A Field Portable Neutron Spectrometer Based on the Bonner Sphere Principles

J. Dubeau[1], S.S. Hakmana Witharana[1], J. Atanackovic[2], A. Yonkeu[2], W. Matysiak[3], A.J. Waker[4], Aslam[4] and J. P. Archambault[5]

[1] Detec, 32 Gatineau Ave, Gatineau, QC, J8T 4J1, Canada [2] AECL, Chalk River Laboratories, Chalk River, ON, Canada K0J 1J0
[3] Dept. of Medical Physics and Applied Radiation Sciences, McMaster University, Hamilton, ON, L8S 4L8, Canada [4] Faculty of Energy Systems and Nuclear Science, UOIT, 2000 Simcoe St. N, Oshawa, ON, L1H 7K4, Canada
[5]National Research Council of Canada, 1200 Montreal Rd, Ottawa, ON, K1A 0R6, Canada

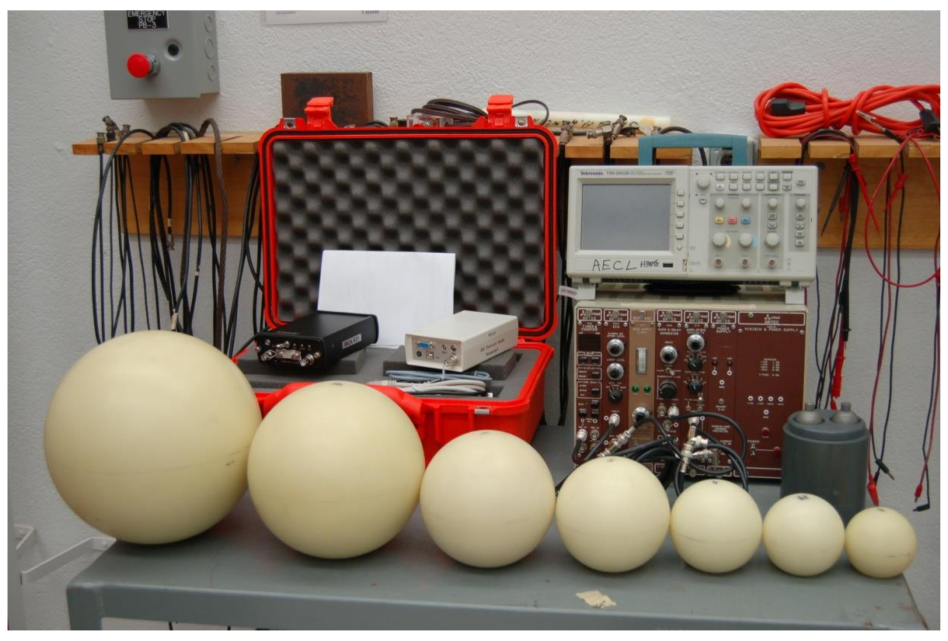
INTRODUCTION

The measurement of the characteristics of neutron fields inside nuclear installations is essential to the radiation safety of the workers at those facilities. Ideally, survey meters should possess an ambient dose equivalent response which is constant with energy, for neutron energies ranging from 25 meV to 20 MeV. However, such perfect instruments do not exist. Real detectors usually under or over respond severely in some interval of the energy range. This is due to the inability of simple instruments, which are usually based on the measurement of counting rates, to have a counting efficiency whose energy dependence matches perfectly that of the ambient dose equivalent.

If the energy differential neutron flux $\Phi(E)$ is measured, then one can calculate the ambient dose equivalent rate by folding this spectrum with fluence to dose equivalent rate conversion coefficients, *C(E)* from ICRP74[1], as follows:

$$\dot{H}^*(10) = \int_{25meV}^{20MeV} C(E)\Phi(E)dE$$

One instrument which has been used since 1960 to measure $\Phi(E)$ is the Bonner Sphere Spectrometer (BSS) [2]. An example is shown below.



