Metrology Laboratory of Ionizing Radiation

Carlos Oliveira

The Metrology Laboratory of Ionising Radiation (LMRI) had been actively involved in activities related to the scientific, applied and legal metrology.

During 2008 efforts have been undertaken to increase the scientific activities and the quality of the services provided to the community.

Concerning the scientific metrology, the LMRI participates in two European projects in the framework of the EURAMET organization:

- as partner in the project entitled "Increasing cancer treatment efficacy using 3D brachytherapy" and
- as collaborator in project "External Beam Cancer Therapy".

These projects arise from the implementation of the "European Metrology Research Programme" (EMRP) and are co-funded by the European Commission.

Still concerning the scientific metrology, the ITN primary standard for the radiation field of ^{137}Cs, participated in a comparison involving the primary standard at the *Bureau International des Poids et Mesures* (BIPM), Paris, France. This comparison allows the recognition of the equivalence of the Portuguese primary standard to the primary standards of other countries as well as the traceability of the measurements to ITN and a decrease of the uncertainty of the measurements.

In order to expand the LMRI metrological capabilities, to be able to answer to the requirements of the new legislation to be published, the characterization and implementation of the diagnostic radiation qualities according the IEC 61267 standard has been initiated.

The collaboration with other ITN research teams continued, namely with the Radiation Dosimetry and Radiobiology Group (GDR) at UPSR and with Radiation Technology Unit (UTR). Technical assistance has been assured to the RPI during its annual maintenance. The collaboration with outside Researcher Groups has been pursued namely with *Instituto Nacional de Saúde Dr. Ricardo Jorge* (INSA).

Special attention has been devoted to the collaboration with the University. The LMRI has collaborated with IST (Technical University of Lisbon) and as a result of that, five master thesis) have been concluded and approved. They have been supervised by a member of the Group.

Meanwhile other five master thesis have been accepted by *Universidade Nova de Lisboa* to be performed at the LMRI during the next year.

Concerning the legal metrology 128 dosimeters were calibrated and about 800 TLD's dosimeters were irradiated.
The Quality System, essential in the LMRI namely to maintain the CMC's (Calibration and Measurement Capabilities) in order to participate in Mutual recognition Arrangement (MRA) of the International Committee of Weights and Measures (CIPM), under the authority given to it in the Metre Convention has been maintained. The annual Internal Audit has occurred at the end of 2008 and the corrective actions will be done during 2009.

One of the members of the team (LS) participate as Manager of the UPSR QS in the Accreditation process which involve the UPSR, also collaborates in the Radiological Protection Programme for UPSR and give support to management of the Data Base of the Environmental Radioactivity Group.

Members of the Group were involved in several committees from EU: Ionising Radiation Technical Committee of EURAMET, Group of Experts of art. 31 (Radiation Protection) and EUTERP.

Research Team

Researcher

C. OLIVEIRA, Princ.

Technical Personnel

J. CARDOSO, graduated technician
L. SANTOS, (50%)

A. CASTRO, technician ITN consultancy contract

Study the Response of an Ionization Chamber

Catarina Simões[1], Margarida Caldeira[1], João Cardoso, L. Santos and C. Oliveira

Objectives

Study the response of an ionization chamber used in Nuclear Medicine by experimental and Monte Carlo simulation methods.

Results

Monte Carlo computer programs such as MCNP have been widely used for simulation of the physical behaviour of the Ionization Chambers (IC) and to obtain correction factors for parameters such as geometry, container type, density and volume of the samples. In this study, MCNP was applied both to determine calibration factors for the radionuclides and the efficiency curve of the IC. The displacement of source position from normal position and its effect on chamber response was studied for most of the radionuclides as well as optimization of the chamber. Monre Carlo simulation calculations were compared with the experimental results.

The measuring system consisted of the Curiementor 2 ionization chamber, from PTW-Freiburg, an electrometer for ionization current measurements and a high voltage supply that provides the chamber with about 1000 V.

The Monte Carlo code MCNP was used to calculate the average energy deposition, E_d, in the gas within the IC per γ ray emitted. The ionization current, I, is given by

$$I = \frac{E_d \cdot p_f \cdot A \cdot e}{W}$$

where A is the activity of the source, p_f the percentage of photons of a given energy emitted by the source, W the average energy required to create an ion pair in the gas and e the electron charge. For argon W is of about 26.4 eV. The calibration factor is given by $C = I/A$, for both experimental and theoretical results, and is expressed in units of pA/MBq.

