPI Storage Crates for Spent and Fresh Fuel
N.P. Barradas, J.G. Marques

The RPI uses two storage crates that can hold up to 20 assemblies in the pool. The existing criticality studies were extended to include the new fuel assemblies. It was concluded that a full crate filled with HEU assemblies, LEU assemblies, or a mix of these is always sub-critical. As part of the safety studies for reactor conversion, the stability of these crates under earthquake was also studied. We concluded that the center of mass of the crates is not affected by loading of fuel assemblies, and that the forces to which it is submitted during the postulated reference earthquake, as defined by Portuguese Legislation, do not lead to a crate overturn. Accidental criticality due to the reference earthquake is therefore ruled out. The crates for storage of fresh fuel, which have a similar geometrical arrangement regarding criticality, are screwed to the building and thus cannot overturn.

Development of Superheated Droplet Detectors (SDD) for Neutron Dosimetry and Spectrometry Applications

A.R. Ramos, M. Felizardo, T. A. Girard[1], J. G. Marques, A.C. Fernandes[1,2], T. Morlat[1], F. Giuliani[1], Bohumil Jansky[3], Evzen Novak[3]

The objective of the project is to develop inexpensive and ecologically friendly SDD detectors for use in neutron dosimetry and spectrometry. The main objectives accomplished in 2007 were the following: -To fully characterize the SDD response using filtered neutron beams provided by passive monochromators; -To investigate the use of the fabricated SDDs as neutron spectrometers. Following the MCNP simulations performed in 2006, two new passive monochromators were finally built and successively installed in beam port E4 to perform the necessary measurements with the SDDs prepared at RPI. Measurements were performed in May 2007 and again in November 2007, after core conversion. Independent beam characterization was performed with proton recoil detectors in November 2007.

[1] CFN da Universidade de Lisboa, Av. Prof. Gama Pinto 2, 1649-003 Lisboa, Portugal
[2] Hospital de Santa Maria, Av. Prof. Egas Moniz, 1649-035 Lisboa, Portugal
[3] Nuclear Research Institute - Nuclear Power and Safety division- Dep. of Experimental Reactor Physics- Czech Republic

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SIMPLE Dark Matter Search

TA Girard[1], T.A. Morlat[1], F. Giuliani[1], M. Felizardo, A. R. Ramos, J.G. Marques, G. Waysand[2], H.S. Miley[3], R.F. Payne[3]

This project is a search for evidence of weakly interacting massive particle (WIMP) dark matter. It is based on superheated droplet detectors (SDDs), which because of their thermodynamic thresholds provide an intrinsic background rejection factor of 10^9 comparable to the noble gas experiments. The search is conducted in the Laboratoire Souterrain à Bas Bruit (LSBB: Rustrel, France); it is R&D-supported by the SIMPLE-Lx laboratory at ITN. The response of small volume SDDs based on C_4F_{10}, C_3F_8, C_4F_8 and CF_3I to neutron and γ irradiations was explored in January using Si+Ti filters on the thermal column of the RPI. Previous SDDs being light nuclei C_2ClF_5, their impact has been primarily in the spin-dependent sector of the WIMP-nucleus interaction. A heavy nuclei CF_3I SDD prototype, intended to probe the spin-independent sector and developed at ITN, was tested underground. The results yielded a 10^{-1} pb minimum in the cross section contour at ~ 200 GeV; operated at 37ºC (8 keV recoil threshold energy) with the same result, the contour minimum is improved by $5x10^3$ pb , with the contour minimum shifted to 50 GeV. This is a factor 10 better than the current result, with 25% of the exposure – the difference resulting from using improved acoustic instrumentation able to discriminate microleaks. Also during the year, a C_2ClF_5 standard detector fabricated with agarose demonstrated a factor 2.5 increase in lifetime. A microphone-based electronics was developed, capable of discriminating true nucleation events from the acoustic backgrounds associated with SDD operation (microleaks, trapped N2 gas, fractures…). Development of a “Big Droplet Chamber” in collaboration with Dr. J. Puibasset (Orleans) was initiated in October, with a design goal of 30 g active freon mass and a previously-measured metastable lifetime of order 2 hrs. At the year’s end, SIMPLE was accepted into FP7 ILIAS-NEXT as part of WP1/3.

[1] Centro de Física Nuclear, Universidade de Lisboa, 1649-003 Lisbon, Portugal
[2] Laboratoire Souterrain à Bas Bruit, 84400 Rustrel-Pays d'Apt, France
[3] Pacific Northwest National Laboratory, Richland, WA 99352 USA

Improvement of the RPI Radiation Protection Monitoring

A. Kling, A. R. Ramos, J. G. Marques

The monitoring of the radiation levels in the interior of the reactor hall and of radioactive gaseous effluents is of high importance for the safe operation of a research reactor. During the year 2007 the main focus was the modernization of the monitoring within the reactor hall. The existing aging real-time aerosol monitor (Merlin-Gerin CMDB) was replaced by a modern Merlin-Gerin ABPM201L aerosol monitoring system, identical with the one recently installed in the stack. Further, new detectors were acquired that will substitute the existing ionization chambers used for the monitoring of the gamma radiation levels at various points. At present, the development of software for a computer-based readout and data recording of these new detectors is in progress.

According to recommendation made by the control team for the Article 35 of the EURATOM treaty during their visit to the RPI in November 2006 the analysis of the data recorded by the various monitoring systems in the reactor hall and the stack exhaust has been further automated by the development of new programs. Further an additional procedure for integral measurements on aerosols and ^{131}I by gamma spectroscopy in the weekly replaced filters from the stack exhaust monitors has been implemented.