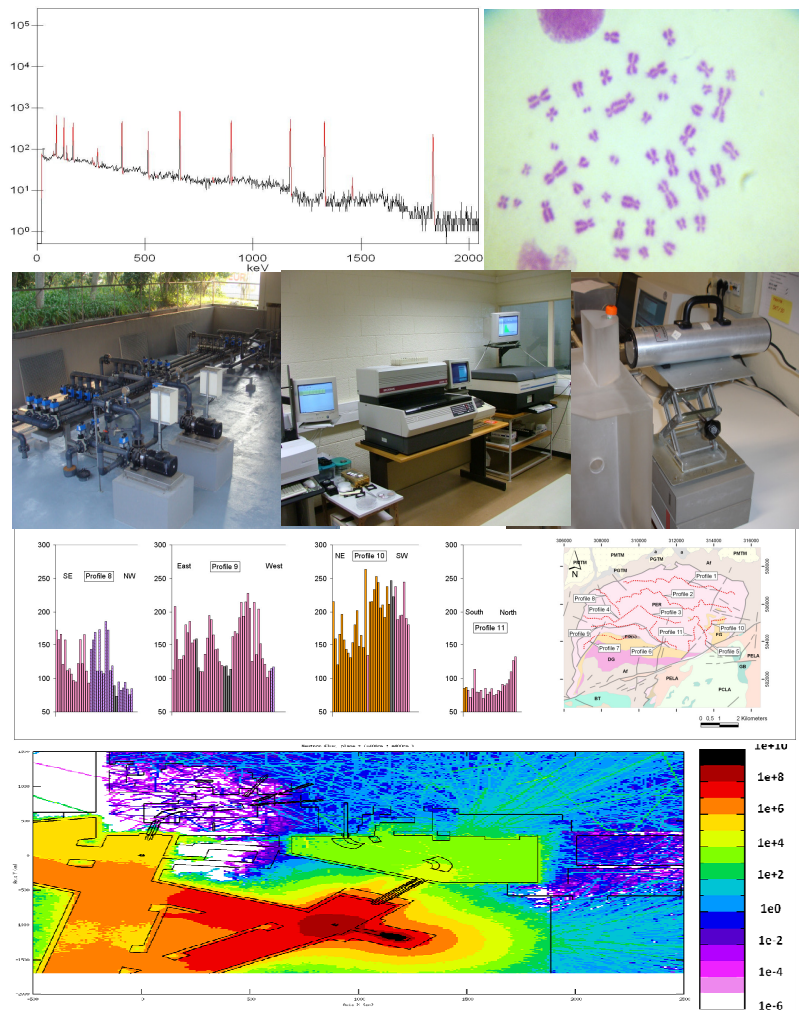


Radiological Protection and Safety Unit



Radiological Protection and Safety Unit

Pedro Vaz

The following events, topics and activities must be highlighted for the year 2011:

Fukushima: The Fukushima catastrophe and its radiological consequences and the need to guarantee the necessary preparedness of response both at the national and international levels acquire paramount importance throughout the year. The need to provide technical and scientific advice to the Portuguese Government and to the Portuguese radiological emergency competent authorities and bodies, the detection in the Portuguese territory of the trace of the radioactive releases as well as the response to the pressure from the media, absorbed a significant part of the manpower and expertise of the UPSR for several months following the nuclear accident.

Accreditation: A major effort was devoted to the final steps of the preparation for the accreditation by the Portuguese Accreditation Institute (IPAC) of 10 radioanalytical, dosimetric and metrological techniques offered by the UPSR. The accreditation audits for 6 of the 10 techniques were successfully conducted in December and are a landmark in the deployment of the UPSR Quality Management System, which implementation started in September 2008.

ICP-MS: The effort towards the installation of the ICP-MS ("Inductive Coupling Plasma Mass Spectrometry") purchased at the end of 2009 was pursued and infrastructural works were undertaken. Again, the financial situation of ITN prevented the completion of the installation of the equipment during 2011. It is anticipated that the ICP-MS will become operational during 2012, allowing a simpler, faster and more complete assessment of radionuclides in environmental and biological samples.

Human Resources: The persistently increasing scarcity of human resources required to meet the increasingly higher volume of work resulting from the legal obligations and service providing duties as well as from the involvement in research and development projects, is presently seriously limiting and hampering the intervention capacity of the UPSR.

Dose DataMed II: Another landmark of 2011 was the successful engagement of ITN together with several other Portuguese institutions and stakeholders, in the assessment of the exposure of the Portuguese population to ionizing radiation in the framework of Radiodiagnostic and Nuclear Medicine procedures. This undertaking, a first of its kind in Portugal, was conducted in the framework of the European Union sponsored project Dose DataMed II.

Research and Development activities:

During 2011, research and development activities were conducted at a sustained rhythm with the involvement of

researchers, technicians, students and collaborators in national and international consortia conducting R&D activities and projects funded by the European Union (7th Framework Programmes) and by the Portuguese Foundation for Science and Technology (FCT), among others.

Collaborative links were fostered with hospitals and research centers in topics related to the medical applications of ionizing radiation.

Involvement in research activities under the umbrella of several Working Groups of EURADOS and EURAMET was continued.

Technical Services (selected topics):

The Environmental Radioactivity Group and the Measurement Laboratory conducted the National Environmental Radiological Survey. The Radioprotection and Radioactive Waste Group performed activities associated to the licensing of radioactive sealed sources, the interim storage of radioactive waste, the detection of radioactive substances in scrap metal, the management of radioactive wastes on medical, and industrial facilities, and the verification of the radiological safety of installations. The Dosimetry and Radiobiology Group pursued its technical activities related to the assessment of the safety of Nuclear Medicine installations and Radiotherapy vaults throughout the country, as well as to individual and environmental monitoring. The Laboratory of Metrology of Ionising Radiation performed the calibration and metrological verification of equipments.

Participation in intercomparison exercises:

The UPSR staff involved in environmental radioactivity measurements and in radioanalytical techniques and methods participated in intercomparison exercises organized by the International Atomic Energy Agency (IAEA), by the European Commission (EC) and other foreign institutions and organizations.

Education and Training:

UPSR researchers participated in training courses in Radiological Protection for professionals in the medical and industrial sectors and taught several disciplines in post-graduation and Masters Courses in Radiological Protection and Safety, in several Portuguese universities. A significant number of Master thesis and post-graduation works, supervised by UPSR researchers, was observed.

Participation in national and international technical and scientific committees:

UPSR researchers acted as Portuguese representatives in international Committees, Working Groups and Task Forces whose activities are organized under the auspices of the EU, the IAEA and the OECD/NEA

Staff

Researchers

P. VAZ, Princ.(Agreg.)
C. OLIVEIRA, Princ.(Habil.)
F.P. CARVALHO, Princ.
M.A. NEVES, Princ. (until July)
M.J. MADRUGA, Princ.
A. D. OLIVEIRA, Aux.
I. PAIVA, Aux.
J. ALVES, Aux.
J. CORISCO, Aux.
M. REIS, Aux.
O. MONTEIRO GIL, Aux.

P. TELES, Aux.
R. TRINDADE, Aux (until July)
S. di MARIA, Post-doc

Admin & Techn.

Personnel

A. CASTRO
A. MOURATO
D. ALVES
G. L. SILVA
I. LOPES
J. ABRANTES

J. CARDOSO
J. OLIVEIRA
J. VENÂNCIO
L. MACHADO
L. PORTUGAL
L. SANTOS
L. SILVA
M. A. LIBÂNIO
M. E. PACHECO
M. MALTA
M. SANTOS
M. SARAIVA
P. PEREIRA (since Dec)

S. RANGEL
T. ANTUNES
Y. ROMANETS

Students

A. BAPTISTA
A. BELCHIOR
A.C. ANTUNES
A.R. GOMES
C. BORGES
C. CARRAPIÇO
C.FIGUEIRA
E. ANDRADE

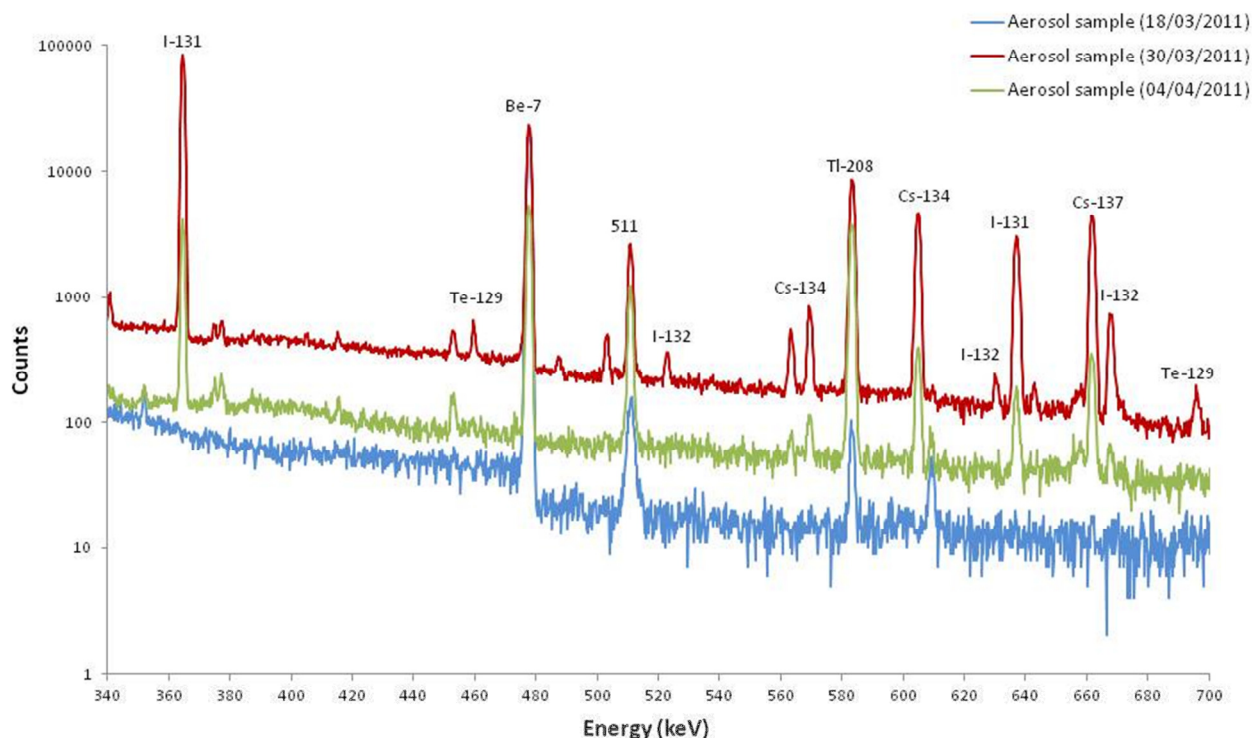
G. CARVALHAL
J. BENTO
J. MELO
M.F. PEREIRA
MARGARIDA CALDEIRA,
R. SARMENTO
R.F. LUÍS
S. BARROS
V. MARTINS

Radiological Protection and Safety Unit

Detection at ITN of Cesium, Iodine and Tellurium isotopes released from Fukushima Dai-ichi

P. Vaz, R. Trindade

At the end of March, the aerosols sampling station ASS500 in the campus of ITN started to detect trace amounts (below 1 mBq m⁻³) of Cesium, Iodine and Tellurium radionuclides due to the Fukushima Dai-ichi nuclear power plant accidents and associated atmospheric releases of radioactivity on the days following March 11. The plume travelled through the Pacific Ocean, North America and the Atlantic Ocean before being detected in several European countries. The filters of the ASS500 station were measured by gamma spectrometry using HPGe detectors. The characteristic signatures of the ¹³⁷Cs, ¹³⁴Cs, ¹³¹I, and other radionuclides are well visible in the spectrum.



The very small levels of radioactivity detected did not pose any hazards to the public health.

Accreditation - Implementation of the Quality Management System at the UPSR

I. Lopes¹

The first stage of accreditation audits took place in December 2011 for the 6 following techniques:

- Determination of the activity of gamma emitters in solid and liquid matrices using high resolution gamma-ray spectrometry;
- Gross alpha/beta in waters using proportional counters or Liquid Scintillation Counting (LSC);
- Tritium determination in waters by LSC.

The second stage of accreditation audits will take place in January of 2012, for the following 4 techniques:

- Metrological control of the linearity of response for *Hp*(10) of individual monitors;
- Metrological control of the linearity of response for *H**(10) of portable area monitors;
- Assessment of *Hp*(10) using whole body dosimeters by termoluminescence;
- Assessment of *Hp*(0.07) using whole body dosimeters by termoluminescence.

These audits result from the dedicated efforts, since September 2008, of researchers, technicians and collaborators in quality activities with the involvement and support of the top level management.

The Quality Manual, management and technical procedures were reviewed and improved during this year. The competence of the staff was taken into account on the basis of appropriate education and training. Internal audits were also carried out by UPSR auditors in November 2011, to verify if the activities are conducted according to the ISO/IEC 17025:2005 international standard requirements.

The implementation of the QA system based on this international standard allows the UPSR laboratories to improve the methods, to identify problems, to implement preventive and corrective actions, to generate valid results and to achieve a stable level of high quality output.

¹ Quality Manager at the UPSR – on behalf of the UPSR's Working Group on the Accreditation

Metrology Laboratory of Ionizing Radiation

Carlos Oliveira

The Metrology Laboratory of Ionizing Radiation (LMRI) has been involved in activities related with scientific, technical and legal metrology.

Scientific and technical activities:

LMRI continues to participate in the European project in the framework of the EURAMET organization: JRP06 “Increasing cancer treatment efficacy using 3D brachytherapy” which has finished in July and the new project “Ionizing Radiation Metrology for Metallurgical Industry” initiated in December. These projects arise from the implementation of the “European Metrology Research Programme” (EMRP) and are co-funded by the European Commission.

Two projects for the construction of the two air kerma primary standards have been submitted to FCT: a cavity chamber for ^{60}Co gamma rays and a free air chamber for low and medium X-ray energies (20 keV to 150 keV). Although classified as very good they were not recommended for funding.

The collaboration with the University has pursued, namely with the IST and FCT-UNL. A Ph.D. degree in the field of air kerma primary standard for ^{60}Co gamma rays is ongoing. Three master thesis have been presented and a new thesis has been accepted by the FCT to be performed at the LMRI during the next year.

A collaboration with the ESTeSL – Escola Superior de Tecnologia da Saúde de Lisboa do Instituto Politécnico de Lisboa took place with the realization of two B.Sc. thesis.

