Report on Neutron Metrology at the National Research Council Canada

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1. Introduction

The Ionizing Radiation Standards laboratory (IRS), part of the Institute for National Measurements Standards (INMS) at the National Research Council Canada (NRC) has a dedicated laboratory for neutron metrology. Over the past several years, an effort has been made to revive and improve upon the extensive history of neutron physics at the NRC.

The main focus has been on maintaining and improving the neutron survey meter calibration service, the revival of the thermal neutron flux density standard, the revival of primary standard for neutron emission rate and the development of a fully-automated, liquid-moderated neutron spectrometer.

2. Facilities

The neutron laboratory at the NRC is a unique facility ideally suited to the measurement of low-intensity neutron fields generated by sealed neutron sources. A large 16 m × 16 m × 10 m room with a false floor permits calibration and irradiation services to be carried out with minimal effects due to room scatter. Several fast neutron sources are available for experiments, including americium-beryllium (AmBe), americium-boron (AmB), plutonium-beryllium (PuBe), and radium-beryllium (RaBe). These are cylindrically shaped, and roughly 2 cm in height and diameter.

3. Neutron Survey Meter Calibration Service

Neutron survey meters are calibrated using an AmBe source with an emission rate of $(1.58\pm0.02)\times10^6$ n/s. The neutron fluence to ambient dose equivalent conversion is calculated using the AmBe neutron energy spectrum provided in ISO-8529-1 and the ambient dose conversion coefficients given in ICRU Report 57. The response of the survey meter is measured as a function of distance with room- and air-scatter corrections applied using the generalized-fit method. In addition, geometric corrections are applied for cylindrical and spherical meters. The sensitivity to gamma radiation is tested for each survey meter in a 100 Ci, ^{137}Cs field, at a distance of 66 cm. Finally, the angular response of the survey meters is tested.

We are currently in the process of automating the calibration system. A Velmex translator and stepping motor system has been installed and C++ software has been written to remotely control the positioning of the neutron source during the survey meter calibration. In addition, C++ software has been written to manage the output from analog survey meters. Work is continuing on the development of software for managing the readout of digital systems.

Over the past few years, the number of neutron survey meter calibrations performed by the IRS has increased from approximately 6 per year to approximately 15 per year from clients throughout Canada.

4. Thermal Neutron Flux Density Standard

The thermal neutron flux density standard at the NRC consists of concentric cylinders. The inner cylinder is comprised of graphite while the outer cylinder is made of polyethylene. A schematic diagram of the standard is provided in Figure 1. At the center of the graphite is a cylindrical cavity where the thermal neutron flux density is measured (using the gold foil activation technique). Placed at the interface of the graphite and polyethylene cylinders are six AmBe neutron sources, located 60 degrees apart. The activation of the gold foils is subsequently measured in a 4π-$\beta\gamma$ counter. The last measurements, performed in 1976, indicate a thermal neutron flux density of $(8.6 \pm 0.1) \times 10^3$ cm^{-2} s^{-1}.

With help from the radionuclide metrology lab at the IRS, preliminary measurements taken in 2010 indicate consistency with the value given above. Work is continuing on decreasing the uncertainties in the new measurements.

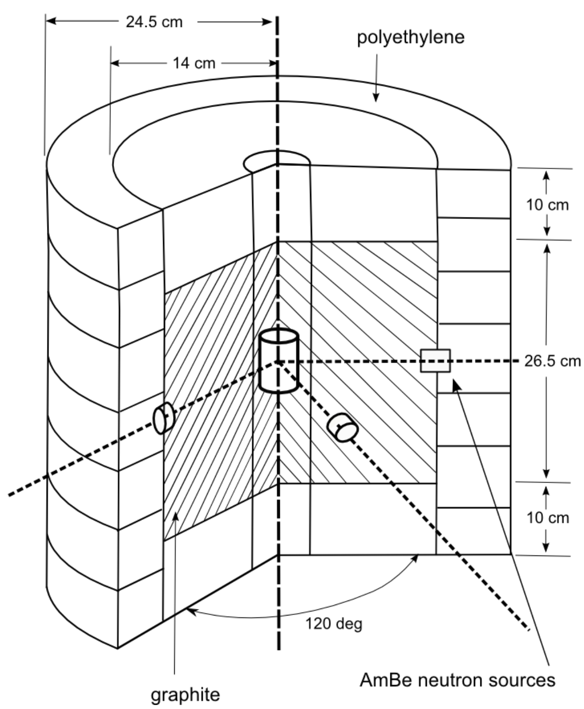

Figure 1: Thermal neutron standard at NRC.

