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

A.J.G. Ramalho, I.C. Gonçalves, N.P. Barradas

The central objective of the operation and exploitation of the reactor is to be able to satisfy the users needs while conducting all activities with the assurance that a highly competent and motivated staff operates the equipment in a safe and reliable manner. 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. Safety, being a permanent consideration in all work around the reactor, interlinks all the activities being or to be performed.

The main set of projects, actual and coming, in which the staff is involved is presented below.

The programme for testing the behaviour of electronic components and circuits to be used at the LHC/CERN, simulating the expected exposure for a 10 years period, has continued during the year with the irradiations being performed in a beam tube that was prepared for the effect and put into operation in the first part of the year.

Isotope production is an important activity in the reactor utilization. Effort continued to be placed in the production of short lived isotopes which can be delivered rapidly to the users in the country. One of the difficulties associated with this activity resides in the handling of the irradiated materials. To improve this situation the utilization of a handling cell located inside the reactor hall was initiated. As a result of this effort it became routine to handle irradiated materials containing ^{198}Au or ^{24}Na to be used as tracers in the quality control of an industrial process in Spain.

The operation of the reactor requires updated reactor physics calculations of parameters such as effective multiplication, reactivity margins, control rod worth, fuel consumption. This activity has continued with vigour but it was not yet possible to initiate the 3D or thermal hydraulics calculations as foreseen. Instead various other situations arose needing evaluation. This included effects of special reflectors, configurations where voids are present, as well as and retrieving and reviewing methodologies to predict temperature rises in materials under irradiation.

There has been significant activity in the field of BNCT. The activity in dosimetry has also to address the characterisation of the irradiation facilities, control experiments and to obtain values for the validation of the calculated vales, test and implementation of new dosimetry procedures which will be more rigorous or suitable, to refer some examples.

The creation of an epithermal neutron beam shows some progress, but it has been going at a lower speed than expected. Most of the external concrete shielding is inside the building and the construction of the collimators and filters is in progress so that it is expected that the system will be operational in the fist part of 2001.

Concerning the installation of neutron physics equipment, i.e. DIDE and EPA, there was some progress.

The main users of the reactor are described in Table I. Fig. 1 indicates the reactor usage in terms of the number of hours of irradiations and the number of irradiations performed.

Table 1

User	Area	Time (%)
ITN-RPI	NAA	36.0
	Dosimetry	6.9
	BNCT Research	2.0
	Other	3.8
ITN-Chemistry	Isotope Production	17.2
	NAA	15.7
ITN-Physics	Beam Users	<0.1
	Other	0.6
Univ. Coimbra	Isotope Production	<0.1
CERN-LHC	Circuits Irradiation	6.3
Univ. Manchester	Dating	8.6
RPI & Physics	Sources for industry	2.8

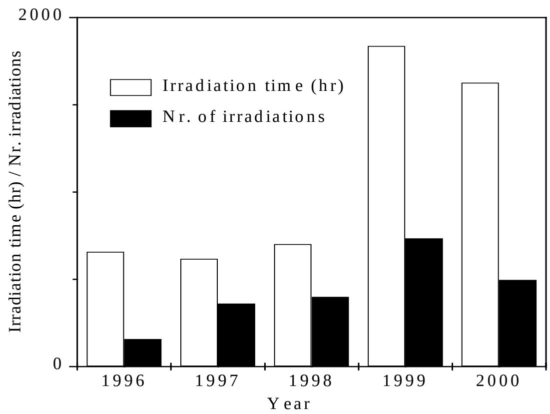


Fig. 1

In the last two years there has been a significant increase in both of these numbers which however are lower in 2000. It is worth noting that, in 1999, the integrated power was 44 MWd and in 2000 it was 47 MWd, i.e., it increased by 6.8%.

It is also interesting to note two other things, namely an increase of users from abroad (Spain, Switzerland, UK), representing about 15% of the total time and an increase in the number of industrial applications.

Research Team

Researchers

- António G. Ramalho **(Group Leader)**
- Isabel C. Gonçalves (Aux. Researcher)
- Fernando Cardeira (Aux. Researcher)
- José G. Marques (Aux. Researcher) (95%)
- Andreas King (Aux. Researcher) (90%)
- Nuno Barradas (Aux. Researcher) (95%)

- Christine Chaussy
- Jean-Marc Chaussy
- Armando Vieira (Post Doctoral)

Reactor Operators

- Rui Carvalho
- Manuel Costa Marques
- Rui Barreiros (retired 17 July 2000)
- Joaquim A.M. Ribeiro
- José Carlos Roxo
- Nuno Serrote (ITN Grant)
- Vitor Páscoa (ITN Grant)
- Rogério Santos (ITN Grant)

