IRSN
LRDE research laboratory in external dosimetry
BNM associated laboratory for neutron metrology

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1. Introduction

The laboratory of external dosimetry studies and researches of the Institute for Radiological Protection and Nuclear Safety (IRSN) is specialized in the fields of neutron metrology, dosimetry and detector developments.

The laboratory, associated to the French metrology office (BNM), provides reference neutron fields which are of primary interest for radiation protection, neutron metrology and nuclear physics. These fields are used for new detector studies, characterization and for calibration purposes.

2. IRSN neutron facilities for radiation protection

The IRSN facilities dedicated to neutron metrology and dosimetry are installed inside the CEA (Commissariat à l'Energie Atomique) center of Cadarache situated in the south of France. These facilities are the following

- an irradiator, called Van-Gogh, containing two radioactive neutron reference sources (Am-Be, ^{252}Cf moderated or not with heavy water) providing ISO [1] recommended standard neutron fields.

The laboratory is organising, in collaboration with NPL and PTB, a key comparison (EUROMET 608) for the Calibration of Ambient Dose Equivalent Ratemeters in ISO Neutron Reference Fields.

- a 1,5 m side graphite cube, called SIGMA, inside which are placed six Am-Be radioactive neutron sources, dedicated to the production of neutron fields mainly composed by thermal neutrons

A new characterisation of the facility is underway: the thermal part has been characterized by the primary laboratory (LNHB) using the activation of gold and copper foils. The epithermal and fast parts are under investigation comparing proton recoil measurements with Monte Carlo simulation.

- A realistic field production set-up called CANEL.

Earlier studies [2] have shown that dosimetric instruments calibrated by radioactive equivalent. For that reason, IRSN and several other institutes have developed facilities able to produce realistic neutron spectra, i.e. wide energy distribution of the neutron fluence simulating workplaces fields. Realistic neutron spectra are in the process to be integrated as ISO recommended neutron fields [3]. To obtain realistic spectra, IRSN uses a 150 kV SAMES (J25) accelerator producing 14 MeV neutrons by the $^3H(d,n)^4He$ reaction, a 120 keV deuteron beam hitting a tritiated target placed inside the CANEL facility [4]. This facility consists of a ^{238}U converter generating, from the original 14 MeV neutron field, a fission neutron spectrum which in turn is moderated by layers of iron and water placed inside a polyethylene duct, as described in [5]. Despite the moderation, there is still a residual contribution of the 14 MeV neutrons that becomes significant in terms of dose equivalent. That is why, since end of 2001 year, a 400 kV SAMES (T400) accelerator (producing 3 MeV neutrons by the reaction $^2H(d,n)^3He$ with 350 keV deuterons up to a production rate of 10^{10} n/s on the target) is used with a slightly modified design of CANEL [6]. The stability of monitor system of the T400 accelerator has been extensively investigated [8] As shown in the Figure 1, the realistic neutron spectrum, calculated with MCNP [7], obtained with CANEL and T400 presents a fast neutron part with a higher mean energy but without a high energy peak contribution.

A detailed study on all results from the Monte Carlo simulations [9] showed that the variation with lateral distance from the central beam axis is small, i.e. that large detectors or a ISO-slab phantom are essentially irradiated with a uniform beam. 96% of the neutrons impinge with an angle less than 40 degrees relative to the normal on the phantom. The thermal, epithermal and fast neutron contributions at different angles of incidence at 50 cm from the exit of the polyethylene duct are detailed in Table 2.

***Table 1**: Neutron fluence contributions in different energy regions for angles of incidence ranging from 0° up to 50° in the calibration zone at 50 cm from the $(CH_2)_n$ duct exit*

Incidence angle (°)	**0 - 10**	**10 - 20**	**20 - 30**	**30 - 40**	**40 - 50**
Fluence contribution (%)	20.7	38.9	24.6	11.3	1.6
Energy domain relative contribution (%)					
$E_n \leq 0.4$ eV	43	51	67	73	72
0.4 eV< $E_n \leq 10$ keV	26	27	23	20	20
10 keV< $E_n \leq 3.35$ MeV	31	22	10	7	8

The characterisation of the new CANEL radiation field was successfully completed by comparing experimental results with simulation [EUROMET project 670]. Figure 1 shows the comparison between the MCNP4C simulated neutron energy distribution and the neutron spectrum measured with the Bonner sphere system (BSS).

