Reactor

José Gonçalves Marques

The Portuguese Research Reactor (RPI), as a unique infrastructure in the Iberian Peninsula, houses as well the ***Atmospheric Elemental Dispersion*** and ***Applied Dynamics*** groups. The RPI also supports activities in the Chemistry Sector, the Physics Sector and in the Department for Radiological Protection and Nuclear Safety. Foreign users from Universities and Research Laboratories accounted for 16% of the total irradiation time of the RPI in 2003, with a relative increase of 50% relatively to the year before.

The staff involved in all aspects of the operation and use of the RPI presents its activities under the common headline of ***Operation and Exploitation of the Reactor, Dosimetry (RPI) and Reactor Calculations***. A significant number of research projects is going on, covering areas of dosimetry, materials science and radiation effects in materials and components.

The ***Atmospheric Elemental Dispersion*** group uses the k0 INAA technique in the RPI and was the main user of the reactor in 2003, accounting for 44% of the total irradiation time. The group is dedicated to cycling and impact of trace elements in the atmosphere. It addresses, specifically, the development and application of nuclear techniques, source apportionment and tracking in the atmosphere, chemical speciation, uptake and release of chemical elements in biomonitoring and monitoring, as well as health linkage through epidemiology and nutrition studies. These objectives are approached through research, included mostly in MSc and PhD theses. The activities are financed by the industry (ValorSul urban waster incinerator) and by the Foundation for Science and Technology.

The research performed by the ***Applied Dynamics*** group is mostly concerned by vibration and acoustic problems displayed by components of nuclear and conventional power plants. As such, a significant part of their research results has been motivated and founded by the French *Commissariat à l'Energie Atomique (CEA)* and the Portuguese *Electricidade de Portugal (EDP)*. However, the techniques developed by this group can and have been used to solve problems, both of industrial and fundamental nature, outside the realm of power generation. In spite of being one of the smallest groups in terms of ITN staff, this fact is compensated by an active collaboration with Universities and Research Laboratories, both in Portugal and abroad. The vitality of this group is well demonstrated by their research contracts and publications.

Structure of the Sector and Technical staff

Research groups in the Reactor sector

- **Operation and exploitation of the Reactor, Dosimetry (RPI) and Reactor Calculations**
- **Applied Dynamics**
- **Atmospheric Elemental Dispersion**

Administrative and Technical staff

- Teresa Fernandes
- Albano Silva

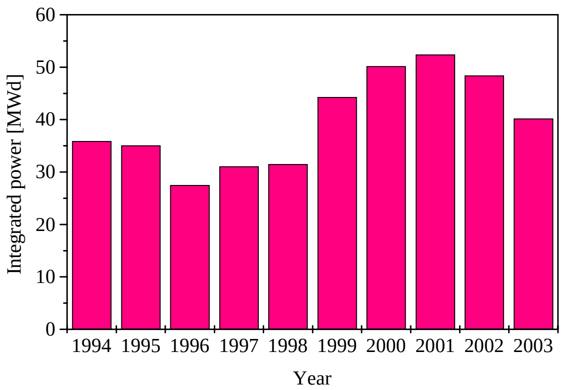
OPERATION AND EXPLOITATION OF THE REACTOR, DOSIMETRY (RPI) AND REACTOR CALCULATIONS

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 electronic circuits for cryogenic thermometry at LHC/CERN under fast neutron irradiation has continued during 2003. The irradiations were performed in a beam tube that was prepared for this effect 3 years ago. Irradiations of electronic components were also performed for several groups in the ATLAS Collaboration at CERN. The same facility was used for the irradiation of rice seeds for IVIA (Spain) and for the irradiation of motion sensors for LIP/Lisbon.

The activity in the fields of dosimetry and BNCT has continued at significant level. Two PhD theses, one in Physics, another in Pharmacy were finalized. The activity in dosimetry has also addressed the characterisation of several facitlities, namely after the new core configurations N2-P1/7A and N2-P1/8.



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, driven mostly by the two core configurations implemented in 2003 and the optimization of some irradiation facilities. Thermohydraulics calculations were also started with the assistance of the IAEA, in order to prepare the core conversion to low enriched fuel, which will have different hydraulics characteristics. The activities using Monte Carlo codes have continued at the same level as last year, with calculation of source terms, shielding and detector response.

The delay in the installation of the Emission Channelling/Blocking Setup could not be recovered during this year. Custom made electronics for processing the signals from the position sensitive detector has been ordered, but not yet received.

The **main users of the reactor** are described in the Table below. Neutron activation analysis (NAA), to users in the Reactor and Chemistry, continues to be the largest activity. Isotope production has continued at a modest level, with 1/3 of the irradiation time for external users and 2/3 for local research groups. One should mention that the new high flux irradiation position in configuration N2-P1/8 has reduced by more than a factor of two the irradiation time for some irradiations, namely for the University of Manchester, when compared with the situation of two years ago.

User	Area	Time (%)
ITN-RPI	NAA	43.9
	Dosimetry and BNCT	11.7
	Other (training, etc)	1.0
ITN-Chemistry	Isotope Production	4.0
	NAA	16.2
ITN-Physics	Neutron Scattering	2.2
ITN-DPRSN	Isotope Production	5.2
Univ. Lisboa	Isotope Production	0.2
Univ. Manchester	Isotope Production	3.7
CERN-LHC	Irradiation of Circuits	10.4
IVIA	Irradiation of Seeds	0.7
LIP/Lisbon	Irradiation of Sensors	0.8

The figure indicates the integrated power produced by the RPI in the last 10 years. A clear increase is seen in the last 5 years reflecting an increase in its use. The integrated power for 2003 (until the second week of December) was 40 MWd, about 10% lower than last year.

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

Research Team

Researchers

- J. G. MARQUES, Auxiliary Researcher
- A. G. RAMALHO, Principal Researcher (retired)
- I. C. GONÇALVES, Principal Researcher
- F. CARDEIRA, Auxiliary Researcher
- A. KLING, Auxiliary Researcher (90%)
- N. P. BARRADAS, Auxiliary Researcher (95%)
- A. FALCÃO, Principal Researcher
- A. R. RAMOS, Auxiliary Researcher
- P. VAZ, Principal Researcher

Reactor Operators

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

Students

- F. GIULIANI, Post-doc Student, ITN, ITN grant
- M. J. PRATA, PhD Student, FCUL, FCT grant
- A. FERNANDES, PhD Student, FCUL, FCT grant
- M.A.F. da COSTA, PhD Student, IST, ITN grant
- J.D.T. CARNEIRO, BSc Student, IST, ITN grant
- N.M.P. ALMEIDA, BSc Student, IST, ITN grant

Technical Personnel

- R. POMBO
- V. TOMÁS
- A. RODRIGUES
- J. S. SOUSA

Funding (€)

Research Projects:	80.871,06
Services:	35.235,19
Total:	**116.106,30**

Publications

Books:		0
Journals:		2 and 3 in press
Proceedings:		4
Conf. Communications:		1
Other publications:		2
Theses:	PhD	1

BNCT Studies at RPI

I. C. Gonçalves, A. J. G. Ramalho, A. C. Fernandes, J. Sousa, N. Oliveira[1], M. Castro[1], J. Rueff[2]

Objectives

The multidisciplinary BNCT (Boron Neutron Capture Therapy) project was developed in collaboration with national and international teams. The participation of ITN focused mainly on the implementation of dosimetric procedures and the study of biological effects caused by the BNC reaction.

