National Laboratory for Metrology of Ionizing Radiation (LNMRI)[1]

1. Introduction.

The Institute for Radiation Protection and Dosimetry (IRD) has its origin in a small dosimetry Laboratory set up in the late 60's created by the Nuclear Energy Commission (CNEN) at the Catholic University in Rio de Janeiro. In 1972, the laboratory was transferred to the newly created institute, in the borough of Barra da Tijuca, and became the calibration division. In 1976, it was joined to the IAEA/WHO Secondary Standard Dosimetry Laboratory Network. By then, activity measurements had started and the "laboratory" became the metrology department. In 1989, the department was designated as the National Laboratory for Metrology of Ionising Radiation (LNMRI) by the National Institute for Metrology, Standardisation and Industrial Quality (INMETRO), through a signed agreement between INMETRO and CNEN. Together with the laboratories at INMETRO (for quantities in the fields of electricity, mass, length, optics, acoustics, etc) and at the National Observatory (for time and frequency), the LNMRI makes up the National Metrology Laboratory (LNM) of Brazil, as defined by resolution 03/89 of the National Council of Metrology (CONMETRO).

The LNMRI has two divisions, Radiation Dosimetry and Radionuclide Metrology, working with clinical dosimetry, radiation protection, source preparation and standardisation, and natural matrices.

Accreditation procedure through ISO Guide 17025 by INMETRO is required, LNMRI has to set the example for the several calibration and testing laboratories which are seeking accreditation in the field of ionising radiation.

Quality control of secondary standards and calibration systems, at therapy level, consists of measurements with a reference source every two months, annual internal intercomparison of LNMRI's chambers, annual intercomparison with the chamber from the Sao Paulo regional laboratory.

LNMRI runs national intercomparison programes, individual monitoring services (11 services, which monitor around 80,000 workers) and environmental radioactivity laboratories (18 laboratories: 10 at research centres, 2 at universities, 2 at nuclear power plant, 2 at nuclear industry, 1 at uranium mine and 1 at state environmental agency). LNMRI has a staff of 32 persons, including secretary, administration clerks, and technical staff, many of them are engaged in M.Sc. and Ph.D.

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2. Laboratory facilities

LNMRI laboratory rooms and national standards are described below.

- Cs-137 and Co-60 Gamma irradiator (made at IRD);
- Am-241, Cs-137, Co-60, and Ra-226 Gamma irradiator (Buchler OB85);
- X-ray 160 kV generator tube (PANTAK);
- X-ray 420 kV generator tube (PANTAK);
- X-ray 300 kV generator tube (Siemens)
- Am-Be, Am-B, Am-Li, Am-F, and Cf-252 neutron sources;
- Two nuclear pure graphite piles for neutron thermalisation;
- Static manganese sulphate bath, with NaI(Tl) detector and associated electronics
- Two Precision Long Counter
- One Bonner Sphere Spectrometer
- Am-241 alpha source;
- C-14, Ci-36, Sr-90+Y-90, and Cs-137 Beta sources (Amersham, DKD);
- Two hospital Co-60 irradiators (AECL);
- Co-60 hospital irradiator (Picker);
- High precision analytical balances (Mattler and Sartorius);
- Radiochemical laboratory and metal coating system (Edwards);
- Coincidence system, pressurised coincidence system, Gamma spectrometry system (Ge), surface barrier detector;
- Well-type ionization chamber, Gamma spectrometry system (NaI);
- Radiochemical laboratory for low activity;

- Gamma spectrometry system (type GMX pure Ge) with Compton suppressor, Gamma spectrometry system, proportional counter.

- Therapy-Level X-ray and γ-ray standards

Quantity: Air Kerma								
Instrument	*Manufacturer*	*Model*	*Serial Number*	*Range/ Value*	*Uncertainty (68,3%CL)*	*Calibration Certificate*		
						Lab	*Ref. Date*	*Number*
Graphite Cylindrical Chamber[1]	OFZS	CC-01	**110**	662 keV [2]	± 0,42%	BIPM	16/11/95	47
Free-air Chamber[3]	Victoreen	480-5	**114**	(60 – 250) kV X-rays	N/A	N/A	N/A	N/A
Graphite Cylindrical Chamber	Nuclear Enterprises	NE-2561	**168**	(100-250) kV X-rays	± 0,25%	BIPM	16/11/95	46
				1250 keV	± 0,17%	BIPM	16/11/95	46
Plane Parallel Chamber	PTW	M23344	**089**	(10-50) kV X-rays	± (0,19-0,20)%	BIPM	15/09/93	63

