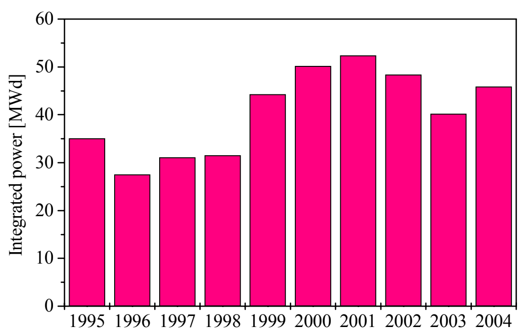
OPERATION AND EXPLOITATION OF THE REACTOR, DOSIMETRY (RPI) AND REACTOR CALCULATIONS

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 activities 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 projects, some of which are repetitive in objective and variable in content, while others address specific aspects of the same end situation. The main set of projects, actual and coming, in which the staff is involved is presented below.

The programme for testing of electronic components and circuits for cryogenic thermometry at LHC/CERN under fast neutron irradiation continued during 2004, as foreseen. The irradiations were performed in a beam tube that was prepared for this effect 4 years ago. The same facility was used for the irradiation of motion sensors for LIP/Lisbon. A systematic study of the behaviour under radiation of commercial pin diodes was also started in this facility.

The activity in the fields of dosimetry has continued at a significant level, mostly addressing the characterisation of irradiation facilities.



The operation of the reactor requires the calculation of parameters such as effective multiplication, control rod worth and safety parameters. An intensive activity in this field has continued, in order to prepare the core conversion to low enriched fuel. Two candidate fuels were examined, namely U_3O_8-Al and U_3Si_2-Al. No significant loss of performance is expected when converting the core to these high density fuels.

The activities using Monte Carlo codes have continued at the same level as last year, with calculation of source terms, shielding and detector response.

A new laboratory for fabrication of Superheated Droplet Detectors was installed this year. The first detectors were tested in the horizontal access of the thermal column, using a setup previously made for a group of the Univ. Paris VII. The installation of the Emission Channelling/Blocking Setup is expected to be finished next Spring.

The main users of the reactor are described in the Table below. The main activity in 2004 was the study of radiation effects in materials (for ITN-Physics and CERN), sensors (for ITN-RPI and LIP Lisbon) and electronic components (CERN), followed closely by Neutron Activation Analysis (NAA), to users in the Reactor and Chemistry. Isotope production has increased by about 50% from last year, but it is still at a modest level.

User	Area	Time (%)
RPI	NAA	21.4
	Radiation Effects	17.0
	Dosimetry and Test of Detectors	6.3
	Other (training, etc)	0.1
Chemistry	NAA	12.8
	Isotope Production	1.7
Physics	Radiation Effects	12.3
	Neutron Scattering	1.7
DPRSN	Isotope Production	4.3
Univ. Lisboa	Isotope Production	12.2
CERN	Radiation Effects	9.8
LIP/Lisbon	Radiation Effects	0.2
	Isotope Production	0.1
Univ. Coimbra	Isotope Production	0.1

The figure indicates the integrated power produced by the RPI in the last 10 years. A clear increase is seen in the last 6 years reflecting an increase in its use. The integrated power for 2004 was 46 MWd, about 15% higher than last year. On average, 1.5 irradiations were performed at the same time.

Operation and Exploitation of the Reactor, Dosimetry (RPI) and Reactor Calculations

Research Team

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- F. CARDEIRA, Auxiliary Researcher*
- A. KING, Auxiliary Researcher (90%)
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- A. FALCÃO, Principal Researcher
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Funding (€)

Research Projects:	35.411,00
Services:	55.888,22
Total:	**91.299,22**

Publications

Books:	
Journals:	4 and 4 in press
Proceedings:	1 and 1 in press
Conf. Communications:	2
Internal reports:	5
Theses:	

* Retired in 2004

Thermoluminescence dosimetry in mixed radiation fields

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Objectives

Commercial thermoluminescent dosemeters (TLDs) with neutron different sensitivities are commonly used for individual monitoring. The application of various TLDs to reactor beam dosimetry has been investigated at the Portuguese Research Reactor, using beams with different energy spectra. Besides the conventional usage of paired TL materials for thermal neutron dosimetry, an innovating method was developed for fast neutron dosimetry, considering the activation of aluminium oxide TLDs.