Results

The EU project for establishing a Code of Practice for BNCT in Europe has been concluded. The ITN team collaborated in the final revision of the report, whose aim is to identify and propose dosimetric procedures for the clinical application of BNCT.

The dosimetric characterisation of the irradiation facility involved in the biological experiments - vertical acess of the thermal column of RPI – has been pursued. A detailed Monte Carlo model was developed for calculating the neutron and photon radiation components. Activation foils, fission and ionisation chambers and thermoluminescent dosemeters were used for measuring the neutron spectrum, neutron and photon doses. Figure 1 shows the neutron spectrum at the irradiation facility and adjusted theoretical distributions.

The thermal neutron fluence profile and the increasing contribution of thermal neutrons to the overall spectrum further away from the core are represented in Figure 2.

The results of biological experiments for the assessment of the BNC reaction effects in human melanoma cells were presented in a PhD thesis (N. Oliveira, "Toxicology of ionising radiations: The BNC reaction as a model for DNA damage by alpha particles", Pharmacy Faculty of the Lisbon University, November 2003 (in Portuguese)). Figure 3 demonstrates the radiosensiting effect of wortmannin in the genotoxicity of the BNC reaction in V79 Chinese hamster cells.

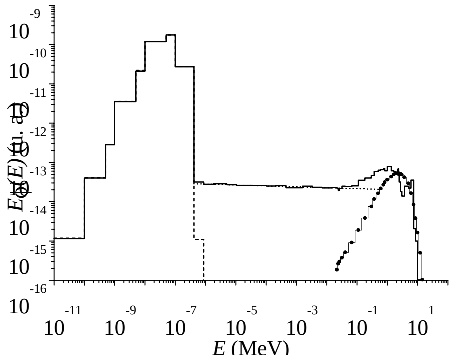


Fig 1: Neutron spectrum at the vertical access of the thermal column (—) and adjusted theoretical distributions (--- Maxwell at 300K; ··· 1/E; -•- Watt-Cranberg).

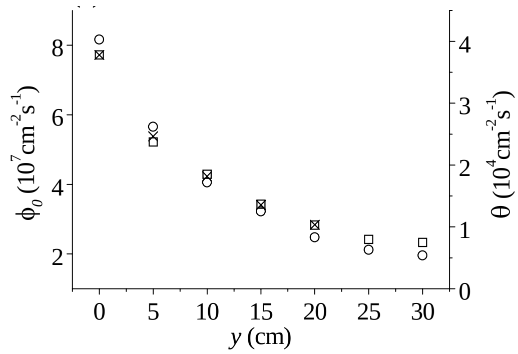


Fig 2: Thermal (ϕ_0) and epithermal (θ) neutron fluence rate profiles at the vertical access of the thermal column (y: distance from closest face to the reactor core; □ thermal neutrons; o epithermal neutrons).

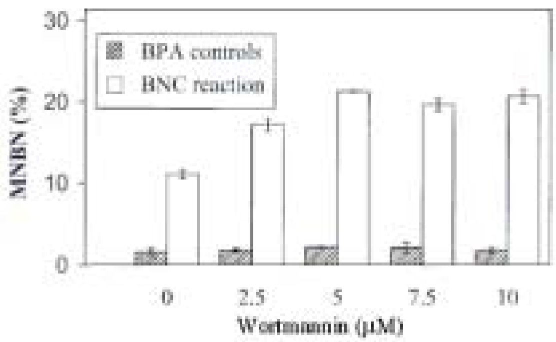


Fig 3: Micronucleated cells as a function of wortmannin concentration. The BNC reaction was performed using a [BPA] of 2.4mM and a thermal neutron fluence of 8×10^{11} cm^{-2}.

Published, accepted or in press work

1. N. G. Oliveira, M. Castro, A. S. Rodrigues, I. C. Gonçalves, O. M. Gil, A. P. Fernandes, J. M. Toscano-Rico, J. Rueff, Wortmannin enhances the induction of micronuclei by low and high LET radiation. *Mutagenesis*, **18**: 37-44 (2003)

2. N. G. Oliveira, M. Castro, A. S. Rodrigues, I. C. Gonçalves, O. M. Gil, A. P. Fernandes, T. Chaveca, J. M. Toscano-Rico, J. Rueff, DNA repair of double stand breaks: Inhibition of DNA-dependent protein kinase (DNA-PK) enhances DNA damage inflicted by low and high LET radiation. *Mutagenesis* (in press).

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

Monte Carlo simulation of mixed radiation fields at RPI irradiation facilities

A. C. Fernandes, I. C. Gonçalves, J. G. Marques, A. Kling, A. J. G. Ramalho

Objectives

The purpose of this task is a full dosimetric characterisation of irradiation facilities at the RPI, based on detailed Monte Carlo models for calculating both neutron and photon components.

Results

The Monte Carlo MCNP-4C code was used to calculate the photon and neutron dose components at various irradiation facilities installed at the RPI. Figure 1 shows an MCNP model developed for these purposes.

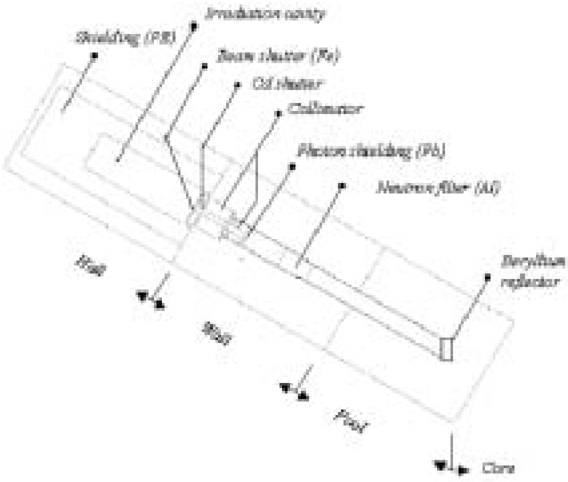


Fig 1: MCNP model of the epithermal neutron beam.

The calculated neutron spectra (figure 2) are further adjusted to the measured responses of activation foils using the unfolding code LSLM-2 (Los Alamos National Laboratory).

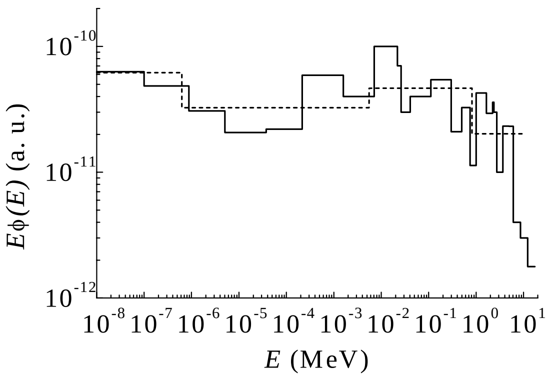


Fig 2: Calculated neutron spectrum at the epithermal neutron beam, in different energy group structures.