The BSS consists of a bare thermal neutron counter and a series of spherical neutron moderating shells made of high density polyethylene (HDPE). The HDPE is used to slow down fast neutrons in order to increase the counting efficiency to epithermal and fast neutrons. This assembly exhibits a particular energy response curve which depends on the moderator size. Thus, by using a set of spheres of different sizes, one has a system that has energy discrimination capabilities. The BSS shown above is used at AECL. It consists of a 17 cm^3 spherical ^3He counter filled to 2 atm. The moderating spheres have diameters of 3, 3.5, 4, 6, 8, and 10 inches. The total mass of HDPE is 17 kg.

The Nested Neutron Spectrometer

The BSS is primarily used as a characterization tool at radiation standards laboratories. It is rarely used for field measurements because it is bulky and the unfolding of the measured count rates to produce an energy distribution is very labor intensive and it requires considerable experience from the user. We report here on a new spectrometer, the Nested Neutron Spectrometer (NNS) and a software tool designed to allow the spectrometry technique to be more readily used in the workplace. The spectrometer was designed around a set of nested HDPE cylinders as shown below. The cylindrical shells can be combined to yield moderator quantities similar to those of the AECL BSS, yet only the equivalent bulk of the largest sphere is carried. The whole spectrometer assembles as a single unit [3].

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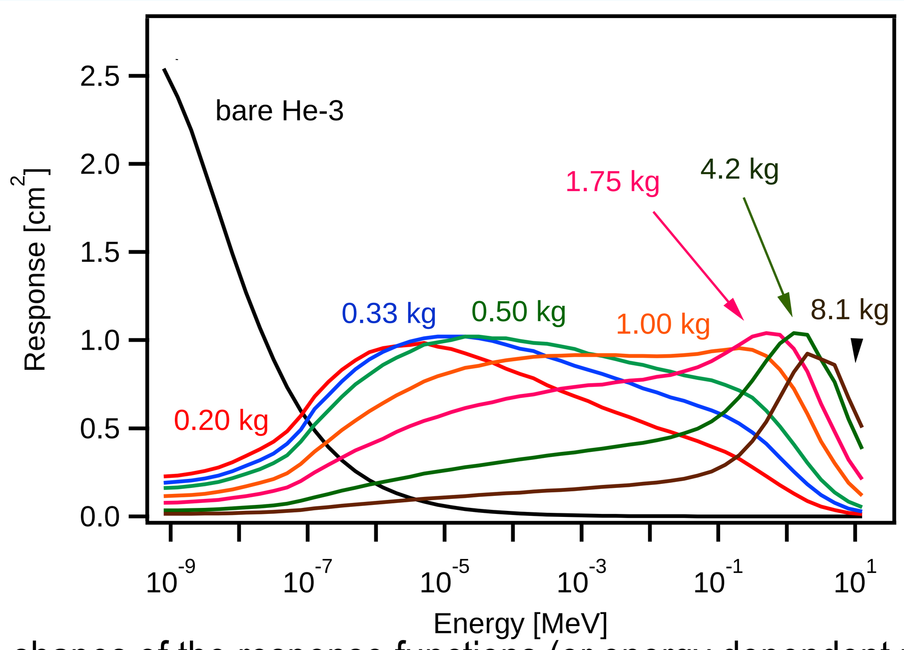
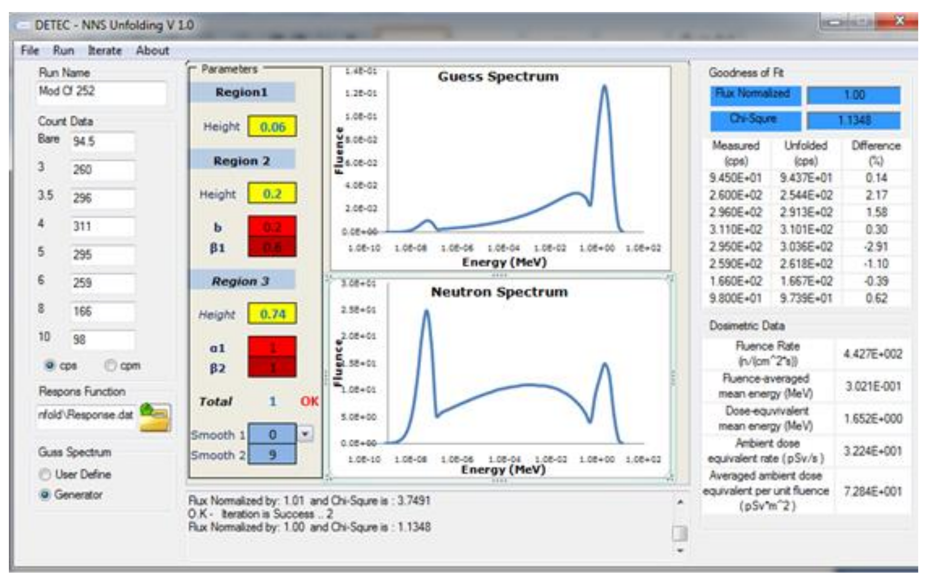
NNS Response Functions