Results

Important dosimetric properties for the application of TLDs in nuclear reactors were investigated. The glow curves after an irradiation in the thermal column are shown in Figure 1, which demonstrates the increase of high temperature peaks of ^{nat}LiF:Mg,Ti (TLD-100, Harshaw, OH). Figure 2 presents the photon and neutron dose responses of TLD-100. In the dose ranges considered, both low and high temperature peaks exhibited a strongly supralinear response for neutron irradiations.

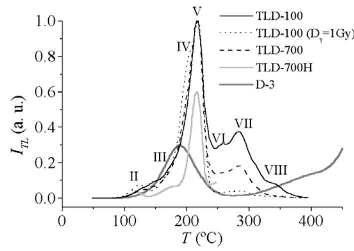

Fig. 1. Glow curves (not to scale) of TL materials irradiated in a mixed radiation field of thermal neutrons.

The results have shown that TLDs with low neutron sensitivity are able to determine photon dose and dose profiles with high spatial resolution. On the other hand, ^{nat}LiF:Mg,Ti TLDs with increased thermal neutron sensitivity show a remarkable loss of sensitivity and a high supralinearity in high intensity fields hampering its application at nuclear reactors.

The activation of Al_2O_3:Mg,Y by fast neutrons has been explored for photon and fast neutron dosimetry. The activity of the reaction products and the self-induced TL signal provide information about the fast neutron component, while the first TL reading after irradiation determines the photon dose. Fig. 3 presents the relation between the fast neutron fluence and the induced TL signal of D-3 TLDs irradiated in the fast neutron beam. The methodology presented expands the application of Al_2O_3:Mg,Y to fast neutron detection in the frame of reactor dosimetry

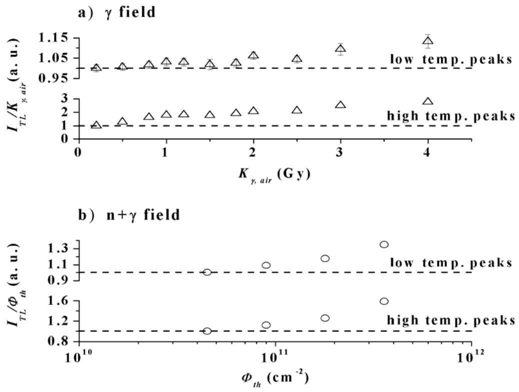

Fig. 2. Sensitivity of TLD-100 as a function of photon kerma in air and thermal neutron fluence.

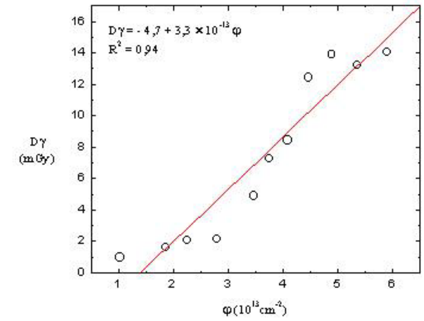

Fig. 3. Induced TL signal *vs.* fast neutron fluence.

Published, accepted or in press work

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2. A. C. Fernandes, I. C. Gonçalves, J. P. Santos, J. Cardoso, L. Santos, A. Ferro Carvalho, J. G. Marques, A. Kling, A. J. G. Ramalho, M. Osvay, Dosimetry at the Portuguese Research Reactor using thermoluminescence measurements and Monte Carlo calculations, *Radiat. Prot. Dosim.* (accepted).

3. J. P. Santos, A. C. Fernandes, I. C. Gonçalves, A. F. Carvalho, L. Santos, J. Cardoso, M. Osvay, Photon and fast neutron dosimetry using aluminium oxide thermoluminescence dosemeters, *Radiat. Prot. Dosim.* (accepted).