All the simulations were done using 3×10^5 histories since for this value there was good agreement between relative statistical uncertainty of the MCNP (smaller than 0.2%) and simulation time (maximum of 30 minutes).

The simulated and experimental results for the calibration factors of the radionuclides studied are reported in tab. 1. The uncertainties, with coverage factor k=1, are the combined uncertainties of the experimental measurements: for Co-57 its value is 2.74% (expressed as relative uncertaintiy) and for the remaining radionuclides is 14.14%; for the MCNP simulations, the estimated relative uncertainty of the energy deposition in the argon of the chamber is 5.24%. Overall, there is excellent agreement between simulated and experimental results.

From the displacement studies it could be observed that the response of the chamber decreases with increasing distance of the source to the bottom.

Radionuclide	$C_{exp.}$ (*pA/MBq*)	C_{MCNP} (*pA/MBq*)
Co-57	3.60	3.77
F-18	11.38	10.68
In-111	6.38	6.23
I-123	6.02	5.85
I-131	4.65	4.44
Tc-99m	3.15	3.18

Table 1 – Results of the experimental and simulated calibration factors for the radionuclides studied.

So, as referred in the IC's manual, the optimal position for measurements is the source in the bottom of the well. This is due to the small height of the Curiementor 2, resulting in great loss of particles through the opening of the IC.

The sensitivity function, S (E), shown in fig. 1, was obtained by simulation with MCNP. This curve is the convolution of three functions: the number of photons inside the chamber, the mass energy-transfer coefficient and the linear relation between emitted energies and E_d. The influence of the absorption effect of the grids is shown to be very small.

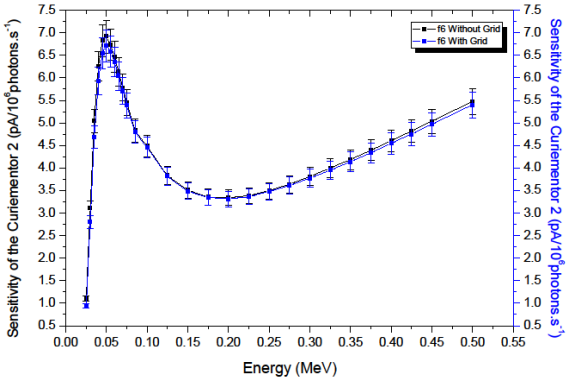


Figure 1 - Sensitivity function *S(E)* for geometry with grids and without grids.

From the optimization results it can be said that high chambers are more suitable for tests with different types of containers and different volumes of solution, since, for source displacement, the response of these ICs presented very small variations. For larger diameters the efficiency increases, but higher supply voltages would be necessary to sustain the good operation of the chamber, which can be very unfavorable. The Monte Carlo program used in the study proved to be suitable for determination of calibration factors, analysis of the sensitivity function and optimization of the IC's response.

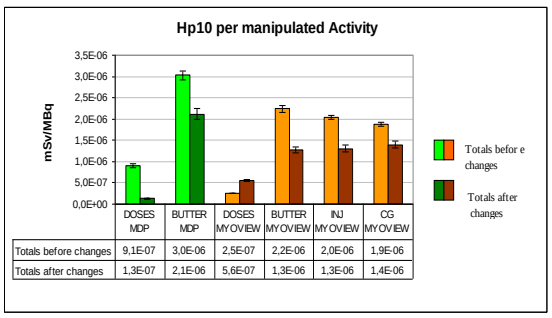
[1] MSc student/IST

Evaluation and Optimization of the Radiation Doses of the Nuclear Medicine Technicians

A. Geão[1]; V. Jerónimo [1]; P. Colarinha[1]; J.G. Alves; A. Calado; M. Neves; C Oliveira

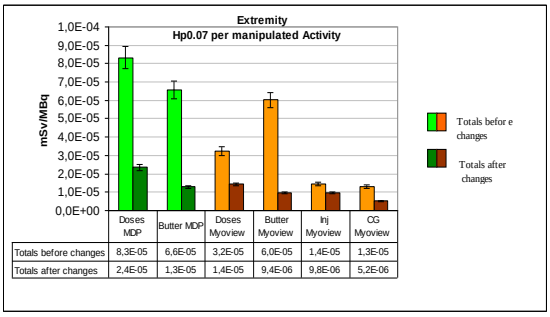
Many procedures used in a Nuclear Medicine service during their daily activity allow the execution of a large number of examinations for diagnosis and therapy. The Nuclear Medicine Technologist (NMT) participates actively in these procedures and is can therefore be subject to a high dose of radiation. The aim of this study was the evaluation and optimization of the exposition to radiation of the nuclear medicine technicians (NMT). This study identifies routine techniques involving the manipulation of high activities, namely: Elution of the 99Mo/99mTc generator; kit preparation of bone and cardiac radiopharmaceuticals; Unit-dose dispensing; administration to the patients and acquiring images. These procedures were monitored with whole-body and extremity dosimeters for a period of 7 months. In procedures where higher values of radiation dose to the NMT were measured, defined strategies for handling practices in order to their minimization were implemented.