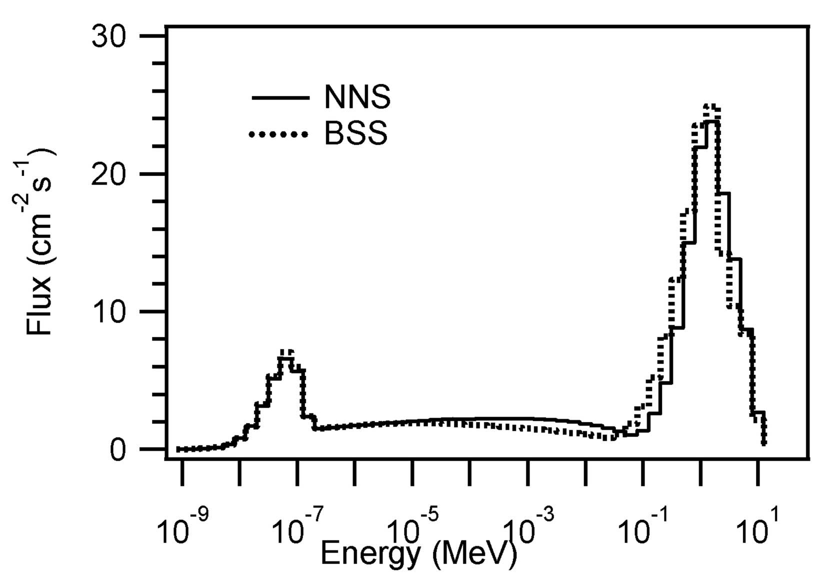
The shapes of the response functions (or energy dependent neutron counting efficiencies) are similar in appearance to those of the BSS. The increasing HDPE mass is as follows: 0 kg (bare detector) and 0.2, 0.33, 0.50, 1.0, 1.75, 4.2 and 8.1 kg.

Spectrum unfolding

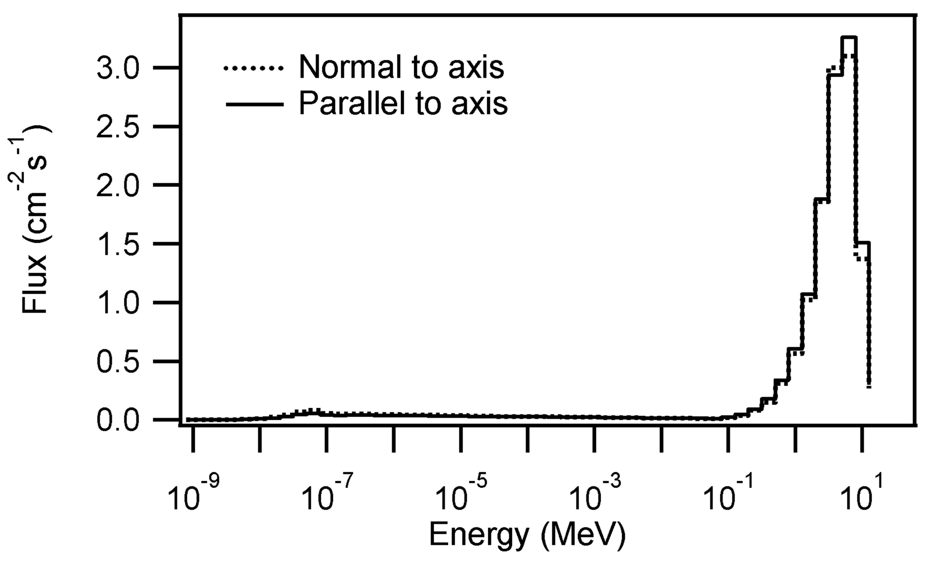


In a given field, 8 measurements are performed with the 8 configurations of the HDPE. The unfolding process creates an energy distribution over 52 energy bins. This requires a dedicated unfolding code. To this aim, we produced a Graphical User Interface over the Stay'SL least square minimization algorithm [4].