A collaboration with the other Institutions, Centro de Instrumentação Científica do LNEC (Laboratório Nacional de Engenharia Civil), Laboratório de Electricidade e Laboratório de Comprimento do IPQ (Instituto Português de Qualidade), Laboratoire National Henri Becquerel, CEA was initiated.

Collaboration with BIPM was agreed in the framework of the construction of a free air chamber, the air kerma primary standard for low and medium X-ray energies (20 keV to 150 keV).

The LMRI has participated in the TLD audit to the absorbed dose to water for ^{60}Co and is participating in the comparison of therapy level ionizing chamber

calibration coefficients, both of them promoted by the IAEA.

The dosimetry of radiation qualities used in diagnostic radiology, including conventional X ray examinations, mammography and computed tomography has been carried out enabling the LMRI to calibrate clinical dosimeters.

A review of the 43 Calibration and Measurement Capabilities (CMC's) was realized according the recommendations of the EURAMET and this includes a revision of technical procedures, uncertainty assessment and inter-comparison reports.

Legal activities:

Taking the opportunity originated by the publications of the revisions of the IEC Standards deep revision of the current law (Portaria n.º. 1106/2009) has been realized. A purpose for this revision was presented to the IPQ for publication.

Concerning the legal metrology, the LMRI, as OVM, has calibrated 15 medical dosimeters and metrological controlled 182 radiation monitors.

Quality System

The LMRI Quality System has been extended to all the UPSR Unit. LMRI has prepared the accreditation process, ready for IPAC audit, for two techniques. The annual report concerning the CMC's has been approved by the Technical Committee of Euramet.

Internal collaborations

The LMRI has participated in the ICARO course and collaborated with the URSN and UFA Units of the Campus. Technical assistance concerning specific equipment of the LMRI has been given by UFA.

International organizations

A member of the Group have been appointed delegate for the Consultive Committee for Ionizing Radiation of International Committee for Weights and Measures (CIPM), is the contact person on the Technical Committee for Ionising Radiation of EURAMET, have participated on the Computational Dosimetry Group of EURADOS and is designated for the Group of Experts of art. 31 (Radiation Protection) of UE.

Research Team

Researcher

C. OLIVEIRA, Princ., (Habil.), Group Leader

Technical Personnel

A. CASTRO (until June)

J. CARDOSO

L. SANTOS, (50%) Quality Manager of the UPSR QS until June

Student

M. CALDEIRA, Ph.D. student, FCT grant

Dosimetry of radiation qualities used in diagnostic radiology.

Mário de Oliveira¹, João Cardoso and C. Oliveira

Objectives

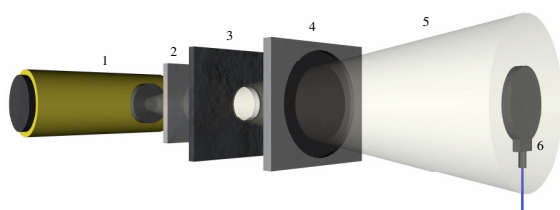
The radiation qualities used in conventional diagnosis are RQR (simulating radiation beam emerging from the target of tungsten), RQA (simulating radiation beam emerging from the patient) and RQT (simulating radiation beam emerging from the tomograph). These radiation qualities are established at the international standard IEC 61267 [1] For mammography, qualities established at the *Bureau International des Poids et Mesures* (BIPM) are the ones used.

Dosimetry procedures necessary to establish appropriated calibration of the dosimeters at the metrology Laboratory of Ionizing Radiation (LMRI) are performed according to the IEC 61267 and the code of practice TRS 457 [2]. The first step of this work was to verify the uniformity and homogeneity of the radiation field. The characterization of radiation qualities namely its dimensions should follow those described on the calibration certified of the ionizing chambers. The additional filtration, in mm of aluminium, was determined, to obtain the values of Half Value Layer (HVL) and homogeneity coefficient described by IEC 61267.

Methods and Results

The experimental arrangement for dosimetry is represented in the Figure 1.

Parameters as distances, dimensions of collimator



aperture, additional filtration and polarizing voltage are different for each set of radiation quality.

The value of air kerma (K_{ar}) was calculated by the equation 1, where N_k is the calibration coefficient, M is the reading of the plane parallel chamber, U is the reading of the monitor chamber, P and T are the air pressure and air temperature during the measurements and C_{PT} is the correction factor for temperature and pressure.

Fig.1 Scheme of dosimetry procedure. 1- X ray tube; 2- Additional filtration; 3- Collimator; 4- Monitor chamber; 5- Radiation beam; 6- Plane parallel chamber.

$$K_{ar} = \frac{M \cdot C_{PT}}{U \cdot C_{PT}} \cdot N_k \quad [mGy/um] \quad (1)$$

The calibration coefficients for RQR, RQA and RQT were determined at AIEA with traceability to the PTB. The calibration coefficients for mammography were realized at BIPM.

Pencil ionization chambers are calibrated in air kerma length. The results of the calibration coefficient of air kerma length versus collimator aperture are represented in Figure 2. For small apertures the sensitive length to scattered radiation is greater, and for full irradiation of the sensitive length, the ends (less sensitive) are irradiated too. Therefore the results suggest that irradiation of the chamber to 50% of its sensitive length, is the best option for carrying out the calibration of such chambers.

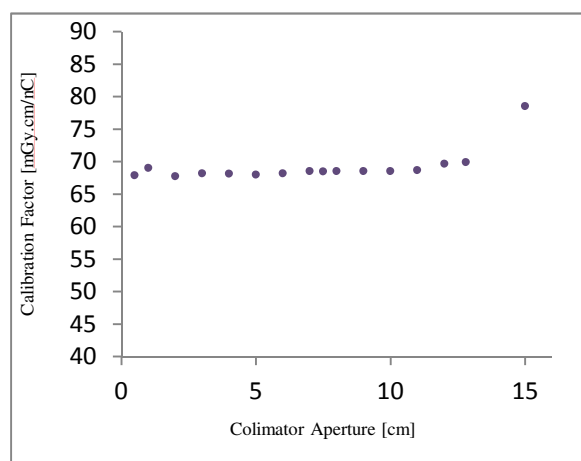


Fig.2 Air kerma length calibration factors versus collimator aperture of the chamber PTW 77336.

The sources of uncertainties were estimated according to the Guide to the expression of Uncertainty Measurement [3]. The calibration coefficient uncertainty is the dominant uncertainty.

¹(FCT-UNL, M.Sc. thesis).

References

- [1] IEC 61267. Medical diagnostic X-ray equipment - Radiation conditions for use in the determination of characteristics. 2005.
- [2] TRS 2007. Technical Reports Series no. 457 - Dosimetry in Diagnostic Radiology: An international Code of Practice. Rapport technique, International Atomic Energy Agency - IAEA. 2007.
- [3] JCGM. Evaluation of measurement data – "Guide to the expression of uncertainty in measurement" JCGM 100:2008.

Full characterisation of the 125I IBt bebig I25.S16 brachytherapy source and sensitivity study of the absorbed dose to water due to the seed dimensional variations

J. Plagnard¹, C. Oliveira, D. Cutarella¹, J. Gouriou¹, I. Aubineau-Lanièce¹, M. Rodrigues², L. Portugal, J. Cardoso

Low dose rate brachytherapy using ¹²⁵I seeds are a worldwide well established technique to treat prostate or ophthalmic cancers in early stage. The angular emission of photons leaving the source seeds and the dose to water distribution around the sources (calculated using the radial dose function and the anisotropy function) are directly linked to the design and composition of the source seeds. The purpose of this study was to quantify the sensitivity of the absorbed dose to water distribution due to the seed dimensional variations. To measure the geometric seed dimensions, two different methods were used. The external dimensions were measured with a calliper rule and the internal dimensions were obtained with radiographic pictures. The photonic emission was measured with a silicon detector (Si-PIN) of 15 mm² of area and 0.5 mm of thickness. The measurements were carried out for eight sources. Results show that the variations of photonic emission within each source and between sources are lower than $\pm 2-3\%$ in the two considered planes.

In the framework of this study an uncertainty analysis was carried out for radial dose function and 2D anisotropy function. For this analysis, uncertainties associated to geometrical seed variations relatively to the reference geometry were considered. To study the uncertainty components associated with radial dose function due to differences in geometry, three causes for these differences were considered: the length of the gold marker, the thickness of the titanium capsule and the thickness of the radioactive ceramic core. The results obtained reveal an overall uncertainty of 0.2 % and 0.1 % for distances of 0.10 cm and 0.25 cm, respectively. For longer distances the uncertainty is negligible. To study the uncertainty contributions associated with the 2D anisotropy function due to differences in geometry, two causes for these differences were considered: the thickness of the ends of the seed and the length of the gold marker. For each angle, the uncertainty decreases with increasing distance r . Uncertainties ranging from 6.7 % to 1.7 % are found for polar angles θ smaller than 20°. For polar angles $\theta \geq 20^\circ$ the uncertainty decreases significantly.

¹ CEA, LIST, Lab. Nat. Henri Becquerel, 91191 Gif-sur-Yvette CEDEX, France; ² Fac. de Ciências e Tecnologia da Univ. Nova de Lisboa, Monte da Caparica

Modelling and uncertainty evaluation for the radiation quality parameters used in metrological management of diagnostic radiology dosimeters

A. Silva Ribeiro¹, C. Oliveira, M.G. Cox², J.A.E Sousa³, L. Lages Martins¹, J. Cardoso, P. Limede⁴

Diagnostic radiology methods require radiation detectors for quality control of X-ray radiation qualities, with the measurement procedure and the parameters to be determined in accordance with International Standard IEC 61267:2005, the first and second Half-Value Layer values (HVL1 and HVL2) and the homogeneity coefficient h (HVL1/HVL2) given in the Standard. A mathematical approach and numerical method are given for obtaining these parameters. The GUM uncertainty framework is used to evaluate the measurement uncertainties associated with the resulting parameter estimates. Because the measurement model used is non-linear and implicitly defined, the results are compared with those from a Monte Carlo method. For all radiation qualities, IEC 61267:2005 gives admissible limits that are not supported by any rationale. For radiation qualities RQR, determinations of uncertainties associated with typical experimental data have been achieved.

¹ Lab. Nacional de Engenharia Civil, Lisboa, Portugal; ² National Physical Lab., Teddington TW11 0LW, UK; ³ Lab. Regional de Engenharia Civil, Funchal, Portugal; ⁴ Fac. Ciências e Tecnologia, Univ. Nova de Lisboa, Portugal

Project, construction and characterization of a cavity chamber for ⁶⁰Co gamma rays

M. Caldeira¹, C. Oliveira

A prototype of a graphite cavity chamber has been constructed at the workshop of ITN. The electrical connections and assemble of the pieces were made at the Laboratory of Electrical Measurements of the Portuguese Institute for Quality (IPQ). After the first tests with radiation developed at ITN, new measurements were made, this time at the facilities of Laboratoire National Henri Becquerel. Tests for stability of measurements of the chamber and working plateau were made at the LMRI. Tests for stability, plateau and polarity effects were performed at LNHB. Also a simulation of the electric field inside the chamber was realized at LNHB. The conclusions taken from these tests should indicate a new methodology in the development of the work, concerning not only the geometrical and electrical aspects of the construction of a cavity chamber, but also those related to the data acquisition and measurement set up.

¹FCT-ITN-IST

Ionizing Radiation Metrology for Metallurgical Industry

C. Oliveira, L. Portugal, I. Paiva, M. Reis, C. Cruz, J. Cardoso, L. Santos, R. Trindade

This new European project, “Ionizing Radiation Metrology for Metallurgical Industry” in the framework of the EURAMET, results from the implementation of the “European Metrology Research Programme” (EMRP) and is co-funded by the European Commission. The project, initiated in December, 2011, has the following scientific and technical objectives: WP1 - The development of reliable, SI traceable methods optimized for the control/measurement of radioactivity at each stage of the smelting process (e.g. scrap loads, metal products, slag and fumes dust), WP2 - The development of reference standards for cast steel (real and composite reference standards), slag and fume dust. Reference standards will be contaminated with potential contaminant radionuclides (e.g. ⁶⁰Co, ¹³⁷Cs, ¹⁹²Ir, ²²⁶Ra) and have different geometries/matrices that correspond to the cast steel probes currently used for on-line measurements and the slag cartridges used for

the calibration of radioactivity detectors, WP3 - The characterisation of the measurement methods recommended in WP1 with the reference standards produced in WP2, using inter-laboratory comparisons and Monte Carlo simulations to cover the large diversity of sample geometries, shapes, densities and elemental compositions, WP4 - The design of an optimised spectrometric device and the production of prototype devices for the measurement of activity in cast steel, fume dust and slag samples using the methods developed in WP1. This work package includes laboratory testing of the prototype devices, WP5 - Evaluation of the prototype spectrometric devices produced in WP4 and the methods developed in WP1, WP4, at end-user facilities (i.e. foundries). Evaluation criteria will be developed based on end-user needs/constraints, WP6 - Demonstration of the prototype spectrometric devices at selected foundries in Europe, development of technical recommendations and input into European and National Standards Committees for the standardisation of radioactivity monitoring (e.g. calibration of measurement systems, on-line monitoring of production and certification of cast steel batches), and worldwide dissemination of project results to end-users, stakeholders and the general society through journal articles, conference presentations and specialised workshops. The project has 14 funded partners and ITN is involved in WP1, WP3, WP5 and WP6 tasks.

Quality System

L. Santos, J. Cardoso, C. Oliveira

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. According to the recommendations of the EURAMET a revision of the CMC's, namely the revision of procedures, uncertainties assessment, update of inter-laboratorial comparison, have been finished and sent to EURAMET.

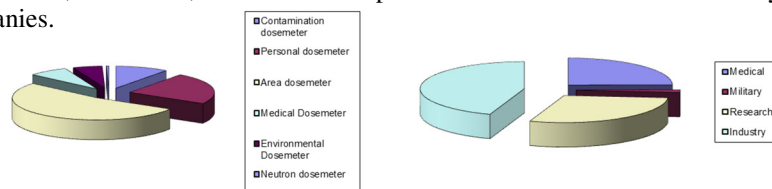
The LMRI submitted for accreditation two techniques in metrological control of radiation protection monitors in terms of the operational quantities, personal dose equivalent, $H_p(10)$, and ambient dose equivalent, $H^*(10)$, according to the standards IEC 61526 and IEC 60846, respectively.

As happened in recent years the LMRI participated in the TLD audit to the absorbed dose to water for ^{60}Co promoted by the AIEA. Besides, LMRI participated in a comparison of therapy level ionizing chamber calibration coefficients also promoted by the AIEA.

