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Technical Protocol for Calibration of Ambient Dose Equivalent (Rate) Meters in ISO Neutron Reference Fields

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1. Introduction

The Neutron Metrology Laboratory (LN), created in 1973, is one of the research laboratories of the National Ionizing Radiation Metrology Laboratory (LNMRI) of the Institute of Radioprotection and Dosimetry (IRD). LN is a reference laboratory in the area of neutron metrology, being responsible for the custody and maintenance of the Brazilian Neutron Fluency Standard, and for realizing the neutron fluence magnitude. In carrying out its institutional mission, it develops research in the areas of metrology and neutron dosimetry, also promoting the dissemination of operational quantities (ambient dose equivalent and individual dose equivalent) for neutron measuring instruments used by industries, research centers and universities nationally and internationally, ensuring their traceability.

In this context, LN is committed to regularly participating in key comparisons organized by BIPM in order to maintain its traceability, but also to promoting proficiency testing through interlaboratory comparisons with Secondary Standard Dosimetry Laboratories (SSDLs), in order to evaluate the participating laboratory's ability to calibrate area monitors to the ambient dose equivalent (H*(10)) quantity, ensuring the reliability of the results generated from in accordance with ABNT NBR ISO 8529 standards and following the ABNT NBR ISO/IEC 17043:2011 protocol.

In general, proficiency tests provides participants with: assessment of laboratory performance; evidence of obtaining reliable results; identification of problems related to the systematic testing; possibility of taking corrective and/or preventive actions; assessment of the efficiency of internal controls; determination of performance characteristics and validation of methods and technologies; standardization of activities in the market and recognition of test results, at national and international level.

Nuclear plants and the area of industry that works with resources based on neutron irradiation fields require monitoring of the ambient dose equivalent (rate) for neutrons, especially within the context of radiological protection. Challenges related to the broad spectrum of energy distribution of neutron fields still require a more careful interpretation when using this equipment, making their traceability in these different spectra essential for a correct reading.

The response or calibration factor of an instrument is a unique property of the instrument type, and may depend on the ambient dose equivalent ratio, the spectrum of the neutron source, or the angle of incidence of neutrons; but is not recommended to be a function of the characteristics of the calibration setup or the experimental techniques employed. Therefore, it is essential to ensure that the calibration is independent of the technique and factors such as the distance from the source to the device and the size of the calibration room [5].

2. Methodology

This proficiency test is aimed at laboratories that perform calibration of ambient dose equivalent (rate) meters in ISO neutron reference fields. Participants will be provided with the following documents:

1) Technical Protocol
2) Laboratory result evaluation report;
3) Final Report - General evaluation report on the performance of the laboratories (in the case of several participants).

2.1. Schedule of the transfer instruments circulation scheme

Two different LN/LNMRI transfer instruments will circulate among the participants. At the beginning of the proficiency test schedule, the reference value of the calibration factor (Nref) will be previously determined by LN/LNMRI. Before and after calibration measurements in each participating laboratory, the transfer instruments will be summited to stability tests in LN/LNMRI, using the same source and the same set up in order to guarantee the repeatability of the measurement conditions. After these checks, the meter will be sent to the next participant and so on until the instruments has been calibrated by all laboratories.
Each laboratory will have a period of one month for measurements at its facilities and one month for administrative procedures relating to the return of the instrument to LN/LNMRI.

2.2. Measurements

2.2.1 Quantity to be measured by the participants

Participants must determine the calibration factor of the transfer instruments in terms of ambient dose equivalent rate, at least for 3 (three) rates of the measuring range: 50 uSv/h, 500 uSv/h and 5000 uSv/h, to the spectrum chosen by the laboratory.
The calibration factor “N” is calculated through the ratio between the reference value of the quantity and the value read by the instrument, both values corrected for all applicable factors (anisotropy, geometric factor, attenuation in air, scattering, etc.). The calibration factor is equivalent to the inverse of the equipment response, when the response is determined under reference conditions. The calibration factor is the factor by which the meter reading is multiplied to obtain the actual measured value of the quantity.

2.2.2. LN infrastructure for proficiency testing

The LN/LNMRI is responsible for preparing the laboratories. The Low Scattering Laboratory (LBE) and the Thermal Flow Laboratory (LFT) can be used in the proficiency test.

The neutron fields (spectra) available for the proficiency test are specified below.

Table 1 – Moderated sources

Spectrum	Source strength	Moderator			
		Diameter(mm)	Height(mm)	Geometry	Thickness of Cd shell.
Cf252(D2O)	120.7 ug	300 cm	-	spherical	0.5 mm

Table 2 – “Bare” neutron sources

Spectrum	Source strength	Anisotropy		Source of traceability	Size (mm) Diameter x height	Geometry
		Factor	uA(%)			
Am241-Be9	185 GBq	1.0164	0.2	Secondary Standard (Long Counter)	35 x 35	cylindrical
Cf252	120.7 µg	1.0107	0.14	Primary Standard (BSM)	5,53 x 11.94	cylindrical
Pu238-Be9	1850 GBq	1.0351	0.10	Primary Standard (BSM)	57.7 x 10.7	cylindrical
Am241-B	3.7 GBq	-	-	Primary Standard (BSM)	17.4 x 19.4	cylindrical

Each laboratory must determine the calibration factor for the chosen spectra available in its facilities.