The $H_p(10)$ before and after the changes in procedures, is shown in graphic 1 (whole body dosimeter) and the Hp(0,07) is shown in graphic 2 (extremity dosimeter). Graphic 1 and 2 show the Hp(10) and the Hp(0,07) divided by the activity manipulated. Graphic 1 and 2 show that Hp divided by the activity manipulated decreased after changing procedures between 25 to 85% for Hp(10) and 32 to 84% for Hp(0,07). After measuring and comparing the doses of whole body and extremities before and after the change in procedures, we conclude that the changes had a positive impact on doses of radiation received by NMT, reducing them.



	DOSES MDP	BUTTER MDP	DOSES MYOVIEW	BUTTER MYOVIEW	INJ MYOVIEW	CG MYOVIEW
Totals before changes	9,1E-07	3,0E-06	2,5E-07	2,2E-06	2,0E-06	1,9E-06
Totals after changes	1,3E-07	2,1E-06	5,6E-07	1,3E-06	1,3E-06	1,4E-06

Graphic 1 – Dose per radiation unit manipulated



	Doses MDP	Butter MDP	Doses Myoview	Butter Myoview	Inj Myoview	CG Myoview
Totals before changes	8,3E-05	6,6E-05	3,2E-05	6,0E-05	1,4E-05	1,3E-05
Totals after changes	2,4E-05	1,3E-05	1,4E-05	9,4E-06	9,8E-06	5,2E-06

Graphic 2 – Dose per radiation unit manipulated

[1] Hospital CUF Descobertas

Evaluation of Thermoluminescence Dosemeters for Extremity Monitoring: Monte Carlo Simulation Results

L. Freire, C. Oliveira

The work done using Monte Carlo simulations aimed at assessing if irradiation conditions other than the ones defined in the ISO 12794, 2000 Standard – defined in terms of the object (number and radius of the rod phantoms and irradiation geometry) can alter the air kerma-to-equivalent dose correlation coefficient values, *ha*, which are used to characterize the radiation field.

From the results, we may conclude that the *ha* coefficient can change by as much as 4% when modifying the geometry of the phantom used to simulate the presence of the human body, and 10% when changing the irradiation geometry; variations can be positive or negative, or both, depending on the simulation. These findings suggest that the contribution of the backscattered radiation field can be under- or over- estimated relatively the direct radiation field.

New Metrologic Capabilities at LMRI

J. Cardoso, L. Santos, C. Oliveira

In order to extend the metrological capabilities of the LMRI, in the field of radiodiagnostic, an experimental work of implementation of the radiation qualities according to IEC 61267 standard was initiated. Consequently, it is necessary to characterize the RQR (Radiation Qualities in Radiation Beams) and RQA (Radiation Qualities based on a phantom made up of an aluminium Added Filter) X-ray radiation qualities which implies the determination of the first and second half-value layers (HVL), for all the X ray tube voltages, namely, 40 kV, 50 kV, 60 kV, 70 kV, 80 kV, 90 kV, 100 kV, 120 kV and 150 kV, for the RQR and RQA radiation qualities. The LMRI RQR and RQA radiation characteristics have been determined. The first HVL (mm Al) obtained for RQR2, RQR3, RQR4, RQR5, RQR6 and RQR7 and the first HVL (mm Al) obtained for RQA2, RQA3, RQA4, and RQA5 satisfy the criteria of the IEC 61267 standard.

A Joint research Project to implement the European Metrology Research Programme in the Framework of the Project Imera- Plus

C. Oliveira, J. Cardoso, L. Portugal C. Cruz, L. Santos

Under the Seventh Framework Programme and to implement the "European Metrology Research Programme" (EMRP), the European Commission (EC) co-funds the pilot project iMERA-Plus within the framework of ERANet-Plus for Research and Development (R&D) according to the EC Grant Agreement No. 217257 between the EC and EURAMET e. V (European Association of National Metrology Institutes).