The usage of photon and neutron source terms for the MCNP calculations allowed to discriminate the contribution of reactor background and neutron interactions to the total photon spectra (figure 3).

Photon and neutron doses are determined using the calculated spectra and tabled interaction coefficients.

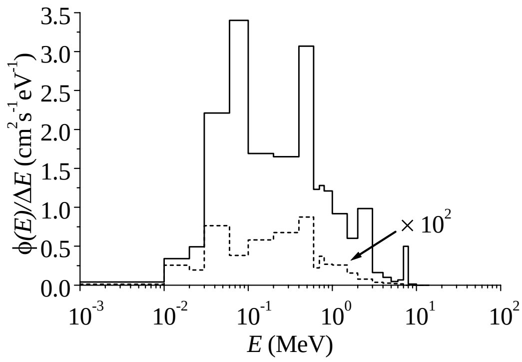


Fig 3: Photon spectrum at the vertical access of the thermal column (— neutron interactions; --- reactor background).

Published, accepted or in press work

3. A. C. Fernandes, I. C. Gonçalves, N. P. Barradas, A. J. Ramalho, Monte Carlo modelling of the Portuguese Research Reactor core and comparison with experimental measurements, *Nuclear Technology* **143** (3): 358-363 (2003).

4. A. C. Fernandes, I. C. Gonçalves, J. Santos, Improved modelling of the neutron field at the Portuguese Research Reactor and its experimental validation, *Proc. 11th Intl. Symp. Reactor Dosimetry, Brussels, 2002*, J. Wagemans et. al. (Eds.), World Scientific, Singapore, 2003, pp. 332-339.

5. A. C. Fernandes, I. C. Gonçalves, J. G. Marques, J. Santos, A. J. G. Ramalho, M. Osvay, Mixed-field dosimetry of a fast neutron beam at the Portuguese Research Reactor for the irradiation of electronic circuits – measurements and calculations, *Proc. 11th Intl. Symp. Reactor Dosimetry, Brussels, 2002*, J. Wagemans et. al. (Eds.), World Scientific, Singapore, 2003, pp. 143-149.

Thermoluminescence dosimetry in mixed fields

A. C. Fernandes, I. C. Gonçalves, J. Santos, A. Ferro Carvalho, L. Santos, J. Cardoso, M. Osvay[1]

Objectives

The assessment of dosimetric characteristics of thermoluminescent dosemeters for mixed-field dosimetry at reactor-based radiation fields requires careful calibration procedures and comparison with the standard methodology of ionisation chambers. The RPI beams were used as neutron sources for the present investigation.

Results

The response characteristics of paired ionisation chambers (Mg/Ar and TE/TE) were studied at the Metrology Laboratory of the Radiological Protection and Nuclear Safety Department of ITN.

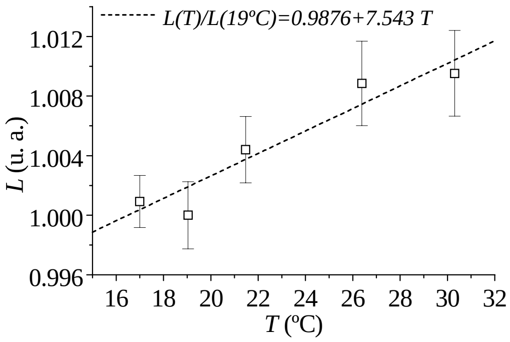


Fig 1: Response of the Mg/Ar chamber as a function of gas temperature.

The linearity and neutron sensitivity of various thermoluminescent materials having different dose range applications (LiF:Mg,Ti, LiF:Mg,Cu,P, Al_2O_3:Mg,Y) was investigated. Figures 2 and 3 show the glow curve and the dose response of one such material, able for high-dose measurements at nuclear reactors.

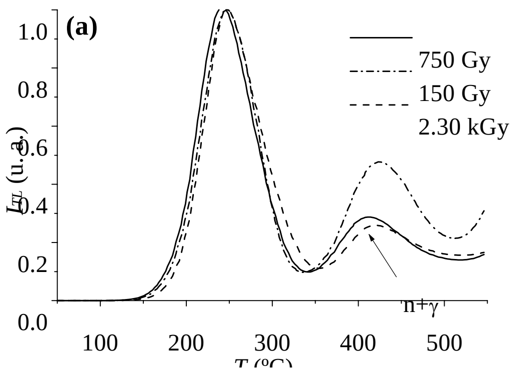


Fig 2: Glow curve of Al_2O_3:Mg,Y (D-3) irradiated with various photon doses and at a mixed fast neutron+photon radiation field.

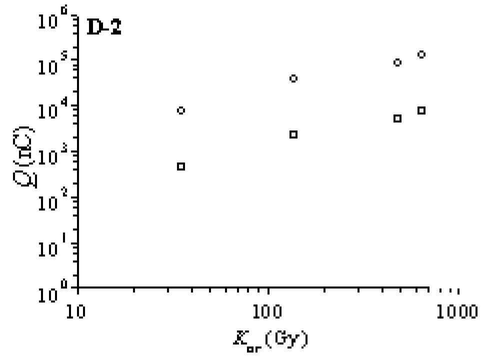


Fig 3: Photon dose response of Al_2O_3:Mg,Y (D-2) (o Peak I; □ Peak II).

Such materials were successfully applied to the measurement of photon doses and dose profiles at full reactor power (figure 4).

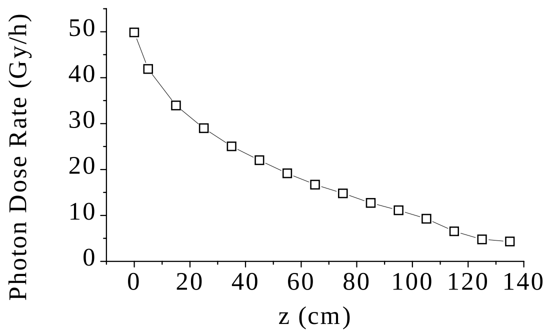


Fig 4: Photon dose rate at the fast neutron beam, measured at 1 MW with D-2 detectors.

Table 1 shows the neutron sensitivity of some investigated materials.

Table 1: Neutron sensitivity (mGy ^{60}Co/10^{10} n_{th} cm^{-2}) of some investigated dosemeters.

Detector	TLD-100	TLD-700	TLD-700H
Measurement	1110	20	5
Literature	650-5350	2-25	0.08-8.3

Published, accepted or in press work

6. A. C. Fernandes, J. P. Santos, A. Kling, J. G. Marques, I. C. Gonçalves, A. Ferro Carvalho, L. Santos, J. Cardoso, M. Osvay, Thermoluminescence dosimetry of a thermal neutron field and comparison with Monte Carlo calculations, *Radiat. Prot. Dosim.* (in press).

[1] Institute of Isotope and Surface Chemistry, Budapest.