Services

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

LMRI provides the community, mainly hospitals, industry, universities, armed forces and ITN Units with calibration and metrological control services. This metrological control of instruments is being carried out under a contract with Portuguese Institute of Quality and is the enforcement of Portaria n°. 1106/2009 dated of 24 of September. During 2011 were calibrated and controlled 197 dosimeters. The following figures describe the work done. In 2011, the LMRI, have irradiated personal dosimeters for the reader system calibration of two private companies.



LMRI COLLABORATION WITH ITN UNITS/GROUPS

Unit of Reactors and Nuclear Safety (URSN)

The LMRI performs, every year, the metrological control of installed detectors and associated instrumentation of the RPI radiological protection system. In 2011 have been verified, calibrated or tested 41 monitors/detectors.

Unit of Physics and Accelerators (UFA)

LMRI has carried out three calibrations: one ionizing chamber calibrated in air kerma and the second ionizing chamber calibrated in air kerma and absorbed dose to water for the "Radiation Technologies: Process and Products Group".

The Ion Beam Laboratory Group and the Nuclear Methods and Instrumentation Group gave technical assistance to the specific equipment of the LMRI.

Unit of Radiological Protection and Safety (UPSR)

Dosimetry and Radiobiology Group

In 2011 about 1050 TLD dosimeters have been irradiated. About 700 for $H_p(10)$ and about 350 for $H_p(0.07)$. Cells and blood have been irradiated. The purpose of the work was the establishment of a dose response curve for biological dosimetry, using lymphocytes from human peripheral blood from healthy donors for both gender and different age group. The dose range studied is from 0.25 Gy to 3.0 Gy using a source of ^{60}Co .

Environmental Radioactivity Group

The technical support to Environmental Radioactivity Group database (SIAC) and the data submission for the Radioactivity European Measurement Database (REM) have been made by a LMRI technician (LS).

Radioprotection and Radioactive Waste

LMRI has carried out the metrological control of 15 radiation protection instrumentation.

Environmental Radioactivity

Maria José Madruga

In 2011, one of the highlight activities of the Environmental Radioactivity Group has been conducting the environmental radioactivity monitoring in Portugal after the Fukushima Nuclear accident that occurred in Japan on March 12. This finding reinforces the importance of the work developed by the Group particularly in the case of nuclear accidents in support of the activities of national (Portuguese Environment Agency, National Authority of Civil Protection, etc.) and international entities (EC, AIEA, etc.).

Legal activities:

One of the main activities of the Environmental Radioactivity Group (GRA) concerns the Radiological Environmental Monitoring Programmes which are performed in collaboration with the Measurement Laboratories (LM), the Dosimetry and Radiobiology (GDR) and the Radiological Protection and Radioactive Waste Management (GRRR) Groups. These surveys were established according to the Recommendations of the Articles 35/36 of the EURATOM Treaty and its execution is legally attributed to ITN (Decree-Law 138/2005 of 17th August). In April, in the framework of the Article 35 requirements, an EC verification team visited the ITN in particular the GRA laboratories where the analyses concerning the radiological surveillance programme for the regions around old uranium mining sites are performed.

Research and development activities:

Current research activities are ongoing to investigate the levels of radioactivity in the environment and the biogeochemical cycles of natural and artificial radionuclides in the atmosphere (aerosols) aquatic and terrestrial environments.

Quality system:

Regarding the quality assurance of the radioanalytical techniques one of the objectives of the Group for this year was achieved. The accreditation concession audit for three radioanalytical techniques (gross alpha/beta in waters by proportional counters and by Liquid Scintillation Counting and tritium determination in

waters by LSC) was conducted by the Portuguese Accreditation Body (IPAC-Instituto Português de Acreditação). The accreditation concession of these techniques by IPAC is foreseen for 2012.

One GRA staff member (Irene Lopes) was nominated (since September 2011) the UPSR Quality Manager.

Participation in intercomparison exercises:

The Group participated in collaboration with the Measurement Laboratories in the following international inter-comparison exercises: determination of radionuclides in soil and water organized by the IAEA/ALMERA (Seibersdorf, Austria); determination of ¹³⁷Cs, ⁹⁰Sr and ⁴⁰K in wild bilberry organized by the EC (IRMM, Geel, Belgium) and determination of natural and artificial radionuclides, global alpha/beta and tritium in water organized by the Consejo de Seguridad Nuclear (CSN, Spain). Regarding the indoor radon the GRA participated in two exercises: one, organized by NIRS (National Institute of Radiological Sciences, Chiba, Japan) and the other one, by the University of Cantabria, Spain. The results published in 2011 are in good agreement/compatible with the reference values.

Technical services:

The technical services developed by the Group were carried out under contract with companies or by request from enterprises or Government organizations. The technical services concern the evaluation of the radioactivity levels in public water supplies (Decree-Law 306/2007), mineral waters, indoor radon measurements (Decree-Law 78/2006; NT-SCE-02), foodstuffs, biological samples, etc.

Participation in national and international technical and scientific committees:

GRA members are involved in several committees and working groups from IAEA, EC and CTBT.

Education and Training:

GRA members are involved in education and training activities in radioanalytical techniques, environmental radioactivity and radiological protection.

Research Team

Researchers

M. J. MADRUGA, Princ., Group Leader
F. P. CARVALHO, Princ.
J. A. CORISCO, Aux.
M. J. REIS, Aux. (25%)

Students

A.R. GOMES, FCT grant
E. ANDRADE, FCT grant
J. MELO, FCT grant

Technical Personnel

A. LIBÂNIO
A. MOURATO
I. LOPES
J. M. OLIVEIRA (70%)
M. M. MALTA

Radioactive Fallout in Portugal Following the Fukushima Nuclear Accident

M. Reis, M.J. Madruga, L. Silva, E. Andrade

Objectives

Following the nuclear accident that occurred in Fukushima Daichi (Japan) complex on March 12, 2011 short (^{129m}Te , ^{131}I , ^{132}Te , ^{136}Cs) and long lived anthropogenic radionuclides (^{134}Cs , ^{137}Cs) were released to the atmosphere and dispersed along the world reaching the European countries including Portugal, around two weeks after the accident (end of March 2011). In Portugal, the radioactivity in the atmosphere was measured using a continuous high volume (ASS-500) aerosol sampling station located at ITN *campus* (Sacavém). Samples of aerosols, grass, leafy vegetables and milk, which give a better indication of the atmospheric radioactive deposition in the case of a nuclear accident, were collected and analysed to the gamma emitter's radionuclides using high resolution gamma spectrometry analysis. Radioactivity on atmospheric aerosols (related to Fukushima accident) was also detected at Açores (S. Miguel island) by the radionuclide particulate station RN53, from the International Monitoring System of the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO).



Fig. 1 Aerosol sampling station ASS-500, located at ITN *campus*.

Results

During about one month (end of March until end of April 2011), traces of ^{131}I , ^{137}Cs and ^{134}Cs , amongst others, were detected in aerosols particles, reaching the maximum values for ^{131}I ($0.9 \pm 0.1 \text{ mBq m}^{-3}$) ^{137}Cs ($0.13 \pm 0.01 \text{ mBq m}^{-3}$) and ^{134}Cs ($0.126 \pm 0.004 \text{ mBq m}^{-3}$) on the last week of March.

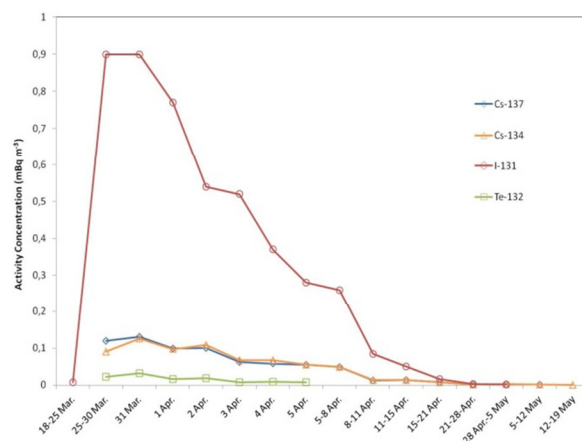


Fig. 2 Evolution of the activity concentration, at Sacavém, of several anthropogenic nuclides related to the Fukushima accident.

The fallout of those aerosols particles contributed to the maximum levels of radioactivity ($2.48 \pm 0.24 \text{ Bq m}^{-2}$ and $0.93 \pm 0.15 \text{ Bq m}^{-2}$ for ^{131}I and ^{137}Cs respectively) measured in grass samples, which were observed during the first week of April. Traces of ^{131}I were also detected in milk and leafy vegetables collected during the same time period. The isotopic ratio of some nuclides ($^{134}\text{Cs}/^{137}\text{Cs}$, $^{137}\text{Cs}/^{131}\text{I}$ and $^{137}\text{Cs}/^{132}\text{Te}$), together with the backward trajectories simulated using the HYSPLIT lagrangian model, clearly indicates that the detected anthropogenic nuclides originate from Fukushima (Japan). However, the levels of radioactivity observed do not raise any concern regarding the Portuguese population exposure and therefore no radiological protection measures were recommended by the competent authorities.

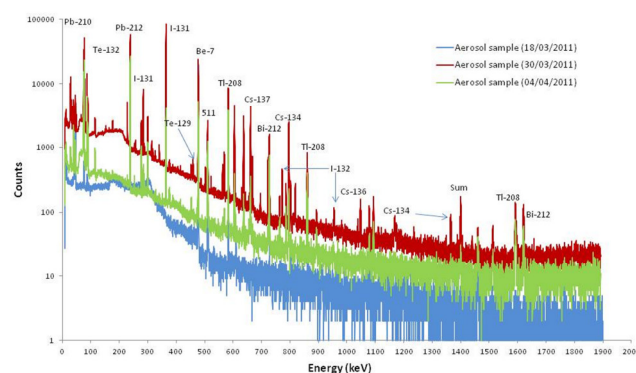


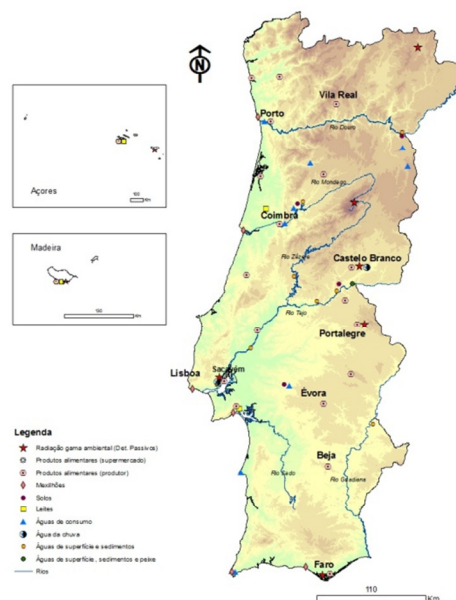
Fig. 3 Comparison of aerosol sample spectra before and after the detection of radionuclides from Fukushima.

Radiological environmental monitoring programmes

M.J. Madruga, F.P. Carvalho, M. Reis, J.G. Alves, J.A. Corisco, R. Trindade, I. Lopes, J. Abrantes, J.M. Oliveira, L. Silva, L. Portugal, M. Malta, A. Libânio, A. Mourato, G. Silva, L. Santos, A. Batista, A.R. Gomes, E. Andrade, G. Carvalhal, J. Melo, M. Pereira

The Radiological Environmental Monitoring Programmes performed according to Article 35 of the EURATOM Treaty include the Programme at a National Level, established by law in 2005 and which execution was legally attributed to ITN (Decree-Law 138/2005, 17th August), the Source Related Programme for the ITN *Campus* and the Specific Programme for the Regions around Old Uranium Mining Sites. The radiological environmental survey has as main objectives to quantify the artificial and natural radionuclide levels in the environment (aquatic, terrestrial and atmospheric) considered as direct pathways of contamination to man and to evaluate the external radiation levels in order to assess the potential exposure of the Portuguese population. The monitoring programme at a national level concerns the radioactivity measurements of environmental and foodstuff samples collected along the country. The monitoring programme carried out for the ITN *campus* includes measurements of external radiation levels (gamma dose) and determination of radionuclide activity concentrations in relevant environmental samples (aerosols, rain water and soils) in order to check the operation conditions and discharge controls adequacy and to maintain a continuing record on environmental radionuclide levels related to the source. Monitoring of the regions around old uranium mining and milling sites in Portugal was performed. Water, soil, and vegetable samples were analysed for uranium series radionuclides. Radon measurements and aerosol samples were collected near the uranium mining waste dumps.

During 2011 about 560 samples (aerosols, rainwater, surface water, drinking water, sediments, fish, mixed diet, complete meals, milk, soils, etc.) were collected accordingly to international sampling procedures and a total of about 1970 analyses were performed for the determination of artificial and natural radionuclides, using gamma and alpha spectrometry, alpha/beta measurements and liquid scintillation technique. Integrated measurements of the ambient dose equivalent with thermo luminescent dosimeters were also performed. The results show that the Portuguese population was not exposed to radioactive contamination levels higher than the radioactive background. Therefore, there is no need to adopt any measures for radiological protection of the population. All the data are published in Internal Reports made available in the ITN website (<http://www.itn.pt>) and included in the European Radioactivity Environmental Monitoring Database (REM) located at the EU Joint Research Centre, ISPRA (Italy).



Biomass combustion and release of radionuclides into the atmosphere

F.P. Carvalho, J. M. Oliveira, M. Malta

This Research Project funded by the FCT and coordinated by the University of Aveiro (Acronym BIOEMI; PTDC/AMB/65706/2006) was completed during the current year. In the time course of project characterization of radioactivity in wild vegetation including bush and forest, was made in order to assess the (organic and radioactivity) compounds released with the smoke into the atmosphere and potentially inhaled. During the occurrence of vegetation and forest fires in the summer period, field sampling was performed in closed collaboration with fire brigades. Filters with the aerosol particles collected near the fire were analyzed for naturally occurring radionuclides. The concentrations of the more volatile radionuclides such as ^{210}Po , ^{226}Ra and ^{210}Pb in smoke particles, especially in the smallest ones ($<0.43\ \mu\text{m}$), were found very high. People exposed long time to the fumes near fire fronts may inhale significant activities of smoke particles and thus of these radionuclides, and especially ^{210}Po . Activity concentration values measured indicate potential for significant radiation exposure and, thus, protection of the respiratory tract is needed to avoid not only the inhalation of smoke particles but also to avoid radiation exposure.

