Introduction

The main activities of the Nuclear Instruments and Methods Group are the development of nuclear methods, techniques and instrumentation for measurement and control. Technical assistance and supply of equipment and services are fulfilled in the framework of a Contract for Industrial Cooperation celebrated with two private engineering companies. In 1996 the following work was carried out:

- Simulation studies using the MCNP code for the Design of a PGNAA system for analysis of cement raw material transported on a conveyor belt. This work was performed under a research contract established with CIMPOR S.A., a Portuguese Cement Company. The results are the base for the design of an industrial prototype of an experimental on-line system using a $^{252}$Cf neutron source;
- Simulations using the MCNP code for BNCT studies in the RPI. The studies consisted, mainly, in the optimisation of a reactor beam tube in order to enhance the epithermal neutron flux. Various combinations of filter materials, thickness and location of the neutron filter were considered. Based on the these results, a beam collimator is under construction;
- Simulations using the MCNP code to study the efficiency of a thermal neutron scatterer with the shape of a flat disk as a neutron source for a small angle neutron spectrometer. The parameters varied were the thickness and the orientation of the disk;
- Determination of electron transport parameters (drift velocity and diffusion coefficients) and reaction coefficients in neon-chlorine plasmas;
- Simulation of Geiger-Müller detectors with a 2D self-consistent fluid model;
- Development of a compact version of a gamma densimeter for measurements in aggressive industrial environments and of a DC Power supply Constant Current.

Research Team

Researchers – 8 (7 PhD or equivalent)
BSc Last Year Student – 1
Technicians – 3*

Publications:
- Journals – 1
- Proceedings – 2
- Special publ.– 2
- Internal Reports – 1
- Conf. Commun.: 12

Theses:
- PhD – 1
- Res. – 1

* with grants from ITN.
Design and optimization of a PGNAA device for cement raw materials in conveyor belts

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Abstract
Multi-elemental analysis of raw materials by prompt γ-ray neutron activation analyses, PGNAA, is becoming a routinely used technique in certain industry branches, because of its advantages when compared to conventional methods.

The gamma count rate from a given element in a sample with fixed dry composition is influenced by several sample parameters such as bulk density, moisture content and effective volume as well as by the characteristics of neutron spectrum. The knowledge of these dependencies is important, in particular, for calibration purposes.

This work reports on design optimization by numerical simulation with the Monte Carlo technique, of a PGNAA device for the measurement of the composition of raw materials in conveyor belts, using a $^{252}$Cf neutron source.

Special attention is given to: (i) source-detector geometry (transmission or reflection mode measurements); (ii) effects of volume and geometry of the moderator material surrounding the neutron source; (iii) influence of a neutron reflector to increase the neutron flux at the sample; (iv) dependence of the count rate on the thickness of the layer of material being analysed; (v) effects of the bulk density and moisture content of the sample on the count rate.


Calculation of fast neutron spectra from a planar source of fission neutrons in various diffusing media using the Monte Carlo technique

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Abstract
Certain experiments involving irradiation of samples in nuclear research reactors, specially those for studies in biology, chemistry, physics and materials science where alteration of properties are to be induced by fast neutrons, require the knowledge of the neutron spectrum, particularly in order to calculate the doses absorbed by the samples on the basis of averaged kerma factors.

Aiming at a general characterization of the fast neutron spectrum at the irradiation facilities of the Portuguese Research Reactor — a pool type reactor, with fuel elements of MTR shape and using different neutron reflectors —, in a way which does not depend on the core configuration and on the irradiation conditions, the following simplified calculation was carried out: (1) the face of the reactor core has been considered as being an uniform plane source of fission neutrons, and (2) using the MNCP–4A code, the spectrum of fast neutrons has been calculated at several distances along the central axis normal to the source, considering various combinations of diffusing media (light water, beryllium, and graphite) of various thicknesses. An analysis is made of the spectra obtained.