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MCNP studies for the Monoblock neutron spectrometer

A.C. Fernandes, L.A. Trykov[1], Yu. Kaschuck[1],V. Volkov[1], J. Burian[2], B. Jansky[2], E. Novak[2]

Objectives

The Bonner sphere (BS) neutron spectrometer consists of a thermal neutron detector at the center of number of different diameter-moderating spheres. The information about the spectrum of neutron field can be derived from the measured readings of a set of spheres. Initially, response functions were determined from measurements with monoenergetic neutrons. Currently, the Monte Carlo method is the most appropriate approach to calculated response functions.

The modification of a set of BS to one block i.e. Monoblock Neutron Spectrometer (MNS) was designed. It consists of a polyethylene (PE) block with shieldings of Cd and boronated PE. Seven thermal neutron detectors are inserted in seven measuring channels with different thickness of PE for on-line measurement in geometry of scattered beam. A special insertion with set of foils is used for irradiation in the direct beam.

MCNP Monte Carlo code runs sufficiently quickly that large numbers of point responses can be calculated in a reasonable time. It allows detailed geometric modelling of the whole block with detectors. Standard unfolding codes supported by personal experience can be used to derive the final neutron energy spectrum from experimental data.

Results

In the investigated setups, both activation foils and Si/Li detectors have been considered for detecting the thermal neutrons. Figure 1 shows the model used for the MCNP calculations of the response functions for each detector. These are represented in Figure 2.

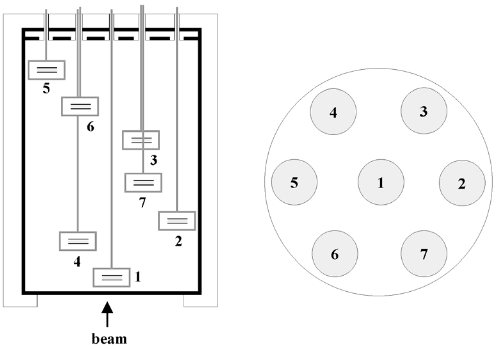

Fig. 1. Schematic view of the MNS with Si/Li detectors (left: vertical view; right: cross section)

The MCNP calculations were used to optimise the detectors positioning and determine the final response functions to be used in the spectrum unfolding. Figure 3 shows the MNS used for spectra measurements.

Finally, Figure 4 shows the result concerning an actual measurement of the neutron spectrum of a ^{252}Cf source.

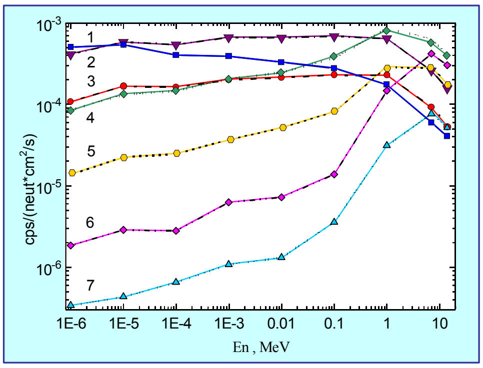

Fig. 2. Calculated response function for the various Si/Li detectors in MNS.

Fig. 3. The Monoblock neutron spectrometer with an evaluation computer.

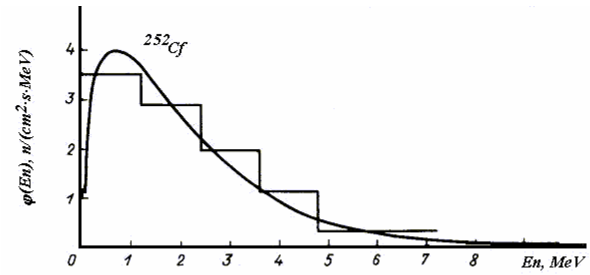

Fig. 4. Theoretical (continuous line) and measured neutron spectrum of ^{252}Cf.

Published, accepted or in press work

1. J. Burian, B. Jansky, M. Marek, E. Novak, L. Viererbl, A. C. Fernandes, Yu. A. Kaschuck, L. A. Trykov, V. S. Volkov, Development of equipments for determination of BNCT source spectral parameters, *Appl. Radiat. Isot.* **61** (2004) 849-852.