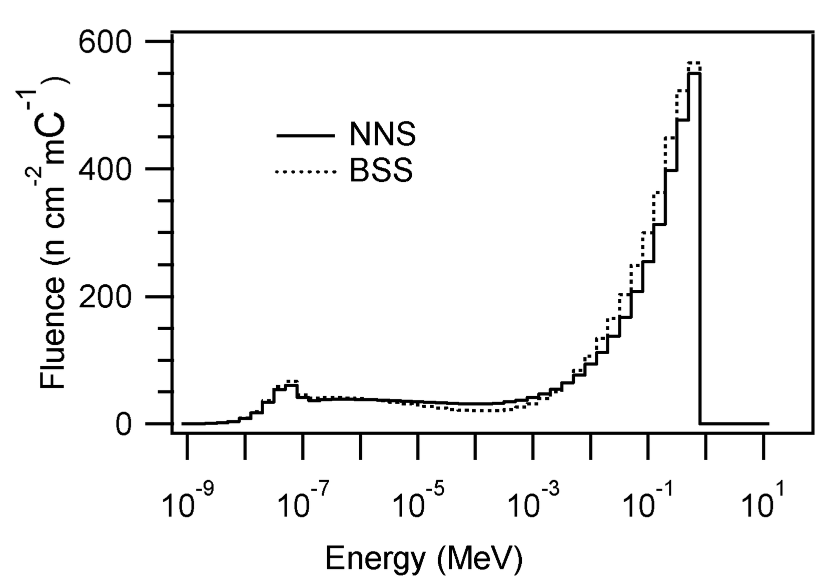
Results



BSS and NNS spectra measured for bare ^{252}Cf at the AECL Chalk River Neutron Irradiation Facility (high scatter condition).

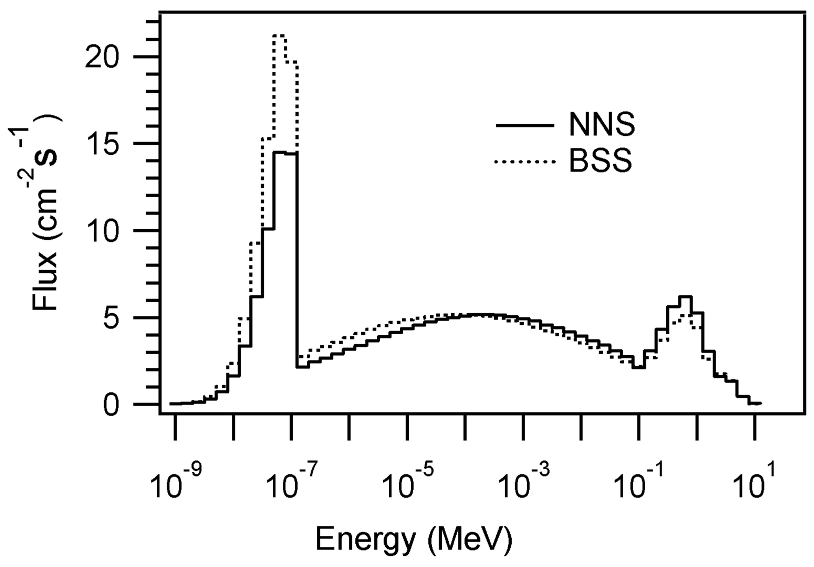


Isotropic angular response of the NNS demonstrated through measurements of AmBe neutrons with detector in two orientations.