Definition of new ENdpoints to assess GENtoxic effects resulting from environmental exposures to Uranium, Uranium daughters and ionizing radiation in bioindicator species-ENGENUR.

F.P. Carvalho, J. M. Oliveira, M. Malta

This research project is funded by the FCT (Acronym ENGENUR; FCT PTDC/AAC-AMB/114057/2009) and aims at defining new markers for exposure to ionizing radiation from uranium mining tailings in the areas of past uranium mining and milling industrial activity. The mining area selected for work was Cunha-Baixa mine (Mangualde), and samples of wild rodents and amphibians were collected in the area for analyses of biological effects of radiation at genetic, chromosome and tissue level. Exposures of the earthworms using standard test protocols to assess the toxicity of uranium were carried out. The project achieved already significant results showing toxicity in untreated acid mine drainage and residual waters and soils containing uranium for the earthworms and wildlife. First results were presented to international conferences and published already or are in press in international journals.

Marine radioactivity

F.P. Carvalho, J. M. Oliveira, M. Malta

Man-made, such as ^{137}Cs and $^{239+240}\text{Pu}$, and naturally-occurring radionuclides, such as ^{210}Pb and ^{210}Po , are introduced in the ocean by atmospheric deposition and coastal discharges. Research and monitoring of radioactivity in marine organisms was carried out in order to pursue the assessment of radiation doses from naturally-occurring and man-made radionuclides to biota and to the human population through ingestion of sea food. Monitoring of radionuclide levels along the Portuguese coast was performed using mussels (*Mytilus galloprovincialis*) as bioindicator organisms collected at various sites at the open coast and in the main estuaries. Determination of radionuclides in mussels, particularly the naturally-occurring ^{210}Po and ^{210}Pb allowed better understanding of the accumulation of these radionuclides by molluscs and allowed making relevant contributions to methodologies used worldwide in coastal monitoring programs using mussels.

Project "CAPTAR"

F.P. Carvalho

Participation in the web-based science education project coordinated by the University of Aveiro and funded by the Calouste Gulbenkian Foundation. The project aims at producing a scientific periodical (CAPTAR: ciência e ambiente para todos) available on line (<http://captar.web.ua.pt/>) for education and motivation of students and young researchers in environmental sciences. Two journal issues were released in 2011. Celebration of the centennial of Marie Curie Nobel Prize for the discovery of polonium and radium was comprehended in the activities of the year.

Radiocaesium Adsorption/Desorption on Geomaterials from "Raña" Deposits

M.J. Madruga, I. Paiva, E. Andrade, M. Gonçalves¹, A. Mateus²

The grain size fraction $< 63\mu\text{m}$ of the *raña* deposits matrix, comprising abundant clay minerals (smectite 15\AA , kaolinite, and illite) and quartz, besides minor amounts of iron hydroxides, was examined for radiocaesium (^{137}Cs) adsorption/desorption in order to test its use as liner/backfill/buffer for low and intermediate level waste (LILW) repositories. The ^{137}Cs adsorption was studied as a function of Cs^+ concentrations in the presence of Mg^{2+} (strongly hydrated competitive ion) using a batch method. The ionic strength of the magnesium solutions was adjusted to concentrations similar to those found in surface natural waters streaming in the region where the *rañas* were sampled. The simulation of *in situ* conditions for ^{137}Cs desorption in case of an incident/accident scenario considered two different procedures, static and dynamic. The ^{137}Cs adsorption is quite rapid, attaining the maximum saturation value after two weeks of contact time. Higher adsorption percentage values were obtained for lower Cs concentrations, in presence of Mg^{2+} . Desorption studies reveal that the solid/liquid equilibrium was more quickly attained in the static system (1-2 days) than in the dynamic system (around two weeks). In addition, the ^{137}Cs retention ranges between 60% and 70% in the static system, being just around 30% in the dynamic system. As expected, cation exchange between Cs and competitive ions is more efficient in the dynamic system. In both systems, the strongly hydrated ion Mg^{2+} , may lead to a wedge-effect in the FES pool, allowing a Cs penetration into the clayed-matrix and a consequent decrease in ^{137}Cs desorption levels. In the static system, the Mg and Cs concentrations in solution reach a dynamic equilibrium; consequently, no further ^{137}Cs is released without renewal of the solutions. Contrarily, in the dynamic system the renewal of Mg-solution leads to an equilibrium breakdown, leading to an increase of ^{137}Cs release. According to these experimental results, the clay fraction of *raña* deposits can be faced as a potential liner/backfill/buffer component to be used in LILW repositories.

¹ Fac. of Sciences/Univ. of Lisbon and CREMINER-LARSys

² Fac. of Sciences/Univ. of Lisbon and CeGUL

Total column and surface ozone variability over the Iberian Peninsula: Dynamical and chemical atmospheric factors - DYNOZONE*M. Reis, M. J. Madruga, E. Andrade, L. Silva*

The DYNOZONE project was approved and funded by FCT. Is a cooperation project between New University of Lisbon, Nuclear and Technological Institute, Aveiro University and Fernando Pessoa Foundation for Teaching and Culture. The project officially started on October 2010. The main objectives of the project are to identify and justify, on a scientific base, the no photochemical origin of some ozone events, namely the stratosphere-troposphere exchange contribution to elevated surface ozone concentrations, as opposed to local production or long range transport from external pollution sources. During 2011, a ten years time series of naturally radioactive atmospheric tracers (namely ^7Be as a stratospheric tracer) were compiled and made available to the project team in order to correlate radionuclide and ozone data, providing a possible confirmation of the stratospheric influence on surface ozone high concentration events. A High Volume Sampler was acquired, as planned, to be installed in different locations and follow, on a daily basis, stratospheric intrusion events.

Building the pieces for a radioeco-toxicological characterization of the upper section of Tejo estuary from the Samouco shoals to the slimy site of Hortas*J.A. Corisco, L. Portugal, M. Almeida*

During the decade 2000-2010 there has been observed an uncommon increase of bivalve catching in the left side of Tejo estuary, in the sedimentary planes extending from the village of Samouco upstream to the village of Alcochete. Native species *Scrobicularia plana* and specially the invasive species *Tapes japonica* appear to be the most prominent. The concerned area of interest has acquired in former decades a very distinct radiological status, from the fact that downstream, in the village of Barreiro, the phosphate industry of Quimigal – currently disabled – was a source of natural long lived radionuclides discharge in the environment. This project started with the intention of making a statement on the distribution of natural radionuclides in both biota and sediments in the area of interest, but quickly that interest has expanded towards the analysis of multiple pollution sources including heavy metals, once their presence resulting from human activities may contribute to a complex ecotoxicological scenario affecting human populations and environmental quality.

Field work has started in February 2011 by collecting biological (plants, bivalves) and sediment samples. Laboratory sample processing has been carried through ever since. High resolution gamma spectrometry of sediment samples has confirmed the presence of components of the natural series of ^{235}U and ^{238}U . Neutron activation analysis is being carried to complementary analysis of heavy metals both in sediments and biota. Scientific/technological partnership is being attempted and an encouraging meeting with a group from UNINOVA dedicated to environmental monitoring and robotics has opened a new perspective to this work. Project is still aiming for financial support, which will be attempted in 2012.

Accreditation of radioanalytical techniques*M.J. Madruga, I. Lopes, A.R. Gomes, J. Melo, J.A. Corisco*

During this year a major effort was devoted to the final steps of the preparation for the accreditation. Improvements were introduced in the management and technical procedures and an internal audit by UPSR auditors was carried out. In December 2011, accreditation concession audit, according to the ISO/IEC 17025 requirements, was performed by two auditors of the Portuguese Accreditation Body (Instituto Português de Acreditação-IPAC) for the three techniques, gross alpha/beta in waters with proportional counters and Liquid Scintillation Counting (LSC) and tritium determination in waters by LSC. During the audit a systematic and independent examination was carried out to determine whether quality activities are implemented effectively and are suitable to achieve the objectives. The audit report highlights the good quality of the work developed, the experience, technical training and the spirit of openness to improvement of the staff involved.

Three papers concerning the quality assurance of these radioanalytical techniques were published at LSC 2010, Advances in Liquid Scintillation Spectrometry. Radiocarbon, Editor: P. Cassette, ISBN: 978-0-9638314-7-7, University of Arizona, Tucson, Arizona, USA. In the framework of the IAEA TC project, RER/ 0/ 031 - “Strengthening Sustainability of Nuclear Research and Development Institutes in the Modern Science and Technology Environment” one GRA staff member (Irene Lopes) has performed a scientific visit (two weeks) to the Central Mining Institute (Poland) taking knowledge of the implementation in this Institute of the Quality System, according to the standard ISO/IEC17025. Training in Sr-90, Ra-226/Ra-228, Rn-222 and uranium analysis in waters, using liquid scintillation counting technique and alpha spectrometry was also performed.

Radon in waters*M.J. Madruga, I. Lopes*

Radon (^{222}Rn) is a radioactive naturally occurring gas, derived from the natural uranium series (^{238}U) and decay to short lived daughters (^{218}Po , ^{214}Pb , ^{214}Bi and ^{214}Po) with a high solubility in waters. The highest activities of ^{222}Rn are found in groundwaters due to its emanation from granite rocks. The consumption of waters with high levels of radon could give a high contribution to the effective dose from ingestion affecting the human health. So, it is important the knowledge of the radon levels in waters. In this context, determination of ^{222}Rn by Liquid Scintillation Counting (LSC) technique is ongoing and an intercomparison exercise in collaboration with STUK institute (Finland) was performed during this year, with good results. A collaborative protocol with Instituto Superior Técnico (IST) laboratories is envisaged for the radon analyses in Portuguese waters.

Radionuclide Particulate Station RN53 of the International Monitoring System for the Verification of the Comprehensive Nuclear Test Ban Treaty (CTBT)*M. Reis*

The radionuclide particulate station RN53, installed in São Miguel - Açores, belongs to the International Monitoring System (IMS) network for the verification of Comprehensive Nuclear Test Ban Treaty (CTBT), signed and ratified by the Portuguese State. The station is managed by ITN, with the collaboration of two local operators from the Meteorological Institute. The station was certified on December 2010 and, since then, was providing data to the International Monitoring System of the CTBT. Between 25 of March and 16 of May, the station registered some isotope detections (iodine and cesium) related to the Fukushima NPP accident. On October 2011, one of the station operators participated in a training course financed by CTBTO: "Technical Training Programme (TTP) for Radionuclide Station Operators with ORTEC Equipment", held at Oak Ridge, USA.

Services**Radioactivity in drinking and mineral waters***M.J. Madruga, J. Melo, A.R. Gomes, A. Libânio, I. Lopes, F.P. Carvalho, J.M. Oliveira*

Regarding the evaluation of the radioactivity levels in drinking waters (Decree-Law nº306/2007) the GRA was requested by Water Suppliers to carry out the determinations of global alpha, global beta, Tritium, ^{238}U , ^{234}Th , ^{226}Ra and ^{210}Po and the Total Indicative Dose parameter in waters. The determination of ^{222}Rn in water samples was also carried out. In order to license mineral waters trade (Decree-Law nº84/90) several enterprises request a radiological study. During 2011, a total of about 300 analyses were performed.

Radioactivity in foodstuff and biological samples*M.J. Madruga, I. Lopes, A. Mourato, F.P. Carvalho, J.M. Oliveira, M. Malta*

Analyses of ^{90}Sr in foodstuff and ^{210}Po in biological samples were carried out, under request of external entities, in order to support commercial activities and research projects.

Indoor Radon*M. Reis, E. Andrade, L. Machado*

Following the National System of Building Energetic Certification for the Indoor Air Quality (Decree-Law 78/2006, 4th April) public and private enterprises request to GRA the measurements of indoor radon. Besides, since November 2003 a collaborative Protocol was established between UPSR-ITN and DECO to answer the associate's indoor radon requests. In 2011, about 750 measurements were performed.

Measurement Laboratories

Mário João Capucho dos Reis

The Measurement Laboratories (LM) provides analytical services in the area of radioactive analysis of low and medium activity samples and in measurement of ions in liquid samples.

Together with the Environmental Radioactivity Group (GRA), which is responsible for collection, chemical preparation of the samples and data organization, the LM carries out Portugal's obligations under Article 35 of the EURATOM Treaty which requires member states to conduct national environmental radiological survey annually.

The LM is also involved in research work and provides analytical services to external clients in order to support industrial and commercial activities.

The techniques used are high resolution gamma-ray spectrometry; gross alpha/beta counting and beta counting of specific radionuclides using gas flow proportional counters; liquid scintillation and alpha spectrometry. The range of radioactivity measurements includes: analysis of radioisotopes in water to assist in the surveillance of ITN's research reactor, control of foodstuffs, export or import products and building materials, analysis of gross alpha/beta and tritium in drinking water (in collaboration with the GRA).

Regarding the external quality control of the measurements, during 2011 the LM group has participated, together with the GRA, in several International Intercomparison Exercises: determination of specific radionuclides in soil and water (IAEA/ALMERA, organized by IAEA), determination of ^{137}Cs , ^{90}Sr and ^{40}K in wild bilberry (IRMM/Geel, organized by EC) and determination of natural and artificial nuclides, gross alpha/beta and tritium in water (CSN/Spain, organized by CSN). Furthermore, the Gamma Spectrometry Laboratory has also participated in a gamma spectrometry

Proficiency Test Exercise covering two different matrices: determination of unknown nuclides in an aqueous sample and determination of ^{60}Co , ^{137}Cs , $^{234,235,238}\text{U}$ and ^{241}Am in a synthetic sand sample. The

Proficiency Test was organized by the National Physical Laboratory (NPL, UK).

Regarding the Quality Assurance System, an important step was done towards the accreditation of several radioanalytical techniques: gross alpha/beta in waters using Proportional Counters and Liquid Scintillation Counting, tritium in waters by Liquid Scintillation Counting and Gamma Spectrometry of liquid and solid samples using HPGe detectors. Internal audits were carried out during this year and the accreditation concession audit, conducted by the Portuguese Accreditation Body (IPAC), took place on December.

The LM continues to collaborate with several on-going projects, mainly by providing different type of measurements: radiological characterization of soil and rock samples and measurement of radioactive stratospheric tracers.

During 2011, the Measurements Laboratories team was involved in education and training activities, namely by lecturing in training courses for external entities and by providing advanced training on radioactivity measurements to foreigner IAEA students.

Throughout the year, the Measurement Laboratories also received a great number of study visits, mainly from groups of students of secondary schools and universities.