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[2]Nuclear Research Institute, Řež, Czech Republic.

Fast Neutron Irradiation of Electronic Circuits for the LHC/CERN

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J. Casas-Cubillos[2]

Objectives

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 $2x10^{13}$ n/cm^2 during a 10 year period, as well as a gamma dose of 500 Gy, and this can affect the operation of the commercial circuits used in their construction. The operating conditions of these circuits are simulated using a fast neutron irradiation facility built in 2000.

Results

The fast neutron irradiation facility is installed in beam tube E4 [1]. On-line measurements of properties of the circuits and components are performed before, during and after irradiation and stand-by periods, to evaluate the irradiation damages as well as possible annealing effects. The irradiation of components continued in 2004 as foreseen. Several CMOS analog switches [2,3] and amplifiers [4,5] were tested under irradiation.

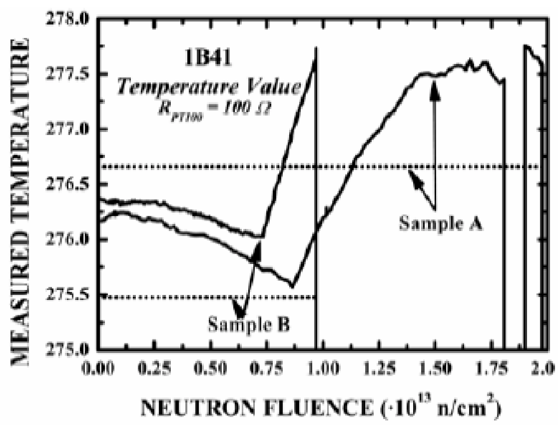

Fig 1. Behavior of two 1B41 signal conditioners used to measure a reference resistance of 100 Ω. The output is within acceptable values until a neutron fluence of about $0.7x10^{13}$ n/cm^2.

Fig. 1 shows an example from the irradiation of two 1B41 signal conditioners used to measure a 100 Ω resistance, simulating a platinum PT100 thermometer. The two irradiated devices were hardly affected by radiation until a fluence of $0.7\text{-}0.8x10^{13}$ n/cm^2. After exceeding this level, the output voltage began to increase until the devices stopped working. However, one of the devices worked until a fluence of $1.8x10^{13}$ n/cm^2, while the other had already stopped at half that fluence. An irradiation of a larger number of samples, not powered during the irradiation, has already been done and the results will be analysed in early 2005.

This work will continue in 2005 with the test of more components in statistically significant amounts, as well as prototypes of the final circuit boards, as they become available.

Published, accepted or in press work

1. J.G. Marques, A.C. Fernandes, I.C. Gonçalves, A.J.G. Ramalho, Test Facility at the Portuguese Research Reactor for Irradiations with Fast Neutrons, *Proc. 5th Workshop on Radiation Effects on Components and Systems, Madrid, September 2004, Eds. E.R. Prudencio, R.T. González, C.S. Fuente, INTA (Madrid, 2004) pp. 335-338.*
2. F.J. Franco, Y. Zong, J.A. Agapito, J. Casas-Cubillos, M.A. Rodriguez-Ruiz, Evolution of the Lowest Supply Voltage and Hysteresis Phenomena in Irradiated Analog CMOS Switches, *Proc. IEEE Radiation Effects Data Workshop, June 2004, IEEE, pp. 91 – 95.*
3. Y. Zong,, F.J. Franco, J.A. Agapito, Using Optimization Techniques to Characterize Irradiated CMOS Analog Switches, *Proc. 5th Workshop on Radiation Effects on Components and Systems, Madrid, September 2004, Eds. E.R. Prudencio, R.T. González, C.S. Fuente, INTA (Madrid, 2004) pp. 279-285.*
4. F.J. Franco, J.A. Agapito, J. Casas-Cubillos, M.A. Rodriguez-Ruiz, Y. Zong,, Neutron Effects on Short Circuit Currents of Bipolar Op Amps and Consequences, *Proc. 5th Workshop on Radiation Effects on Components and Systems, Madrid, September 2004, Eds. E.R. Prudencio, R.T. González, C.S. Fuente, INTA (Madrid, 2004) pp. 213-220.*
5. J.A. Agapito, J. Casas-Cubillos, A.P. Fernandes, F.J. Franco, I.C. Gonçalves, A.H. Cachero, J.G. Marques, M.A. Rodriguez-Ruiz, Y. Zong, Rad-Tol Pt-100 Isolation Amplifiers for the LHC Cryogenic System, *Proc. 10th Workshop on Electronics for LHC Experiments, Boston, September 2004 (in print).*

