Nuclear Instruments and Methods

Introduction

The activity of the Group was oriented towards *(a)* modelling and simulation of gamma and neutron fields and electronic discharges in gases; *(b)* development of nuclear methods, techniques and instrumentation for measurement and control; *(c)* technical assistance and supply of equipment and services.

The work in the field of modelling and simulation of gamma and neutron fields, carried out using the MCNP code, was the following:

- Influence of the material thickness on the count rate of a PGNAA system for elemental analysis of cement raw material transported on a conveyor belt. The study enabled the establishment of generalised calibration curves;
- Response of superconducting detectors (Sn and Re) to electron irradiation;
- Dosimetric calculations for the Portuguese Gamma Irradiation Facility;
- Dosimetric calculations for radiotherapy linear accelerators;
- Feasibility studies of adapting the horizontal access of the RPI thermal column for a BNCT therapy installation;
- Calculation of fast neutron and gamma radiation spectra inside a lead hollow cylinder from a planar source of fission neutrons and reactor gamma photons.

The work in modelling and simulation of electronic discharges in gases included:

- Computation of photoelectric emission probability in 2D geometry, taking into account radiation imprisonment in the gas;
- Re-engineering of a software code for 2D hydrodynamic simulation of gas discharges.

The work in the design of instrumentation included:

- Up-grading of the Time of Flight Diffractometer detector bank;
- Design and construction of the temperature controller and power supply of the High Resolution High Temperature Double Crystal X-Ray Diffractomer chamber;
- Design and construction of the sample chamber of the Small Angle Neutron Spectrometer;
- Up-grading the DC Power supply Constant Current and the Cell Electrodeposition Set for the determination of radioactive element traces.

Technical assistance and services in the field of electronic and information technologies were extended to:

- Different ITN Groups (Two-Axis Neutron Diffractometer, Mass Spectrometer of the Chemistry Department, Radiological Protection System of the Portuguese Research Reactor).
- External users (International Atomic Energy Agency, Instituto Geológico e Mineiro, Air Portugal, Portucel, Cimpor, ABB-Metalomecânica de Setúbal, Solvay Portugal).

Research Team

Researchers –	8	(8 PhD or equivalent)
Technicians –	2	

Publications

Journals –	3	(2 in press)
Proceedings –	3	
Special publ.–	5	
Internal Reports –	1	
Conf. Commun. –	2	

	10^3 PTE
Expenditure:	**4.394**
Missions:	204
Others Expenses:	767
Hardware & Software:	1.509
Other Equipment:	1.914

		10^3 PTE
Funding:		**4.956**
External Projects:	1996	86 [1]
	1997	2.934
Others		1.936

[1] Funding not used in 1996

Density and Water Content Corrections in the Gamma Count Rate of a PGNAA System for Cement Raw Material Analysis Using the MCNP Code

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Abstract
A MCNP simulation study for a prompt gamma neutron activation analysis system for on-line characterisation of cement raw materials has been carried out. A neutron source is located below a conveyor belt. Two detector banks were used: a lower bank positioned symmetrically around the source to detect γ-rays emitted downwards; an upper bank detects the radiation emitted upwards. The count rate of both detector banks for a given composition depends on the bulk density and water content. This paper reports a few corrections, which linearize the dependence of the corrected count rate on the mass content.

Applied Radiation and Isotopes, in press.

Calibration Curves of a PGNAA System for Cement Raw Material Analysis Using the MCNP Code

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Abstract
In large samples, the γ ray count rate of a prompt gamma neutron activation analysis system is a multi-variable function of the elemental dry composition, density, water content and thickness of the material. The experimental calibration curves requires tremendous laboratory work, using a great number of standards with well-known compositions. Although a Monte Carlo simulation study does not avoid the experimental calibration work, it reduces the number of experimental calibration standards.
This paper is part of a feasibility study for a PGNAA system for on-line continuous characterisation of cement raw material conveyed on a belt (Oliveira *et al*. 1997, 1997a and 1997b). It reports on the influence of the density, mass water content and thickness on the calibration curves of the PGNAA system.
The MCNP-4A code (Briesmeister 1993), running in a Pentium-PC and in a DEC workstation, was used to simulate the PGNAA configuration system.

Applied Radiation and Isotopes, in press.