Research Team

Researcher

M. REIS (75%), Aux., Group Leader

Technical Personnel

G. SILVA
J. ABRANTES
J.M. OLIVEIRA (30%)
L. SILVA

Student

G. CARVALHAL, FCT grant

Accreditation of radioanalytical techniques

J. Abrantes, G. Carvalhal, M. Reis, L. Silva, G. Silva

During 2011 a great effort was undertaken in order to finish the preparation for the accreditation of several radioanalytical techniques: gross alpha/beta in water samples using Proportional Counters and Liquid Scintillation Counting, tritium in water by Liquid Scintillation Counting and Gamma Spectrometry of liquid and solid samples using HPGe detectors. All the management and technical procedures were revised and updated and an internal quality audit was carried out. On December, a two days accreditation concession audit was conducted by experts of the Portuguese Accreditation Body (IPAC) to verify the fulfillment of the ISO/IEC 17025 requirements.

Education and training of IAEA fellows

J. Abrantes, G. Carvalhal, M. Reis

During the second half of October 2011, two trainees (as IAEA financed fellows) from the Radiation Protection Center of Lithuania (Department of Expertise and Exposure Monitoring, Division of the Public Exposure Monitoring) were received by the Measurements Laboratory (LM) and Environmental Radioactivity Group (GRA) for a training programme. The aim of the technical training consisted on measuring of gross alpha/beta activities in waters by Gas Proportional Counters and Liquid Scintillation Counting as well as radon activity in waters by Liquid Scintillation Counting. At LM the topics included on the training programme were: alpha/beta detection systems, calibration processes, MDA and uncertainty calculations, related activity calculations and results.

Fukushima related radioactivity measurements

L. Silva, M. Reis

Following the Fukushima NPP accident in March 2011, a set of different type of samples were measured by high resolution gamma spectrometry to rapidly detect the presence of anthropogenic nuclides that could be related to the accident. Samples of aerosol particles, leafy vegetables, milk, rain water and grass were measured and it was possible to detect traces of radioactive isotopes of iodine, cesium and tellurium in very low levels but clearly related to the Japan NPP accident.

SERVICES**Analytical services on radioactivity measurements**

J. Abrantes, G. Carvalhal, J.M. Oliveira, M. Reis, L. Silva, G. Silva

In 2011, more than 2000 analysis have been performed (excluding analysis for calibration, quality control and intercomparison exercises). The above mentioned analysis were carried out in the framework of the national environmental radiological survey, as services for external entities and for research projects, either of UPSR or other ITN sectors. During this year, as a consequence of the Fukushima NPP accident, several measurements of foodstuffs and related items imported from Japan were carried out by request of the Portuguese competent authorities, in order to detect eventual contaminations.

Dosimetry and Radiobiology

Pedro Vaz and Octávia Monteiro Gil

The main components of activity of the Group of Dosimetry and Radiobiology (GDR) are Individual Dosimetry, Computational Dosimetry, Internal Dosimetry, Biological Dosimetry, Radiobiology and Radiological Safety Assessment of installations.

In order to address the multidisciplinary, cross-cutting leading-edge scientific and technical issues in dosimetry and radiobiology, the synergies of the competences held by the GDR researchers and technicians were further strengthened.

Researchers and students from the GDR have participated:

- In R&D projects conducted and submitted by international consortia, in the E.U. 7th Framework Programmes or in collaboration with CERN;
- In R&D projects funded by the Portuguese Foundation for Science and Technology
- In the activities of EURADOS Working Groups.

Computational Dosimetry: the existing competence in Monte Carlo modelling and simulations was deployed in support of radiological protection, dosimetry and shielding assessment studies of nuclear technology facilities, of radiological installations, and of the modelling of medical radiological equipments and of HPGe-based detection systems, including the Whole Body Counter operated by the GDR. Expertise in the manipulation of voxel phantoms was consolidated during this period.

Medical applications of ionizing radiation: Collaborative links with hospitals were fostered. Activities related to the dose assessment and computational modelling of medical radiological equipments were undertaken, namely in Mammography, Computorized Tomography (CT) and in Fluoro-CT. Research activities and studies in Nuclear Medicine in external radiotherapy and in brachytherapy were pursued.

ITN led a Portuguese consortium of institutions that gathered data to assess the exposure of the Portuguese population to ionizing radiation in the framework of the medical applications. The frequency of the most commonly performed exams and the associated dosimetric characterization was performed in the framework of the DoseDataMed II project.

Biological Dosimetry and Radiobiology: the expertise and competences in several radiobiology and bio-dosimetric techniques namely Comet assay dicentric, micronuclei, and γ -H2AX and, were further strengthened.

The dose-response curves for dicentric and micronuclei assay, using gamma radiation for the Portuguese population were finalized.

Low dose radiation research: the occupational or environmental exposure to low radiation doses and the medical exposures to ionizing radiation for diagnostic or therapy purposes are currently very hot scientific and regulatory-related topics and issues. Major findings in the biological effects of radiation should allow to narrow the persisting uncertainties about the mechanisms of response of cells, tissues and biological systems in the range of low doses, what will pave the way for developments of the international system of Radiation Protection. The ITN participated as a full member in the activities of the EU-platform MELODI (Multidisciplinary European LOW Dose Initiative”) namely in the definition of a strategic research agenda for the low dose research in Europe.

Internal Dosimetry: the expertise in the manipulation of biokinetic models and in internal dosimetry studies was consolidated during the period.

Technical Services

A Task Force was created to respond to the high number of requests of radiological safety assessments mainly from Nuclear Medicine and radiotherapy installations but also from cargo x-ray scanners and industrial applications of accelerators.

The GDR continued to operate its individual dosimetry and monitoring services.

The Central Dose Registry (CDR) for occupational exposure continued to collect and store on a quarterly basis the dosimetric data from the seven monitoring services and companies operating in Portugal.

Higher Education and Training

Several researchers maintained regular collaborations with Portuguese universities and higher education institutions, teaching Radiation Protection- and Dosimetry-related disciplines in the framework of Masters and post-graduation programmes and supervised Masters and Ph.D. theses. Several technicians and students participated in international training courses in radiation protection, dosimetry and radiobiology.

International and national representation activities
Researchers from the GDR acted as national representatives in Committees and Working Groups under the auspices of the EU, the IAEA and the OECD/NEA and assisted the Portuguese Government in the drafting of legislation and regulations.

Research team

Researchers

P. VAZ, Princ., (Agreg.)
M.A. NEVES, Princ. (until july)
A.D. OLIVEIRA, Aux.
J. ALVES, Aux.
O. MONTEIRO GIL, Aux
P. TELES, Aux.
S. di MARIA, Post-Doc

Admin & Techn. Personnel

M. SARAIVA
S. RANGEL
T. ANTUNES
Y. ROMANETS, Ph.D. student

Students & Collaborators

A. BELCHIOR, Ph.D. student, FCT grant
A.C. ANTUNES, FCT grant
C. BORGES, Ph.D. student, FCT grant
C. CARRAPICO, Ph.D. student, FCT grant
C. FIGUEIRA, FCT grant
J. BENTO, FCT grant
M.N. PEREIRA, ITN grant
R.F. LUIS, Ph.D. student, FCT grant
R. SARMENTO, Ph.D. student, FCT grant
S. BARROS, Ph.D. student, FCT grant
V. MARTINS, FCT grant

Construction of a dose response curve for dicentric chromosomes

V. Martins, A.C. Antunes, O. Monteiro Gil

A dose response curve, for dicentric chromosomes, was developed at ITN using the chromosomal aberrations assay. This curve is an important tool, in biological dosimetry, allowing the estimation of dose in cases of accidental exposure to ionizing radiation where, often, no knowledge of the physical dose exists. The dose response curve was obtained studying *in vitro* irradiated samples of 16 healthy, non-smoker individuals, from both genders, in the 20 to 60 years age range. Samples of peripheral blood lymphocytes were irradiated, using a ^{60}Co source from LMRI. For each individual and dose studied, a total of 200 metaphases were scored. A total of 22,395 metaphase spreads were analyzed. The dose response calibration curve was constructed and statistical analysis was performed using the Chromosome Aberration Calculation Software (CABAS, v.2). The validation of the dose response curve was already done.

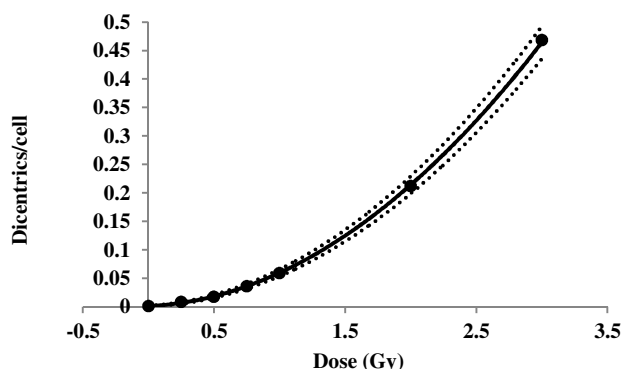


Fig. 1 Dose response curve for γ -rays. The solid line represents the fitted dose-response curve obtain using CABAS software. The observed frequencies of dicentrics per cell are represented by •. The 95% confidence intervals are represented by dotted lines.

Dose response curve using cytokinesis-blocked micronucleus assay –Study on Portuguese population

A.C. Antunes, V. Martins, O. Monteiro Gil

We continued the development of the work that will lead us to the implementation of a dose-response curve for the Portuguese population using the cytokinesis-blocked micronucleus (CBMN) assay. The establishment of another endpoint, in biological dosimetry is of utmost importance. Moreover, is the first time that this kind of study is done in Portugal, namely in ITN. The study will be undertaken in 16 healthy donors without smoking habits, being the subjects, from both genders, distributed in four groups from 20 to 60 years. For this work, the samples of peripheral blood were irradiated at LMRI with 0.25, 0.50, 0.75, 1.00, 2.00, 3.00 Gy air kerma, using a ^{60}Co source. Until now, a set of 105,000 binucleated cells were analyzed in terms of micronuclei frequency. Figure 1 shows a clear dose dependent increase and a larger intervariability between individuals at higher doses. Our future work will focus on the calculation of calibration curve parameters and its validation.

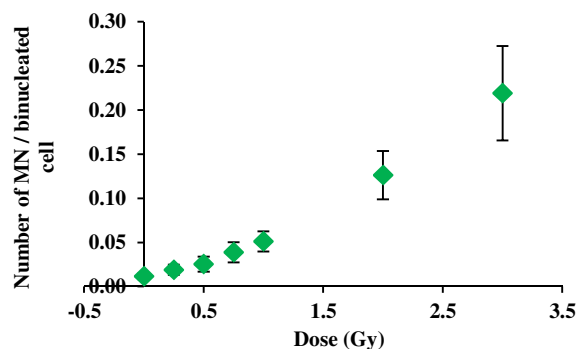


Fig. 1 Distribution of micronuclei per binucleated cell in function of dose, considering 15 donors (105,000 binucleated cells scored).

Implementation and optimization of γ -H2AX assay using peripheral blood human lymphocytes

O. Monteiro Gil, A.C. Antunes, V. Martins, A.S. Rodrigues¹

DNA double-strand breaks (DSB) are a high cytotoxic form of DNA damage and, if not correctly repaired, can initiate genomic instability, chromosome aberrations and may eventually lead to cancer. Exposure to ionizing radiation induces DSB that can be quantified by the detection of the phosphorylated form of H2AX histone in the vicinity of a DSB (green spot), being the number of foci proportional to the damage induced. γ -H2AX is a very important bioindicator for biodosimetry. For this reason, we are implementing γ -H2AX assay at ITN, with the help and knowledge of the Genetic Department of UNL. Our objective is to implement a dose-response curve.

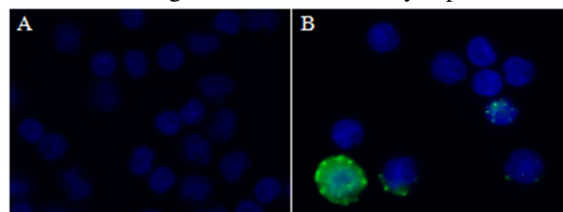


Fig. 1 Foci of γ -H2AX. (A) Cells with no radiation exposure, (B) Cells exposed *in vitro* to 2 Gy.

¹ Genetic Dep. UNL

Evaluation of the bystander effects induced by α radiation in an A549 cell line

A. Belchior, O. Monteiro Gil, P. Almeida¹, P. Vaz

The major adverse consequences of radiation exposures are attributed to DNA damage in irradiated cells that have not been correctly restored by metabolic repair processes. However, this has been challenged by observations in which effects of ionizing radiation arise in non-irradiated cells.

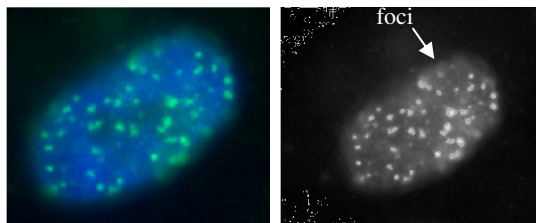


Fig. 1 Foci of γ -H2AX. This cell was exposed to 100 mGy of α -radiation.

The main purpose of our studies was to evaluate the induction of untargeted effects by low doses of α -radiation depending on time and dose values. Our results suggest that lesions induced in cells are dependent of dose value, since the damage significantly decreases with decreasing dose values. They also suggest a time-dependent bystander response, as the cellular damage decrease after 5 days after irradiation when compared with cellular damage induced 2 days after irradiation. The quantification of the spatial and temporal distribution of the bystander response is also paramount. The aim of this on-going work is to evaluate the

spatial distribution of the bystander signal in the cell monolayer, i.e., study how far the untargeted effects are induced in cells that are in the same culture but are not directly irradiated. These observations are relevant in terms of low dose exposition but also in terms of tumor delimitations for therapy. For this, we use the γ -H2AX technique, which allow us to study the cells exactly in the same place where they were irradiated.

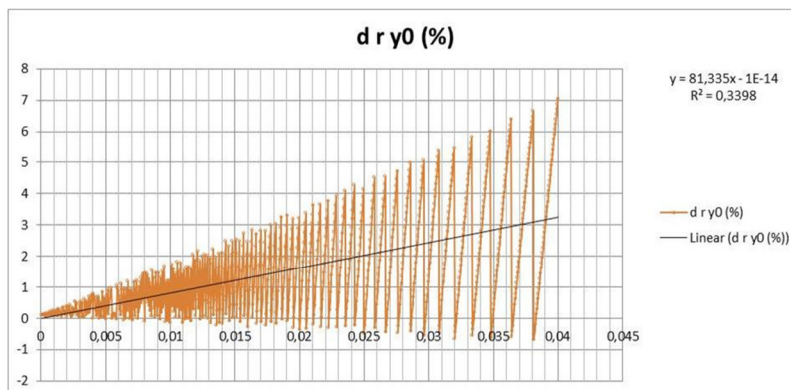
¹ IBEB-Fac. Ciências, UL

BioKinModels – A computational tool to solve bio-kinetic models. New version 3.0

A.D. Oliveira

Technical details of the numerical implementation of the well-known ICRP Human Respiratory Tract model are under development in the BioKinModels format.