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Response of SIMPLE SDDs to Monochromatic Neutron Irradiations

F. Giuliani[1], C. Oliveira, J.I. Collar[2], TA Girard[1], T. Morlat[1], D. Limagne[3], J.G. Marques, A.R. Ramos, M. Felizardo, A.C. Fernandes, G. Waysand[3,4]

Objectives

SIMPLE is an experiment employing superheated droplet detectors (SDDs) to search for evidence of weakly interacting massive particles (WIMP). An SDD is a dispersion of small droplets of superheated liquid freon fixed in a hydrogenated gel, each droplet of which functions as a mini-bubble chamber. Such devices are best known in neutron detection and light ionization radiation discrimination.

Previous SDD neutron response measurements have been generally made at energies between thermal and several MeV. For SIMPLE, the typical recoil energies of interest range from ~2-400 keV. WIMP searches also require large active mass: typical SIMPLE SDDs are 1 liter devices containing 10 g active mass of R-115 (C_2ClF_5).

We here report on the response of SIMPLE SDDs to quasi-monochromatic neutron beams obtained by filtering the thermal column of the Portuguese Research Reactor.

Results

We have measured the responses of large concentration SDDs to monochromatic neutron beams of 54 and 144 keV. The results show a generally good agreement with the anticipated responses, and consistency with the predictions from the Seitz model. The observed response at neutron energies below filter energies points to a downscattering of the incident beams to lower energies, due to the interaction of neutrons in the gel+water bath. The results indicate significantly lower response at low temperatures than indicated in the previous neutron calibration measurements performed with the ^{252}Cf source. However, the previous results were obtained with higher energy neutrons than those of the filtered beams, so that the SDDs should have a generally higher low temperature response. Why this response is higher than simulation in both experiments remains unclear, but the results in any event confirm that this is not intrinsic to the SDD since now the higher energy rates are lower.

As previewed by thermodynamical simulations, the energy resolution is severely degraded for neutron energies above ~50 keV; the response is compressed into small temperature intervals and increasingly larger differences in recoil energies fall below the temperature resolution of the measurements. This effect is independent of gel.

Resolution degradation does not imply loss of sensitivity. Translated into background neutron sensitivity of WIMP searches with these detectors, the experimental results suggest a good choice of operating conditions to be 9ºC at 2 atm. While most neutrons of energies up to at least ~144 keV are shifted below threshold due to the observed neutron beam degradation, WIMPs are not affected by the gel. The 9ºC corresponds to 8 keV in fluorine recoil energy, implying a sensitivity to WIMP masses > 5 GeV given a sufficient background reduction in the detector response at lower temperatures.

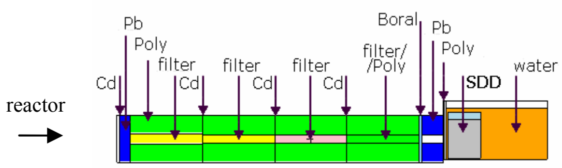

Fig. 1. Experimental set-up used in the experiment. Each filter module has 20 cm length; with a 2.5 cm ∅ for the first module and 2.0 cm ∅ for those following. Other materials thicknesses are: Cd-0.05 cm; Pb (first cylinder)–3.0 cm; BorAl–0.8 cm; Pb (second cylinder)–6 cm. For radiological protection, the filter rods are inserted into polyethylene cylinders of 12 cm ∅, covered with a 0.5 mm Cd sheet. The SDD is 9.0×9.0×10 cm^3.

