Recent Developments in Neutron Metrology at the National Physical Laboratory

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The activities of the Neutron Metrology Group (NMG) at NPL can be divided into six topic areas: 1. Radionuclide Sources Based Standards, 2. Accelerator Based Neutron Fluence Standards, 3. Comparisons and Demonstrations of Equivalence, 4. Neutron Spectrometry, 5. Neutron Dosimetry, and 6. Major Facilities Maintenance and Development.

1 Radionuclide Source Based Fluence Standards

Activities which presently fall under this heading include the maintenance and development of the manganese sulphate bath, routine measurements of the radionuclide sources used to provide fluence standards at NPL, and investigation of the amounts of ^{250}Cf in ^{252}Cf sources.

The manganese bath provides a service for source emission rate measurements, both for internal use and for outside users, and a programme of continuous development and investigation of corrections is undertaken. Recent improvements have been to the knowledge of the system dead time, and to the various corrections for losses by capture reactions. Corrections for these losses were originally made using codes written in-house, but the entire manganese bath has now been carefully modelled with the transport code MCNP and new corrections calculated. Differences arise mainly because of changes in cross sections between ENDFB-V, used by the in-house code, and ENDFB-VI used with MCNP. The ability to model non-spherically symmetric features has also had an effect. The revisions to the corrections vary with source spectra and source size, but can be up to 1.2% for a large ^{241}Am-Be source(1). These corrections continue to evolve as improved information is obtained about the source spectra.

One spectrum about which improved spectral information is available is that from an ^{241}Am-Li source. Calculational work over the last year has confirmed earlier experimental work which showed the presence of a low energy component in this spectrum which hitherto had not been suspected(2). The measured and calculated spectra are shown in Figure 1.

The fact that ^{252}Cf sources contain ^{250}Cf, in amounts which vary both because of the ^{250}Cf concentration in the original source, and also because the relative amounts vary with time due to the different half-lives, is known to most neutron metrology labs. The full effects of the presence of ^{250}Cf, in terms of the uncertainty in predicting the emission rate as a function of time, are perhaps not so well known, particularly by secondary standardising labs who also use ^{252}Cf sources. For example, for one NPL ^{252}Cf source, use of the first emission rate measurement made in March 1989, rather than the most recent one, made in April 2002, would result in a 6% error in the source emission rate calculated for May 2003. A project is

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underway to measure ^{252}Cf source emission rates as a function of time for the NPL sources, to analyse the data to provide the ^{250}Cf content from the effective decay half life, and to publicise information about the potential problems.

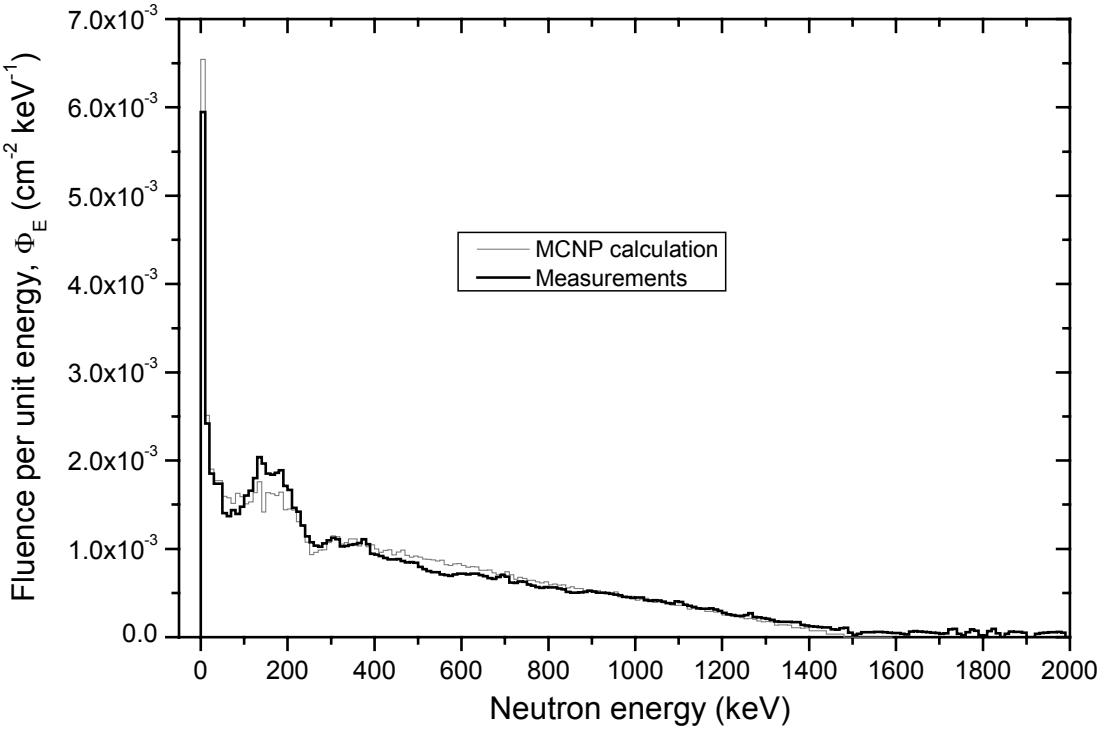

Figure 1. Comparison of the MCNP calculated ^{241}Am-Li spectrum with the best estimate of the spectrum from a set of measurements with several instruments. Data have been normalised to unit fluence between 50 and 1500 keV.

