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

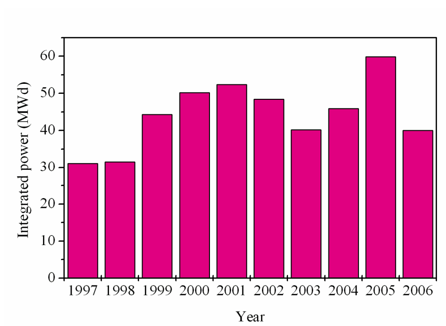
José Gonçalves Marques

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.

An intensive activity in reactor calculations has continued, to prepare the core conversion to low enriched, high density, U_3Si_2-Al fuel. The safety studies were completed this year with assistance from the Argonne National Laboratory (USA). No loss of performance of the reactor is expected after conversion.

The laboratory for fabrication of Superheated Droplet Detectors installed in 2004 was in full use, with three research projects funded by FCT.

Significant improvements were made in the signal to noise conditions for the Emission Channelling and Blocking setup. Fast electronics was developed for a state-of-the-art setup for Perturbed Angular Correlation Experiments with short-lived isotopes.



The programme for testing of electronic components and circuits under fast neutron irradiation for CERN was completed. Two setups, for neutron tomography, and another for monochromatic neutron beams, are being prepared, to share this beam line without significant changes to the existing installation.

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

User	Area	Time (%)
RPI	NAA	25.3
	Dosimetry and Test of Detectors	17.3
	Other (training, etc)	0.1
Physics	Radiation Effects	17.8
	Neutron Scattering	8.1
Chemistry	NAA	15.4
	Isotope Production	3.1
DPRSN	Isotope Production	4.2
Univ. Lisboa	Isotope Production	7.6
LIP/Lisboa	Isotope Production	0.5
	Radiation Effects	0.1
IVIA	Radiation Effects	0.3
Univ. Coimbra	Isotope Production	0.1
Univ. Porto	Isotope Production	0.1

The figure indicates the integrated power produced by the RPI in the last 10 years. A clear increase in the use of the reactor is seen since 1999. The integrated power for 2006 was 40 MWd, lower than the previous year, but close to previous years. This decrease reflects a somewhat lower NAA activity at ITN due to the renewal of the laboratories as well as a significant period of no-operation of the reactor until an agreement was reached with the US on a prolongation of the use of the current fuel.

Research Team

Researchers

J.G. MARQUES, Principal Researcher
A. KLING, Auxiliary Researcher (90%)
N. P. BARRADAS, Principal Researcher (95%)
A. FALCÃO, Principal Researcher
A.R. RAMOS, Auxiliary Researcher (90%)

Students

A. FERNANDES, Post-doc, ITN, FCT grant
M.A.F. da COSTA, MSc Student, IST, ITN grant

Reactor Operators

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

Technical Personnel

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

Collaborators

T. Girard, CFNUL
Tomoko Morlat, Post Doc, CFNUL
Franco Giuliani, Post Doc, CFNUL

Core Conversion of the RPI to LEU Fuel: Safety Analyses

J.G. Marques, N.P.Barradas, A. Kling, A.R. Ramos, J.E. Matos[1], J.G. Stevens[1], E.E. Feldman[1], J.A. Stillman[1], F.E. Dunn[1], M. Kalimullah[1]

Objectives

The core conversion of the Portuguese Research Reactor (RPI) to Low Enriched Uranium (LEU) fuel will be performed within IAEA's Technical Cooperation project POR/4/016. This project was approved in the end of 2004, with financial support from the US and Portuguese governments. The safety analyses for core conversion [1] were made by ITN and the RERTR program at Argonne National Laboratory.

Results

LEU 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 existing manufacturers. The procurement of the assemblies was made by the IAEA in 2006, based on the feasibility study made in 2005.

An extensive study was completed in 2006, addressing the reactor design, performance and safety analyses that would enable conversion of the reactor fuel from HEU to LEU. Documents that were reviewed by ANL as bases for the design and safety evaluations were the RPI Operating Limits and Conditions (OLC), design drawings, and historic analyses of the facility. All of the additional information and data needed to construct the reactor models and perform the analyses were provided by ITN. The methods and codes that were utilized have been qualified by extensive conversion analysis experience and international benchmark. Accident analyses were completed for a number of postulated initiating events, following the recommendations in the 2005 edition of the Safety Requirements for Research Reactors of the IAEA (NS-R-4).