Fast Neutron Irradiation of Electronic Circuits for the LHC/CERN

J.G. Marques, I.C. Gonçalves, A.P. Fernandes, N.P. Barradas, F.M. Cardeira, A.J.G. Ramalho, J.A. Agapito[1], F.J. Franco[1], J. Lozano[1], Y. Zong[1], J. Casas-Cubillo[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. The circuits are placed inside a cylindrical cavity, 100 cm long and 15 cm wide, inside the beam tube. The irradiation goal is to achieve a fast neutron fluence of $5x10^{13}$ n/cm^2 during one week of operation of the reactor [1,2].

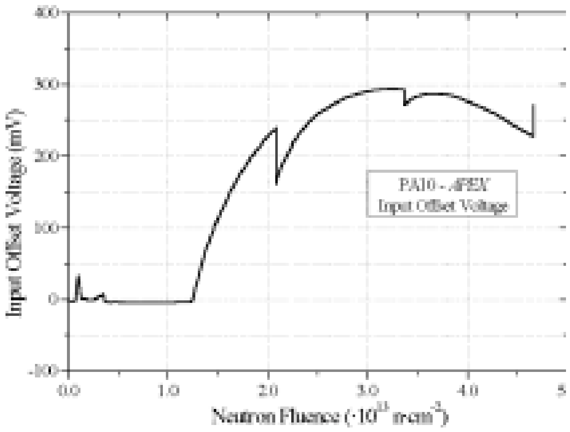


Fig 1. Input offset voltage of power amplifier PA10 as function of the fast neutron fluence. The offset voltage increased abruptly after a fluence of $1.2x10^{13}$ n/cm^2.

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 2003 as foreseen. Several power amplifiers, supervisory circuits and digital-to-analog converters were tested under irradiation [3].

Fig. 1 shows an example from the irradiation of PA10 power operational amplifiers (Apex Microtechnology), for which the offset voltage increased abruptly to more than 200 mV after a fluence of $1.2x10^{13}$ n/cm^2, rendering this component useless. The most tolerant power operational amplifier found in the initial trials was the OPA541 (Burr-Brown). A second irradiation of 8 samples of the component has shown the input offset voltages to be in the 2-6 mV range for a neutron fluence up to $8x10^{13}$ n/cm^2

This work will continue in 2004 with the testing of more components in statistically significant amounts as well as prototypes of the final circuit boards.

Published …

1. J.G. Marques, A.P. Fernandes, I.C. Gonçalves and A.J.G. Ramalho, A Fast Neutron Irradiation Facility at the Portuguese Research Reactor, *Proc. Int. Conf. Research Reactor Utilization, Safety, Decommissing, Fuel and Waste Management, Santiago, Chile, 2003 (in print).*
2. J.G. Marques, A.P. Fernandes, I.C. Gonçalves and A.J.G. Ramalho, New Facility at the Portuguese Research Reactor for Irradiations with Fast Neutrons, *Rad. Prot. Dosim. (submitted).*
3. J.A. Agapito, J. Casas-Cubillo, A.P. Fernandes, F.J. Franco, I.C. Gonçalves, J. Lozano, J.G. Marques, M.A. Rodriguez-Ruiz, Y. Zong, Radiation Tests on Commercial Supervisory Circuits, Power Opamps and DACs for the LHC Cryogenic System, *9th Workshop on Electronics for LHC Experiments (extended abstract).*

[1]Universidad Complutense de Madrid
[2]CERN, LHC/ACR Division

Spin-dependent WIMP-nucleon Couplings from the SIMPLE Experiment

F. Giuliani and TA Girard[1]

Objectives

The SIMPLE experiment is reanalyzed within the context of the WIMP model independent framework of Tovey et. al.. The results are compared with those of the UK NAIAD and NaF experiments as recently reported by the Tokyo group, together with those of the latest UK NAIAD results in 2003, and further constrain the allowed parameter space.

Results

The comparison of results from different spin-dependent WIMP searches conventionally relies on a translation of WIMP-nucleus cross sections to WIMP-proton cross sections. This conversion requires assuming a value for the ratio of WIMP-proton ($\sigma_p^{lim(A)}$) and WIMP-neutron ($\sigma_n^{lim(A)}$) cross sections, which is highly WIMP-model dependent. Because of the negative sign in the ratio of proton-to-neutron spins in fluorine, the LiF/NaF measurements – although seemingly less significant than UKDM in the former exclusion phase space – have been shown to significantly reduce the allowed σ_n-σ_p phase space of the UKDM experiment. To complete the picture, we reanalyzed the previous SIMPLE experimental results within an model-independent framework.

Fig. 1 shows the limit WIMP-proton cross sections for all isotopes/experiments considered.

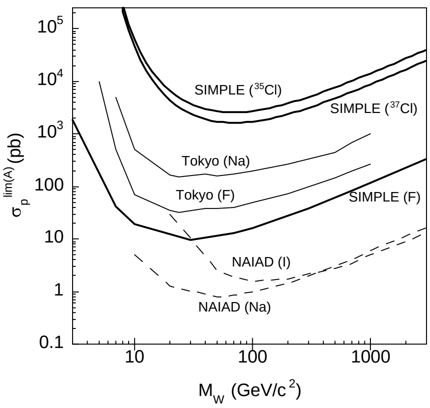


Fig. 1: (a) $\sigma_p^{lim(A)}$ of SIMPLE (thick lines, 0.19 kg day), NAIAD (dashed lines, 3879 kg day), and Tokyo NaF (thin lines, 3.38 kg day) spin dependent WIMP-proton exclusion plots for each nuclide.

Fig. 2 shows the reanalysis of 1999 SIMPLE results obtained with 0.19 kgdy exposure, together with the recent 3.38 kgdy NaF results by the Tokyo group, and two results by NAIAD: the 1080 kgdy used in 1996 and the improved 3879 kgdy published in 2003. The M_W is 50 GeV/c^2, which is in the DAMA-preferred range. Fig. 2 shows the essential contour of the SIMPLE results, which is highly elliptical owing to the weaker constraint from Cl.

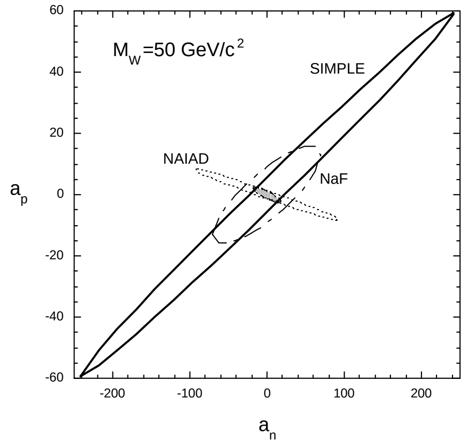


Fig. 2: spin dependent exclusion plots for WIMP mass of 50 GeV/c^2, for SIMPLE (solid), Tokyo NaF (dash-dotted); NAIAD results are represented as a dashed (2003 results) and a dotted (2000). The region permitted by each experiment is the area inside the respective ellipse.