Published, accepted or in press work

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2. C. Oliveira, TA Girard, J.G. Marques, J. Salgado, J.I. Collar, T. Morlat, D. Limagne, F. Giuliani and G. Waysand, MCNP Optimization of Filtered Neutron Beams for Calibration of the SIMPLE Detector:, *Nucl. Instr. and Meth*., **B213** (2004) 172.
3. , A.R. Ramos, F. Giuliani, T.A. Girard, C. Oliveira, J.G. Marques, D. Limagne, T. Morlat, G. Waysand, Neutron spectrometry with large volume, heavy-loaded superheated droplet detectors: a SIMPLE spin-off (accepted for publication in *Radiation Protection Dosimetry*).

[1]Centro de Física Nuclear, Universidade de Lisboa, 1649-003 Lisbon, Portugal.
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Identification and Measurement of Bubble Nucleation in Superheated Emulsion Detectors (SED)

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Objectives

In SDDs (Superheated Droplet Detectors) the neutron spectra is assessed by measuring the bubble nucleation rate. The simple setting of an amplitude threshold for the signal acquired does not guarantee that the signal observed corresponds to a nucleation; it might correspond to spurious noise from the setup.

This work aims at developing a simple pulse shape validation routine in which each pulse is first amplitude demodulated and then the decaying constant determined through an exponential fit.

The event counting and validation routine executes the following steps:

1. Setting of an amplitude threshold.
2. Based on the previous threshold, identify the beginning and ending of each spike.
3. Amplitude demodulates the time evolution of the spike.
4. Measure the decaying constant of the pulse.
5. Suppress the pulses which exhibit a time constant below a given threshold.

Results

The rapid bubble expansion associated with the boiling of the superheated droplets is accompanied by oscillating pressure pulses of <10ms duration which can be acoustically recorded. To that end a very simple electronic setup has been devised in which a piezoelectric microphone is connected to a low-noise preamp which then couples to the input of an acquisition channel. Mechanically the piezo is within the vial which contains the detector emulsion, just above a protective glycerine layer. The connection between the piezo and the preamp stage is done through a short (< 2m) twisted pair cable. The data is acquired at a constant rate of 100 kBps for a period that varies between 10s and 1 minute.

Using this setup we were able to indirectly measure the mechanical energy associated with the events and from this information to selectively discard spurious noise.

Further work is actively being pursued to correctly identify phantom events. For this purpose the experimental setup is somewhat different, using four microphones outside the vial and one inside.

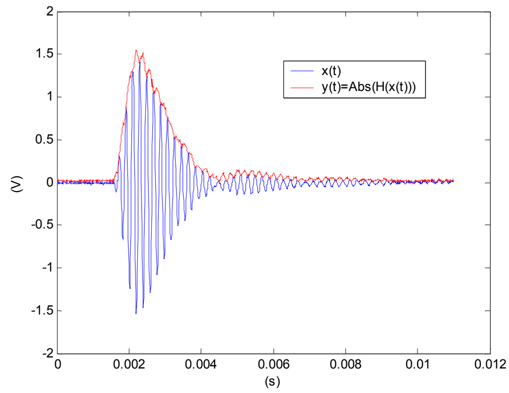

Fig. 1 Pulse shape of a bubble nucleation (blue line) and its amplitude envelope (red line) as assessed by means of $y(t) = |\mathrm{H}\{x(t)\}|$.

The phantom suppression will hopefully be achieved by spatially-locating the bubble nucleation and correlating that information with the time interval of events, their relative phase information and time constant at each microphone.

Published, accepted or in press work

1 A.C. Fernandes, T. Morlat, M. da Costa, J.I. Collar, J. Puibasset, G. Waysand, H.S. Miley , A.R. Ramos, T.A. Girard, F. Giuliani, D. Limagne, J.G. Marques, R. C. Martins, C. Oliveira, The SIMPLE SDD, (accepted for publication in *Radiation Protection Dosimetry*).