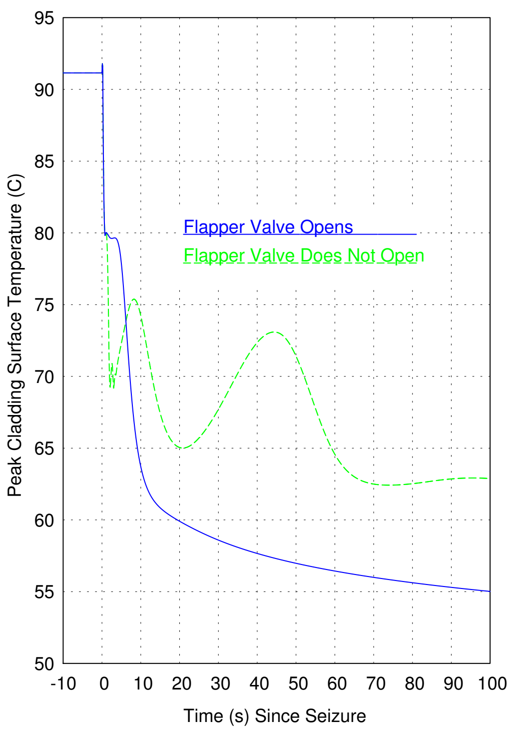


Fig 1. *Peak cladding surface temperature as function of the time after primary pump seizure.*

Figure 1 shows the peak temperature of the fuel cladding as function of time after a postulated seizure of the pump of the primary cooling system, with the reactor working at the nominal power of 1 MW. A failure of the fastest acting safety shutdown system was also considered. Peak cladding surface temperatures of about 93 ^{o}C were reached before the scram was initiated. The maximum temperatures attained in all simulated transients are far below the safety limit of 530 ^{o}C for the fuel and cladding temperatures recommended by the US Nuclear Regulatory Commission and show that the LEU core can be adequately cooled by natural convection.

The results of neutronic studies, steady-state thermal-hydraulic analyses, accident analyses, and revisions to the OLC demonstrate that the RPI can be operated safely with the new LEU fuel assemblies. The conversion is expected to occur in 2007.

Published work

J.E. Matos, J.G. Stevens, E.E. Feldman, J.A. Stillman, F.E. Dunn, K. Kalimullah, J.G. Marques, N.P. Barradas, A.R. Ramos, A. Kling, Core Conversion Analyses For the Portuguese Research Reactor, *Proc. Int. Meeting on Reduced Enrichment for Research and Test Reactors,* Cape Town, South Africa, 2006, Argonne National Laboratory, Paper 5-1.

[1]RERTR Program, Argonne National Laboratory Argonne, IL USA 60439

Fast Neutron Irradiation of Electronic Circuits

J.G. Marques, A.C. Fernandes, J.A. Agapito[1], F.J. Franco[1], Y. Zong[1]

Temperature measurement is a key issue in the LHC facility at CERN, as it will be used to regulate the cooling of the superconductor magnets. The signal conditioners for cryogenic thermometry are expected to receive a fast neutron fluence of the order of 2E13 n/cm^2 during a 10 year period, as well as a gamma dose of 500 Gy, and this can affect the operation of commercial circuits used in their construction. The operating conditions of the circuits are simulated using a fast neutron irradiation facility built in the RPI in 2000. The irradiation of components for CERN was concluded in 2006. The same facility was used to irradiate seeds for IVIA (Spain) and motion sensors for LIP (Lisboa). The use of their facility will continue in 2007-2009 in the framework of FP6 Integrated Infrastructure Initiative for Materials Testing Reactors Innovations (MTR-I3) that started in October 2006.

[1] Universidad Complutense de Madrid.