In all cases, both SIMPLE and the Tokyo experiments eliminate a large part of the phase space allowed by NAIAD 2000. In the case of M_W=50 GeV/c^2 for example, the SIMPLE results further reduce the parameter space allowed by the intersection of NAIAD and Tokyo by almost a factor two. When the improved NAIAD 2003 results are taken into account, the allowed regions reduce to the shaded areas of Fig. 2; for M_W=50 GeV/c^2, $|a_p| \le 3$, $|a_n| \le 17$.

Published, accepted or in press work

1. F. Giuliani and TA Girard, Exclusion Limits on Spin-dependent WIMP-nucleon Couplings from the SIMPLE Experiment, Astro-ph/0311589 and submitted to Phys. Lett. B.

[1]Centro de Física Nuclear da Universidade de Lisboa

Neutron Irradiations of SIMPLE SDDs

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

Objectives

SIMPLE is an experiment employing superheated droplet detectors (SDDs) to search for evidence of weakly interacting massive particles (WIMP).

Previous SDD neutron response measurements have been generally made at energies between thermal and several MeV, on commercially available devices of generally low freon concentration (0.03g/10ml). Like all WIMP search detectors, the observation is of the induced nuclear recoil: since the WIMP mass can range from 10 to 1000 GeV, the typical recoil energies of interest for SIMPLE range from ~2-400 keV. WIMP searches however require large active mass: typical SIMPLE SDDs are 1 liter devices containing 10 g active mass of R-115 (C_2ClF_5).

In preliminary measurements of a SIMPLE SDD response using a distributed ^{252}Cf neutron source (0-10 MeV), a significantly larger than anticipated neutron response was recorded at temperatures below 5°C, corresponding to the higher energy neutrons, and in significant disagreement with simulations calculated on the basis of the Seitz model.

Results

Seven SIMPLE R-115 SDDs, fabricated according to procedures described elsewhere with freon masses ranging from 6.3-15 g, were irradiated.

A typical result is shown in Fig. 1. 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. This effect is foreshadowed in the MCNP and should be stronger here due to the large size of the SIMPLE detectors.

The results provide good support for the calculated device calibration in temperature, as seen in Fig.2.

A spinoff of SIMPLE is SIMPLE-Lx. A part of this activity is the creation of an experimental facility to a) produce new SDDs based on CF_3Br or CIF_3 with the intent of providing new limits in spin-INdependent dark matter candidates and b) to develop SDDs for neutron dosimetry.

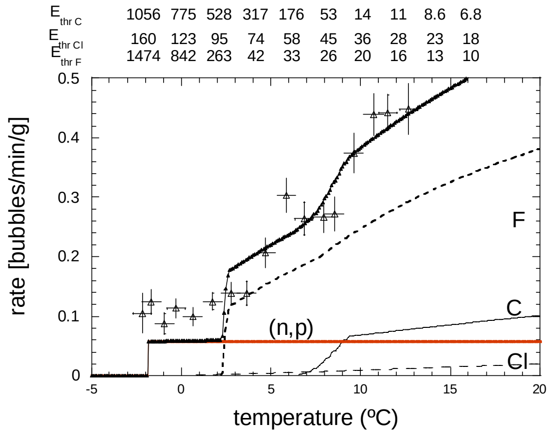


Fig. 1: Si+S filter data at 1 atm; in comparison with raw*0.095 (—) simulation results; dotted lines indicate the respective refrigerant constituent responses as indicated, detector = 15 g.

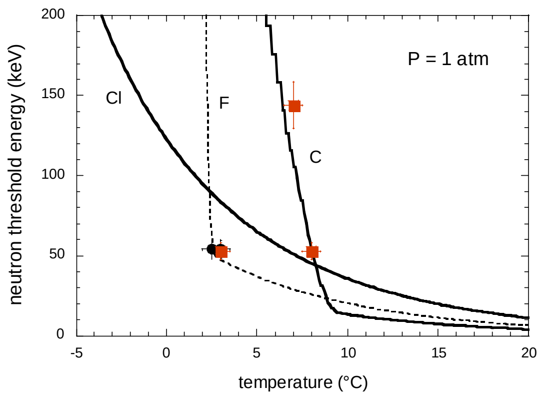


Fig. 2: energy calibration of SDDs, in comparison with calculations, for 1 atm operating pressure.

Published, accepted or in press work

1. F. Giuliani, J.I. Collar, D. Limagne, T. Morlat, J.G. Marques, C. Oliveira, TA Girard, A.R. Ramos and G. Waysand, Response of SIMPLE SDDs to Monochromatic Neutron Irradiations, Nucl. Instr. & Meth. A (in press).

[1]Centro de Física Nuclear da Universidade de Lisboa
[2]Groupe de Physique des Solides, Universités Denis Diderot and Pierre et Marie Curie, France
[3]Department of Physics, University of Chicago, USA

MCNP Studies of Filters for Monochromatic Neutron Beams

N. Almeida, J. Carneiro, C. Oliveira, , TA Girard[1], F. Giuliani, J.G. Marques, J.I. Collar[2,3], T. Morlat[2], D. Limagne[2] and G. Waysand[2]

Objectives

Three composite filters of the RPI thermal column to produce neutron beams of 25, 54 and 149 keV neutrons for calibration of SIMPLE superheated droplet detectors (SDDs) were investigated by MCNP.

In addition the feasibility of a proposed low energy quasi-monoenergetic neutron beam, provided by a Ni-based filtering and an Sc-based filtering of the RPI thermal column, was also investigated.

Results

The filter model consisted of several co-linear, cylindrical rods, of 2 cm ∅ and 10 cm length, of each material. The basic filter compositions were Fe+Al+S (25 keV), Si+S (54 keV) and Si+Ti (149 keV). A large collection of filters was considered. The optimized compositions, determined without the detector environment, were: (40 cm Fe, 20 cm Al, 20 cm S), (100 cm Si, 20 cm S), and (100 cm Si, 20 cm Ti). A reference measurement was also considered by substituting the S of the 25 keV filter with a polyethylene moderator.

To calibrate at lower energies (higher temperatures) Ni-based and Sc-based filters were also studied.

Simulations were performed for a Ni-based filter construct, with a first set of combinations based on Ni-58 since analysis of the materials cross sections indicated that a transmission peak at ~ 13 keV could be expected. Such a peak was indeed observed in the transmission study, but with an extremely weak reaction rate. A response at 107 keV is observed, which bears further examination.

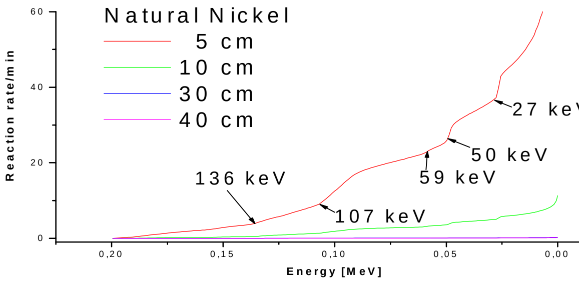


Fig. 1: natural Ni filter detector response

Filters composed of Ni-60 and Fe-56 were also studied since the combined cross section pointed to the existence of a 3.8 keV transmission peak. While no traces of it were found, a 14 keV transmission peak was observed which requires further investigation.