2.2.3. Traceability of the reference value

The neutron fields proposed in this document are included in the LNMRI Measurement and Calibration Capability (CMC) lines registered with the Bureau International des Poids et Mesures (BIPM), available at https://www.bipm.org/kcdb/cmc/quick-search.
The neutron source emission rate that will be used was determined by the primary standardization procedure, which is validated by key international comparisons. This ensures the traceability of reference values provided by LN/LNMRI standards.

2.2.4 Transfer instruments

The two different geometry meters chosen as the traveling standard in this proficiency test are the Ludlum Model 2363 and the Thermo Cientific FH40G-L / FHT 752, whose measurement records of the last stability survey will be presented to the participating laboratories.

2.3. Shipping and returning transfer instruments

On the date set out in the proficiency test schedule, LN/LNMRI will send to each participating laboratory (national or international) the transfer instrument mentioned in item 2.2.4.
After the calibration period, the equipment must be LN returned to /LNMRI. Deadlines must be strictly observed and recorded, so that the irradiation schedule and subsequent evaluation are met.
The costs of shipping and returning the transfer instruments are the sole responsibility of each participating laboratory (national or international).

3. Report from the participants

After the measurements are completed, the participating laboratory must prepare a report on the calibration procedure, presenting the results obtained and sent to LN/LNMRI within a maximum period of up to 3 months from the end of the measurements. The report must contain:
• Date and location of calibration.
• Description of the laboratory (size, position of the source in the room, reference point, …).
• Description of the neutron source(s) used: emission rate, anisotropy factor, traceability source, source size and geometry. In case of 252Cf(D2O) sources: source emission, moderator diameter, casing thickness, moderator design (if available), information on the H/D ratio in heavy water, thickness of the Cd layer.
• Details of reference conditions, calibration conditions and/or standard test conditions.
• Description of the calibration procedure and geometry.
• Method used to correct neutron scattering.
• Description of shadow cones, if used.
• Fluence conversion factor for ambient dose equivalent used with its uncertainties (hφ*(10))
• Calibration factor N in terms of H*(10);
• List of uncertainties considered. Uncertainties must be calculated according to the "Guide to Uncertainty in Measurement" (GUM) [7], for a coverage factor k=1.

4. Statistical evaluation of results

The limits and performance approval criteria for analyzing results follow that established in the ABNT NBR ISO/IEC 17043:2011 standard [4]. This standard establishes the normalized error as one of the possible evaluation metrics for a proficiency test, which is the quotient of the deviation between the measured value declared by the participant and the reference value and the combined standard uncertainty of these two values.
Normalizing the measured values to the LN/LNMRI reference value, we have that xi = Ni/Nref and xref = 1, where:
Ni calibration factor measured by participating laboratory
Nref calibration factor measured by LN/LNMRI

xi normalized value measured by the participating laboratory
xref normalized LN/LNMRI reference value (xref=1)
The deviation between the normalized value measured by the participating laboratory (xi) and the normalized LN/LNMRI reference value (xref) is defined by Equation 1 [6]:

$$D_i = x_i - x_{ref} = x_i - 1 \qquad (1)$$

Di = deviation of the normalized value measured by the participating laboratory in relation to the reference value.
Therefore, the normalized error can be written as follows:

$$E = \frac{D_i}{\sqrt{((u_{x_i})^2 + (u_{x_{ref}})^2)}} \qquad (2)$$

where,
uxi standard uncertainty of xi
uxref standard uncertainty of xref
Interpretation of E value:
The closer the "E" value gets to zero, the better the performance achieved by the participating laboratory.
For |E| >2 the result is "Out of Control".
For 1< |E| < 2 the result is considered "Acceptable", but a warning remains.
For |E| ≤ 1 the result is considered "Good".

5. Final evaluation of the proficiency test

Each participating laboratory will receive a Test Report containing its performance evaluation. In the final report, all results from participating laboratories will be presented in coded form.
These reports will be available exclusively in digital format.

5.1. Confidentiality/Appeals or complaints

Each participating laboratory will receive a code. The code is known only to the participant and the proficiency test coordination. Participation in the proficiency test implies agreement to allow the use of the results in LN/LNMRI publications, respecting the confidentiality of each participating laboratory.
As established in item 4.10.4 of the ABNT NBR identification ISO/IEC 17043:2011 standard, in exceptional circumstances, a regulatory authority may request the result(s) and identification of the participant(s) from the provider. If this occurs, LN/LNMRI will formally notify the participant(s).
If necessary to formalize a complaint or appeal regarding the proficiency test, it must send an electronic message to karla.patrao@ird.gov.br within 15 days after receiving each final report received.

References

[1] International Standard ISO 8529-1 *Reference neutron radiations: Characteristics and methods of production* (2001).
[2] International Standard ISO 8529-2 *Reference neutron radiations: Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field* (2000).
[3] International Standard ISO 8529-3 *Reference neutron radiations: Calibration of area and personal dosimeters and determination of their response as a function of neutron energy and angle of incidence* (1998).
[4] NBR ISO/IEC17043 Conformity assessment- General requirements for proficiency testing, 2011.
[5] Technical Protocol, Supplementary Comparison for the Calibration of Ambient Dose Equivalent (Rate) Meters in ISO Neutron Reference Fields – CCRI(III)-S1, 2020.
[6] G. Ratel, *Evaluation of the uncertainty of the degree of equivalence*, Metrologia 42 140-144 (2005).
[7] ISO, International Organization for Standardization, "GUM, *Guides to the expression of uncertainty in measurement, International Organization for Standardization", Edição* Revisada, Terceira Edição Brasileira, 2003.