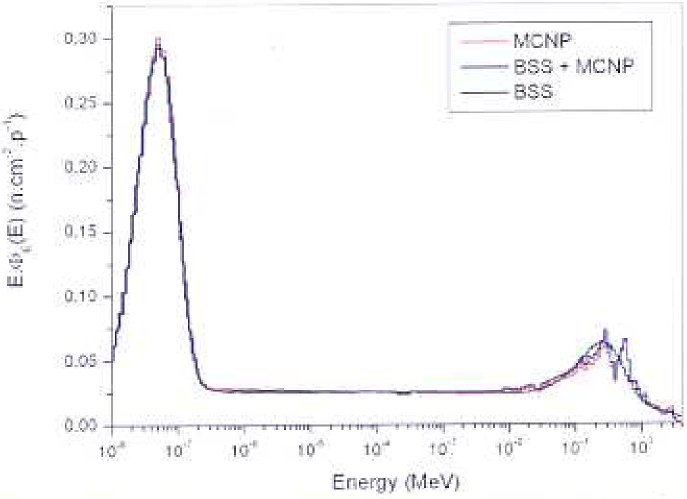

Figure 1: *Neutron energy distribution measured with BSS and simulated with MCNP Blue curve (BSS+MCNP): BSS data unfolded with an unfolding code using the MCNP data as prior information (MAXED). Black curve (BSS): BSS data unfolded with an unfolding code using no prior information (MITOM) but analytic function with predefined corresponding parameters.*

The photon contribution determination in this field is under way and will be finished beginning 2003. Results from MCNP4C simulations are shown in Figure 2.

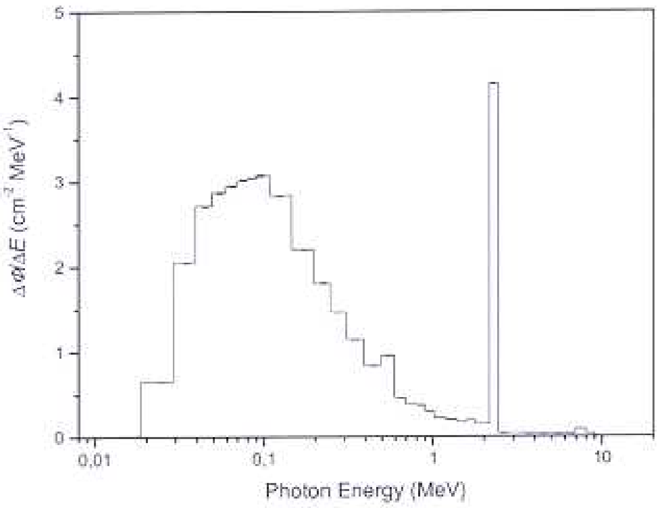

***Figure 2**: MCNP4C simulation of the energy distribution of the photon fluence*

The MCNP4C simulations showed that at the nominal calibration point, the integral neutron fluence is (2.52 ± 0.17) cm^{-2}, and the neutron ambient dose equivalent is (117.6 ± 8.2) pSv. The estimated integral photon fluence and the photon ambient dose equivalent are respectively about (1.96 ± 0.14) cm^{-2} and (12.24 ± 0.85) pSv. All fluence and dose equivalent values are given per count of the proton counter which is used as a beam monitor. The calculated conversion factor is $(7.16 \pm 0.50)\times10^5$ neutrons per detected proton.

A final confirmation of the energy distributions and the neutron and gamma fluence is expected summer 2003 due to an EUROMET project presently carried out with reference spectrometers by IRSN, NPL and PTB [EUROMET project 670].