Numerical research and algorithm development concerned with time step and uncertainty estimation are under developed in the new BioKinModels version 3.0. These studies led to the algorithm OTS/TS Optimization of Time Step value version 1.0.



Uncertainty assessment of a portable NaI based detection system for thyroid monitoring

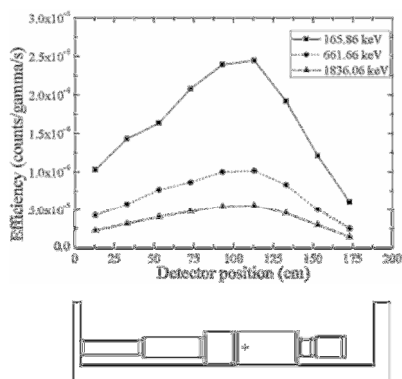
J. Bento, B. Martins^{1,2}, P. Teles, M. Neves, P. Colarinho¹, F. Alves³, N. Teixeira⁴, P. Vaz, M. Zankl⁵

Performance assessment and uncertainty evaluation were studied in a portable NaI based detection system. For the purpose, patients to whom ^{99m}Tc and ¹²³I marked radiopharmaceuticals were administered in the framework of Nuclear Medicine diagnostic procedures were monitored. The measured activities in the thyroid using the NaI detector were compared to the expected activities using the ICRP biokinetic models for radiopharmaceuticals. The state-of-the-art Monte Carlo program PENELOPE and two voxel phantoms (male and female) were used to evaluate the uncertainties influencing the thyroid monitoring. A computational parametric study was performed to quantify the influence of several parameters in the activity quantification (neck-detector distance, thyroid shape, thyroid size and overlying tissue thickness). The comparison between the measured and expected activities showed significant deviations (14% - 73%). The neck-detector distance proved to play an important role in measurement accuracy, since its 1 cm increase results in a 20% efficiency decrease. The comparison between the detector response using a physical phantom and the voxel phantoms reveals that the detection efficiency is lower for the voxel models: -25% for the male phantom and -7% for the female phantom. The variations in the thyroid volume and overlying tissue thickness evidenced an uncertainty of approximately 10% in the thyroid activity calculation.

¹ Hospital CUF Descobertas; ²Medical Consult, SA, Portugal; ³Escola Superior de Tecnologias da Saúde de Coimbra, Portugal; ⁴ Escola Superior de Tecnologias da Saúde de Lisboa, Portugal; ⁵Helmholtz Zentrum München, Germany

Monte Carlo simulation of the WBC detector movement and efficiency using a BOMAB phantom

J. Bento, S. Barros, P. Teles, M. Neves, I. Gonçalves, J.C., Pedro Vaz



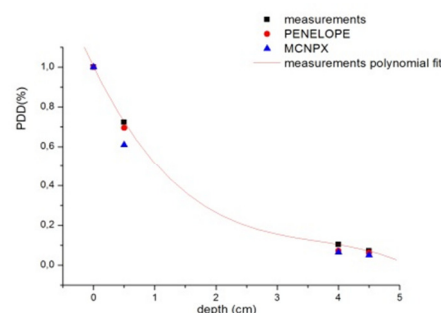
This work was performed as part of a new set of whole body counter (WBC) experimental calibrations using a BOMAB phantom, which improved the quality standards of this detection system. We performed a computational analysis of the WBC experimental calibration using two Monte Carlo simulation programmes: PENELOPE and MCNPX. Both the BOMAB phantom and the detection system were accurately implemented in the Monte Carlo codes. The WBC possesses a moving detector system, which poses a challenge for Monte Carlo simulations, as most codes only accept static configurations. The continuous detector movement was approximately described in the simulations by averaging several discrete positions of the detector throughout the movement. The computational efficiency values obtained with the two Monte Carlos codes have deviations of less than 3.2%, and the obtained deviations

between experimental and computational efficiencies are less than 5%.

TLD measurements and Monte Carlo simulations for glandular dose and scatter fraction assessment in mammography: a comparative study

S. Di Maria, S. Barros, J. Bento, P. Teles, C. Figueira, M. Pereira, P. Vaz, G. Paulo¹

The main purpose of this study was to validate and compare Mean Glandular Dose (MGD) values obtained using Monte Carlo simulations with experimental values obtained from Entrance Surface Dose (ESD) and depth dose measurements performed in a Portuguese hospital mammography unit. ESD and depth dose were measured using ThermoLuminescent Dosimeters (TLDs), and a tissue equivalent mammography phantom recommended by the American College of Radiology (ACR). The good agreement between measurements and simulations (Percent Depth Dose) is shown in the figure. One of the results of this study was the dose variation inside the breast that goes from 12% to 230% of the total MGD (1.17 mGy in this case).



¹Escola Superior de Tecnologia da Saúde de Coimbra

Extremity dose assessment in CT-Fluoroscopy, with measurements using a hand-phantom and Monte-Carlo simulations

P. Teles, F. Becker¹, S. Di Maria, C. Figueira, G. Paulo², J. Santos², P. Vaz



create voxelised geometries of the experimental set-up for use in Monte-Carlo simulations, a number of CT scans was performed. Furthermore, a Monte-Carlo model of the CT device was implemented, which was validated by making use of CTDI measurements which were compared to the simulated Monte-Carlo values. A renormalization method was used to obtain directly dose in CTDI using Xu's method. In the future, we intend to use this model to perform simulations with the voxelised geometries and compare these results with the measurements. We intend to perform a detailed evaluation of dose distribution in the hands, as well as in the eye-lens, using this model.

¹KIT – Germany; ²Escola Superior da Tecnologia da Saúde de Coimbra

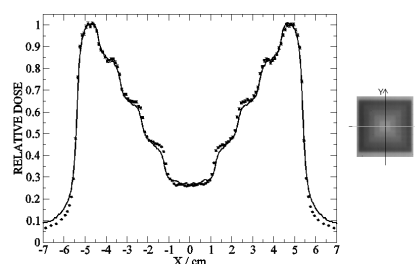
Monte Carlo modeling and simulations of the High Definition (HD120) micro MLC and validation against measurements for a 6 MV beam

C. Borges^{1, 2, 3}, N. Teixeira^{2, 4}, P. Vaz

The BEAMnrc[®] code was used to simulate the brand new micro multileaf collimator (HD120MLC) mounted on a Varian[®] Trilogy[®] linac, by developing a new component module (CM) named HDMLC CM.

Validations of the implementation were performed using ionometric (lateral and depth doses profiles) and photographic dosimetry (in a solid water phantom) of several open and irregular fields shaped by the MLC. Both the static and dynamic modes were implemented and validated.

The results were accepted and are to be published in Med Phys 39 (1) 2012, AIP ID: 048201MPH.



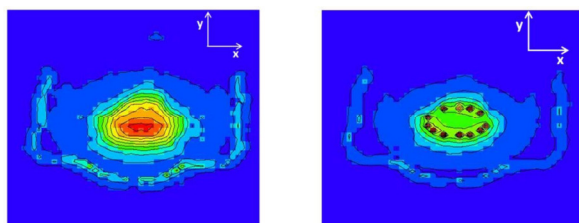
Dynamic MLC field of an inverse pyramid pattern: the continuous line corresponds to the film measurement; the full dots represent the Monte Carlo simulation results. The results were normalized to the maximum dose.

¹Medicalconsult, SA; ²Fac. of Medical Sciences, UNL; ³UPSR; ⁴Escola Superior de Tecnologia da Saúde de Lisboa

A dosimetric study of prostate brachytherapy using Monte-Carlo simulations, measurements, and a comparison with a treatment planning procedure

S. Barros, P. Teles, S. Cardoso¹, A. Faccure², L. da Rosa³, M. Santos³, P.P. Pereira Jr⁴, P. Vaz, M. Zankl⁵

In order to study the uncertainties in the dose distribution delivered to the prostate in brachytherapy treatments,



different Monte-Carlo simulations were performed in the generic GOLEM voxel phantom. We have used a detailed computational model of the *Amersham 6711* ¹²⁵I seed, with the dosimetric parameters of which were previously determined under the guidelines of the AAPM TG 64. A careful analysis of the volume variation of the prostate, which swells after the seeds are inserted, the influence of using different seed

arrangements, and the influence of interested effects, as well as of seed inter-spacing, since the seeds can migrate inside the prostate, was performed. Also, dosimetric measurements with the *Amersham 6711* source, using TLDs and a RW3 tissue equivalent phantom were performed and simulated, and the results compared. This was undertaken to increase the reliability of the Monte-Carlo simulations with a voxel phantom. Finally, we have also simulated a real treatment planning procedure with the GOLEM phantom. Variations of these parameters can lead to up to 30% changes in the total dose delivered to the prostate. Moreover, when compared to a real treatment planning dose estimation, our results are in between 14%-37% lower than those obtained with the real treatment planning.

¹Univ. Federal do Rio de Janeiro, Brasil, ²Comissão Nacional de Energia Nuclear, Brasil, ³Inst. de Radioproteção e Dosimetria, Brasil, ⁴Dosimetrika, Brasil, ⁵Helmholtz Zentrum, München – German Research Center for Environmental Health

EURADOS Working Group 2: Harmonization of individual monitoring in Europe

J.G. Alves, P. Ambrosi¹, D. Bartlett², C. Cherestes³, M.A. Chevalier⁴, J.W. van Dijk⁵, E. Fantuzzi⁶, M. Figel⁷, P. Gilvin⁸, T. Grimbergen⁹, E. Carinou¹⁰, M. Lehtinen¹¹, A. McWhan¹², B. Obryk¹³, A. Romero¹⁴, F. Rossi¹⁵, H. Stadtmann¹⁶, B. Vekic¹⁷

The motivation of WG02 is to foster Harmonization of Individual Monitoring in Europe. Three main tasks are identified: the organization of regular self-sustained intercomparison (IC) exercises, the identification of problems and issues for the improvement of measurements, dose reporting and record keeping, and the dissemination of the activities.

The organization of regular IC exercises provide to individual monitoring services a method to show compliance with the ISO/IEC 17025 requirements, as accreditation in conformity to this standard is gradually becoming important in Europe. Two IC exercises are presently being prepared: IC2012ph and IC2012n, respectively, for whole body dosimeters for photon fields and for neutron dosimeters in mixed fields.

Under the improvement of measurements, dose reporting and record keeping, several issues requiring discussion and a harmonized approach were identified. A questionnaire is currently being prepared for distribution within the WG02 extended network.

The dissemination of WG02 activity is being addressed in several ways: presentations at workshops and conferences as well as the organization of a Training Course (TC). A TC on the implementation of RP 160 *European technical recommendations on for monitoring individuals occupationally exposed to external radiation* and from the lessons learned from IC exercises is currently being prepared and will probably take place next autumn, in Krakow (Poland).

¹ PTB, Germany; ² formerly HPA, UK; ³ Dozimed, Romania; ⁴ IRSN, France; ⁵ formerly NRG, Netherlands; ⁶ ENEA, Italy; ⁷ Helmholtz-Zentrum, Germany; ⁸ HPA, UK; ⁹ NRG, Netherlands; ¹⁰ GAEC, Greece; ¹¹ STUK, Finland; ¹² Babcock International, UK; ¹³ IFJ, Poland; ¹⁴ CIEMAT, Spain; ¹⁵ AOUC, Italy; ¹⁶ Seibersdorf Lab., Austria; ¹⁷ RBI, Croatia.

Medical staff and patient dose assessment studies

J.G. Alves, M.F. Pereira¹, A.D. Oliveira, J.V. Cardoso, L.M. Santos, A. Pascoal², S. Tecelão³, J. Vaz³, I. Arêde³, J.M. Santos⁴, S. Sarmento⁴

The main objective of this line of activity is to carry out occupational and patient dose assessment studies in specific medical applications. ITN is partner in two research projects funded by *Fundação para a Ciência e a Tecnologia* (FCT) prepared under the framework of collaborations with *Universidade Católica Portuguesa* (PTDC/SAU-BEB/100745/2008 for mammography) and *Instituto Português de Oncologia do Porto* (PTDC/SAU-ENB/115792/2009 for fluoro-CT guided interventional procedures). A third collaboration with *Universidade Atlântica* for interventional procedures in angiography is also under way.

In the case of interventional procedures in angiography and in fluoro-CT guided procedures for lung biopsy collection, the team at the surgery room is likely to be exposed to higher dose levels, particularly to the hands, and the upper and lower limbs. The dose assessment methodology is based on the measurements of several dosimeter types. Ten whole-body dosimeters were distributed over the radiologist's body and a special glove was designed to hold 11 extremity dosimeters inserted in casings. Per-procedure dose distributions were obtained using this method and the first results (on fluoro-CT) were published. The work is still in progress and is considered of interest for the EURADOS Working Group 12 on European Medical Alara Network.

¹ ITN Grant holder and Ph.D. student; ² Univ. Católica Portuguesa, Fac. Engenharia; ³ Univ. Atlântica; ⁴ Inst. Português de Oncologia do Porto, Grupo de Física Médica.

Optimization studies of the ISOLDE targets, at CERN

R. Luís, J. Marques, T. Stora¹, P. Vaz

The ISOLDE facility is one of the most important radioactive ion beam facilities worldwide. In its present configuration, a 1.4 GeV pulsed proton beam hits a tungsten spallation target, generating intense neutron fluxes that induce fission in a UCx target. The objective of this work is to propose an optimized target configuration which optimizes the production of neutron-rich isotopes, while reducing the contamination by proton-rich isobars. After several design iterations, a completely revised target configuration is now proposed, with the UCx target surrounding a thicker converter. Simulations with FLUKA and the cross section codes ABRABLA and TALYS clearly indicate that the new configuration will produce higher yields of neutron-rich isotopes while reducing the yields in the proton-rich side of the nuclear landscape. A prototype target system based on the new design will be built and operated at CERN during 2012, to test if the predicted improvements can be verified experimentally.