Visiting Researchers

- Pedro Vaz (Aux. Professor), IST

Students

- M.J. Prata (PRAXIS XXI **PhD** student)
- Ana Fernandes (PRAXIS XXI **PhD** student)
- Rafael Patrício (**Last year BSc** Student)
- Joana Almeida Santos (**BSc** ITN Grant)

Technical Personnel

- Rudolfo Pombo (ITN Grant)
- Vitor Tomás

Publications

Journals:	1	
Proceedings:	7	and 4 in press
Conf. Communications:	4	
Internal Reports:	4	

Funding

	$\times 10^3$ PTE
Research Projects[(a)]:	10 682
Services:	498
TOTAL:	11 180

(a)

	$\times 10^3$ PTE
- Fast Neutron Irradiation of Electronic Components for the LHC/CERN in the Portuguese Research Reactor (CERN/P/FIS/15181/1999) (1999-2000) (8500 $\times$ 10^3 PTE) ITN/Co-ordinator**: J.G. Marques**, Partners: Univ. Complutense Madrid, Spain (J.A.Agapito), CERN (J. Casas)	8500
- A Code of Practice for Dosimetry Boron Neutron Capture Therapy (European Contract SMT4-CT98-2145) (1998- 2001) (147 829 $\times$ 10^3 PTE $\rightarrow$ ITN/9180 $\times$ 10^3 PTE) Co-ordinator: NRG, The Netherlands (F. Rasmussen), ITN/Partner: **Isabel C. Gonçalves**...........	1607
- Round Robin Characterisation of the Thickness and Composition of Thin to Ultra-thin AlNO Films (Atomic Energy Agency Co-ordinated Project, under Research Contract No. 11317/R0/Regular Budget Fund) (2000-2001) (1150 $\times$ 10^3 PTE) ITN/Co-ordinator**: Nuno Barradas**..	575
- Emission channeling/blocking using thermal neutron induced nuclear reactions for the study of defect structures in single crystals (Dec. 2000- Dec.2002) (9000 $\times$ 10^3 PTE) ITN/Co-ordinator**: Andreas Kling**..	—

Assuring the safe utilization of the Portuguese Research Reactor

J.M. Chaussy, A.J.G. Ramalho, J.G. Marques, F.M. Cardeira

Objectives

Guaranteeing a safe utilization of Portuguese Research Reactor (RPI) is a permanent aim of the reactor team.
This aim preconditions all the operations involving the utilization of the reactor and the experiments from their design to the actual carrying out in the RPI.

Results

During the year, new situations arose created, for example, by the irradiation program of the electronic circuits for CERN. This required the preparation of analysis and the reevaluation of procedures in existence or the development of new ones.
The writing of the procedures bring the assurance that the know-how acquired by the operators, in the exercise of their work, is preserved and also facilitate the training of the new operators. The procedures constitute both the guide and the memory of the interventions in the installation.

In addition, all the experiments carried out in the RPI are object of a safety analysis. This analysis, prepared by the person in charge of the experiment must describe, in the more complex cases, the various components of the experiment its interface with the reactor and also the risks, which it can present to the people, the reactor and its environment.

To facilitate the preparation of those analysis, the reactor team of the RPI began a to create a guide for the preparation of a safety analysis report.

The guide will contain:

- ✓ a list of questions on which the person in charge must reflect during the design of his experiment, and have the answers included in the safety analysis report associated,a summary and a list of contents of the safety analysis report.

- ✓ The guide should lead to a uniform presentation of the safety report of the future experiments, of which copies will maintained at the RPI. It will also facilitate its reading and evaluation by the safety commission and reduce the risk that the persons in charge of experiments will not consider a situation being able to present risks for the people, the reactor and its environment.

Further work

The reactor team will continue the drafting of procedures for the operations of utilization and maintenance of the reactor.
The work on the establishment of the guide for the preparation of the safety analysis report of experiments will be pursued.

Monte Carlo simulation of the radiation field at the vertical access of the Thermal Column of RPI

A.C.Fernandes, I.C.Gonçalves, A. Vieira, A.J.G. Ramalho, N.P. Barradas, J. G. Marques

Objectives

The radiation field at the vertical access of the thermal column was calculated with code MCNP4B. The purpose is to obtain theoretical neutron and photon spectra and dose values and validate the calculations with experimental measurements.

Results

The simulations included the reactor core through the criticality mode of MCNP. A simple model of the fuel elements allowed predicting the order of magnitude of the thermal neutron flux and gamma dose at the vertical access. By comparing calculated and experimental results, we concluded that the present model is overestimating the neutron thermalisation and must therefore be improved.