2 Accelerator Based Neutron Fluence Standards

In addition to the regular validation of the fluence and energy standards, projects under this heading include: a determination of the optimum position for shadow cones, a determination of long counter effective centres, a project to provide spectrometry for target condition monitoring, and one to develop time-of-flight capabilities.

The NPL 3.5 MV Van de Graaff is capable of pulsed operation, but the pulser system has not been used for some years. A need to perform time-of-flight investigations of target spectra has led to work being undertaken to re-instate this system. After some repairs, the pulser system appears to be working, and the detectors used in the past, an NE912 lithium-glass scintillator for low energies and a KL-236 plastic scintillator for higher energies, both appear to be operational although improved electronics may be needed to optimise the timing.

Time-of-flight techniques can be used to determine the condition of neutron producing targets, but the measurements are long and relatively complex, and a quicker method is needed simply to check that the spectra from the various targets do not change after their first characterization. To achieve this a set of dedicated spectrometers will be characterized and made available for routine monitoring of the target condition.

Following extensive calculational and experimental work to determine the efficiency of the long counters used at NPL to measure monoenergetic neutron fluences, one of the largest

remaining uncertainties in the determination of fluence is the knowledge of the effective centre values for these devices as a function of energy. Attempts to calculate this quantity using MCNP have resulted in some problems, namely the presence of unexplainable structure in the variation of effective centre with energy, discrepancies when trying to calculate effective centres for broader neutron distributions by two approaches, and poor agreement with experiment. The problem is exacerbated by the fact that the measurements do not seem to be reproducible. Recent work has indicated that the problem with the calculations may be due to correlations introduced by the fact that, by default, the same starting random number is used by MCNP for every calculation.

The problems with measuring effective centres may be the result of inexact shadowing when performing background correction measurements with the shadow cone technique. Partly for this reason a programme of measurements has been undertaken to investigate the optimum position for a shadow cone. In this project data has been provided by IRSN which will be used in compiling a final report.

3 Comparisons and Demonstrations of Equivalence

In the area of fluence measurements, NPL is presently participating in three CCRI comparison exercises, and one Euromet comparison.

Measurements have been performed for the CCRI thermal neutron comparison using the transfer instrument provided by NIST, and a report is being prepared.

A report has been written[3] on the NPL contribution to the monoenergetic neutron comparison exercise held at PTB in March 2001.

For the comparison exercise involving circulation of an ^{241}Am-Be source for measurements of total emission rate NPL has made one measurement using the manganese bath technique, and plans to make another measurement at the end of the exercise to check that there has been no change in emission rate.

The Euromet comparison is of the calibration of area survey instruments by European Labs and is being organized by IRSN with some assistance from NPL.

4 Neutron Spectrometry

NPL has a number of neutron spectrometers, developed mainly for characterising workplace fields, but also used for characterising calibration fields. They consist of: two Bonner sphere sets, one with a spherical ^{3}He proportional counter central sensor, and the other with gold foils as the central sensors; a set of three SP2 spherical hydrogen recoil counters (1, 3, and 9 atm.); two NE213 scintillators (one 6cm diameter by 6 cm thick and the other 2 cm diameter by 2 cm thick); and a ^{3}He gridded ion chamber.

Projects are underway to find a battery powered system to power the ^{3}He based Bonner sphere set, to investigate combined unfolding from several neutron spectrometers, to extend the range of hydrogen recoil counters below 50 keV, and to improve the response functions for the NE213 scintillators.

Several of these instruments were used recently in a Euromet spectrometry exercise to characterise a simulated realistic field at the IRSN CANEL facility at Cadarache.

5 Neutron Dosimetry

The projects which fall under this heading are all aimed at improving measurements of dose equivalent for radiation protection. They include one to validate a simple technique for neutron dose measurements around hospital LinAcs, one to devise a dual instrument approach to area survey measurements, one to provide realistic calibration fields, and one to extend microdosimetric measurements with tissue equivalent proportional counters (TEPCs).

Measurements of the stray neutron fields around LinAcs producing photon or electron beams for radiotherapy can be performed with the gold foil based Bonner sphere set, but these measurements are long and complex. A project is underway to compare doses derived from a full Bonner sphere spectrum measurement with those made with bubble detectors. These devices are much quicker and simpler to use, but their results need to be validated. Measurements have recently been performed at a hospital around a 25 MeV accelerator.

By using two area survey instruments, with very different response characteristics as a function of energy, rough information can be derived about the spectrum of the field and improved ambient dose equivalent measurements can be performed. This project is looking in detail at the performance of a particular pair of instruments.