Development of Signal Processing Units 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 project is underway to install at the Portuguese Research Reactor a state-of-the-art spectrometer for Perturbed Angular Correlation studies using short-lived isotopes produced in the reactor. This is one area where a medium power reactor (1 MW) can be competitive at the European level. The thermal neutron flux available for this application is 2E13 n/cm2/s, which makes it possible to produce in just a few minutes enough activity to analyze the sample. No long and bureaucratic transports of radioactive isotopes, which hamper the use of short-lived isotopes, are necessary, since the analyzing facility is at the reactor. High count rate 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. Surface mounted ECL logic circuits were used for the signal processing units, which allowed a high integration scale, with a significant reduction in the number of units and interconnections. The spectrometer is expected to be ready in the Spring of 2007.

The SIMPLE Project

T.A.Girard[1], F.Giuliani[1], T.Morlat[1], J.I.Collar[2], D.Limagne[3], G Waysand[3,5],J.Puibasset[3],H.S. Miley[4],M Auguste[5], D. Boyer[5], A. Cavaillou[5], J.G. Marques, C. Oliveira, A.C. Fernandes[1,6], A.R. Ramos, M. Felizardo, R.C. Martins[7]

During 2006 a new underground (210 mwe) SDD fabrication station was made operational in the Laboratoire Souterrain à Bas Bruit. Initial testing consisted of the fabrications of two each CF3I SDDs and two each R-115 devices, all of which were installed in the deeper (1500 mwe) GESA site and operated (one of the R-115 devices remains running, to determine if underground fabrication increases the device lifetime). The radio-assays of detector construction materials, and of LSBB rock samples collected during the MAY/2006 mission, have been completed at PNNL via low-level α- and γ-spectroscopy. The U/Th contamination of the gel, measured at the level of $\leq$0.1 ppb, yields an overall α background of < 0.5 evts/kgfreon/d; the same levels were observed with the glass of the detector containment. A new DAQ electronics, based on a new high-quality Panasonic MCE-200 electret microphone cartridge with adaptive electronics (PGA2500), continued to undergo testing. In this design, the electronics have been removed from close proximity to the microphone to outside the detector itself. Extensive studies of the new instrumentation were made, involving variations of the SDD volume, refrigerant, temperature & pressure, and droplet size. Response studies of new SDDs based on C4F10, CF3I, C4F8 and C3F8 were initiated using the Si+Ti (155 keV) filtered neutron beam column on the RPI thermal port. A new C4F10 device was made without the addition of heavy salts to density match the gel and refrigerant; two prototypes were delivered to PICASSO in July as part of the MOU between projects, and their response tested.

[1] Centro de Física Nuclear, Univ. Lisboa, [2] Dep. Physics, Univ. Chicago, USA, INSP, Univ. Paris, [4] Pacific Northwest Nat. Lab., Richland, USA, [5] Lab. Souterrain à Bas Bruit, France, [6] Hospital de Santa Maria, Portugal, [7] Dep. Electronics, Instituto Superior Técnico, Portugal

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Test of the Emission Channeling Experiment with Neutron Induced Reactions

P. Marques, A. Kling, J. G. Marques

Emission channeling is a powerful tool for the investigation of structural properties of crystalline materials. In contrast to the classical method using radioactive probe atoms incorporated in the lattice, the set-up at RPI uses charged particles arising from thermal neutron induced nuclear reactions. Channeled particles leaving the crystal are detected by a two-dimensional position sensitive detector located about 60 cm from the target. In the course of the installation of the set-up in 2006 first experiments with a thermal neutron beam from RPI were performed. Charged particles arising from the ^{6}Li(n,τ)α reaction induced by thermal neutrons impinging on a lithium niobate crystal were detected by the position-sensitive detector for the first time. It was possible to increase strongly the number of charged particles produced and detected by optimizing the alignment of the beam with the target and by the reduction of the noise level in the data acquisition system.