Natural Ni filters have also been examined, since analyses of the cross sections suggests a transmission peak at ~8 keV. In the lead channel flux plot, a 10 keV peak is observed but again is extremely weakened by interactions with the detector gel. A response at 107 keV is again observed. As seen in Fig. 1, no transmission kinks are observed below 27 keV in the detector response, and in consequence no high gradient variations were detected.

The feasibility of a proposed 2 keV filtered neutron beam is provided by a Sc-based filtering

The first composites were combined with Ni-60 which also presents a resonance absorption minimum for the same energies; zinc was added in order to smooth the absorption spectrum elsewhere. Typical results are shown in Fig. 2.

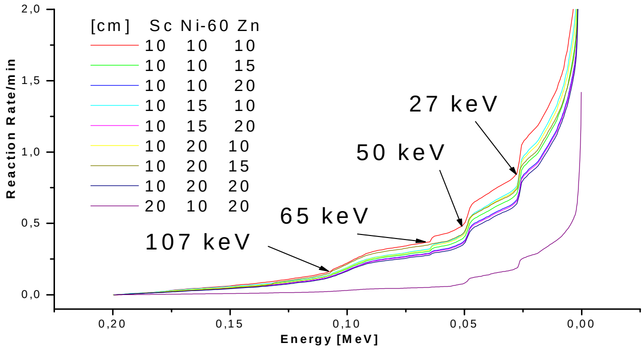


Fig. 2: Sc / Ni-60 / Zn filters – detector response, indicating the 2 keV-associated kink in inset.

Although transmission peaks of 2, 6 and 8 keV are observed at the SDD entrance, these were significantly weakened in the detector gel; the response curve shows a variation corresponding to 2 keV which is not obvious at first glance.

Considering that the cost of Sc is ~EUR 1150 per 5 g, and that that 10 cm length filter comprises 153 g of material, the cost of a marginally feasible 2 keV calibration is prohibitive and the filter will not be pursued further.

Published, accepted or in press work

1. 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. & Meth. B (in press).

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[3] Department of Physics, University of Chicago, USA

Neutronics and thermohydraulics calculations for the RPI

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 [1].

Results

The computer program PREP1345 produces sections 001, 003, 004 and 005 of the input file for the neutron diffusion CITATION code. It had been previously developed at ITN to deal with the cores including only the building blocks (such as fuel elements) used so far at the RPI, and for grids resembling the RPI one. It has now been extended in order to be able to deal with any Cartesian, rectangular, building blocks, and any Cartesian, rectangular, grid [1]. It has been applied to study the storage rack of the RPI, including detailed reactivity calculations for different situations [2], and to the Core I of the RPI, that used LEU (<20%) MTR fuel elements, for which a wealth of data existed, but only few calculations [3].

The average thermal flux and macroscopic absorption and fission cross sections are parameters required to calculate the antireactivity effect of the Xe poison. We developed a code, FLUXZONES, that calculates these parameters for the core II of the RPI. The inputs are files that are either input or output files of CITATION in the calculation of fluxes or k_{eff}. This means that, for configurations that have been previously calculated, all the input files required for FLUXZONES already exist, and hence there is no further work involved [4].

We performed steady state thermohydraulics calculations for configuration N2-P1/8 of Core 2 of the RPI. Medium channel calculations, that correspond to all working parameters being set at its normal operational values, led to a calculated maximum temperature of the fuel meat of 51ºC, and to a calculated water temperature difference between the core inlet and outlet of 4.1ºC. Hot channel calculations, corresponding to the least favourable operating conditions, and taking into account error margins in the determination of parameters, led to a maximum fuel meat temperature of 84.3ºC, which is well within safety margins. A plot of the fuel meat and water temperature along the channel between fuel plates is given in Fig. 1.

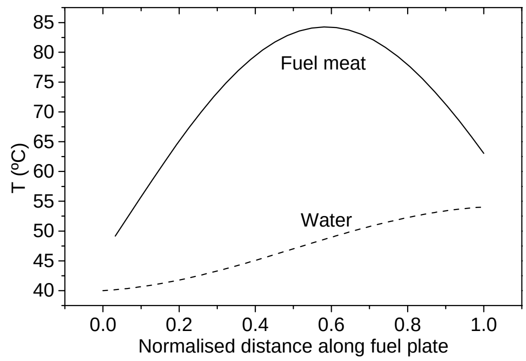

Fig. 1. Hot channel analysis: Temperature in the fuel meat and water along the channel between fuel plates.

Published, accepted or in press work

1. Estudo da configuração N2-P1/7 do RPI; J.G. Marques, N.P. Barradas, F.M. Cardeira, A.C. Fernandes, I.C. Gonçalves, A.R. Ramos, A.J.G. Ramalho, *Internal Report* ITN/RPI-R-02/71.
2. Computer program PREP1345; N.P. Barradas, *Internal Report* ITN/RPI-R-03/75.
3. Neutronics calculations for the storage grid of the Portuguese Research Reactor (RPI); N.P. Barradas, *Internal Report* ITN/RPI-R-03/78.
4. Neutronics calculations for Core I of the Portuguese Research Reactor (RPI); N.P. Barradas, *Internal Report* ITN/RPI-R-03/76.
5. Computer program FLUXZONES; N.P. Barradas, *Internal Report* ITN/RPI-R-03/77.

Reactor Based Production of Isotopes for Targeted Radiotherapy

A. Kling, M. Neves, A. Oliveira

Objectives

Radiopharmaceuticals have been used intensively in diagnostics and also have a seen rapid growth in the past few years in therapy, e.g., bone palliation, bone marrow ablation, synovectomy, and radioimmuno-therapy. The recent revival of interest on radionuclide therapy (also called targeted radiotherapy - TR), is a consequence of improvements in tissue-specific biomolecules (monoclonal antibodies, bone-seeking bisphosphonates, etc.) and its potential advantages over external radiotherapy.

Besides the proper choice of the chemical compound targeting a tumour the properties of the radionuclide (type of emission, partition of the energy to the different type of radiation and half-life) are of the highest importance. Radioisotopes that can be produced by neutron induced reactions (mainly radiative capture) are usually available in large quantities and high specific activities as necessary for therapeutic purposes. Therefore the relevant properties of more than hundred isotopes were screened in this work in order to identify new possible nuclides for therapeutic purposes.

Results

Taken into account the conditions for a proper radionuclide used in radiotherapy (average gamma emission lower than 600 keV and a half-life between 20 minutes and 130 days) eight new isotopes are proposed for radiotherapy: ^{51}Cr, ^{103}Pd, ^{123}Sn, ^{141}Ce, ^{170}Tm, ^{173}Tm, ^{197}Hg and ^{197}Pt [1]. Except for the case of ^{173}Tm all isotopes can be produced in nuclear reactors. The use of highly enriched targets was found to be recommendable in the cases of ^{103}Pd, ^{123}Sn and ^{197}Hg while ^{51}Cr and ^{170}Tm yield high specific using targets with natural isotopic composition. Irradiation of platinum and cerium targets was found to yield also significant amounts of other unwanted isotopes but a sufficient cooling time after irradiation is able to reduce the radiocontamination to acceptable levels. As an example calculations for the specific activities of ^{141}Ce (desired isotope) and ^{143}Ce (contaminant) for irradiation of natural cerium at position 44 of the core N2-P1/7A are shown in Fig. 1 together with the effect of cooling on the radiocontaminant level.