(1) Primary Standard compared with the international primary standard of BIPM (1986 and 1995) which results were published by BIPM (Rapport BIPM-86/12 and Rapport BIPM-96/3)
(2) Considered as a Secondary Standard for this purpose
(3) Primary Standard used with a transfer standard

Quantity: Absorbed Dose to Water								
Instrument	*Manufacturer*	*Model*	*Serial Number*	*Range/ Value*	*Uncertainty (68,3%CL)*	*Calibration Certificate*		
						Lab	*Ref. Date*	*Number*
Graphite Cylindrical Chamber[2]	OFZS	CC-01	**110**	1250 keV	± 0,44%	BIPM	16/11/95	47
Graphite Cylindrical Chamber	Nuclear Enterprises	NE-2561	**168**	1250 keV	± 0,44%	BIPM	16/11/95	46

- Diagnostic-Level X-rays Standards

Quantity: Air Kerma								
Instrument	*Manufacturer*	*Model*	*Serial Number*	*Range/ Value*	*Uncertainty (95,45% CL)*	*Calibration Certificate*		
						Lab	*Ref. Date*	*Number*
Ionization Chamber	RADCAL Corporation	20X5-3	**20647**	(40-150) kV X-rays	± 1,4%	PTB	30/09/99	3877
Ionization Chamber	RADCAL Corporation	20X5-6M	**20700**	(20-50) kV X-rays	± 1,4%	PTB	30/09/99	3879
Ionization Chamber	RADCAL Corporation	20X5-180	**20788**	(40-150) kV X-rays	± 1,4%	PTB	30/09/99	3878

- Protection-Level Neutron Standards

Quantity: Neutron Emission Rate								
Standard	*Manufacturer*	*Model*	*Serial Number*	*Range/ Value* s^{-1}	*Uncertainty (N/A)*	*Calibration Certificate*		
						Lab	*Ref. Date*	*Number*
Am-Be Neutron Source	CEA/LMRI	SN-03	**066**	2.217×10^6	± 0,67%	BIPM	04/07/94	N/A

- Protection-Level X-ray and γ-ray Standards

Quantity – Air Kerma								
Instrument	*Manufacturer*	*Model*	*Serial Number*	*Range/ Value*	*Uncertainty (95,45% CL)*	*Calibration Certificate*		
						Lab	*Ref. Date*	*Number*
Parallel Plate Chamber	Nuclear Enterprises	NE 2575C	**507**	(10-300) kV X-rays (narrow)	± (1,5-2,2)%	PTB	30/09/99	3876
				(10-300) kV X-rays(wide)	± (1,5-2,2)%	PTB	30/09/99	N/A
				662 keV	± 1,7%	PTB	30/09/99	N/A
				1250 keV	± 1,7%	PTB	30/09/99	N/A
Spherical Chamber	PTW	M32002	**025**	(40-300) kV X-rays (narrow)	± 1,5%	PTB	30/09/99	3875
				(40-300) kV X-rays(wide)	± 1,5%	PTB	30/09/99	N/A
				662 keV	± 1,7%	PTB	30/09/99	3875
				1250 keV	± 1,7%	PTB	30/09/99	3875

3. Main routine activities, research, and development activities

Routine activities, research, and development activities are considered to be those of calibration of instruments and sources, including their preparation. The main projects are listed below. Further information on them can be obtained from LNMRI upon request.

- clinical dosemeters: Around 40 dosemeters/year (200 calibration points), for X-ray and Co-60 beams;

- survey meters: Around 1200 meters/year Cs-137 and Co-60 beams, around 70 meters/year for neutrons;

- Irradiation of TLDs and films: Around 1000/year, for quality control of personal dosimetry services;

- Irradiation of personal neutron dosemeter: Around 50/year, for quality control and calibration;

- Neutron sources: around 10/year, for quality control of calibration system;

- reference sources: They can be prepared as sealed sources on either Al, stainless steel or acrylic, as deposited on thin films, and as liquid sources, in volumes ranging from 2 to 2 000 cm^3. The larger demand is for sources of Na-22, Mn-54, Co-57, Co-60, Zn-65, Cs-137, Bi-207 and Am-241, and around 500 are prepared per year, half of them for internal quality control programmes.