Use of the Thermal Column of the Portuguese Research Reactor (RPI) for BNCT Therapy

I.F. Gonçalves, I. C. Gonçalves, A.J.G. Ramalho and J. Salgado
Nuclear and Technological Institute, Sacavém, Portugal
(see RPI - Dosimetry)

Work in the Field of BNCT Using the Portuguese Research Reactor

I.C. Gonçalves[1], A.G. Ramalho[1], I.F. Gonçalves[1], J. Salgado[1], J. Pertusa[2], A. Irles[2], F. Mascarenhas[3], M. Castro[4], F. Valle[4], J. Toscano Rico[4] and V. Alcober[5]
[1]*Nuclear and Technological Institute, Sacavém, Portugal,*
[2]*Departamento de Biologia Animal, Universidade de Valência, Espanha,*
[3] *Serviço de Radioterapia, Hospital de Santa Maria, Portugal,*
[4]*Centro de Farmacologia Experimental e Clínica, Faculdade de Medicina de Lisboa, Portugal,*
[5] *Universidade Politécnica de Madrid, Espanha*
(see RPI - Dosimetry)

Current work

Radiation-induced Thermal Destruction of the Geometrical Barrier in Superconducting Tin

V. Jeudy [1,2], M.J. Gomes[2], T.A. Girard[2], D. Limagne[1], C.Oliveira[4], G. Jung[5], J.I. Collar [2,1,3], G. Waysand[1]

[1] Groupe de Physique des Solides (UA 17 CNRS), Universités Paris 7/6, France
[2] CFN/UL (Linha 5)
[3] PPE Division/CERN, Switzerland
[4] Departamento de Física, Instituto Tecnológico e Nuclear, Portugal
[5] Department of Physics, Beer-sheva University, Israel

The existence of a geometric barrier in Type I structures at low temperatures is a well-recognised phenomenon: experiments involving both magneto-optical techniques and studies of the current-carrying capacity of samples [1], of various widths and thicknesses, have identified the essential features of the geometric barrier behaviour. These experiments have however only examined the magnetic nucleation channel.

We initiated first thermal nucleation studies of such structures, based on measurement of the flux changes in the material induced by irradiation, using a technique which gives direct access to the size of the penetrating normal domain, and variation in the size of the flux bundle. Measurements were performed on a 20μ thick (θ) tin polycrystalline foil at T>390mK. The irradiation source was 43 kBq of ^{109}Cd evaporated into a 20μ thick, absorbent paper. Flux penetration was detected by a copper wire loop surrounding the strip, connected via two pulse transformers to a pulse amplifier: only irreversible flux variations are detected; reversible changes are outside the bandwidth of the preamplifier. Since the time variations of the magnetic flux in the coil ($d\phi/dt$) is integrated by the electronics, the recorded pulse-height ≈ ϕ ≈ surface area of the penetrating flux tube. The observed linearity of the spectrum then implies that the nucleated volume (θS_{tube}) is proportional to the deposited energy. Fig. 1 shows the linear variation of the 62 keV electron peak position with $(1-t)^{-1/2}$, consistent with the Landau model prediction of $S_{tube}(T) \propto \xi(T)$.

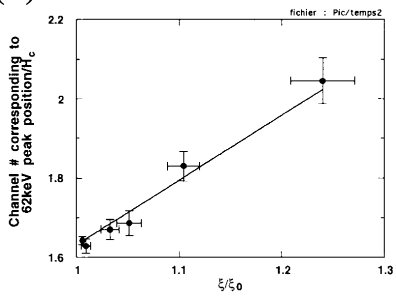

Fig. 1 – Variation of the penetrating flux bundle size with the coherence length.

The Landau non-branching model [2] further predicts that the intermediate state edge structure has a curtain-like topology whose folds are perpendicular to the strip border and periodically spaced, with a distance "s" separating two consecutive folds of $10[\xi(T)\theta]^{1/2}$. The width of a normal fold ≈s/2. Assuming that the flux nucleation results from the pinching off of one fold of the normal-superconducting interface, the flux bundle contains approximatively 1500 flux quanta; the bundle size increases with increasing magnetic field.

[1] J.R. Clem, R.T. Huebener and D.E. Gallus, Jour. Low Temp. Phys. 12 (1973) 449.
[2] P.G. de Gennes, Superconductivity of Metals and Alloys (W.A. Benjamin, Inc. New York, 1966).