[1] Instituto de Telecomunicações, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal.
[2] Centro de Física Nuclear da Universidade de Lisboa, Av. Prof. Gama Pinto 2, 1649-003 Lisbon, Portugal.
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Neutronics Calculations: Preparation for the RPI Core Conversion

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

Objectives

This activity is determined by the operational needs of the RPI, present and future. The main objective is to provide calculations to ensure the safe working of the reactor, with a well-characterised radiation field. The expected conversion of the RPI core from HEU to LEU poses a particular challenge, demanding timely studies of possible future fuel types and configurations.

Results

The Core I of the Portuguese Research Reactor (RPI) was composed of MTR LEU fuel elements, with enrichment just under 20%. It first attained criticality the 25th April 1961. The Core II of the RPI, active since 1990 and now in its eigth configuration, uses HEU MTR fuel elements. The neutronics calculations use the standard codes WIMSD5 and CITATION, and lead to accurate predictions of the reproduction factor and flux values. From 2006 on, HEU will no longer be used at the RPI, and a transition back to LEU MTR fuel elements is envisaged. We used WIMSD5 and CITATION to simulate the Core III of the RPI, considering one given type of MTR LEU elements, based on U_3O_8 fuel [1]. Compact configurations, smaller than the current ones, can be achieved due to the high U density in this type of fuel elements. The calculated thermal neutron flux distribution is shown in the figure for one test configuration.

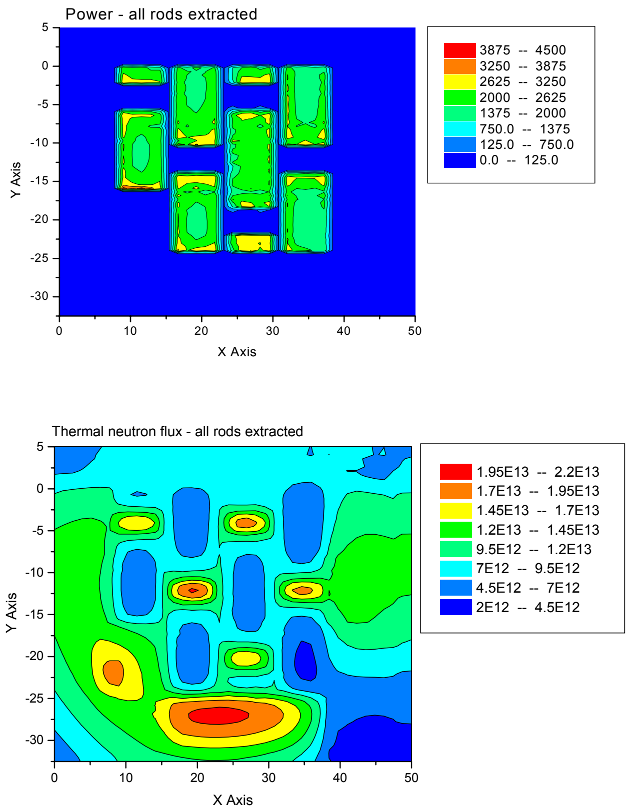

Fig. 1. Calculated power distribution and thermal neutron flux for a test configuration using LEU U_3O_8 fuel elements.

We also performed a burnup inventory of all fuel elements at the end of configuration N2-P1/7A, calculating the burnup of each element and the remaining ^{235}U in each element. Based on this, we estimated the amount of energy that the RPI could produce utilising the 93% enriched HEU fuel currently existing at the RPI. We concluded that around 250 MWd of utilisation can be achieved without changing significantly the core configuration or the neutron flux. A further 250 MWd could be obtained by increasing the size of the core, thus reducing the neutron flux.

Previous neutronics calculations considered the Be blocks to be made of pure Be, as no data on its composition was available. We now used newly obtained data on the Be composition to recalculate the entire history of the RPI core 2. We also used improved data of the structural Al composition. We achieve a better agreement with experimental reactivity data for configurations with small burnup, and worse agreement for configurations with high burnup. This reflects a need for improvements in the burnup calculations, in particular by implementing a descritpion of individual fuel plates in the calculations.

We calculated the heating and influence in the reactivity of several experimental devices.

Published, accepted or in press work

1. N.P. Barradas, A. R. Ramos, J. G. Marques, Neutronics calculations for the Portuguese Research Reactor (RPI) with LEU U_3O_8 fuel elements; *Internal Report* ITN/RPI-R-04/87.