3. AMANDE facility

In order to extend its set of neutron reference fields, the IRSN has decided to acquire a new accelerator (named AMANDE as Accelerator for Metrology and Neutron Applications in External Dosimetry) to produce monoenergetic neutron fields within the energy range of 2 keV- 19 MeV. The neutrons are created by nuclear reactions between accelerated protons, deuterons with thin targets like scandium, lithium, deuterium, tritium, as defined by ISO standards [1] at a production rate up to several 10^8 n/s on the target. Reference high energy (7 MeV) and secondary standard gamma rays for calibration purposes will also be available, following recommendations of the ISO-4037 standard [8].

AMANDE will be installed in a new building, just beside the above-mentioned facilities.

3.1. AMANDE accelerator

The AMANDE facility is based on a HVEE 2 MV Tandetron accelerator system. The characteristics of the accelerator have been determined in order to meet at least the recommendations of the ISO and IEC standards [10] and to be able to define well characterized low energy neutron beams.

As a detector calibration typically requires irradiations of a few hours, this imposes a very good long-term stability, current and energy reproducibility of the accelerator.

AMANDE is able to run in a DC or in a pulsed mode. The latter mode will be used for time of flight experiments in open geometry at a flight distance between 0,5 and 6 meters. The pulsing system will have a repetition frequency of the pulses ranging between 62,5 kHz and 2 MHz and a pulse width lower than 2 ns.

AMANDE main specifications in DC and pulsed mode are given in Table 1.

Table 1: Specifications of AMANDE (worst case expected values)

	DC mode	Pulsed mode
(at 2 MHz)		
Current range	0,1 - 50 µA	0,1 - 8 µA
Current stability	< 1 %	< 3%
Ion energy range	0,1 - 4 MeV	0,1 - 4 MeV
Energy stability (8 hours)	< 500 eV	< 700 eV
Energy spread	< 500 eV	< 4 keV
Energy Long term reproducibility	< 1 keV	< 3 keV

H^- and D^- ions will be directly extracted at an energy of about 30 keV from a multi-cusp ion source (maximum current of 500 µA). After a 15° injector magnet, the beam enters the pulsing (chopper-buncher) system and then go through the accelerator. Leaving the accelerator, the accelerated positive ion beam passes through the following magnets : a 90° magnet (with NMR teslameter) for beam-energy stabilization and absolute energy calibration, a 35° magnet to compensate for the timing differences created in the first magnet in pulsed mode, and a switching magnet to direct the ion beam in one of the beamline of the experimental hall. In a first step, only one beamline will be equipped, allowing 4 other beamlines for further applications. A layout of the accelerator is shown in the Figure 3.

3.2. *Neutron reference measurements*

An important program of detector development will be associated to this facility. In a first step, the neutron fluence and energy distribution will be determined by the use of several proton recoil reference detectors as SP2 proportional counters [11], BC501A liquid scintillators [12] in DC mode. For time of flight measurements, BC501A and lithium glass detectors will be used [13].

An automated transport system will place the detectors at any distance between 0,5 and 6 m and angle between -150° and +150° from the neutron-producing target mounted at the end of the beamline. The precision on the position of the detector is specified to limit the induced uncertainty on the neutron fluence at less than 0,1 %.

3.3. *Building*

AMANDE will be housed in a new building which consists of two parts :

- a concrete part containing the accelerator room, the control room, offices and several technical rooms,
- a 20 m x 20 m x 16 m experimental hall with metallic walls and a floor grating placed at 6 meter above the ground, over all the hall surface at the exception of a 6 meter-radius hole (the experimental area).

Between them, a 40 cm thick concrete wall will protect the personnel from radiation coming from the experimental area.

The accelerator will be installed in the machine room on the first floor of the concrete part.

The neutron-producing target will be placed at the center of the hole in the floor grating at the end of the beamline, i.e. at 7,2 m high from the ground of the experimental hall.

Since this facility will be at the center of a 300-meter radius excluding area, there is no need to stop the neutrons inside the building. For that reason, the other walls and the ceiling of the experimental hall will consist of two metallic layers surrounding thermal insulating matter in order to minimize neutron scattering, while maintaining, in the experimental area, temperature and humidity in the standard test condition recommended by the IEC standards.

As shown in the Figure 3, if the distance of the detector from the target is greater than 1 m, the use of metallic walls will reduce significantly the background due to neutrons scattered by the building if compared to the use of concrete walls, as it is the case in similar facilities [14][15].