To be submitted to Physical Review Letters

Response of a Geometrically Metastable Superconducting Detector to Electron Irradiation

T.A. Girard[1)], C.Oliveira[2)], V. Jeudy [3,1)], D. Limagne[3)], J.I. Collar[1,4)], G. Waysand[3)]
[1)] *CFN/UL (Linha 5)*
[2)] *Departamento de Física, Instituto Tecnológico e Nuclear, Portugal*
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[4)] *PPE Division/CERN, Switzerland*

Abstract
The first energy-resolved spectrum of ^{109}Cd obtained with a 20 μm thick Sn strip at 400 mK, consisted of an uncorrected sum of 19 measurement cycles. Generally however, we find that only three contained both peaks. We show below in Fig. 1 the noise-corrected sum of these spectra together with their gaussian fits.

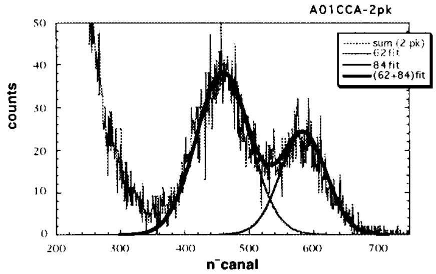

Fig. 1: Experimental ^{109}Cd decay spectrum.

The area ratio for the two is in disagreement with the tabulated 0.93. The peak in evidence at 25 keV is preliminarily identified with the Sn Kα X-ray activated by the incident electrons, although the decay itself includes both low intensity electron and X-ray emissions in the range of 22-25 keV: it may also be either a remnant noise contribution, or measurement systematic. The FWHM energy resolutions are 19% (15%), for the 62 (84) keV line. In principle, the resolution of the 25 keV peak should be independent of the source configuration, more nearly reflecting the intrinsic resolution of the strip; its FWHM resolution is however 23%, in rough agreement with the $1/\sqrt{E}$ dependence of the 62/84 keV lines.
A MCNP simulation, performed for the 20 μ source paper thickness, is shown in in Fig. 2 (b). This simulation incorporates both primary and secondary scattering processes; it includes the complete detector geometry, and both electron and photon decay channels; it does not however contain the thermodynamic response of the strip, nor include the emission spectrum of the intrinsic Sn decays. The FWHM resolution of the 62/84 keV peaks are in reasonable agreement with experiment; as seen in Fig. 2(a), this resolution should improve significantly with decrease in source thickness.

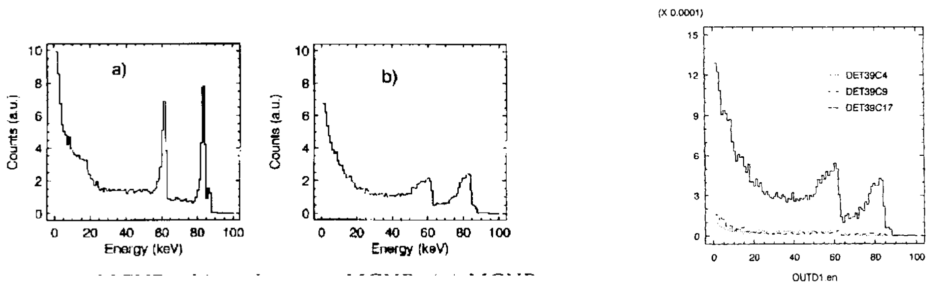

Fig. 2: (a) thin source MCNP; (b) real source MCNP; (c) MCNP energy deposition in nearest-source slab of 9μ thickness.

A MCNP simulation study was performed in which the sensitive volume was confined to various regions near the strip edges. For a nearest-slab, of width 9μ, the spectrum of energy deposition in this region is similar to that observed experimentally, as seen in Fig. 2(c). An electrodeposited ^{109}Cd source has been obtained from Orsay; new experiments to confirm the above are scheduled.