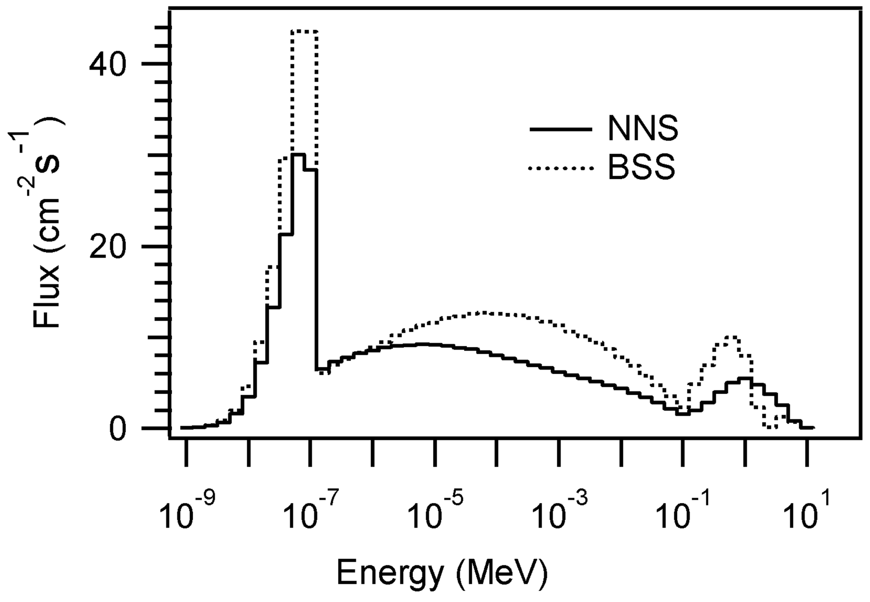


Spectrum measured for neutrons produced by the $^7Li(p,n)^7Be$ reaction on thick Li targets. The measurements were performed at the 3MV KN accelerator facility at McMaster University. The maximum neutron energy was 510 keV in this case..

Results (continued)



NNS and BSS measured neutron energy distributions at the Basement Perimeter Wall (BPW) at the Gentilly 2 (G2) CANDU nuclear power reactor. NNS and BSS were at slightly different locations.



NNS and BSS measured neutron energy distributions inside the Heat Transport Assembly Room (HTAR) at the Gentilly 2 (G2) CANDU nuclear power reactor. NNS and BSS were at slightly different locations.

The table below compares the measured H*(10) for the NNS, the BSS and a tissue equivalent proportional counter (TEPC) simulating a 2 μm site diameter.

Fields	Expected [μSv h^{-1}]	NNS [μSv h^{-1}]	BSS [μSv h^{-1}]	TEPC [μSv h^{-1}]
Bare ^{252}Cf (2m)		566	620	
Mod. ^{252}Cf (1m)		399	453	
AmBe	18.3	17.2	18.3	
88 keV neut.#		17	23	
510 keV neut.#		442	470	
G2 – BPW		42	46	14.6
G2 - HTAR		51	67	23.3

Marks data given in units of nSv per mC of integrated beam current for accelerator generated neutrons

Conclusion

The NNS improves upon the Bonner Sphere Spectrometer by increasing its ease of use in the field, and providing a user friendly data analysis package. These improvements are accomplished without compromising measurement accuracy. The NNS delivers an improved neutron spectrometer for use by radiation protection professionals in the workplace.

References

[1] International Commission on Radiological Protection, "Conversion coefficients for use in radiological protection against external radiation", ICRP Publication 74, *Ann. of ICRP*, vol. 26, No. 3/4, 1996.

[2] R. L. Bramblett, R. I. Ewing, T. W. Bonner, "A new type of neutron spectrometry", *Nucl. Instrum. Methods*, vol 9, 1960, pp. 1-12.

[3] DETEC, US patent application 2011/0049380 A1.

[4] F. G. Perey, "Least square dosimetry unfolding: the program Stay'SL", ORNL/TM 6062, ENDF 254, October 1977.

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Contact information

Jacques Dubeau
DETEC,
32, Gatineau Ave,
Gatineau, QC
J8T 4J1, Canada

Tel : (1) 819 777-1926
Email: jdubeau@detec-rad.com