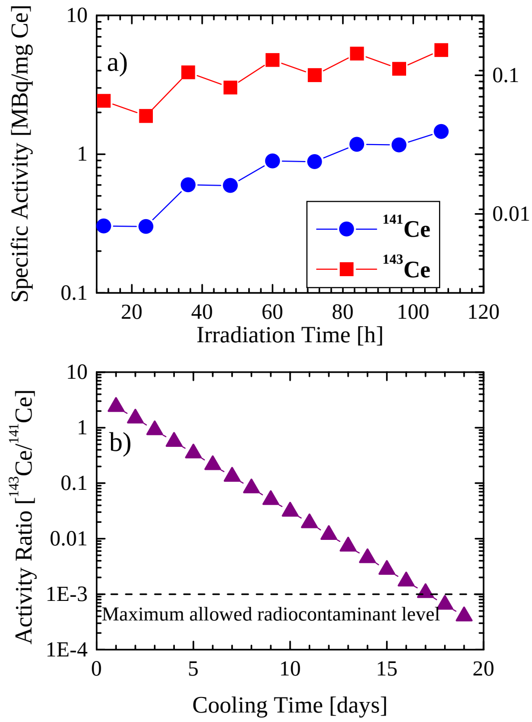

Fig. 1: a) Specific activities of ^{141}Ce and ^{143}Ce vs. irradiation time for the irradiation of natural Ce. b) Evolution of the ^{143}Ce radiocontaminant level with cooling time.

Published, accepted or in press work

1. M. Neves, A. Kling, A. Oliveira, Targeted Radiotherapy: Radiobiological Selection of Nuclides, submitted to *Nucl. Med. & Biol.*

Improving the Radiological Control at the RPI

A. Kling

Objectives

For a safe operation of nuclear installations a thorough radiological control and its documentation is mandatory. Due to the steady technical evolution also the acquisition and analysis of the radiological control data undergoes a continuous improvement process. Also the development of reliable calibration procedures for the detection systems is a field that requires constant attention.

Consequently, the major concerns during the past year were the improvement of the statistical basis of radiological data available at RPI and their more detailed analysis. A further important topic was the development of a calibration procedure for the noble gas channel of the AIRMON-91 system in order to make periodic calibrations of the channel.

Results

One of the main improvements introduced into the radiological control at RPI during the last year is the use of the data sets recorded by the radioprotection control system installed in the second half of the year 2002 instead of the radiological control sheets. The main problem that had to be solved was to overcome the limitation that the data were only accessible in graphical form. A program that analyses the structure of the binary data files and extracts the measured values and the corresponding time information from was developed and put into operation. Compared to the previous years where only the daily radiological control sheets (for the working days) were available, for analysis the statistical basis of the radiological was strongly improved. The number of available data points rose from ca. 12000 values per year to about seven millions. In addition the time periods at which the reactor is out of operation (e.g., weekends, maintenance) are now also fully covered.

A further improvement of the radiological control was achieved by detailing the data according to the power levels of reactor operation. This allows to correlate important parameters, e.g., the air activity in the reactor hall or the noble gas release rate through the stack, with the operating conditions of the reactor. It also will ease the detection of eventual anomalies during operation that may be hidden when using a simple integral analysis of the data.

In order to perform a calibration of the noble gas channel in AIRMON-91 system the necessary equipment and experimental procedures have been studied. Based on previous Monte Carlo calculations a suitable Marinelli beaker has been built at the ITN workshop. It will enable us to detect and quantitatively measure the ^{41}Ar concentration in the stack exhaust of RPI using the typical 1294 keV gamma emission of this isotope. First test calibration measurements were performed during December 2003 (Fig. 1).

Fig. 1: View of the Marinelli beaker with a HPGE detector installed at the AIRMON-91 system during calibration measurements.

Published, accepted or in press work

1. A. Kling, Radiological Control at the Portuguese Research Reactor (RPI) - Report January 1 – December 31, 2002, *Internal Report* ITN/RPI-R-03/72.
2. A. Kling, Radiological Control at the Portuguese Research Reactor (RPI) - Report January 1- June 30, 2003, *Internal Report* ITN/RPI-R-03/80.

Preliminary Design Studies of an eXperimental Accelerator Driven System (PDS-XADS)

P. Vaz, N.P. Barradas, R. Pires[1], I.F. Gonçalves[2]

Scope and Objectives

The European Commission´s Green Paper entitled "Towards a European Strategy for the Security of Energy Supply" clearly pointed out the importance of nuclear energy in Europe. With 145 operating reactors producing a total power of 125 GW_e, the resulting energy generation of 850 TWh per year provides 35% of the electricity consumption of the European Union. Most of the hazard from the *spent fuel* from nuclear power plants stems from only a few chemical elements – plutonium, neptunium, americium, curium and some *long-lived fission products* such as iodine and technetium at concentration levels of grams per ton. At present approximately 2500 tons of spent fuel are produced annually in the EU, containing about 25 tons of plutonium and 3.5 tons of the "*minor actinides*" neptunium, americium, and curium and 3 tons of long lived fission products. These radioactive by-products, although present at relatively low concentrations in the spent fuel, are a hazard to life forms when released into the environment. Accelerator Driven Systems (ADS) consist of a high-intensity proton accelerator of energies in the range 600-800 MeV impinging a target of an heavy element. The spallation reactions in the target material generate a very high neutron flux that feeds a surrounding sub-critical core system. The very high-flux of neutrons is required to sustain the *transmutation* processes by which the minor actinides and long-lived fission products can be "transformed" in nuclide species with a shorter lifetime, typically of hundreds of years (instead of dozens of thousands of years), and smaller radiotoxicity. Accelerator Driven Systems would have a great potential for nuclear waste transmutation and could be used to reduce the burden to underground repositories.

Results

The PDS-XADS project is co-funded by the European Union under contract N° FIKW-CT-2001-00179. It is carried out by a consortium of 25 institutions (nuclear industry, universities and state laboratories) in European countries. Thw studies are organized around Work Packages (WP). The ITN team is directly involved, in the computational activities of:

WP 4.3 – Target Unit design – Spallation and neutronic calculations of the target unit (heat distributions, evaluation of the spallation and activation products, their energy and volume distributions). Work in cooperation with Framatome-ANP (WP leader), Ansaldo Nucleare (Italy), ENEA (Italy), FZK (Germany), SCK-CEN (Belgium), UPM (Spain), KTH (Sweden) and UMM (Poland).