- Study of the performance of survey meters in terms of the new quantities for radiation protection (Ramos M M O);

- Characterisation of neutron spectra (da Fonseca E S and Pereira W W);

- Optimisation of absorbed dose determination in neutron irradiated individuals (da Fonseca E S);

- Implementation of ISO neutron spectra at LNMRI/LN – Neutron Laboratory (da Fonseca E S and Pereira W W);

- Application of Monte Carlo computer codes to neutron metrology (da Fonseca E S and Pereira W W);

- Response of large volume ionization chambers to scattered photons from diagnostic X-ray beams (Peixoto J G);

- Absorbed dose to water determination (Rodrigues L N, da Silva C N M, and Peixoto J G);

- Secondary standard calibration in terms of absorbed dose for photons and electrons;

- Primary standardisation for Co-60 beams (Rodrigues L N);

- Primary standardisation for X-ray beams (Peixoto J G);

- Evaluation of long-term stability of secondary standard chambers used in clinical dosimetry (Rodrigues L N, da Silva C N M).

4. Technical activities abstracts

Individual monitoring: The LNMRI/IRD has given support and performed quality control tests in the services that provide individual monitoring of external radiation in the country, and promote intercomparisons and performance.

The Committee for evaluation of external individual monitoring services established a national policy for accreditation of individual monitoring services, where the role of the LNMRI/IRD is mainly to verify the compliance of any individual monitoring system to the minimum accuracy requirements for the photon dose equivalent evaluation, and has executed any specific type-test to verify the results stated by the service itself. In 1997 the Committee started the audit process within the accreditation program for 13 Brazilian services, these services have been evaluated in the "trumpet curves" following the rule for which 90 % for the points, at least, should be between the curves. The Quality Control Program for all accredited services was started in 1998, and it is maintained by the LNMRI/IRD a test program with the 11 authorized services, which are responsible for occupational dose monitoring of more than 80000 workers in Brazil.

CALCRI - Committee for Evaluation of Ionizing Radiation Calibration Laboratories: This Committee developed accrediting criteria based on ISO Guide 17025, and specific technical requirements that have to be obeyed by laboratories pursuing accreditation. The ever increasing need for calibration of personal, survey, and contamination monitors in Brazil were not completely satisfied by the two operating laboratories, LNMRI/IRD and IPEN. To overcome this deficiency a Radiation Metrology Network has been implemented with the support of the International Atomic Energy Agency - IAEA. This Network counts now with four calibration laboratories (LNMRI/IRD, IPEN, CDTN, DEN), and other three are being installed (IEN, CRCN, LCR/UERJ) in different regions of the country.

The LNMRI/IRD coordinated two IAEA cooperation projects, that provided each new laboratory with standard measuring instruments (ionization chambers), electrometers, temperature and pressure measuring apparatus, and large area calibrated sources.

To strengthen the traceability of the laboratory's standards, a Radiation Protection Laboratory Comparison has been annually performed at LNMRI/IRD since 1996. The results for Cobalt-60 and Cesium-137 energies agree well between ± 2%, when compared to LNMRI/IRD standards.

1st National Workshop about Ionizing Radiation Metrology: In November 2000 LNMRI/IRD hosted a meeting with 8 calibration laboratories that participated in Radiation Metrology Network. This meeting that gathered 16 representatives, was planed to strengthen the Network, standardize procedures and the operation of laboratories, identifying regional needs and prioritizing resources. A list of each laboratory needs and intentions were discussed together with recommendations and conclusions. An agreed report was developed and distributed to the participants and to financing bodies within the country (MCT).

Present status of the manganese sulfate bath at the LNMRI: The Neutron Laboratory use to calibrate isotopic neutron sources the Primary Standard System Manganese Sulfate Bath, namely Manganese Sulfate Bath. The Manganese Sulfate Bath that was donated by BIPM to arrive in Brazil at LN in 1996. This system is composed by one stainless steel sphere with 1 m of diameter, to fill with concentrate manganese sulfate solution (~524 liters). In the calibration process the neutron source to be calibrated is deep in the sphere. The neutrons emitted by the neutron source are moderated in the solution and captured by the manganese atoms. After an immersion period of 25 hours, the neutron source is removed from the bath, and is replaced by a scintillation detector (NaI(Tl)), to measure the gamma rays from manganese atom decay activated by neutrons from the source. All these measurements, permit us to obtain the neutron source emission rate, with a total uncertainty of 1.4% within confidence level of 2σ.

Compared with other systems used to measure neutron source emission, this one shows better accuracy and uncertainty. Because this system has many important parameters used to calculate the neutron source emission rate, like: volume, solution density, electronic system dead time, counting rate, etc. those may be changed, affecting the value of MnSO4 solution saturation activity.