Improvements in the Radiological Control at the RPI

A. Kling, N. P. Barradas

Objectives

The safe operation of nuclear research reactors requires a well-established control of radiological data, e.g. the determination of the amount of radioactivity released. Consequently, recent efforts to improve the radiological control at the RPI focussed on the gaseous effluents at the RPI stack.

Results

One of the main improvements in the radiological control at RPI was the construction of a setup for the periodic calibration of the noble gas channel at the AIRMON-91 system installed at the RPI stack exhaust [1]. In a first step, the Marinelli beaker with HPGe detector was calibrated for the detection of 1294 keV gamma rays arising from ^{41}Ar using a sample of activated air. It was found that a count rate of 1cps is equivalent to an ^{41}Ar air activity of 9.09(±0.35)×10^{4}Bq/m^3.

By sampling air from the RPI stack during operation at 1 MW into the Marinelli beaker (Fig. 1) and correlating the count rates of the HPGe with those of the plastic scintillator (Fig. 2) a calibration factor (0.96 ±0.07 Bq/m^3/cps) for the noble gas channel was obtained. This agrees very well with the default value of 1.00 Bq/m^3/cps confirming the validity of previously obtained noble gas release rates, e.g. in [2].

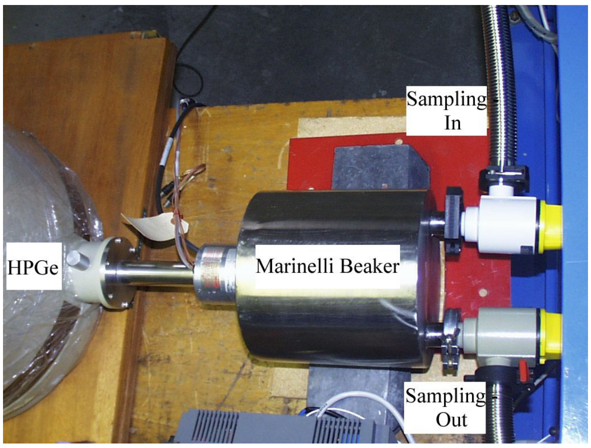

Fig. 1. Set-up used for calibrating the noble gas channel of AIRMON-91 in the RPI stack.

Further it was verified that, in case of a malfunction of the AIRMON-91 plastic scintillator, the Marinelli beaker system can act as replacement system to monitor the noble gas activity released through the RPI stack.

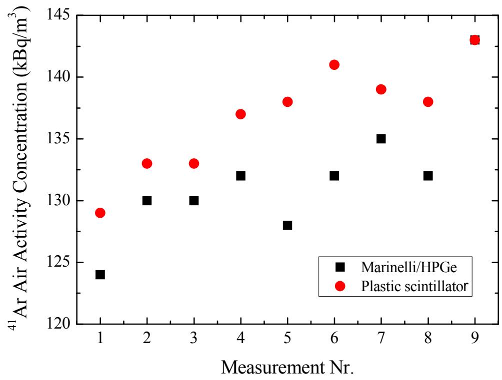

Fig. 2. Air activity concentration in the RPI stack as determined using the calibrated Marinelli/HPGe and the AIRMON-91 plastic scintillator (with default calibration value).

Five ionisation chambers, and dust, radioactivity, and fission products detectors, perform radiological control in different points of the reactor building. These signals are subject to non-physical transients, which is noise that must be eliminated from the calculation of the average and standard deviations of each one. The files are very large (6 months of data can generate over 300 Mbyte), and it is impossible to do that task manually. A code was written to recognise transients automatically, and calculate transient-free average and standard deviations automatically for each quantity

Published, accepted or in press work

1. A. Kling, Calibration of the AIRMON-91 Noble Gas Detector, *Internal Report* ITN/RPI-R-04/83.
2. A. Kling, Radiological Control at the Portuguese Research Reactor (RPI) - Report January 1 – December 31, 2003, *Internal Report* ITN/RPI-R-04/84.