The influence of the geometry and structural materials on the count rate of a PGNAA system for cement raw materials analysis

C. Oliveira, J. Salgado, I.F. Gonçalves, F. Leitão and F. G. Carvalho

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2Technical Centre, Cimpor, R. Alexandre Herculano, 35, 1106 Lisboa Codex, Portugal

Abstract

The MCNP 4A code, running in a Pentium-PC, was used to simulate a conveyor belt system for on line cement raw materials analysis, particularly calcium, silicon, iron and aluminium contents. The system consists of a \(^{252}\)Cf neutron source encircled by a sphere containing lead and or polyethylene for γ-ray shielding and neutron moderation or reflection and two sets of scintillator detectors. The neutron source is located below the conveyor belt. One set of detectors has four detectors symmetrically placed around the source and detects the gamma rays emitted downwards; the other set, with a central detector and eight symmetrically disposed around it, is placed above the material. Between the material and the upper detectors and also under the conveyor belt a layer of a neutron moderator/reflector material is placed. Polyethylene is used as moderator and lead, bismuth and zircon are simulated as neutron reflectors. All detectors are shielded by a lead cylinder. The conveyor belt is made of rubber with internal iron wires.

The count rate, namely the background count rate, depends on the geometry and on the composition of the structural materials (conveyor belt, neutron moderators/reflectors and detector shielding). The objectives of the simulation are to decrease the background and to enhance the contributions from γ-rays produced in (n, γ) reactions within the material to be analysed. The 2.223 MeV hydrogen γ-ray is the principal background component; the 2.615 and 7.368 MeV γ-rays due to (n, n'γ) and (n, γ) reactions in lead, respectively also have important contributions. In particular, attention is given to the (n, γ) reactions in the iron contained in the conveyor belt which contribute significantly to the iron count rate.

The paper describes simulation results using different arrangements. In each run, one parameter has been varied (distance between the raw material surface and the upper detectors and between the material surface and the moderator layer above it; composition and thickness of moderator/reflectors materials). The effect of shielding certain parts of the arrangement (neutron moderators/reflectors and detector lead shields) with neutron absorbing materials (cadmium and gadolinium) is also studied.

The influence of the geometry and structural materials on the system performance can be expressed by the count rate ratios calcium/hydrogen and calcium/lead. For the simulated arrangements and considering a raw material of standard composition, the ratios vary from 0.015 to 0.23 for Ca/H and from 1 to 30 for Ca/Pb.


Theory of the discharge in halogen-quenched Geiger-Müller radiation detectors

N. Pinhão † and P. Ségur ‡

† ITN - Departamento de Física, Estrada Nacional 10, 2685 Sacavém Codex, PORTUGAL
‡ CPATT- Laboratoire Associé au CNRS n° 277, Route de Narbonne, Toulouse, FRANCE

The Geiger-Müller detector is one of the oldest gas-filled radiation detector, frequently used in introductory studies in atomic physics. It’s probably one of the nuclear detectors best known to the general public.

In spite of its production process has been well established, the development of these detectors is mostly empirical due to the absence of a comprehensive theory of the gas discharge.

To understand the complex discharge mechanism present in these detectors and be able to optimize their performance a 2D numerical model was developed.

The model is built on the local field approximation, and solves self-consistently and for a cylindrical geometry, the continuity equations for charged and excited species, the Poisson equation, and the chemical kinetics equations. Transport parameters and collision frequencies are computed using a Boltzmann code based on the first moments of the Boltzmann equation in the hydrodynamic regime[1].

The results reveal several complex discharge mechanisms very sensitive to small changes in halogen concentration, confirming some previous qualitative hypothesis for discharge propagation[2].

The rare gas ionization is limited and occurs only in the vicinity of the anode. In spite of the smaller concentration, the halogen is the main source of ions - either by direct electron impact or by Penning ionization with rare gas excited states - and it’s ionization occurs in regions with relatively low reduced field. The rare gas main role is to shift to higher energy values the electron energy distribution function.

Photoelectric emission at the cathode is responsible for the transition from the proportional regime to the Geiger-Müller regime and to the extension of the discharge along the axial direction.