Fig. 1 shows the geometric model used in the simulations, and Fig. 2 shows the calculated neutron spectrum at the vertical access of the thermal column.

At the present stage, the calculated thermal neutron flux and gamma-ray dose are two times lower and the Cd ratio of Au foils is two times higher than measured.

Published (or in press) work

[1] Fernandes, A.C., Vieira, V, Gonçalves, I.C., Ramalho, A.J.G., Monte Carlo Characterisation of the Radiation Field in the Thermal Column of the Portuguese Research Reactor, *Proceedings of the International Conference on Advanced Monte Carlo for Radiation Physics, Particle Transport Simulation and Applications, MC2000*, Lisbon, 23-26 Oct. 2000, eds. A. Kling, F. Barão, M. Nakagawa, L. Távora, P. Vaz, Springer Verlag, Berlin, Heidelberg, in press.

Further Work

A better agreement between experimental and calculated values is strongly dependent on a good simulation of the reactor core. More detailed models of the fuel elements will be used.

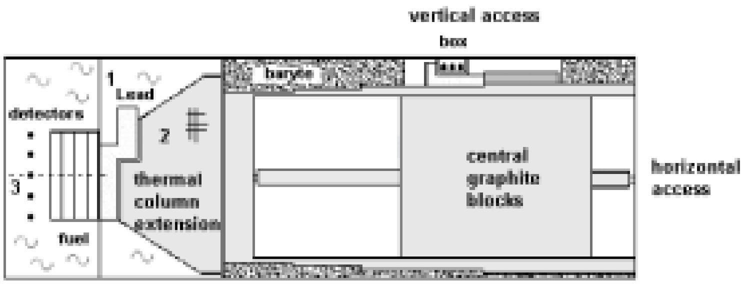


Fig. 1

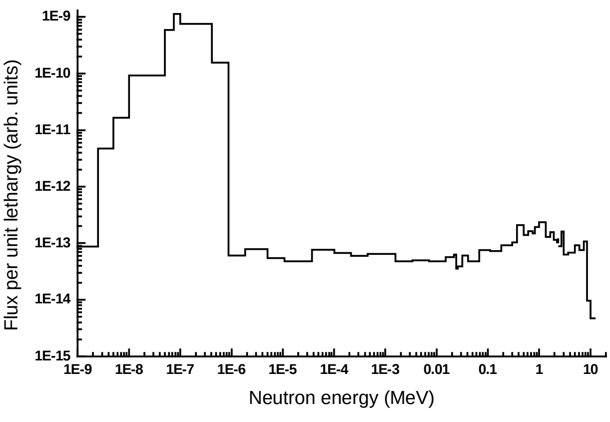


Fig. 2

Thermoluminescent dosimetry in mixed fields of neutrons and photons

A.C.Fernandes, I.C.Gonçalves, A.F.Carvalho, J. A. Santos, L. Santos, J. Cardoso

Objectives

Implementation of thermoluminescence dosimetry in radiation fields around the Portuguese Research Reactor.

Results

For gamma-ray dosimetry, neutron–insensitive TLDs are being used and studied at the Portuguese Research Reactor, RPI. For doses up to approximately 500 mGy, GR207 (^{7}LiF:Mg,Cu,P) circular chips (dia. 1.5mm, 0.8mm thick) from the Solid State Laboratory, Beijing, China, are being studied. For higher doses, up to approximately 2Gy, TLD700 (^{7}LiF:Mg,Ti) square chips (4×4×0.8)mm from the same manufacturer and Aluminium Oxide (Al_2O_3:Mg, Y) circular chips (dia. 8mm, 1mm thick), from the Institute of Isotopes, Budapest, Hungary, are being tested.

Neutron dosimetry with TLDs is performed with neutron-sensitive detectors. At RPI, the use of TLD100 (LiF:Mg, Ti) square chips (4×4×0.8)mm from the Solid State Laboratory, Beijing, China, is being optimised, in the neutron-dose range up to 1Gy.

The reproducibility of the detector measurements in 10 consecutive irradiations in a pure gamma field and in a mixed field of neutrons and photons is shown in Table 1, regarding the individual sensitivity factors. In this Table, g/g, n/n and g/n refer to consecutive irradiations in a Co-60 source, consecutive irradiations in the mixed-field of the thermal column of RPI, and alternate Co-60 and mixed-field irradiations, respectively.

Further work

The above mentioned TLDs will be used for the dosimetry of experiments performed at the Portuguese Research Reactor.

	g/g	n/n	g/n
TLD 100	2 (250mGy) 4(2Gy)	6(φ_{th}=2.2×10^{11}n.cm^{-2}) (D_γ = 200mGy)	11(250mGy)
TLD 700	3(250mGy) 3(2Gy)	5(φ_{th}=2.2×10^{11}n.cm^{-2}) (D_γ = 200mGy)	5(250mGy)
Al_2O_3	3(250mGy) 3(2Gy)	7(φ_{th}=2.2×10^{11}n.cm^{-2}) (D_γ = 200mGy)	7(250mGy)

Table 1 – Reproducibility of the individual sensitivity factor (%).