To be submitted to *Nucl. Instr. & Meth.*

The Geometrical Barrier in Superconducting Rhenium

M.J. Gomes[1], T.A. Girard[1], C.Oliveira[2], V. Jeudy [3,1], D. Limagne[3], J.I. Collar[1,3,4], G. Waysand[3]

[1] *CFN/UL (Linha 5)*

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[4] *PPE Division/CERN, Switzerland*

In the Clem 2-D model [1], the geometric barrier of Type I material in a perpendicular magnetic field is described by the change in the Gibb's free energy associated with the presence of a flux-bearing normal zone in the diamagnetic volume:

$$\Delta G = \Delta G_{in} + \Delta G_{out} - \Delta W_{apl} \quad (1)$$

where ΔG_{in} is the sum of the loss of condensation energy and the gain of the magnetic energy inside the domain, ΔG_{out} is the self-magnetic field energy of the normal domain outside the superconductor, and ΔW_{apl} corresponds to the work done by the source of the applied magnetic field when a normal domain is introduced into the sample. The precise physics of the detector behaviour in the irreversible region of flux penetration is not yet well-understood: generally, Eqn.(1) must be modified to include the presence of an increasingly normal central zone, and the varying demagnetisation in the last term.

Rhenium provides – in principle – a laboratory in which both magnetic and thermal nucleation channels compete simultaneously, owing to the intrinsic beta decay of the 62% naturally-occurring ^{186}Re. In principle, these can be separated be selection of the magnetic ramping speed: the flux penetration in general can be fit two exponentials, corresponding to magnetic and thermal contributions.

Measurements were performed on a 25μ thick Re foil at 300 < T < 600 mK. Systematic studies of the flux penetration as a function of field up-and down-ramping time, threshold variation and temperature, were conducted with and without a pause inserted in the field ramp. Typical results are shown below.

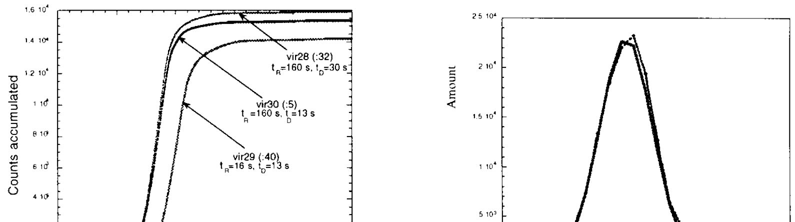

Fig. 1 - (a) variation of penetration fields with ramping speed; (b) variation of flux penetration with pause field.

As seen in Fig. 1 (a), the field at which the flux first penetrates is lowered with slower ramping time. The penetration of flux during a pause inserted in the ramp, for various pause fields, is shown in Fig. 1(b), together with a gaussian fit. Since each penetration connects two equilibrium states of the barrier, these results provide information on the behaviour of ΔW_{apl} in the irreversible regime. Interpretation of the results remains in progress.

[1] J.R. Clem, R.T. Huebener and D.E. Gallus, *Jour. Low Temp. Phys.* **12** (1973) 449.

To be submitted to *Physical Review Letters* or *Physical Review B*

Measurement of the Decay Spectrum of ^{187}Re

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4) *PPE Division/CERN, Switzerland*

Currently, the best limits on neutrino mass derive from precision measurements of the near-endpoint tritium decay spectrum; these are generally mass-limited in order to avoid the effects of multiple event summing (pileup) into the interest region of the spectrum, and have considerable difficulty to achieve resolutions of 10 eV near the decay spectrum endpoint. The Genoa group has suggested [1] the alternative measurement of 187Re decay towards addressing both the rate limit and energy resolution difficulties: with a decay endpoint energy of 2.667 keV, the fraction of decays into the last 10 eV of the spectrum is 10^{-4}, three orders of magnitude larger than the ^{3}H experiments.

Fig. 1 presents a first ^{187}Re spectrum, obtained at 330 mK by threshold variation during identical pauses in magnetic field ramps, with a 6 mg geometrically-metastable superconducting detector prototype constructed from a 25μ thick, natural Re strip. An estimate of the maximum energy resolution yields a step-size of 7 eV.

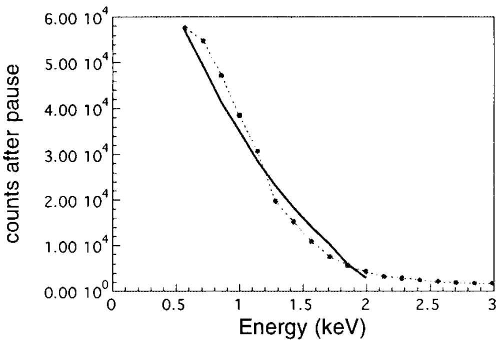

Fig. 1: (•) preliminary beta decay spectrum of ^{187}Re, in comparison with the most recent Genova results (-).