Numerical Modeling of the Discharge in halogen-quenched Geiger-Müller radiation detectors

N. Pinhão† and P. Ségur‡

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Introduction
The Geiger-Müller detector is one of the oldest gas-filled radiation detector and its production process is well established. However the development of the detectors is mostly empirical due to the absence of a comprehensive theory of the gas discharge.
Modern detectors using rare gas - halogen mixtures have low working voltages (≤ 500 V), and sometimes rather large anodes or shapes (i.g., “umbrella” anode). The discharge mechanisms in these detectors cannot be explained by the classical model of a Townsend avalanche.

Modeling
To understand the complex discharge mechanism present in these detectors and be able to optimize their performance a 2D numerical model was developed.
The model is built on the local field approximation, and solves self-consistently and for a cylindrical geometry, the continuity equations for charged and excited species, the Poisson equation, and the chemical kinetics equations.
The mixtures studied are Ne-Cl₂-Cl (Cl originating in the dissociation of Cl₂) with neon concentrations between 80% and 99% and Cl₂ dissociation fractions between 0 and 30%. Transport parameters and collision frequencies are computed using a Boltzmann code based on the first moments of the Boltzmann equation in the hydrodynamic regime[1].
In the description of the chemical kinetics, the species: Ne⁺, Cl⁻, Cl⁺, Cl₂⁺, were taken into account as well as radiative and metaestable states related to Penning ionization. The photoelectric effect at the cathode was included but the imprisonment of the resonance radiation was only dealt with through the classical ’escape factor’. The response of the electric circuit is also accounted for.
A power-law scheme for the charged particles and an upwind scheme for the excited species, are used with a variable grid[2].
The results confirm the slow build-up of the discharge and the importance of chlorine’ resonance photons for discharge propagation[3].
The neon ionization is limited and occurs only in the vicinity of the anode. In spite of the smaller concentration, the ionization in chlorine is much stronger and occurs in regions with relatively low reduced field. Neon’s main role is to shift to higher energy values the eedf. Photoelectric emission at the cathode is responsible for the transition from the proportional regime to the Geiger-Müller regime.


Design of PGNAA system for cement raw material analysis transported on a conveyor belt

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Abstract

The MCNP-4A code, running in a Pentium-PC, was used to simulate a conveyor belt system for on line cement raw material analysis, namely, the determination of calcium, silicon, iron and aluminium contents. The conveyor belt is made of rubber with embedded iron wires. The belt glides on a polyethylene stand. This stand acts as an external neutron moderator.

The influence of different system and sample parameters on the count rate of a given element (overall system geometry, neutron moderator/reflector composition and thickness, neutron absorber lining of detector shields, sample composition, bulk density, water content and thickness) is studied.

An optimized configuration is obtained which corresponds to a smaller background due to structural materials and a relative enhancement of the contributions from γ-rays produced in (n,γ) reactions in the bulk raw material.

In such a configuration, the $^{252}$Cf neutron source is enclosed in a lead ball, 2 cm thick, encircled by two hemispherical bodies, each, also 2 cm thick. The material of the inner body is polyethylene, for neutron moderation. The external sphere is filled with lead which acts as neutron reflector and absorber of the γ rays from neutron capture in the polyethylene.

Two detector banks are used: a lower bank formed by four detectors positioned symmetrically around the source, to detect gamma rays emitted downwards; an upper bank, with a central detector and eight other detectors symmetrically arranged around the first.

A formalism is proposed which enables the correction of the experimental count rate of an arbitrary element for the sample bulk density, water content and thickness.

This simulation study is the theoretical base for the design of an experimental on-line system using a 100 to 300 μg $^{252}$Cf neutron source. The estimated statistical deviations for a 10 min analysis are shown in the Table.