BNCT Activities at RPI

A.J.G.Ramalho, I.C.Gonçalves, A.P.Fernandes, J.G.Marques, M.J.Prata, I.F.Gonçalves, A.Vieira, M.Castro[1], N.G.Oliveira[1], J.Rueff[2]

Objectives

The BNCT project is a multidisciplinar project developed in collaboration with national and international teams, having several objectives. Clearly therapy cannot be applied unless various other requirements are fulfilled. The activity under this heading includes:

i) irradiations with thermal neutrons of biological systems (mice and cells) loaded or not with boron,

ii) the radiation dosimetry of the experiments being performed,

iii) preparation and characterization of radiation fields adequate for experimentation in radiation fields similar to the ones that must exist in the case of therapy,

iv) involvement in work aiming at the establishment of standards for methodologies for the practice and its control and also for quality control and safety.

Results

The work on the implementation of an epithermal neutron beam in RPI has been going on and it's foreseen to have it available in the first part of 2001.

Studies aiming at the implementation of specific dosimetric procedures are being performed that include:

- TLD dosimetry in mixed fields, in collaboration with Radiological Protection and Nuclear Safety Department of ITN and the Institute of Isotopes of the Hungarian Academy of Sciences (the results are presented under the title "Thermoluminescent dosimetry in mixed fields of neutrons and photons")
- Implementation of the twin-ionisation chamber method, that is the reference method in mixed radiation fields.The calibration of two ionization chambers, one Mg-Ar as gamma detector and a TE/TE chamber, sensitive to both neutrons and photons, is being performed.
- Calibration of proton recoil detectors for neutron spectrometry, in collaboration with the team from NRI at REZ - Prague. The calibration of a spherical detector was already performed in reference fields at REZ and the calibration of a cylindrical one will be done in the next future.

Genotoxic effects study in human melanoma cells irradiated in the vertical access of the Thermal Column of RPI. This work is being conducted in collaboration with teams from Pharmacy and Medicine Faculties of the University of Lisbon and from the Faculty of Medical Sciences of the New University of Lisbon.

Published work

[1] Oliveira, N.G., Castro, M., Rodrigues, A.S., Gonçalves, I.C., Cassapo, R., Fernandes, A.P., Vale, F.M., Chaveca, T., Ramalho, A.J.G., Toscano Rico, J.M., Rueff, J., Genotoxic effects of Boron Neutron Capture Reaction in human melanoma cells, Extended abstracts of the *Ninth International Symposium on Neutron Capture Therapy for Cancer*, (2000), pg.209-210.

Further work

Implementation of dosimetric methodologies at RPI irradiation facilities; prosecution of the study of genotoxic effects in biological samples irradiated at RPI.

[1]Faculty of Pharmacy, University of Lisbon.
[2]Faculty of Medical Sciences, New University of Lisbon.

Production of Radioisotopes to Test a Process in Industry

C. Chaussy, A.J.G Ramalho, J.G.Marques,F. Cardeira, I.C.Gonçalves, J.M. Chaussy, A. Kling, Operators of the reactor

Objectives

The production of radioisotopes to be used in an aluminium production plant in Spain has been done in the Portuguese Reactor, RPI. The isotopes of interest, ^{198}Au and ^{24}Na, were produced by irradiating gold wires, contained in pure Al cylinders and NaCl pellets, wrapped in pure Al foil. To prepare the irradiated materials for shipment the handling was performed in the cell installed in the reactor hall.

Results

Currently, the manipulation of radioactive samples is done in the hot laboratory facilities, where low activities can be easily manipulated. In this case, the cell situated in the hall of the reactor, was used because the activity to be manipulated was higher than usual and better accessibility of transport castle could be gained. As this cell has not been used, the full manipulation process had to be accessed and clearly established.

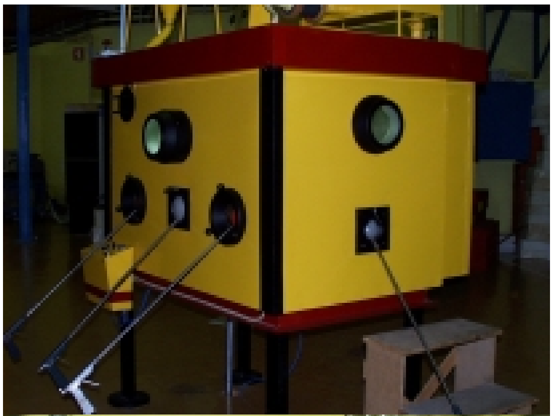
This includes:

(1) the preparation of the material for the optimisation of the manipulation
(2) the manipulation of the samples under water
(3) training in the use of the telemanipulator
(4) assure that the radioprotection rules were followed
(5) assure the decontamination of the cell and the materials

A procedure, for all these manipulations, was written and applied.