The ITN participate as partner in the Joint Research Project T2.J06 "Increasing cancer treatment efficacy using 3D brachytherapy".

The aim of the project is to develop methods for the direct measurement of the quantity absorbed dose to water and to extend the use of this reference quantity to brachytherapy dosimetry. The task of the WP were the LMRI is involved is to develop an accurate and convenient procedure to verify the dose distributions in irregularly shaped fields by BT sources in water or a water equivalent phantom. The expected output are suitable portable methods with assessed reliability and accuracy - leading to the target of a dose delivering with an uncertainty less than 5% (k=1), at clinical level for the verification of dose distributions for BT sources (e.g., Ir-192 for the treatment of gynaecological cancers and I-125 applied in ophthalmic applicators). This includes the determination of energy and dose response curves of the detection methods, determination of spatial dose distributions around BT sources used in clinical applications, in water or water-equivalent phantoms, supported by Monte Carlo simulations using EGS, PENELOPE, and MCNP codes.

The ITN participate as collaborator in the Joint Research Project T2.J07 "External Beam Cancer Therapy". This status gives the freedom to participate only when and if possible.

The central objective of JRP7 is to provide a reliable metrology for all radiation based forms of cancer therapy. This includes freshly emerging techniques like High Intensity Therapeutic Ultrasound (HITU) and modern forms of (ionizing) radiation therapy, like Hadron Therapy and Intensity Modulated Radiation Therapy. This JRP is conceived in a way as to draw maximum synergetic advantages from combing two, as yet separate metrological disciplines: ultrasound and ionizing radiation. It is interesting to note that the two disciplines have conceptually a lot in common: radiation is generated, transported through the body with techniques to optimize the impact on cancer.

ITN Air Kerma Primary Standard for ^{137}Cs Key Comparison at BIPM

J. Cardoso, L. Santos, C. Oliveira

Following the 2007 work with the air kerma primary standard, a CC01 graphite cavity ionisation chamber, in the radiation field of Cs-137, it was decided that the ITN primary standard should participate in a comparison at the *Bureau International des Poids et Mesures* (BIPM), Paris, with their primary standard.

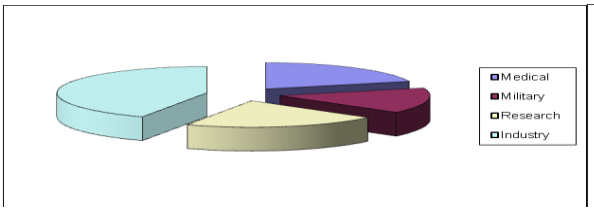
The BIPM acts in matters of world metrology, particularly concerning the demand for measurement standards of ever increasing accuracy, range and diversity, and the need to demonstrate equivalence between national measurement standards.

The main consequences of this comparison exercise are, the recognition of the equivalence of the Portuguese primary standard to the primary standards of other countries, the traceability of the measurements will be to ITN, the uncertainty of the measurements decreased from 0.9% to 0.4% (1 σ). These are very positive consequences for ITN.

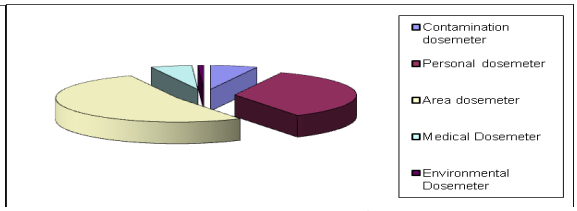
SERVICES

L. Santos, J. Cardoso, A. Castro, C. Oliveira

The LMRI provides calibration services mainly for industry, universities, hospitals, armed forces, research organics units of ITN and services of metrological control throughout the country. This metrological control of instruments for measurement of ionising radiation is being carried out under a contract with Portuguese Institute of Quality and is the enforcement of *Portaria* nº. 423/98. During 2008, 128 dosemeters were calibrated. The following figures group this calibration work by users activity and by type of use.