<table>
<thead>
<tr>
<th>Element</th>
<th>Compound</th>
<th>Content (%)</th>
<th>Deviations (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>Fe$_2$O$_3$</td>
<td>1.8</td>
<td>0.004</td>
</tr>
<tr>
<td>Ca</td>
<td>CaCO$_3$</td>
<td>76.6</td>
<td>0.015</td>
</tr>
<tr>
<td>Si</td>
<td>SiO$_2$</td>
<td>15.5</td>
<td>0.07</td>
</tr>
<tr>
<td>Al</td>
<td>Al$_2$O$_3$</td>
<td>6.1</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Both detector sets (upper and lower) are suitable for PGNAA. As their responses are different, two independent systems for composition measurements are available.

Contract Report: - CIMPOR CEDI/DIR/51
CIMPOR- Cimentos de Portugal S.A. - a Portuguese Cement Company

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Prototypes

DC Power Supply Constant Current model 9611

C. Cruz, F. G. Carvalho
Instituto Tecnológico e Nuclear, Estrada Nacional nº 10, 2685 Sacavém, Portugal

The DC Power Supply Constant Current model 9611 is a stabilised current source designed for operation with the ITN Cell Electrodeposition Set for the determination of radioactive element traces.

The total current is displayed in a LCD and the current may be varied continuously between 0 and 5 A.

Technical specifications:
Power source: AC 220 V ±10 % 50/60 Hz
Power consumption: 154 VA
Output current range: 0 to 5 A continuously adjustable
Maximum output voltage @ 5 A: 17 V ± 0.1 V
LCD display: 3 digits, 0.5”
Insulated outputs: short circuit protected
Current limit: internally adjusted to 5 A
Output voltage limit: internally adjusted to 17 V ± 0.1 V
Current regulation: < 1 %
Ripple/noise: <10 mV @ 4.8A
Operating temperature range: 0ºC to 40ºC
Output terminals: 8×4 insulated screw terminals at the front
Dimensions (W×H×D): 115 mm × 160 mm × 215 mm
Weight: 4.3 kg.
Compact Gamma Densimeter

C. Cruz, N. Cheis Rodrigues, J. Salgado and F. G. Carvalho
Instituto Tecnológico e Nuclear, Estrada Nacional nº 10, 2685 Sacavém, Portugal

A compact version of a gamma densimeter is being designed for density measurements in aggressive industrial environments. The customised logic circuits were developed using PAL’s in order to achieve space and size reductions. The local operation of the system is user-friendly and a 4×20 LCD is utilized for menu guided operations.

Technical specifications:
- Microcontroller based system with continuous diagnostics
- Data calibration backed up in E²PROM
- Caesium or Cobalt source decay compensation based in a Real Time Clock IC
- Detector unit: NaI(Tl) scintillation counter
- Locally operated by a keypad or totally remote controlled by a 4-20 mA isolated current loop
- Product temperature compensation
- Integration time: 1 to 500s
- Density measurement range: 900 - 2000 kg/m³
- Accuracy: 0.1% for 10 s measuring time
- Mounting: rugged stainless steel housing.
Current Work

Research on Cl2 and rare gas-Cl2 mixtures for plasma etching

Nuno R. Pinhão
Instituto Tecnológico e Nuclear, Estrada Nacional nº 10, 2685 Sacavém, Portugal

Molecular chlorine, Cl2, is widely used for plasma etching of semiconductor devices. Used alone, chlorine etches aluminium vigorously and isotropically although anisotropic etching is obtained with the inclusion of additives promoting ion-enhanced etching. However, like most of the gases used in the production of semiconductor devices, chlorine has significant environmental effects. Also it is a scavenge gas for electrons demanding relatively high maintenance fields.

During a previous research on neon-chlorine mixtures we observed a marked increase of net reaction rates for the production of Cl2+ and Cl+ ions of several orders of magnitude while the production of Cl was somehow reduced although within the same magnitude. These results were obtained at low reduced electric field (E/N) and chlorine concentrations below 10%. These results compelled us to undertake a broader study of rare gas - Cl2 mixtures to evaluate its potential use in plasma etching.