The current timing resolution of the metastable device is of 1μs, suggesting the ability to accommodate a factor 10^3 more event rate than Genoa: more than 99.7% of the decay electrons can be fully absorbed within the detector, with the remainder yielding only partial energy depositions insufficient to produce a signal.

Also shown is a recent spectrum [2] of the decay obtained by Genoa, normalized to the events of the present work. The variation of the present results about those of Genoa is unexplained. However, for R≈7 decays per sec into the entire strip, and a sensitive geometry ratio of 2.9%, the expected signal rate is only 2 Hz, well-below that observed. A large part of the excess is likely due to magnetic nucleation events generated at the onset of each pause; it is also possible that each decay produces a percolation of flux penetration, with the number of flux tubes proportional to the deposition energy of the decay event.

[1] E. Cosulich, G. Gallinaro, F. Gatti and S. Vitale, *Phys. Lett.* ***B*295** (1992) 143.

[2] A. Swift *et al., in* Proc. Identification of Dark Matter [Sheffield, UK 1996].

To be submitted to *Physics Letters B* or *Nucl. Instr. & Meth.* or *Phys. Rev. Lett.*

MCNP Calculations of dose Distributions in the Portuguese Gamma Irradiation Facility

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Nuclear and Technological Institute, Est. Nac. 10, 2685 Sacavém, Portugal
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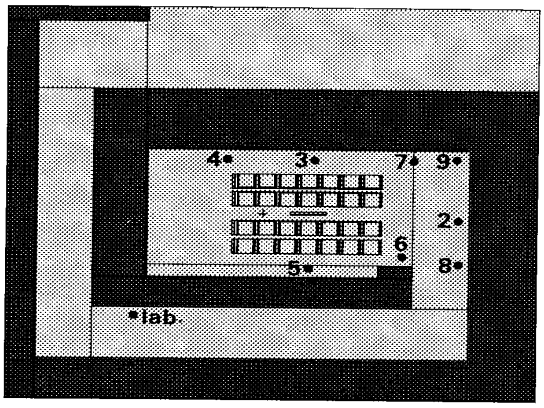
Abstract

A simulation study of the Portuguese Gamma Irradiation Facility is being carried out using the MCNP code. The irradiator consists of 30 stainless steel tubes containing 156 ^{60}Co sources, doubly encapsulated in welded stainless steel. The product to be irradiated is transported by 28 carriers. The objectives of the simulation are *(a)* the optimisation of the dose distribution inside the irradiation cell, in order to obtain higher doses and a better homogeneity, *(b)* dose calculations inside irradiated samples and *(c)* dose calculations in critical points for protection purposes.

Preliminary calculations in 9 different places show the contributions from source, irradiator structure, samples material, carriers, walls, ceiling and floor for the total photon spectra in those points. Figure 1 shows the irradiation cell, the position of the chosen points and the photon contributions (in %). Figure 2 shows gamma spectra for some of these points. The spectrum 3 reveals the presence of ^{60}Co peaks; 33% of the photons that arrived at the respective point are directly emitted by the source. In the spectrum 2, the ^{60}Co peaks are absent; the photons have suffered multiscattering before reaching this point. Experimental measurements are also being performed. A difference of the order 20% between simulated and experimental was found. Such reasonable agreement confirms that the simulation can be used to optimise the dose distribution and to calculate doses of irradiated samples.



Photon contributions (%)

	P3	P2	P9	lab
Co sources	33	-	14	-
Irradiator structure	10	3	6	-
Samples	22	15	12	-
Carriers	12	10	8	-
Walls	17	19	41	70
Ceiling	-	5	4	10
Floor	3	5	8	9
Others	3	12	7	11