Optimization of Filtered Neutron Beams for the Calibration of Superheated Droplet Detectors at the RPI

A.R. Ramos, F. Nascimento[1], A.C. Fernandes[2,3], M. Felizardo, T. Morlat[2], J. G. Marques, F. Giuliani[2], T. A. Girard[2], J. A. Paixão[1]

The neutron spectrum from a nuclear reactor covers a wide energy range, from meV to several MeV. Beams of quasi-monochromatic neutrons can be generated by filtering neutrons emerging from the core with suitable materials, such as Fe (for 24 keV neutrons) and Si (144 keV and 54 keV). These materials have windows in their neutron cross sections, so that neutrons corresponding to these windows are transmitted, whereas neutrons with other energies are attenuated. We have performed an MCNP simulation study of passive monochromators of Si+S and Si+Ti for the production of quasi-monochromatic neutron beams of 54 keV (Si+S) and 144 keV (Si+Ti) at the E4 beam tube of RPI. The simulations allowed the purity versus intensity of the neutron beams to be optimized, within the geometrical constraints of the beam port. The passive monochromators will be used to study the detector response of Superheated droplet detectors (SDDs) prepared in the new SDD lab of RPI.

[1] Univ. Coimbra, Fac. Ciencias & Tecnol, Dept. Fis.,3004-516 Coimbra, Portugal
[2] CFN da Universidade de Lisboa, Av. Prof. Gama Pinto 2, 1649-003 Lisboa, Portugal
[3] Hospital de Santa Maria, Av. Prof. Egas Moniz, 1649-035 Lisboa, Portugal

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Development of a CF3I SDD for Spin-INdependent Dark Matter Searches

T. Morlat[1], M. Felizardo, A. R. Ramos, J.G. Marques, F. Giuliani[1], T. A. Girard[1]

The direct detection of DM relies in measuring the nuclear recoil produced by their elastic scattering off target nuclei. In the case of WIMPs (DM non-relativistic hypothetic particles) of m ~ GeV to TeV, the nuclear recoil energy is in the range of 1-100keV. Due to the low critical energy (Ec) of CF3I e.g. Ec(30ºC)=10.8keV, Ec (20ºC)=33keV increasing to Ec(0ºC)=525 keV, this refrigerant is a good device for either spin dependant (target nuclei=fluorine) and spin independent (target nuclei=Iodine) searches. Heavy CF3I SDDs have never been made before because of the high density of this refrigerant liquid (2 g/cm3) hence require the R&D of a suitable chemistry for device fabrication. Recently a CF3I droplet suspension prototype has been made by using a matrix more viscous than usual. Although the process result is a homogeneous distribution of micron-sized CF3I droplet, improvements are still needed to increase the lifetime of this device.

[1] Centro de Física Nuclear, Universidade de Lisboa, 1649-003 Lisbon, Portugal

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Neutron Tomography at the RPI: First Steps

J G. Marques, A.R. Ramos P. Marques, A. Rico

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 (typically 200) in digital form of the observed object rotated over 180 degrees related to its central axis. With the advent of 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/cm2/s. A setup for neutron tomography will be installed at the RPI. It will be implemented in beam line E4, currently being used for the irradiation of electronic components, through the installation of a removable divergent collimator in the irradiation cavity. The setup includes a ZnS:Ag scintillator screen, a Finger Lakes Proline CCD camera with fast readout and a rotary table where the object to be analysed is placed in front of the beam. The beam will have 20 cm diameter, which is enough for a significant number of applications. After some initial difficulties, the beam collimator is ready for field tests. The setup is expected to be ready in the summer of 2007.

Modernization of the RPI Stack Exhaust Monitoring

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

The monitoring of airborne radioactive effluents is of high importance for the safe operation of a research reactor and the basis for the determination of the radiological impact on the environment. During the year 2006 a main focus was the reinforcement of redundancy of the RPI stack monitoring and the modernization of the existing AIRMON-91 system. The redundancy of the stack exhaust monitoring has been improved by the acquisition and installation of a Merlin-Gerin ABPM201L aerosol monitor. In addition to the existing unit in the AIRMON-91 monitor the new system enables to distinguish alpha- and beta-activity in the aerosol. Further its automatically advancing filter band allows it to work for long periods autonomously. The refurbishment of the AIRMON-91 monitor included the replacement of the quantometer for the flow measurement and the obsolete programmable logic controller by a modern one. These modifications assure that the monitoring of radioactive gaseous effluents from the RPI continues to be performed in a reliable manner.