A revision on published data on electron collision cross sections and transport parameters on Cl2

Nuno R. Pinhão1, A. Chouki2
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2 CPAT - Laboratoire Associé au CNRS nº 277, Route de Narbonne, F-31062 Toulouse Cedex, FRANCE

Halogen molecules have important application in gas discharge physics, namely in plasma etching, and UV lasers. However, due to both experimental difficulties and complicated electronic spectra, the electron collision cross section and transport parameters in many of these gases are not well known. This hampers the theoretical analysis of gaseous mixtures with these gases. Recently the authors and several other groups have reported new data on Cl2. Due to the technologival interest of this gas and, in particular, for the work under development in this group we reviewed the set of electron collision cross sections previously presented.

The deconvolution method used is well suited to the low energy region characterizing the electrical discharges. Starting with a good set of electron collision cross sections the Boltzmann equation was solved to obtain estimations of transport parameters (drift velocity, longitudinal and transverse components of diffusion tensor) and both momentum and energy transfer frequencies. Comparison with experimental values allows us to introduce corrections on the collision cross section and to obtain better estimates. The code used for solving the Boltzmann equation is based on the hydrodynamic regime.

The new set thus obtained leads to a better agreement with the available experimental data.
Technical Assistance in the field of engineering applications of radiations and radioisotopes

J.M. Manteigas, J. Salgado and F. G. Carvalho
Instituto Tecnológico e Nuclear, Dep. Física, Estrada Nacional n° 10, 2685 Sacavém, Portugal

A summary of the more relevant technical assistance rendered in 1996 is presented in the Table.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Number</th>
<th>Client</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply of Personal Dosemeters RAD X 50</td>
<td>4</td>
<td>Força Aérea Portuguesa</td>
</tr>
<tr>
<td>Supply of Personal Dosemeters RAD X 50</td>
<td>2</td>
<td>Philips</td>
</tr>
<tr>
<td>Supply of Personal Dosemeters RAD X 50</td>
<td>1</td>
<td>Somincor</td>
</tr>
<tr>
<td>Supply of Personal Dosemeters RAD X 50</td>
<td>1</td>
<td>Soc. Montagens Metalomecânicas</td>
</tr>
<tr>
<td>Supply of Personal Dosemeters RAD X 50</td>
<td>4</td>
<td>Inst. Superior de Qualidade</td>
</tr>
<tr>
<td>Supply of Gamma Level detectors</td>
<td>1</td>
<td>Portucel - Viana do Castelo</td>
</tr>
<tr>
<td>Supply of Gamma Level detectors</td>
<td>1</td>
<td>Cimpor - Souselas</td>
</tr>
<tr>
<td>Supply of Dc Power Supply</td>
<td>1</td>
<td>DPSR - Dir. Geral do Ambiente</td>
</tr>
<tr>
<td>Supply of Electrodeposition Kit</td>
<td>1</td>
<td>IAEA - Bulgária</td>
</tr>
<tr>
<td>Supply of Electrodeposition Kit</td>
<td>1</td>
<td>IAEA - Roménia</td>
</tr>
<tr>
<td>Supply of Electrodeposition Kit</td>
<td>1</td>
<td>IAEA - Turquia</td>
</tr>
<tr>
<td>Supply of teflon cells (Po traces determinat.)</td>
<td>12</td>
<td>IAEA - Mónaco</td>
</tr>
<tr>
<td>Supply of Electron deposition cells</td>
<td>4</td>
<td>DPSR - Dir. Geral do Ambiente</td>
</tr>
<tr>
<td>Supply of Electroplating disks</td>
<td>500</td>
<td>DPSR - Dir. Geral do Ambiente</td>
</tr>
<tr>
<td>Supply of $^{192}$Ir gamma sources</td>
<td>15</td>
<td>Siderurgia Nacional</td>
</tr>
<tr>
<td>Others (Container repair, source recharging)</td>
<td>2</td>
<td>Solvay</td>
</tr>
<tr>
<td>Others (Container repair, source recharging)</td>
<td>3</td>
<td>Soporcel</td>
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<tr>
<td>Others</td>
<td>1</td>
<td>Tap - Air Portugal</td>
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