The idea of using realistic calibration fields to improve neutron dosimetry measurements has been around for some time. At NPL a realistic field is being developed based on the 3.5 MV Van de Graaff. In order to obtain a spectrum with a very low mean energy, similar to the spectra measured around UK gas-cooled reactors (also similar to those found around PWR reactors), low energy primary neutrons are used together with moderation. The neutrons are produced by the ^{7}Li(p,n) reaction, and the moderation is provided by heavy water. Figure 2 shows a comparison of the spectrum calculated for this facility using MCNP and measurements with the ^{3}He based Bonner sphere set.

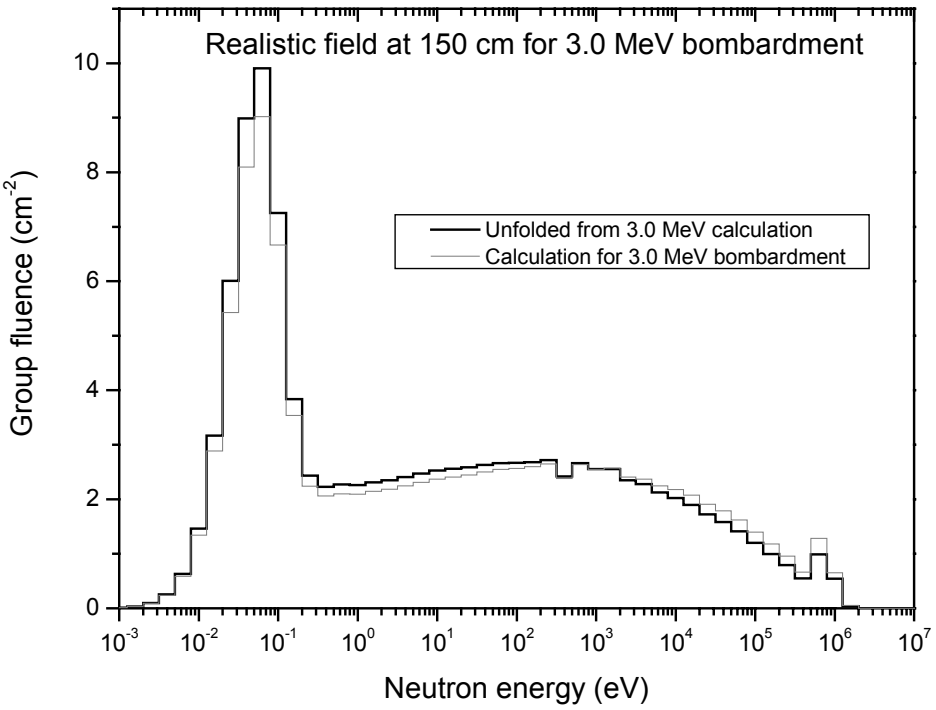

Figure 2. Simulated realistic field obtained by moderating neutrons from the ^{7}Li(p,n) reaction in a thick target by a 40 cm diameter shell of heavy water.

The number of thermal neutrons in the field was found to be very sensitive to any H_2O contamination in the D_2O. The thick lithium target was simply a piece of aluminium-lithium alloy. Although the lithium content is not high, the target appears stable under bombardment. From a comparison of measurement with calculation there is some evidence of a very thin layer on the target surface where the lithium concentration is either low or there is no lithium.

TEPCs have been around for many years, but have not found many applications in radiation protection because of their poor low-energy response. Recently, however, they have found an important use in measuring cosmic ray doses at aircraft flight altitudes. Because of the high energy neutron spectrum in these environments the poor low energy performance is not thought to be a problem, and these devices are considered the 'reference' instrument for this type of measurement. NPL have a collaboration with Virgin Atlantic Airways, the UK Civil Aviation Authority, and the Mullard Space Science Laboratory to study cosmic ray doses and in particular to investigate the influence of space weather on these doses.

6 Major Facilities Maintenance and Development

Projects under this heading involve mainly the maintenance and development of the Van de Graaff accelerator, but do also include work to transfer 14 MeV standards from NPL to AWE Aldermaston. The NPL SAMES accelerator which was used to produce 14 MeV fluence standards has been decommissioned and dismantled, and NPL staff are providing assistance to AWE staff to offer these standards.

References

1 N.J. Roberts, *MCNP Calculations of Correction Factors for Radionuclide Neutron Source Emission Rate Measurements using the Manganese Bath*, NPL Report CIRM 45, May 2001

2 Hamid Tagziria, Neil J. Roberts, and David J. Thomas, *Measurement of the ^{241}Am-Li radionuclide neutron source spectrum,* accepted for publication in Nucl. Instrum. & Meths. A.

3 David J. Thomas, Neil J. Roberts, Andrew Bennett and Peter Kolkowski, *The NPL contribution to a CCRI international comparison of fast neutron fluence measurements performed at the PTB in March 2001,* NPL report CIRM 51, April 2002.