Fig 1. Irradiation cell

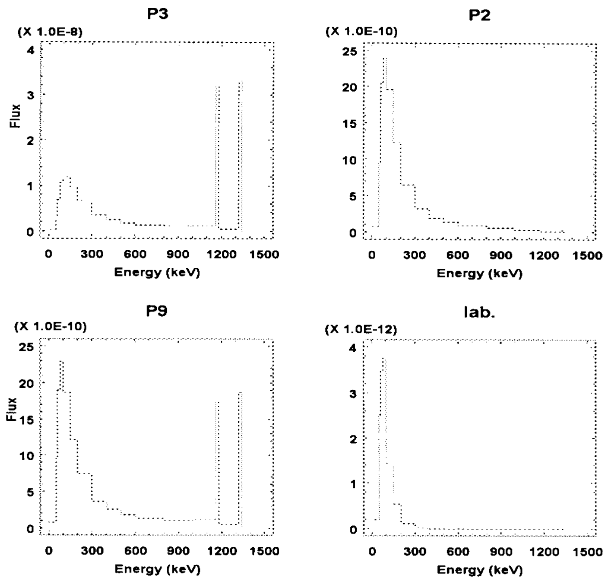


Fig. 2 Gamma spectra at different points

Dose Simulations on a Linear Accelerator for Radiotherapy

M. Carmo Lopes[1], Adérito B. Chaves[1], Carla C. Oliveira[1], Carlos Oliveira[2], José Salgado[2], Luís Peralta[3], João Carlos Seco[3] and Margarida Fragoso[3]
[1] *Centro Regional de Oncologia de Coimbra (CROC), Coimbra, Portugal*
[2] *Instituto Tecnológico e Nuclear, Sacavém. Portugal*
[3] *Laboratory of Instrumentation and Particles Physics (LIP)*

Abstract
The accuracy of dose calculations in treatment planning for radiation therapy is very important and the overall error in dose delivered to patients should not exceed 5% [(1,2)].
Current clinical dose calculation codes generally rely on semi-empirical methods that are fast and work well for geometrically simple problems, but are less accurate for practical complex situations, such as: small irradiated volumes limited in lateral and/or forward directions; interface regions, etc.
In alternative, Monte Carlo calculations can solve problems of real life that are otherwise difficult or even impossible. Its ability to simulate any 3D geometry enables its use for clinical routine radiotherapy treatment planning.
The Centro Regional de Oncologia de Coimbra (CROC) has a linear accelerator, Siemens Mevatron KDS-2, where 50 patients per day are treated.
The objectives of the work are *(a)* characterisation of the radiation field originated in the head of the linear accelerator; *(b)* dose calculation at exit of the collimation systems used for radiosurgery; and *(c)* comparison of simulated and measured doses in clinical phantoms.
The work involves the co-operation among ITN, CROC and the Laboratory of Instrumentation and Particle Physics (LIP).
The study of the head of the linear accelerator has been initiated.

[1] ICRU Report 50 Prescribing, recording and reporting photon beam therapy (1993).
[2] Recommendations by the Nordic Association of Clinical Physicist, NACO Specification of dose delivery in radiation therapy (1994).

A Research on the Conditions for Self-Sustaining and Non Self-Sustaining Discharges Between Coaxial Cylindrical Electrodes

Nuno R. Pinhão
Nuclear and Technological Institute, Sacavém, Portugal

Abstract
During a previous research on halogen quenched Geiger-Müller detectors we observed the development of several discharge types depending on gas mixture pressure and composition, applied voltage and external circuit characteristics. These observations compelled us to undertake a broader study on the conditions for development of non self-sustaining and self-sustaining discharges between coaxial cylindrical electrodes.
A previous developed 2D fluid model is being applied to model gases in selected conditions. The model is built using the local field approximation and solves self-consistently the continuity equations for charged and excited species, the Poisson equation, and the chemical kinetics equations. Transport parameters and collision frequencies are approximated by step functions with representative values. Boundary conditions include the photoelectric effect at the cathode surface, taking into account radiation imprisonment. Also the response of the external circuit is accounted for.

Development of Software for Self-Consistent Kinetic Modelling of dc Gas Discharges

Nuno R. Pinhão
Nuclear and Technological Institute, Sacavém, Portugal

Abstract
A general purpose software package for self-consistent 2D kinetic modelling of dc non-equilibrium gas discharges is under development.
The software combines a Boltzmann code for computation of electron energy distribution functions and transport parameters with the set of chemical equilibrium reaction equations in the plasma, taking into account the externally imposed conditions. The program sequentially solves the electron Boltzmann equation and the plasma chemical equations until convergence is obtained.
The electron Boltzmann equation solver is based on the work of Ségur *et al*[1] and considers a density gradient expansion of the *eedf*. A stiff equation solver is used for the chemical equilibrium reaction equations.
The package can also be used for the deconvolution of electron collision cross sections from experimental transport parameters

1 Ségur et al. J. Comp. Phys. 50, 116 (1983); Ségur et al. J. Phys. D 17, 2199 (1984)

Technical Assistance in the Field of Engineering Applications of Radiations and Radioisotopes

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A summary of the more relevant technical assistance rendered in 1997 is presented in the Table.