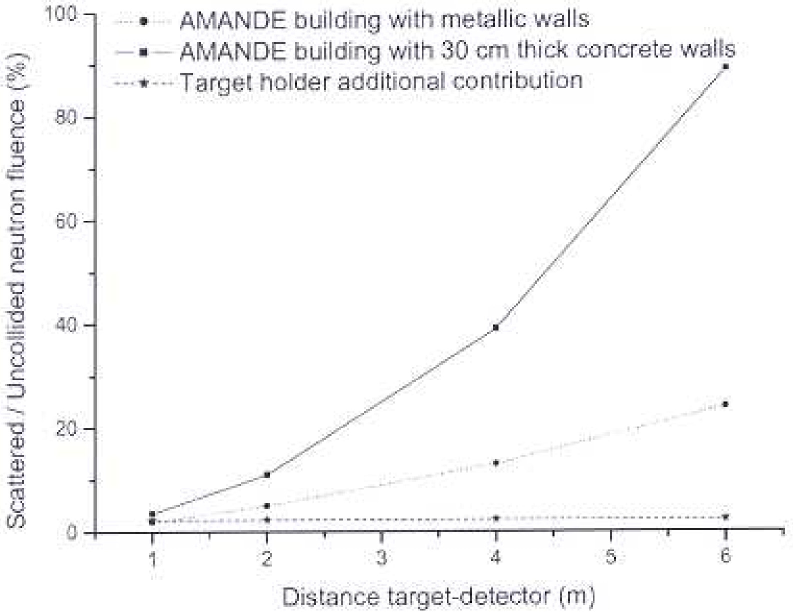

Fig. 3. Neutron background scattered by two kinds of building walls (calculated by MCNP) in AMANDE experimental area at 1,2,4 and 6 m from a 565 keV neutron producing target, at an angle of 0 and comparison with the target holder contribution.

4. Conclusion

The AMANDE accelerator will be installed in the new building beginning of 2004. The first neutron fields available for instrument calibration and investigation purposes are expected at the beginning of 2005.

Thanks to the accelerator performances and the building specific design, AMANDE should provide high quality monoenergetic neutron beams. Together with the already available facilities, IRSN will dispose of one of the most complete set of neutron reference fields for metrology and dosimetry.

References

[1] ISO 8529-1, Reference neutron radiations: Characteristics and methods of production (2001).
[2] T. Lahaye et al., IPSN/DPHD/SDOS report 2001-02 (2001).
[3] ISO /DIS 12789-1, Reference neutron radiations: Characteristics and methods of

production of simulated workplace neutron fields (2001).
[4] D.J. Thomas et al, Radiat. Prot. Dosim. **70** (1997), 313.
[5] J.-L. Chartier et al., Radiat. Prot. Dosim. **44** (1992) 125.
[6] Ph. Alexandre, IPSN/DPHD/SDOS report 2000-19 (2000).
[7] LA-13709-M, MCNP - A general Monte Carlo N-particle transport Code, version 4C (2000).
[8] V. Gressier et al., Monitorage du champ neutronique de l'accélérateur SAMES T400 à l'aide de diodes Silicium, rapport SDOS 2002-11 (2002)
[9] V. Lacoste, V. Gressier, MCNP4C Simulation of the Neutron Radiation Field at the IRSN CANEL/T400 Facility, rapport SDOS 2002-12 (2002)
[10] IEC 61005/Ed.2 CDV, Radiation protection instrumentation - Neutron ambiant dose equivalent (rate) meters (2000).
[11] G. Pichenot et al., Nucl. Instr. and Meth. A476 (2002) 165.
[12] D. Schmidt et al., Nucl. Instr. and Meth. A476 (2002) 186.
[13] A.R. Spowart, Nucl. Instr. and Meth. 135 (1976) 441.
[14] A. G. Bardell and D. J. Thomas, Proc. Of radiation dose management in the nuclear industry, Windermere, Cumbria, 9-11 October 1995, 71.
[15] H.J. Brede et al., Nucl. Instr. and Meth. 169 (1980) 349.