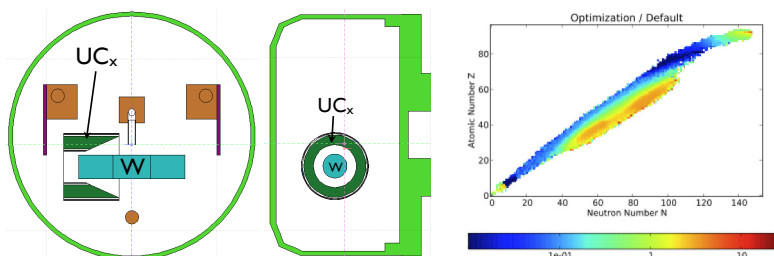


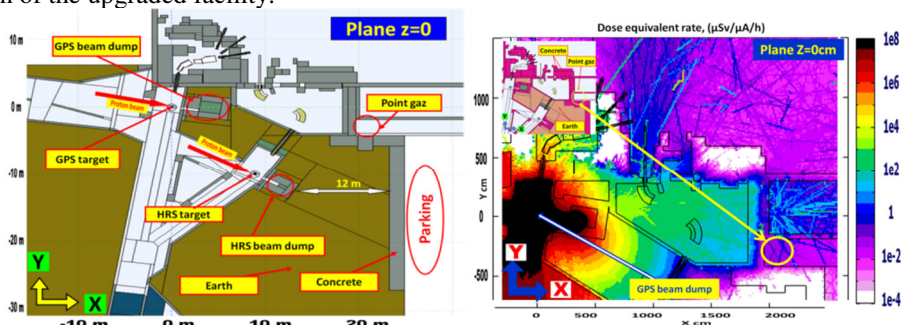
Fig (Left) Optimized targets configuration. (Right) Ratio optimized/default yields for all nuclides.

¹ CERN-ISOLDE

Radiation Protection, Dosimetry and Shielding studies for the HIE-ISOLDE facility at CERN

Y. Romanets, A.P. Bernardes¹, A. Dorsival¹, I. Gonçalves, Y. Kadi¹, P. Vaz, V. Vlachoudis¹, J. Vollaïre¹

The High Intensity and Energy ISOLDE (HIE-ISOLDE) project is an upgrade of the existing ISOLDE facility at CERN. The currently existing ISOLDE facility uses the proton beam with an energy of 1.4 GeV and an intensity currently limited to 2 μ A. After upgrade (final stage) the HIE-ISOLDE facility is supposed to run at energy up to 2 GeV and intensity up to 4 μ A. The foreseen upgrade imposes constraints, from the radiation protection and the radiation safety point of view and requires validation of existing geometry and shielding of the facility. The state-of-the-art Monte Carlo particle transport simulation program FLUKA are used to perform the computation of the dose rate distribution (shown in the Figure) and particle fluxes in order to assess the radiation safety and radioprotection of the upgraded facility.



¹ CERN-ISOLDE

Participation of ITN in the FREYA project

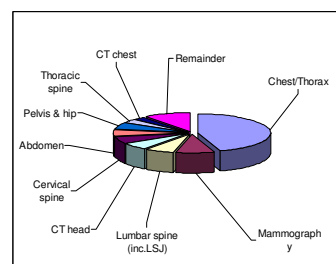
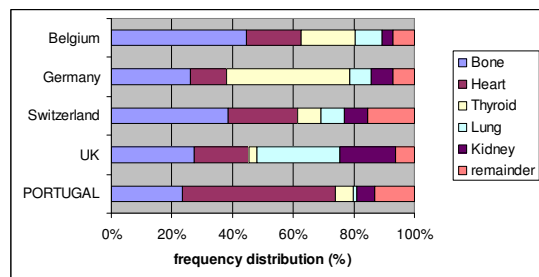
P. Vaz, S. Di Maria, P. Teles

The project FREYA (Fast Reactor Experiments for hYbrid Applications) is a four-year (2011-2015, started in March 2011) European Union co-financed Collaborative Project in the 7th Framework Program. Building up on the former activities accomplished in the previous FPs, namely Muse in FP5 and EUROTRANS in FP6, it is proposed in the FREYA project to extend the investigations of the subcritical configurations for validation of the on-line reactivity monitoring methodology in ADS systems. FREYA intends to investigate the configurations with $K_{eff} = 0.99, 0.95$ and the deep subcritical mode ($0.85 < K_{eff} < 0.95$). The contribution of ITN (task leader) will be on neutronic Monte Carlo simulations aiming to the optimization of the measurements (like detector sensitivity simulations, criticality and delayed neutron fraction calculations).

Project Dose Datamed 2 – Portugal - Assessment of the exposure of the Portuguese population to ionizing radiation due to medical practices

P. Teles, P. Vaz and Dose Datamed 2 – Portugal consortium¹

In the framework of the European Union sponsored Dose Datamed II project, we evaluated the exposure of the Portuguese population to ionizing radiation due to medical activities. We setup a multidisciplinary consortium, comprising representatives of research institutions, universities hospitals and other healthcare providers, administrative services of the National Healthcare System, professional associations, and outsourcing companies. We followed the guidelines provided by the RP 154 report. The estimated collective dose due to nuclear medicine (NM) exams is of 0.08 mSv/caput. Our data also show a high number of Cardiac exams (~50% of total) in NM performed in Portugal. The estimated collective dose for the TOP 20 exams (the 20 exams which contribute the most to the European collective dose) is of about 0.9 mSv/caput. There's a great prevalence of CT examinations, which account for 74% of the entire collective dose. The consortium intends to continue performing periodical evaluations of collective dose in the population due to medical practices.



which account for 74% of the entire collective dose. The consortium intends to continue performing periodical evaluations of collective dose in the population due to medical practices.

¹For further information about the members of this consortium please visit <http://www.itn.pt/projs/ddm2-portugal/>

Participation of ITN in the Central Design Team (CDT) for a Fast-Spectrum Transmutation Experimental Facility

S. Di Maria, P. Teles, P. Vaz

The project CDT is a European Union co-financed Collaborative Project in the 7th Framework Program EURATOM (Grant agreement n°: FP7-232527). An important issue regarding the MYRRHA/FASTEF nuclear reactor design is the in-vessel fuel storage facility, both for fresh and spent fuel. The model design and calculations were done with the state-of-art MCNPX Monte Carlo code. In particular a parametric study (see figure on the right) with the fuel assembly pitch on the multiplication factor (k_{eff}) was performed. The fuel assembly pitch was calculated in order to reach a k_{eff} value less than 0.95 for safety purposes. Moreover neutron flux, displacement per atom (*dpa*) and decay heat calculations were performed in order to fully characterize the four in-vessel fuel storage facilities.

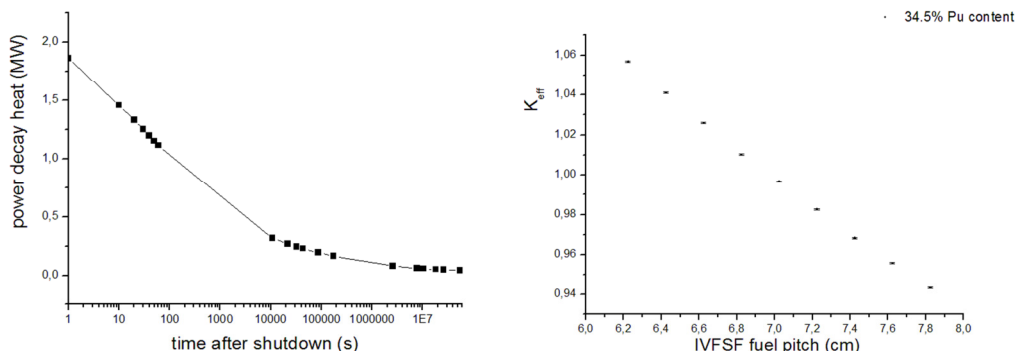


Fig. 1 **Left:** Power decay heat calculation performed for 68 Fuel Assemblies (33% Pu MOX fuel) with the ORIGEN program. **Right:** parametric study that shows the K_{eff} dependence by the IVFSF pitch (in the x-axis of the graph the half-pitch is shown).

ENETRAP-II: European Network for Education and Training in RAdiation Protection (Part-II)*P. Vaz*

The project ENETRAP-II (Grant agreement number 232620) is a Coordination Action of the European Union in the 7th Framework Programme, in the context of the development of the Euratom Fission Training Schemes (EFTS) in all areas of Nuclear Fission and Radiation Protection.

ENETRAP-II aims at the development and implementation of a high-quality European standard for initial education and continuous professional development for Radiation Protection Experts (RPEs) and Radiation Protection Officers (RPOs). The project aims at developing a methodology for mutual recognition and setting up “reference” training schemes as an instrument to facilitate this mutual recognition, within the relevant regulatory framework. ITN participates in the: Work Package 3 entitled “Define requirements for RPO competencies and establish European guidance for RPO training”, Work Package 4 entitled “Establish the reference standards for RPE training”, Work Package 5 entitled “Develop and apply mechanisms for the evaluation of training material, events and providers”, Work Package 8 entitled “Organise pilot sessions, test proposed methodologies and monitor the training scheme effectiveness”, Work Package 10 entitled “Collaboration for building new innovative generations of specialists in radiation protection”

TRaining Schemes on Nuclear SAFETy culture (TRANSNUSAFE)*P. Vaz*

Safety Culture is of paramount importance for the operation of nuclear and radiological installations. The objectives of the TRANUSAFE project, in the framework of the FP7-EURATOM are: i) to perform the assessment and to promote Safety Culture for the top managers of nuclear and radiological installations, such as nuclear power plants and nuclear installations, radiotherapy installations, facilities for the production of radioisotopes, among others and ii) study the mutual recognition and harmonization of good practices and behaviors associated to the development and effective implementation of the Safety Culture (Nuclear and Radiological). The study of the relationship between Safety Culture and the ALARA (As Low As Reasonably Achievable) principle deserves particular emphasis in the framework of TRANUSAFE.

The TRANUSAFE project team includes representatives from the European ALARA network and the EUTERP platform, from universities, research institutions, regulatory bodies, industrial companies and hospitals. ITN is responsible for organizing a “pilot session” on the Safety Culture in the medical installations.

During the reporting period, ITN participate in Reflection Groups addressing the aforementioned topics. A questionnaire was prepared by the consortium and submitted to managers in hospitals, industrial companies, regulatory bodies and several other “stakeholders” in the EU member countries, including Portugal.

Participation of ITN in the n-TOF-Ph2 experiment (PS213) at CERN*I.F. Gonçalves¹, P. Vaz, C. Cruz¹, J. Neves¹, C. Carrapiço², R. Sarmiento², L. Ferreira¹, L. Távora³*

An experimental programme is being carried out since 2001 by the n-TOF Collaboration (a consortium of 40 laboratories in Europe, U.S.A. and Japan) 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/cm²/pulse is available for cross section measurements in the detectors station located 185 m downstream the target area.

These cross-sections measurements are required in many applications such as the design of innovative Accelerator Driven Systems (ADS) for incineration of nuclear waste and energy production, radioisotope production for medical and industrial applications and 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. During 2010, the ITN team members in cooperation with researchers from CEA/Saclay and INFN/Bari, participated in: the analysis of the ²³³U neutron capture data sets, the analysis of the ²³⁶U neutron induced fission data sets, the data taking campaigns at CERN, the data analysis work is part of two on-going Ph.D. thesis. The ITN participation was undertaken in the framework of a project funded by the Portuguese Foundation for the Science and Technology (FCT).

¹ IST / Physics Dep.; ² FCT Ph.D. student; ³ C. de Instrumentação / U. Coimbra

Services

Risk and Safety Assessment

A.D. Oliveira, T. Antunes, A. Baptista, Y. Romanets, P. Vaz

The “Document for the Safety Culture” (DCS), introduced in 2009 became a routine document used in the radiation safety assessment activities performed by ITN. Safety assessment of the cargo scanners of the Ports/marine harbors in Mozambique and Cape Verde were performed by ITN and led to the development of the DCS for non-medical applications. The DCS is a document jointly established by ITN and the responsables of the radiological facilities, based in IAEA recommendations, European Directives and Portuguese legislation. Next it is shown a list of the radiation safety assessments concluded in 2011:

Facility	Type
IPOPFG	7 LINACs (external radiotherapy)
Centro Hospitalar Barreiro Montijo	1 LINAC (external radiotherapy)
Fundação Champalimaud	1 LINAC (external radiotherapy)
Dr. Júlio Teixeira / Hospital de Braga	1 LINAC (external radiotherapy)
Instituto CUF / Dr. Júlio Teixeira	1 Brachytherapy HDR
IPOIFG	1 Brachytherapy HDR
IPOPFG	1 Brachytherapy PDR
IPOPFG	1 Brachytherapy HDR
Hospital da Luz	1 Nuclear medicine
Hospital dos Lusíadas	1 Nuclear medicine
Kudumba Investments, Mozambique	5 cargo-scanners: marine harbors of Maputo, Beira and Nacala; railway in Matola and border with South Africa in Ressano Garcia
ENAPOR, Cape Verde	3 cargo-scanners: marine harbor of Praia, Mindelo and Palmeiras.
Sines	1 cargo-scanner, marine harbor

These services provided an income of more than 300 000 euros, corresponding to an average of 2 evaluations per month and a total of 46 reports, i.e. approximately 4 reports per month.

Individual and Environmental monitoring performed by ITN’s individual monitoring service

J.G. Alves, M.F. Pereira¹, S. Rangel, M. Saraiva

The Individual Monitoring Service (IMS) for external exposure at ITN is based on a TLD system that consists of two 6600 Harshaw readers and on the whole body dosimeter Harshaw 8814 TL card and holder containing two LiF:Mg,Ti (TLD-100) elements for the evaluation of $H_p(10)$ and $H_p(0.07)$. In 2011, approximately 2,850 workers were monitored, 2,650 on a monthly basis and 200 workers on a quarterly basis.

Following the Fukushima nuclear power accident in Japan and upon the request of the Ministry for Foreign Affairs, ITN provided whole body dosimeters to the diplomatic staff at the Portuguese Embassy in Tokyo. Three measurement periods of two month duration each were performed and results showed that staff was not exposed to external gamma radiation.

Environmental monitoring for the assessment of the ambient dose equivalent $H^*(10)$ is performed at four sites at ITN *campus* and at nine sites spread over the country on a quarterly basis. The results are used to compute the annual average dose equivalent rates for the monitored sites and are published in the National Radiological Environmental Monitoring programme annual report.

Following ITN’s application to IPAC-*Instituto Português de Acreditação* for the accreditation of its laboratories according to the EN ISO/IEC 17025 standard, the quality system was improved and the accreditation audit is due to take place in January 2012.

¹ ITN Grant holder and Ph.D. student.