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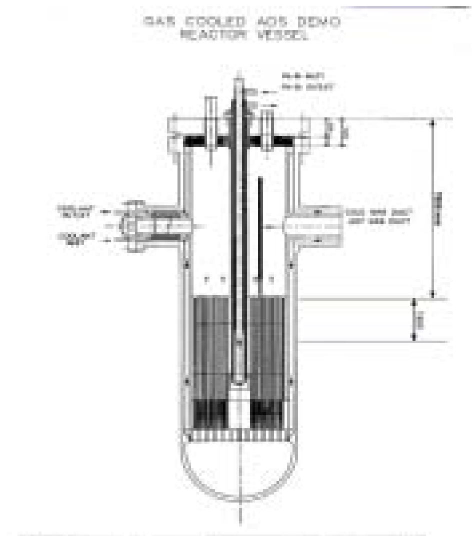
WP 3 – Accelerator studies – Requirements for the operation of the XADS Accelerator (6 to 10 mA nominal proton beam current and 600 to 800 MeV energy) & the technical answers on issues such as stability, accidental situations and potential for other applications. Work in cooperation with FE-UCP (Faculdade de Engenharia da Universidade católica Portuguesa), CEA, CNRS and IN2P3 (France), INFN (Italy), IBA (Belgium), Univ. Frankfurt (Germany).

The following picture shows one of the possible configurations for the XADS in which the ITN team is involved. It consists of a gas-colled Lead-Bismuth Eutectic target with a window separating the accelerator and the target. Studies and Monte Carlo simulations concerning this design are currently being performed using the state-of-the-art computer program MCNPX.



XADS configuration of gas-cooled primary system (Framatome ANP)
Penetration of the proton beam from the top
Fig. 3

Published, accepted or in press work

Technical reports:

1. "Accelerator: Feedback Systems, Safety Grade Shutdown & Power Limitation", *Deliverable D47 of the PDS-XADS project, Work Package 3*
2. "Spallation/ Neutronic Calculations Generating the Heavy Particles and Spallation Products Volumetric Distribution and Energy Spectrum", *Deliverable D60.1 of the PDS-XADS project, Work Package 4.3*

Conference proceedings:

1. "Window Target Unit for the XADS Gas Cooled Primary System", by S: Cuesta et. al., in Proceedings of International Workshop on P&T and ADS development", Mol , Belgium (2003)

Participation of ITN in the n-TOF experiment (PS213) at CERN (Second Year)

(FCT project POCTI/FNU/49557/2002)

P. Vaz, C. Cruz[1], I.F. Gonçalves[1], J. Neves[1], J. Salgado[1], J.C. Soares[4], R. Crespo[2], L. Ferreira[2,] T. Peña[2], L. Távora[3], A. Melo[4], A Carrillo[5], L. Marques[5], J.C. Brás[5]

Scope and Objectives

The n-TOF Collaboration, a consortium of 40 laboratories in Europe and U.S.A., has proposed an ambitious programme to perform high accuracy measurements of neutron cross-sections in the range from 1 eV to 250 MeV. An experimental programme (PS213) is being carried out since 2001 at the neutron time of flight (TOF) facility at CERN, using the CERN/PS accelerator complex. A single proton pulse of $7 \cdot 10^{12}$ protons of 20 GeV impinges on a lead target every 2.4 seconds. After collimation, a neutron flux of the order of 10^5 neutrons/cm^2/pulse is available for cross section measurements in the detectors station located 185 m downstream the target area.

These cross-section measurements are required in many emerging applications that require the use of high-intensity and medium-energy (in the hundreds of MeV) proton beams impinging on a thick target of an heavy element. These applications range from the design of innovative Accelerator Driven Systems (ADS) for incineration of nuclear waste and energy production, radioisotope production for medical and industrial applications and to many other subjects in Astrophysics, Nuclear Physics and Nuclear Technology. New or improved measurements of neutron cross-sections will also be very valuable for Radiation Shielding, Dosimetry and Monte Carlo Radiation Transport calculations.

Results

This project deals with the following issues: i) radiation transport calculations using state-of-the-art Monte Carlo programs, ii) radiation detection and measurement techniques iii) particle detectors and associated electronics iv) high-precision measurements of neutron cross sections and v) physics analysis and nuclear data evaluation

During 2003, ITN researchers:

- Participated in the data taking shifts at CERN,
- Developed and tested prototypes for the voltage divider circuit attached to the photomultipliers equipping the the Barium Fluoride (BaF_2) calorimeter modules
- Participated in the Monte Carlo simulation studies to assess the new experimental conditions arising from future changes in the shielding and collimating systems of the TOF spectrometer,
- Prepared the files for the simulation of the detection efficiency to photons and to neutrons of the newly built BaF_2 calorimeter modules, namely those containing the geometric description of the detector modules
- Evaluated the importance of neutron elastic scattering in the simulation of proton and neutron-induced reactions in thick targets and assessed the availability and needs of experimental and evaluated data

The simulations performed involved the utilization of the state-of-the-art Monte Carlo programs MCNPX and GEANT4 (simulation of the BaF_2 calorimeter). The construction of the calorimeter is of the responsibility of a consortium of organizations led by FZK (Germany). ITN participates in the development of the voltage divider circuits attached to the photomultipliers.

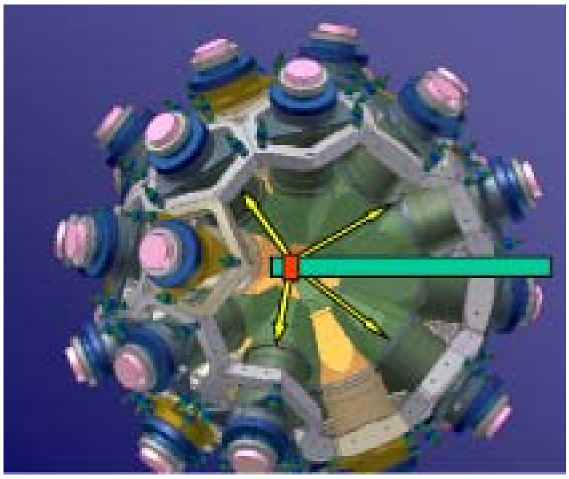


Figure: The n-TOF Barium Fluoride calorimeter – A 50 cm diameter sphere made of 40 BaF_2 modules of prismal pentagonal and hexagonal geometry, each equipped with a photomultiplier and a voltage divider and mounted on a aluminium honeycomb structure. In the picture, the beam pipe and sample are schematically shown.

Published, accepted or in press work

1. "CERN n-TOF Facility: Performance Report", by U. Abondanno et. al., CERN report CERN-SL-2002-053 ECT (2002), submitted for publication to NIM-A.

2. "New Experimental validation of the Pulse Height Weighting Technique for Capture cross-section measurements", *by U. Abondanno et. al., Nuclear Instruments and Methods in Physics Research A, NIM A(2003, in press)*

[1]ITN, Physics Department, [2]IST – (Technical University of Lisbon), Physics Department, [3]Centro de Instrumentação – Universidade de Coimbra, [4]CFNUL – Centro de Física Nuclear da Universidade de Lisboa, [5]ITN (project fellowships)