The radiation metrology network related to the field of mammography: Implementation and uncertainties analysis of calibration system: It is recognized by the international guidelines that there is a need to offer calibration for the mammography beam qualities by the radiation metrology network in order to improve the quality of the clinical diagnostic procedures. Major efforts have been made by

several laboratories to establish appropriate and traceable calibration infrastructure to provide the basis for a quality control program in mammography.

The contribution of the radiation metrology network to the users of mammography is reviewed in Peixoto and de Almeida (2001). Also, it is presented the steps required for the implementation of a calibration system for mammography using a constant potential x-ray and a clinical mammography x-ray machine. The different mammography radiation qualities discussed in this work are in accordance with the IEC 61674 and the AAPM recommendations. They are presently available at different Primary Standard Dosimetry Laboratory, namely PTB, NIST and BEV and few SSDL such as University of Wisconsin and the IAEA' SSDL. A discussion is conducted on the uncertainties involved in all steps of the calibration chain as contained in the ISO recommendations

Computed Tomography: A pilot programme has been carried out in the area of Rio de Janeiro with the participation of 11 CT facilities with 12 CT units. The background information follows EUR 16262 "European Guidelines of Quality Criteria for Computed Tomography". Initially practice data were collected through structured interviews using a standardized questionnaire; In regard to the assessment of clinical image quality, two examinations were selected: brain general and abdomen general. Three radiologists specialized in computed tomography evaluated the image quality criteria from a sample of examinations from the participant facilities. Considering technical parameters of the examinations; image physical parameters (noise, spatial resolution, sensitivity profile) and radiation dose. Radiation dose and image quality criteria were fulfilled by 7 of 12 brain general examinations analyzed and only 5 of 10 abdomen general examinations analyzed. Dose and image quality criteria shall be the basis of an accreditation programme in CT and Brazilian College of Radiology has to use the experience of this work to implement a programme at national level.

Activities developed by the Radiotherapy group at LNMRI-IRD: IAEA Postal comparisons of absorbed dose to water for ^{60}Co beam. Comparison of the radiotherapy secondary standards of the LNMRI and the Regional Laboratory of the IPEN/CNEN/SP, in terms of air kerma and absorbed dose to water, at x-rays and ^{60}Co beams. Supply of numerous calibrations in ^{60}Co and x-rays for hospitals, in terms of air Kerma, and at the same time studies for the implementation of the new formalism of absorbed dose to water and its dissemination among physicists hospitals. The Monte Carlo method was used to simulate brachytherapy sources (^{192}Ir, ^{125}I), to provide basic dosimetric data. These calculations had been carried out through the new Monte Carlo system EGSnrc.

Comparison of the data in the IAEA, IPEMB, DIN and NCS dosimetry protocols: A comparison of four of the most commonly used dosimetry protocols for the determination of absorbed dose to water in therapeutic kilovoltage x-rays using an ionization chamber (IAEA TRS-277, IPEMB,

DIN and NCS) has been carried out. Owing to the different energy ranges and HVLs recommended by each protocol, back-scatter factors, water to air mass energy absorption coefficient ratios, and perturbation correction factors, have been recasted to a common quality range that all protocols satisfy individually and make a comparison possible. The results of the comparison show that in the sometimes reduced quality range originally included by the different protocols, determinations of absorbed dose to water at all beam qualities agree within ± 1.0% with that obtained using the second edition of the IAEA TRS-277. The extrapolation of data to a common beam quality range practically preserves the agreement for all the protocols except for that issued by the NCS at the extremes of the range, where differences up to 1.8% and 1.4% have been found for low- and medium-energies respectively. The DIN protocol yields in all cases very good agreement with TRS-277.

Electrical Calibration of Electrometers: Calibration of electrometers cannot be done with conventional calibration systems since as the order of magnitude of currents and accumulated charges involved are to small. For this reason, we have developed and put into operation a standardized calibration system for electrometers covering the pA range. Our system employs two 1nF standard air capacitors (model 1404 GenRad), an ultra-high precision capacitance bridge (AH 2500), a multipurpose electrical calibration system (Fluke 5500), and a data acquisition system.

Identifying a corresponding need for the Latin America Region we have implemented an ARCAL (IAEA Regional Cooperation Project for Latin America). As a result, we have now in Latin America 3 Regional Calibration Centers (Brazil, Cuba and Mexico) and 8 National Centers with a capacity not only to calibrate low current/low charge measuring instruments but also to take care of their repair. In addition, within this project small portable current source and a stationary laboratory current/charge source were developed, assembled and distributed to the 11 participating countries. For assuring measurements consistence between these centers and for quality assurance measures periodical intercomparison runs are performed. Intercomparison runs with similar centers located outside the region are under preparation.