Radioprotection and Radioactive Waste

Romão Trindade

The Radioprotection and Radioactive Waste Group (GRRR) has pursued its involvement in KADRWASTE (FCT), ACS PET (FP7) PETRUS II (FP7), JRP06 Increasing cancer treatment efficacy using 3D brachytherapy (EURAMET) and Ionizing Radiation Metrology for Metallurgical Industry (EMRP) research projects.

Members of the Group were continuing to be involved in several national and international committees, working groups and task forces related to radwaste management, transport of radioactive materials, radiological protection and monitoring, surveillance of contaminated scrap metal and radiological emergencies.

During 2011 and considering ITN's legal obligations, **135** requests for collecting and storing radioactive waste, from medical, industrial and research applications, were received and processed. To do these activities, GRRR has only one person, despite the efforts done in order to have the necessary personnel.

Also related to legal obligations, the Group has issued **532** licensing for medical, industrial, teaching and research applications. This year, **458** gamma spectrometric analyses for research, radiological protection and monitoring purposes were carried out at the Radioactive Samples Measurement Laboratory (LMAA/GRRR).

Despite financial and personnel restrictions, ITN's Treatment Station, the ECoDELi,R, used to monitoring radioactive liquid effluents discharges into the Borough treatment station, still pursues introduction of BAT at various levels, in order to increase a greater compliance with Artº 35º of Euratom Treaty recommendations.

The *Campus* environmental gamma radiation dose continued to be assessed through the gamma monitoring network, GAMMANET, and the data reported in compliance of Artº 35 of Euratom Treaty. Detection of radioactive materials in scrap metal is still continued and this year, **16** events requested GRRR intervention.

Radiological surveillance was carried out by GRRR during the stay of **4** military nuclear vessels in the Lisbon Harbour.

This year, **41** radiological verifications and monitoring of radiological facilities and equipment were also performed.

The Monitoring Programmes of the radioactive liquid discharges from public and private nuclear medicine facilities into the public sewage of Lisbon as well as the monitoring of the four ETAR'S (Lisbon City waste water treatment facilities), was as continued in 2011, in collaboration with Lisboa Council Borough. Concerning Education & Training, a Ph.D. degree in the field of radioactive waste management in collaboration with Sciences Faculty of Lisbon (Dpt. Geology) is in its writing phase. One M.Sc. in research on trends in radioactive discharges from Nuclear Medicine establishments with Escola Superior de Tecnologias da Saúde de Lisboa, is also in its writing phase.

Members of the GRRR have participated in a total of 17 different E&T actions, as lecturers and invited professors in **4** Advanced and Post-Graduation Studies (Masters, and Graduation Seminars) at IST, FCUL, FCM/UNL and ESTSL in the field of radiological protection, radioactive waste management, transport of radioactive materials and radiological emergencies. They have also participated in **13** training courses for professional (graduate and specialised workers) on radiological protection and safety, through the Training Centre and upon external and internal request.

Members of GRRR were involved on the process of obtaining the accreditation for the gamma spectrometry using NaI(Tl) detectors technique (the request for granting is expected to be made in 2012), as internal auditors and members of the groups involved in the Quality Management System of UPSR.

*New GRRR Coordination starting 18th July: Isabel Paiva and Luis Portugal

Research Team

Researchers

R. TRINDADE, Aux., Group Leader,
(until 30th June)
M.I. PAIVA, Aux., Group Leader,
(Starting 18th July)

Technical Graduate

L.M. PORTUGAL, Group Leader,
(Starting 18th July)
P. PEREIRA (Starting 5th December)

Technician

J. VENÂNCIO

Student

A. BAPTISTA

KADRWASTE – Study of the Adsorption Mechanisms and Kinetics in Geomaterials and Their Structural Characterisation: Implications for Processes of Natural Attenuation of Heavy Metal Contamination and Radioactive Wastes Confinement

M. Abel¹, A. Mateus¹, I. Bobos², I. Paiva, R. Trindade, P. Duarte, M. Reis, M. F. Araújo, M. J. Madruga, J. Mirão³ et al.

The project KADRWaste (PTDC/CTE-GEX/82678/2006) has pursued in 2011 with the continuation of its tasks, the presentation of communications in national and international conferences and the submission and publication of papers. It finished in July 2011 and the Final Report was sent to FCT, September 2011. A memorandum related to the technical, scientific public and political implications of the KADRWaste and its further developments was sent to the Minister of Education and Science.

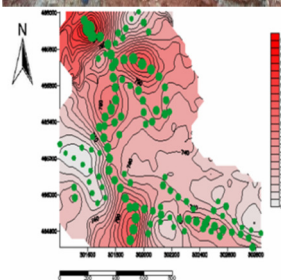
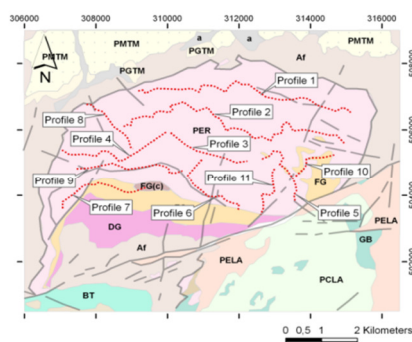
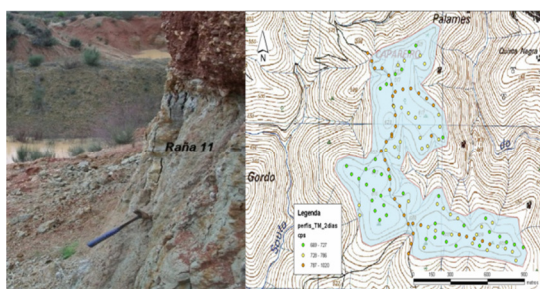
This project, Coordinated by Department of Geology of FCUL, has also, as members, Nuclear and Technological Institute (ITN), Department of Geoscience, Environment and Territorial Planning of FCUP, Department of Geosciences of UÉvora and the University of Bath (UK) as Consulting partner in the modelling tasks.

Three progress reports and the final report were delivered. From the 9 projected papers in international reviews, 3 have been published, 2 have been accepted for publication; 2 have been submitted, 2 are undergoing revision and 2 other papers are being finalized to be submitted in the first quarter of 2012. However, more experimental results are still in data treatment process. In terms of education and training, 3 Master Theses (ITN/FCUL; ITN/FCUP and ITN/U Aveiro) and 2 Post-Graduation Thesis (ITN/FCUL) were finished. One Ph.D. Thesis (FCUP) was concluded and another Ph.D. Thesis (ITN/FCUL) is still in preparation. The overall results of KADRWaste have open-up many collaborations, not only within the ITN (UPSR/UCQR/URSN) but also between ITN and the universities: FCUL, FCUP, U. Évora, U. Aveiro and U. Bath (UK).

KADRWaste was the first project to have in mind a scientific approach in order to reach a resolution for the disposal of radioactive wastes produced in Portugal. Besides the scientific results obtained in different areas, the main achievement was the establishment of a specific methodology for the characterization of a surface or near-surface repository adequate to the Portuguese situation.

The proposed methodology takes into account similar structures in other Countries, IAEA international recommendations and the implementation of the EURATOM Directives related to the safe management of radioactive wastes.

¹(FFC/Geology/Creminer/FC/UL); ²(ADFC/Geology/FC/UP); ³(U. Évora)



Published work

P. Duarte, A. Mateus, I. Paiva, R. Trindade, P. Santos: *Usefulness of systematic in situ gamma-ray surveys in the radiometric characterization of natural systems with poorly-contrasting geological features (examples from NE of Portugal)*, J. Applied Radiation and Isotopes, 69, 463-474, 2011.

ACSEPT-Actinide reCycling by SEparation and Transmutation (7th Programme EURATOM- FP7-Fission 2007)

I. Paiva, J. Marçalo, C. Lourenço, R. Trindade, P. Vaz

ITN has delivered two ACSEPT's progress reports (HYBAR's) in Domain 1, WP1.2, M 1.2.2, M1.2.4, D1.2.1. Experiments continued to be carried out at ITN/UCQR by the Inorganic and Organometallic Chemistry Group. Studies were performed by ESI-QIT/MS to probe the relative affinity of several N- and O-donor bases, building blocks of representative ACSEPT ligands (BTBPs, malonamides), towards several LnX_2^+ ions ($\text{X} = \text{NO}_3, \text{Cl}$).. The ACSEPT grantee has been to Marcoule (CEA) working at ATALANTE Facility for 2 months, where she carried out ESI-QIT/MS experiments of the complexation of Am(III) with N-donor ligands and bases.

PETRUS II—Towards an European training market and professional qualification in Geological Disposal (Coordination and Support Action Project)

I. Paiva, P. Vaz, R. Trindade, et al.¹

PETRUS II has pursuing its activities in identifying existing EU training and education actions in radioactive waste management/geological disposal E&T and setting-up the recognition of European training programs on geological disposal based on the EFTS-FP7 (European Fission Training Schemes). A significant development from a pure training and mobility programme to one dedicated rather to structuring research training and researchers' career development across the EU, is the base of the new training scheme. Important issues are being dealt with such as address life-long learning and career development of experienced researchers in all areas of nuclear fission and radiation protection, touching upon both the public and the private sector. ITN has been supporting at the PETRUS II meetings the maximisation of transfer of higher level knowledge and technology with emphasis on multi-disciplinary and/or trans-national and inter-sectorial mobility to other partners, with nuclear industry, in transit to this energy option or in being trained and educated, independently of the future mix energy market. The public target has been clearly defined: research workers and industrial experts at least at post-graduate or equivalent level, i.e. from doctoral students to senior visiting scientists. Definition and testing of the different steps in the systematic approach to higher level training (e.g. analysis, design, development, implementation and evaluation) has been the core of the work of the last 24 months with an ultimate goal in mind: develop an *European passport for Continuous Professional Development*, which relies on the principles of modularity of courses and common qualification criteria, a common mutual recognition system, and the facilitation of teacher, student and worker mobility across the EU. This will only be possible by using the *European Credit system for Vocational Education and Training* (ECVET) that has already been launched by PETRUS II. PETRUS II will end up September, 14, 2012 and the final report will be delivered later on.

¹Partners: INPL, CU, TUC, MA, POSIVA, ANDRA, ARAO, RWRA, ITC, REESN, GRS, NDA

Characterization of Suitable Areas for a Long-Term Radioactive Waste Repository Facility in Portugal

P. Duarte¹, I. Paiva, A. Mateus², R. Trindade

The work in progress is the core of a Ph.D. thesis being carried out in a collaboration between ITN/UPSR/GRRR and Department of Geology/FCUL. Part of the experimental work was carried out within the KADRWaste as one of the project's objectives. Ph.D. Thesis is in elaboration process.

¹- In ITN until December 2009' ²- Dep. Geologia, FCUL.

Services

1. Radioactive waste management

During 2011, **135** requests for radioactive waste collection were received, collected, segregated, and transported for the interim storage facility “Pavilhão de Armazenamento Interino de Resíduos Radioactivos”, (PAIRR) at ITN *Campus*. Concerning radwaste, continues to be very important and urgent to define and to establish a national plan related to radioactive wastes produced in Portugal. In the last years only one technician is working at PAIRR, which is not enough to carry out all duties

2. Sealed sources licensing

According Decree-Law nº 38/2007 and Decree-Law nº 165/2002, **532** sealed sources licensing were issued: national territory introduction licences (**133**), transfer licences (**90**), transport licences (**129**) and ownership licences (**180**). Only one person is related with this activity. It was developed a data base for radioactive sealed sources

3. Gamma Monitoring Network (GAMMANET) of Instituto Tecnológico e Nuclear (ITN)

The environmental dose gamma radiation at ITN *Campus* is continuously being measured by the gamma network, GAMMANET. The data are collected, analysed and reported to the EU, according to articles 35º and 36º of the Euratom Treaty and also to the National Report “Programas de Monitorização Radiológica Ambiental”.

4. Radioactive Liquid Discharges from Hospitals in Public Sewage of Lisboa Borough Council (CML)

Radioactive liquid discharges from public and private nuclear medicine facilities in Lisbon public sewage as well as residual effluents from Lisboa’s four Water Treatment Plants (ETARs) have been monitored in 2011. The Project was divided in 3 different programmes related to the sites where the samples were collected. Programme I involved sequential collection of discrete samples in sampling points from nuclear medicine facilities. In Programme II, discrete samples were taken at one single discharge point of each Lisboa’s ETARs. The Programme III has involved the affluent to ETAR’s and their effluents. Sampling was carried out in order to identify the radionuclides present and their activities. About 155 samples of liquid effluents were collected and analysed by quantitative and qualitative gamma spectrometry.

5. Radioactive liquid discharges from Instituto Tecnológico e Nuclear (ITN)

Radioactive liquid wastes originated at ITN are analysed and measured at “Estação de Controlo das Descargas dos Efluentes Líquidos Radioactivos” (ECoDELiR) before being discharged into Estação de Águas Residuais (ETAR). The data are reported to the EU according Articles 35º and 36º of Euratom Treaty and to the Radioactive Substances Committee of OSPAR Convention and also to the National Report “Programas de Monitorização Radiológica Ambiental”. In 2011 the work to improve ECoDELiR was pursued

6. Radioactive liquid discharges from Instituto Português de Oncologia (IPO), Coimbra

In 2011 and as requested by IPO-CROC, EPE, Coimbra, the radiological survey of radioactive liquid effluents from the IPO’s Medicine Nuclear Retention Tanks, was carried out by the Group before discharge into the public sewage.

7. Nuclear vessels radiological monitoring

Environmental radioactivity survey programmes consisting on continuous monitoring of radioactive aerosols and airborne radioiodine, sampling of water, sediments and biological species for gamma spectrometry analysis were carried out when nuclear vessels reach the Portuguese harbours. This year, **4** nuclear vessels stayed at Portinho da Costa harbour and estuary of Rio Tejo. The reports were sent to Ministry of Defence.

8. Radioactivity in scrap metal

In 2011, and as result of radiological surveys requested by the smelting industry, **16** events related to the detection of radioactive materials in scrap metal at smelting factories have been reported. The material collected has been stored at Pavilhão de Armazenamento Interino de Resíduos Radioactivos, (PAIRR) as radioactive waste. Reports were sent to the smelting company.

9. Radiological protection and safety verifications and monitoring

During 2011, GRRR has carry out **458** gamma spectrometry analysis and **41** verifications and monitoring concerning radiological protection and safety at medical and industrial facilities. The technique of gamma spectrometry using NaI(Tl) detectors has applied for the accreditation under the ISO/IEC 17025. The audit will be due in 2012.