The establishment of the irradiation conditions implied optimising the cooling time to permit the elimination of the short live products and satisfying the requirements of the user, which were referred to the beginning of the application. To optimise the process from the health physics point of view, all the steps of the manipulation were controlled.

In this campaign, 48 pellets of ^{198}Au and 54 pellets of ^{24}Na for radioactive tracing in industry were produced.



Intenal Report

[1] Chaussy, C., Ramalho, A.J.G, Marques, J.G., Cardeira, F., Gonçalves, I.C., Chaussy, J.M., Kling, A., and Operators of the reactor, Irradiações de amostras para a fábrica de alumínio ALCOA em AVILES – ESPANHA, ITN/RPI/R-00/61.

Further Work

This work establishes methodologies for the cell usage in the future. Some of them will be very specific and adaptation of the material to the needs has to be done.

Another campaign of irradiation for industry is expected for the next year. Organisation of the hot laboratory and this facility will be pursued and optimised. At the occasion, up grading the material and making it more ergonomic will be attempted.

Fast Neutron Irradiation of Electronic Circuits for the LHC/CERN

A.J.G. Ramalho, J.G. Marques, I.C. Gonçalves, A.P. Fernandes, N.P. Barradas, A. Vieira, M.J. Prata, F.M. Cardeira, J.A. Agapito[1], J.P. Santos[1], P. Gomes[2], J. Casas[2]

Objectives

The operation of the Large Hadron Collider (LHC) at CERN will require the use of electronic circuits in a mixed field of γ and fast neutrons. The circuits are expected to receive a neutron fluence of 2×10^{13} n·cm^{-2} and a γ dose of 500 Gy during a 10 year period. To simulate these conditions irradiations have been performed at the Portuguese Research Reactor using a new facility built in 2000.

Results

A dry irradiation cavity with 100 × 60 × 60 cm was created at the end of tube E4. A 100 cm long cylinder with 15 cm diameter was placed inside the beam tube creating an inner cavity where circuits can also be placed to achieve higher fluxes. A Pb filter reduces the intensity of the γ field to obtain a neutron/γ ratio close to the one expected for the LHC and a boral filter cuts the thermal component of the beam. The components are mounted on several PCBs, inside boxes. Normally each irradiation campaign runs from Monday to Friday with 13 hours of irradiation followed by 11 hours of stand-by per day, due to the two-shift per day mode of operation. The goal is to achieve during one week a neutron fluence of 5×10^{13} n/cm^2 for the central PCB. Fig. 1 shows the fast neutron fluxes measured at the center of each box containing a PCB in two different positions of the boxes' holder. PCB nr. 1 is the one closer to the reactor's core.

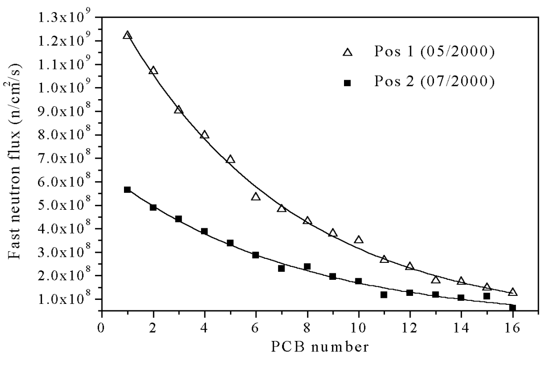


Fig. 1

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.

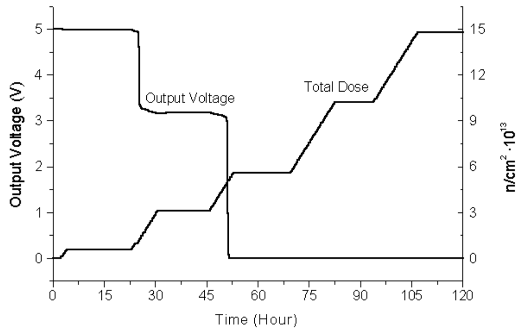


Fig. 2

Fig. 2 shows an example of a commercial reference voltage that failed after a neutron fluence of 2×10^{13} n·cm^{-2}. The stepwise shape of the neutron fluence curve is due to the daily operation and stand by periods of the reactor. Results on other components are detailed in Ref. [1].