5. Neutron Emission Rate Primary Standard

The manganese sulfate bath technique was previously operational in the 1960's at the NRC. Along with the radionuclide metrology lab, work is in progress to revive the primary standard. The majority of the work has been concentrated in the radionuclide lab, focusing on the production of $Ca(MnO_4)_2$ solution, testing two methods of production: 1) ion exchange columns using zeolite and 2) chemical production.

Thermal neutrons from the apparatus mentioned in Section 4 are then used to produce a pure source of ^{56}Mn by isolating insoluble MnO_2 molecules from the calcium permanganate solution via the Chalmers-Szilard effect. A small amount of the activated ^{56}Mn is used to create thin sources and the rest used to create the bath.

6. A Fully-automated, Liquid-moderated Neutron Spectrometer

Development is underway for a new low-cost neutron spectrometer, based on the principles used in Bonner Sphere Spectrometers. However, rather than embedding the thermal neutron detector in a set of solid spheres of discrete size, the detector is immersed in a water-filled vessel and translated remotely to any position within the volume. In this way, the Bonner Sphere dependence on discrete moderation radii gives way to a continuous selection of effective moderation thickness, thus yielding an arbitrarily large number of data points for use in the unfolding algorithm.

A schematic diagram of the preliminary experimental setup is provided in Figure 2. A 33 cm × 33 cm × 37 cm PMMA phantom with 1.2 cm thick walls, filled with 26 cm of water, is located on top of a low-mass aluminum table at the center of the neutron facility.

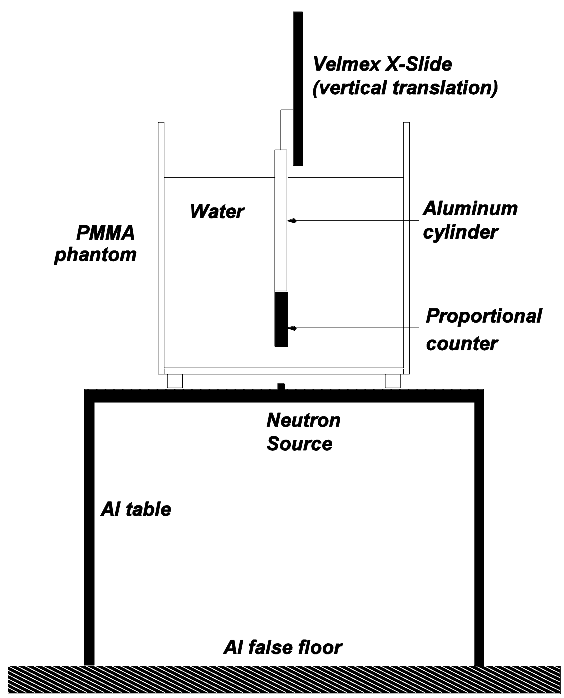

Figure 2: Schematic diagram of the experimental configuration for the neutron spectrometer.

A BF_3 proportional counter is employed as the detector. It is oriented vertically along the symmetry axis of the phantom and mounted to a Velmex X-slide translator, used to position the detector remotely.

The count rate is measured as a function of distance from the bottom face of the vessel and compared to Monte Carlo simulations using MCNP5. The response functions of the system are also calculated using MCNP5, while the data unfolding is performed using singular value decomposition. Preliminary studies were performed and presented at the IEEE Nuclear Science Symposium and Medical Imaging Conference in Knoxville, Tennessee, November, 2010.

Work is continuing on the optimization of the spectrometer system. The PMMA tank will be exchanged for a 2 mm thick aluminum cylinder to decrease the moderating effects of the vessel, while a low-mass support structure is currently being built to house two Velmex X-slides. The two X-slides, along with a rail system that is mounted on the false floor of the neutron lab will allow positioning of the proportional counter anywhere within the water vessel.

7. Talks

A Fully-automated, Liquid-moderated Neutron Spectrometer System, John Paul Archambault, Patrick R.B. Saull. IEEE Nuclear Science Symposium and Medical Imaging Conference. Knoxville, Tennessee, Oct. 30–Nov. 6, 2010.