Instruments calibrated by users activity

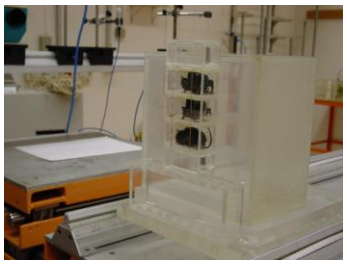


Instruments calibrated by type of use

EXTERNAL SERVICES

LMRI collaboration with INSA group

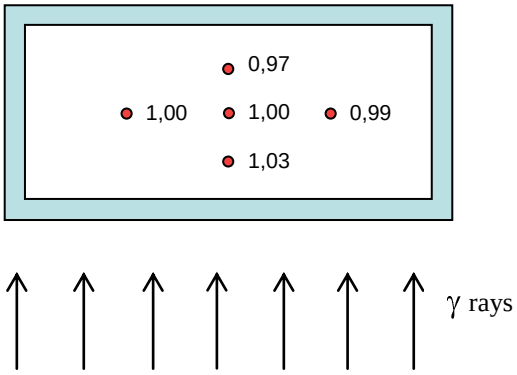
L. Santos, J. Cardoso, C. Oliveira



The collaboration with INSA (National Institute of Health), in the field of radiobiology, concerns the irradiation of mice in order to induce genetic anomalies. They are irradiated in PMMA boxes in order to maintain a static position during irradiation, as can be seen in figure 1.

Figure 1: Irradiation position in front of Co-60 source.

In order to optimise the dose to mice, two boxes filled with water were added and positioned in the top and bottom of the mouse boxes. This will provide a uniform dose for all mouses in this experimental set up.
The absorbed dose inside the central box varies according to figure 2.



According to the relative absorbed doses inside the box, it was decided to irradiate in two-steps, to take this in account. So, after the first irradiation, the box was rotated and the initial face to the radiation is now the posterior face. With this procedure the mouses are uniformly irradiated.

Figure 2: Relative absorbed doses inside the box.

INTERNAL SERVICES

LMRI collaboration with ITN groups

L. Santos, J. Cardoso, C. Oliveira

Portuguese Research Reactor (RPI)

The LMRI performs, every year, in the RPI maintenance period, the metrological control of installed detectors and associated instrumentation of the RPI radiological protection system. This includes the hand-foot contamination monitor, MAB HFM 2102; the area monitors measuring system MGP C/EIP 51 with five ionisation chambers; the area monitors measuring system Automess 632.1 with four Geiger-Muller detectors; the fission products detection system, Tracerlab, Inc. MWP-1A; the Iodine detection system, AIEA AIRMON; two, alpha and beta radiation detection systems in aerosols, ABPM201L; detection system for beta radiation on samples or filters, ECM21+BCF31; iodine detection system, IM201S; and, also, metrological control of fourteen personal electronic monitors, three area monitors and one contamination monitor.

Radiation Dosimetry and Radiobiology Group (GDR)

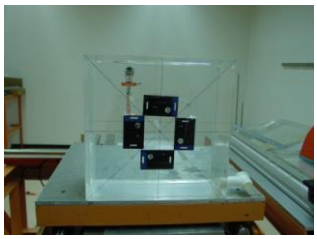


Figure 1: Irradiation of a set of dosemeters

Cells and blood irradiation for the UPSR GDR group has been one of the most important collaboration. The samples have been irradiated with several doses of the Co-60 radiation. More than 20 hours of irradiation in Co-60, (about 50 irradiations) has been provided, of all kind of human cells, to their research programs.

Still in collaboration with the UPSR GDR group, about 1000 TLD dosemeters (about 700 for *Hp*(10) and about 300 for *Hp*(0,07)) have been irradiated.

Radiation Technology Unit (UTR)

Measurements in the UTR facility inside the irradiation room and in the maze have been performed. This exercise was done with ionisation chambers, with volumes ranging from 0.6 cm^3, 30 cm^3, 1000 cm^3 and 10000 cm^3.

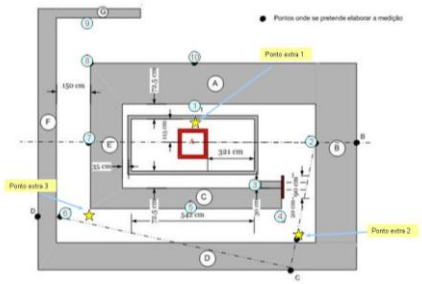


Figure 1: Points position, for experimental measurements, inside the room and maze of UTR.

Quality System

L. Santos, J. Cardoso, C. Oliveira

In order to meet the requirements of the NP EN ISO/IEC 17025:2005 a special attention has been deserved to the Quality System. All 2007 internal audit non conformities have been closed, a new Quality Manual edition has been issued, all administrative procedures have been reviewed and some technical procedures have been reviewed.

Seven non-conformities have been detected and eight recommendations have been proposed by auditors in 2008 internal audit.

A survey has been send to our customers. The following chart displays the survey results.