Published (or in press) work

[1] Agapito, J.A., Barradas, N.P., Cardeira, F.M., Casas, J., Fernandes, A.P., Franco, F.J., Gomes, P., Goncalves, I.C., Cachero, A.H., Lozano, J., Martin, M.A., Marques, J.G., Paz, A., Prata, M.J., Ramalho, A.J.G., Rodriguez-Ruiz, M.A., Santos J.P., Vieira, A., Instrumentation Amplifiers and Voltage Controlled Current Sources for LHC cryogenic Instrumentation, *Proceedings 6th Workshop on Electronics for LHC Experiments - LEB2000, Cracow*, (http://lebwshop.home.cern.ch/lebwshop/LEB00_Book/LEB00_Proceedings.html).

Further work

This project will continue in 2001 with the irradiation of 16 bit ADCs. Forced cooling of the circuits will be installed, in order to reduce the temperature during the irradiation.

[1]Universidad Complutense de Madrid, Cuidad Universitaria, E-28040 Madrid, Spain
[2]LHC Division, CERN, CH-1211 Geneva 23, Switzerland

Implementation of a Multipurpose Beam Tube

M.J. Prata, A.J.G. Ramalho, J.G. Marques

Objectives

Several applications require a neutron beam where the epithermal vs. fast component ratio is maximised. Among those applications is the determination of hydrogen at ppm levels in materials with interest for fission and fusion by profiting of the anisotropic scattering of neutrons by hydrogen. Other envisaged applications are activities connected with Boron Neutron Capture Therapy and boron determinations using Prompt Gamma Neutron Activation Analysis (PGNAA).

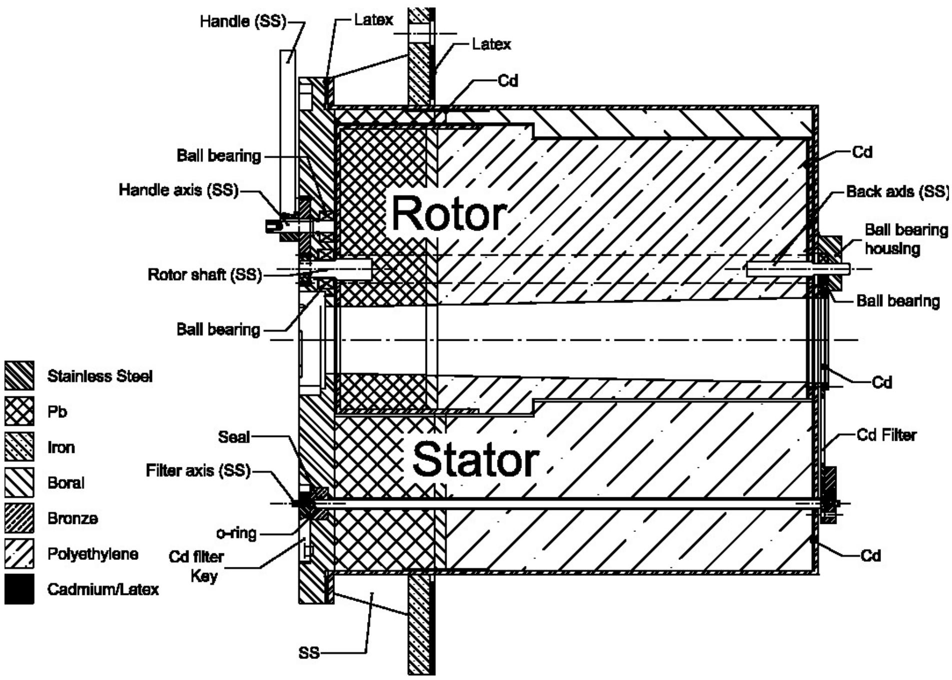
Results

All the mechanical components are under construction or were already constructed in the central workshop of ITN. No external companies were hired. The filter that will be inserted in the beam tube to modulate the neutron beam is under construction. The fail-safe shutter is nearly finished. A cut of the shutter is shown below. Two beam openings with 2 and 5 cm diameter are provided, with the possibility of leaving or eliminating the thermal component with a Cd filter.

The outer shielding of the facility was built and is essentially installed. One of the lateral faces of the shielding has two openings, one for an HPGe detector for PGNAA and another for passage of cables such as those of the active neutron detectors used in the determination of H. The HPGe detector is placed at 60^o, relatively to the incoming beam, protected by Pb and Li_2CO_3 shields. Monte Carlo simulations of the layout of the active detectors are underway.

Further work

It is expected that the facility will be operational in the first part of 2001.