5. Publications by LNMRI staff during 1999 and 2000

Becker P H B and Peres M A L 2000 Sistema de aquisição de dados para a implantação de padronização primária para dosimetria com ^{60}Co *Encontro Nacional de Aplicações Nucleares* Rio de Janeiro - Brazil.

Becker P H B and Peres M A L 2000 Calibração de pequenas cargas e correntes elétricas, , *International Conference on Advanced Metrology in Chemistry and Laboratory Quality*, Proceedings of the II Brazilian Congress of Metrology, METROCHEM-2000, São Paulo, Brazil.

Becker P H B and Peres M A L 2000 Implantação de um laboratório para calibrar divisores de tensão utilizados em radiologia *International Conference on Advanced Metrology in Chemistry and Laboratory Quality*, Proceedings of the II Brazilian Congress of Metrology, METROCHEM-2000, São Paulo, Brazil.

Carlos M T, Peixoto J E, Koch H A 1999 Certificação da qualidade em tomografia computadorizada, *Acta Radiológica Paulista*, **4** 98-100.

da Fonseca E S and Pereira W W 2000 Calibração de dosímetros individuais de nêutrons utilizando o fluxo térmico padrão *International Conference on Advanced Metrology in Chemistry and Laboratory Quality*, Proceedings of the II Brazilian Congress of Metrology, METROCHEM-2000, São Paulo, Brazil.

da Fonseca E S and Pereira W W 2000 Calibração de monitores de nêutrons nas novas grandezas *International Conference on Advanced Metrology in Chemistry and Laboratory Quality*, Proceedings of the II Brazilian Congress of Metrology, METROCHEM-2000, São Paulo, Brazil.

da Fonseca E S and Pereira W W 2000 Determinação da incerteza total da atividade de saturação do banho de sulfato de manganês (MnSO4) *International Conference on Advanced Metrology in Chemistry and Laboratory Quality*, Proceedings of the II Brazilian Congress of Metrology, METROCHEM-2000, São Paulo, Brazil.

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da Silva C N M, Marechal M H H, da Fonseca E S and Pereira W W 2000 Simulação do espectro de fótons de sementes de iodo-125 no ar utilizando o método de monte Carlo, , *International Conference on Advanced Metrology,* Proceedings of the II Brazilian Congress of Metrology, São Paulo, Brazil.

de Araújo M M and Rodrigues L N 2000 Implementation of the quality system at LNMRI/IRD *International Conference on Advanced Metrology in Chemistry and Laboratory Quality*, Proceedings of the II Brazilian Congress of Metrology, METROCHEM-2000, São Paulo, Brazil, p.276-282.

de Araújo M M, Rodrigues L N and Knofel T M 2000 Development of the Quality System at National Metrology Laboratory for Ionizing Radiation in Brazil, *CD-ROM, abstracts of papers of the 2000 World Congress on Medical Physics* **TH-CXH-43**, Chicago, July.

de Oliveira L M, Rossi A M, Lopes R T and Rodrigues L N 2000 EPR dosimetry with synthetic A-type carbonated apatite *Rad. Prot. Dos*.(Submited)

Peixoto J E, Carlos M T, Rocha M S, Barbosa R G, and Koch H A 1999 Análise da qualidade da imagem em tomografia computadorizada, *Acta Radiológica Paulista,* **4**, 103-4.

Peixoto J G P and Andreo P 2000 Determination of absorbed dose to water in reference conditions for radiotherapy kilovoltages x-rays between 10 and 300 kV: a comparison of the data in the IAEA, IPEMB, DIN, and NCS dosimetry protocols *Phys. Med. Biol.* **45** 563 – 75.

Peixoto J G P and Andreo P 2000 Determinação da dose absorvida para a água em condições de referência para raios-x terapêuticos entre 10 e 300 kV: Comparação de dados dos protocolos de dosimetria IAEA, IPEMB, DIN e NCS.VIII CGEN – Rio de Janeiro.

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Peixoto J G P and de Almeida 2000 The radiation metrology network related to the field of mammography: Implementation and uncertainties analysis of the calibration system *Meas. Sc. and Tech* (submited).

Peres M A L 1999 Padronização da calibração de Eletrômetros Utilizando Cargas e Correntes Elétricas, Report MSc., Instituto Militar de Engenharia, Rio de Janeiro - Brazil.

Ramos M M O 1999 Teste de bateria de monitores de radiação portáteis – Eles são confiáveis?, *Congresso Geral de Energia Nuclear - VII CGEN*, Belo Horizonte, Brazil, agosto/1999.

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