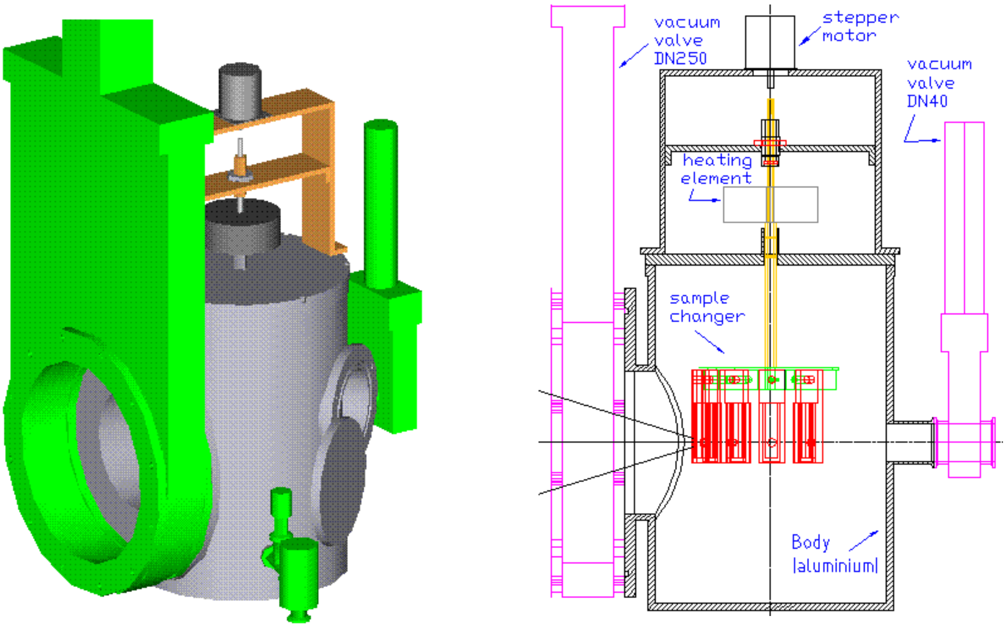
Activity	**Number**	**Client**
Supply of Personal Dosemeters RAD X 50	2	ABB- Setúbal
Supply of Gamma Level control and detector units	3	Portucel - Setúbal
Supply of Gamma Level detectors	1	Portucel/Tejo
Supply of Gamma Level detectors	1	Cimpor/Souselas
Supply of Electrodeposition Kit	2	IAEA - Algeria
Supply of Electrode plating disks	2 000	IAEA - Algeria
Supply of teflon cells	6	IAEA - Mónaco
Supply of ^{192}Ir gamma sources	18	Siderurgia Nacional
Repair of aircraft elevator pieces containing U	19	Tap- Air Portugal

PROTOTYPES

Sample Chamber of the Small-Angle Neutron Scattering Instrument - EPA

A.J. Saraiva, J. L. Neves, F. M. Margaça and F. G. Carvalho,
Physics Dept., Nuclear and Technological Institute (ITN), E.N. 10, 2685 - Sacavém, Portugal

Progress is reported in design, construction and testing of the Sample Chamber of EPA (Fig.1).



(a) (b)

Fig.1 Sample Chamber (a) 3-D general view (b) cross-section view

The chamber is intended to house the 5-sample holder and sample changer and will be installed between the Beam Collimator and the Position Sensitive Neutron Detector, keeping the entire beam path under vacuum.

The main components of the chamber are:

- the aluminium body with the beam entrance and exit valves designed to permit access laterally to the sample changer without interfering with the vacuum in other sections of the beam path;
- the 5-sample holder made of copper and aluminium;
- the heating element for measurements above ambient temperature up to ca. 80 ºC.

The mechanical design of the sample chamber was completed and construction is under way in the ITN workshop.

Positioning of the samples in the beam is automated. The sample holder is driven by a small stepper motor. An electronic driver module and power supply unit were designed and built as well as a card to interface the module with a PC. Software was written in Visual Basic.