Neutronics Calculations for the RPI

N.P. Barradas, J.G: Marques, A.J.G. Ramalho

Objectives

The work developed along the year was centred in the study of situations required by the operational needs of the reactor. This involved primarily the following aspects: core change to configuration N2-P1/6; study of reflectors to enhance the fast flux in an experimental location; and the effects of voids in the vicinity of the core.

Results

In the context of the core configuration change, over 140 configurations were analysed and documented [1-4]. The work involved:

- Fuel replacement and reshuffling
- Moderator relocations
- Replacement of moderator by non thermalising materials to enhance the fast flux at an experimental location
- Fuel burnup and configuration life time
- Introduction of voids in the reflector
- Comparison of void effects with moderator replacement by non moderating materials
- Flux calculations at various locations
- Effect of small displacements of the beryllium reflector blocks on the reactivity of the reactor

Internal Reports

[1] Barradas, N.P., Ramalho, A.J.G., Neutronics study of Core 2 of the Portuguese Research Reactor (RPI): Full report of relevant neutronics calculations up to December 1999 using WIMSD5, CITATION, and other auxiliary programs, including the analysis of a proposed configuration change, ITN/RPI-R-00/57.

[2] Barradas, N.P *et al.*, Calculation of neutron fluxes in configuration N2-P1/6, 8 August 2000, unpublished.

[3] Barradas, N.P., Calculation of the effect in k_{eff} of introducing different volumes of air and polyethylene in the hole of the Be-S block, at the beginning of configuration N2-P1/6, 2 November 2000, unpublished.

[4] Barradas, N.P., Calculation of k_{eff} as a function of the water gap thickness between the core and the Be-S block, at the beginning of configuration N2-P1/6, 3 November 2000, unpublished.

Further work

The calculations performed so far were two-dimensional. One of the objectives for 2000, which was not reached due to concentration on the change of configuration, was to implement code for three-dimensional calculations. This is work that still remains to be done.

Establishment of a New Core Configuration at the RPI

N.P. Barradas, F.M. Cardeira, C. Chaussy, J.-M. Chaussy, A.P. Fernandes, I.C. Gonçalves, J.V. Henriques, A. Kling, J.G. Marques, M.J. Prata, A.J.G. Ramalho, A. Vieira

Objectives

The objective is to study situations which, initiated with the establishment of the new core configuration, will permit the operation of the reactor during a reasonable period of time with minimal changes in the core, and with an increased fast neutron flux available at an experimental location [1-3].

Results

A number of core situations was analysed which corresponded to core configurations with various levels of excess reactivity. An experimental plan was established so that confirmation of theoretical results was obtained in the process of establishing a new configuration. The configuration N2-P1/6 was obtained following a route of minimal movements in the core obtaining at each step the excess reactivity to be compared with the calculations. Control rod worth was calculated for the selected configuration and the verification that the applicable safety rules were abided by was also tested and confirmed.

The selected configuration includes an aluminium reflector located at the face of the beam tube E4, to enhance the fast flux in this tube. The reactivity worth of the reflector as well as of the control rods was calculated and measured experimentally. Likewise the neutron fluxes in the experimental facility were measured and compared with previous situations. In the new configuration N2-P1/6, there is no degradation of the neutron flux in the irradiation positions available in the grid, and there is a significant increase of the fast flux available in the tube E4 by a factor of about 3.

Internal Reports

[1] Ramalho, A.J.G., Barradas, N.P., Cardeira, F.M., Chaussy, C., Kling, A., Marques, J.G., Alteração da configuração do núcleo do RPI - Configuração N2-P1/6 - Análise de segurança; Coordenado por A.J.G. Ramalho, March 2000.

[2] Ramalho, A.J.G., Barradas, N.P. , Cardeira, F.M., Chaussy, C., Fernandes, A.P., Gonçalves, I.C., Henriques, J.V., Kling, A., Marques, J.G., Prata, M.J., Vieira, A., Criação de um feixe de neutrões rápidos num tubo de irradiação - Análise de segurança; Coordenado por A.J.G. Ramalho, 9 February 2000, unpublished.

[3] Ramalho, A.J.G., Barradas, N.P., Cardeira, F.M., Chaussy, C., Fernandes, A.P., Gonçalves, I.C., Kling, A., Marques, J.G., Alteração da configuração do núcleo - Estabelecimento da configuração N2-P1/6 - Relatório de execução; Coordenado por A.J.G. Ramalho, September 2000.

Further work

The work to be developed will centre in the validation of the calculations by experimental measurements. In the present core configuration, the effects of voids on the reactivity will be further evaluated.

Heating of Materials Under Irradiation at the RPI

N.P. Barradas, F. Cardeira, J.G. Marques, A.J.G. Ramalho

Objectives

Calculating of heating of materials under irradiation at the RPI was initiated six years ago with a model developed by CR Carlos [INETI/DEEN-N-94/16, 1994] and others [INETI/DEEN-R-94/34, 1994, ITN/RPI-R-97/45, 1997]. However, no systematic applications have been done. The change in core configuration and new measurements of the intensity of the gamma and neutron field around the reactor, as well as temperature rises in materials under irradiation, lead to a development and expansion of work in this field.

Results

We have developed an integrated set of computer programs to calculate on the one hand the energy absorption by materials in a given radiation field, and on the other hand the heat diffusion in systems consisting of a number of concentrical cylindrical layers [1]. The energy absorption and consequent heating of several different experimental devices was calculated. Calculations were also done in order to find ways of decreasing the temperature rise in the materials being irradiated. This included both changing the sizes of currently utilised sample containers, and simply filling empty spaces with different materials in order to improve the heat conduction. The calculations highlight, inter alia, the importance of reducing the air gap between the samples and the internal wall of the irradiation containers, as well as the advantages of introducing small amounts of conducting materials such as Al in that gap. The calculations were carried out for the irradiation positions currently available at the RPI. As a first result, some irradiations were changed from position 36 to position 56, where the lower gamma dose leads to considerable less heating while requiring only a moderate increase in irradiation time as the change in neutron flux is small.

Internal Report

[1] Barradas, N.P., Programs CYLINDER_HEAT, ABSORBED_DOSE and AQAM - Stationary heat conduction through a series of concentric cylindrical layers with internal heat generation by gamma absorption in the Portuguese Research Reactor (RPI); ITN/RPI-R-00/60, November 2000.

Further work

The code developed is easy to use and rather general within the assumptions accepted. New calculations on other experimental devices, or with changed neutron and gamma radiation fields, are hence simple to perform. This will be done as required for the operation of the RPI. A new experimental programme will be implemented aiming at the validation of the models presently being used.

Calculations on the Activities of Materials Irradiated in the RPI

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Objectives

Calculations on the activity to be expected after the irradiation of materials are an important topic for the use of the RPI reactor. On the one hand the possibilities for the production of new isotopes for medical and industrial research have to be explored, on the other hand the activities to be expected after the irradiation of samples has to be estimated in order to prepare appropriate handling procedures.

Results

After studies on the possible production of standard radioisotopes at low power research reactors like the RPI (Neves, M., Kling, A., Lambrecht, R.M., Utilization of low power reactors on therapeutic radiopharmaceuticals, IAEA-SM-360-010 (2000)) the focus moved to the investigation of new isotopes, e.g., ^{77}As and ^{197}Hg. ^{77}As can be produced by the irradiation of natural germanium through the reaction ^{76}Ge(n,γ)^{77}Ge which subsequently decays ($T_{1/2}$=11.3 h) into ^{77}As. After chemical separation of the As from the Ge very high specific activities can be achieved. For the production of ^{197}Hg by thermal neutron capture calculations on the use of targets enriched in ^{196}Hg (48%) have been performed since the mercury with natural isotopic composition (0.15% ^{196}Hg) yields specific activities that are far too low for practical applications. Fig. 1 depicts the calculation results for the irradiation of enriched mercury in the RPI assuming a continuous irradiation or a 12 hour cycles regime as it is currently used at RPI.

Another important issue was the determination of the irradiation time for the production of ^{24}Na and ^{198}Au for investigations in an aluminum smelter at Avilés, Spain. Due to the high-energy γ-radiation emitted by ^{24}Na the irradiation time had to be calculated precisely in advance in order to avoid unnecessary radiation exposure during handling, transport and use or this isotope. For the generation of ^{24}Na pellets of 0.5 to 1 g NaCl wrapped into Al foil were provided. This made it necessary to study also the production of unwanted radioisotopes (especially ^{38}Cl) which could have impact on the radiation exposure of the RPI staff during handling and – due to the mass of the pellets – the effects of self-shielding. For the irradiation of the Au wires (embedded in Al) the same issues had to be studied. The irradiation and cooling times predicted by using the NAC program turned out to be a good estimate and only a minor adjustment after the first irradiation was necessary.

For a long-time irradiation (ca. 140h) of lunar rock an estimate on the expected activation products and their activities had to be performed in order to determine the time that has to elapse before a safe shipment of the irradiated samples. The complete radioisotope inventory resulting from the irradiation of the more than 10 different main constituents of the minerals had to be calculated for irradiation cycles given by the weekly operation scheme. It turned out that from the radiological viewpoint the most important radioisotopes produced are ^{46}Sc, ^{51}Cr and ^{59}Fe in the minerals themselves and ^{24}Na in the Al container used during irradiation.