

1. Nested Neutron Spectrometer Calibration and Field Test Results

Extensive calibration and rigorous testing of the Nested Neutron Spectrometer (NNS) has been carried out in both standard (national standards laboratories), and in non standard fields (work place facilities). This document contains a summary of these calibration tests. The results of each test have been validated by comparing them to a known standard. In the national standards laboratories, the NNS was tested in fields conforming to ISO 8529-2. For the work place tests the NNS results are compared to measurements made using a Bonner Sphere Spectrometer (BSS) calibrated at NIST and NPL (UK).

Table 1 shows a summary of the dose rates calculated from the neutron spectra obtained from the NNS measurements. Also included in the table are the standard dose rates from ISO, or in the case of work place measurements, the dose rate as calculated from the neutron spectra obtained using a BSS. As can be seen, dose rates agree to within approximately 5% at standards laboratories and 10% in the field.

Figures 1 and 2 show the neutron spectra obtained from the NNS measurements and compared to the standard spectra of the reference laboratories. Figures 3 to 5 show results of the NNS and the standard BSS for various non standard fields found in workplace facilities. The data show good agreement between the two spectra across the full energy range.

Measurement Type	Neutron Source	ISO/NIST ($\mu\text{Sv h}^{-1}$)	BSS ($\mu\text{Sv h}^{-1}$)	NNS ($\mu\text{Sv h}^{-1}$)	NNS/Exp.
ISO 8529-2 Standard Fields	Bare ^{252}Cf (NIST)	54	-	55.4	1.03
	Mod. ^{252}Cf (NIST)	17	-	17.1	1.01
	AmBe (IRS-NRC)	18.3	-	17.4	0.95
Work Place Non Standard Fields	^{252}Cf (bare, high scatter facility)	-	620	566	0.91
	^{252}Cf (Mod., high scatter facility)	-	453	399	0.88
	CANDU Reactor Fields	-	46	42	1.10
	$^7\text{Li}(p,n)^7\text{Be}$ Accelerator Reaction	-	442	470	1.06

Table 1: Summary of dose rates calculated from neutron spectra found by the NNS. These Dose rates are compared with standardized values for both calibration and field measurements. In the case of calibration measurements standardized dose rates are from ISO or NIST. Field dose rates are compared to the dose rates calculated from neutron spectra obtained from a Bonner Sphere Spectrometer.

Nested Neutron Spectrometer and ISO:8529 Recommendations

- ISO:8529 details recommendations for the calibration of area-survey instruments using radionuclide sources, linear accelerators and reactors.
- NNS has been calibrated at two national standards labs (NIST, IRS-NRC) in accordance with ISO:8529 standards.
- NNS calibration completed at a linear accelerated facility with comparison to NIST and NPL calibrated Bonner Sphere Spectrometer.

2. Neutron Spectra Obtained from NNS Measurements

2.1 National Standards Laboratory Neutron Spectra Measurements

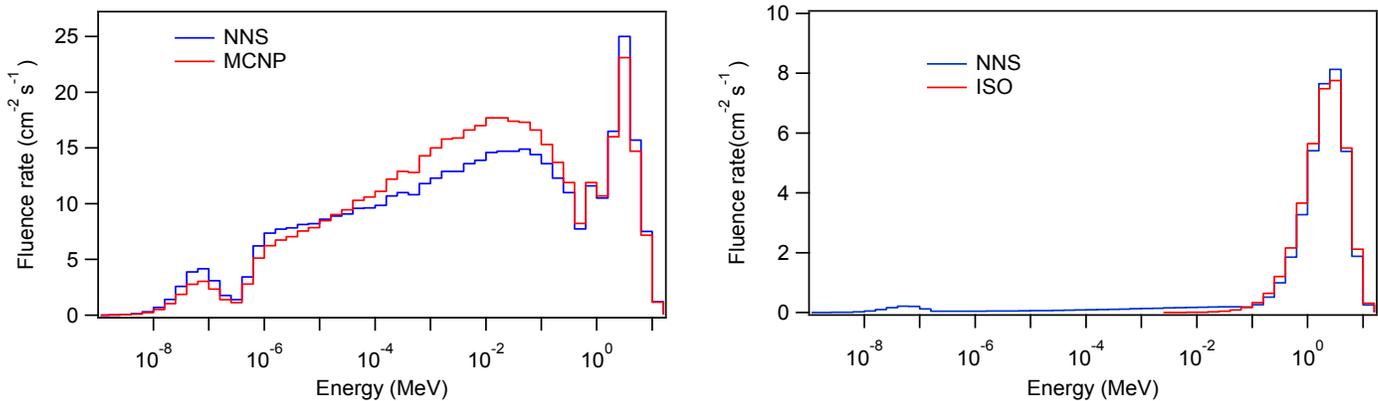


Figure 1: The neutron spectra of bare (right) and moderated (left) Californium-252 as measured by the NNS. For comparison the ISO/NIST standard spectrum is included. Both tests were conducted in the low scatter facility at the National Institute of Standards and Technology (NIST) in the United States [1].

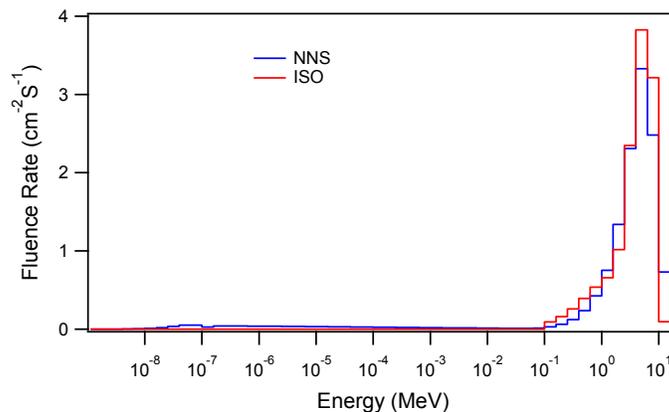


Figure 2: AmBe neutron spectrum as measured by the NNS and compared to the ISO standard spectrum. These measurements were conducted at the low scatter facility in the Ionizing Radiation Standards Laboratory of the National Research Council of Canada (IRS-NRC) [1].

2.2 Field Measurements of Neutron Spectra

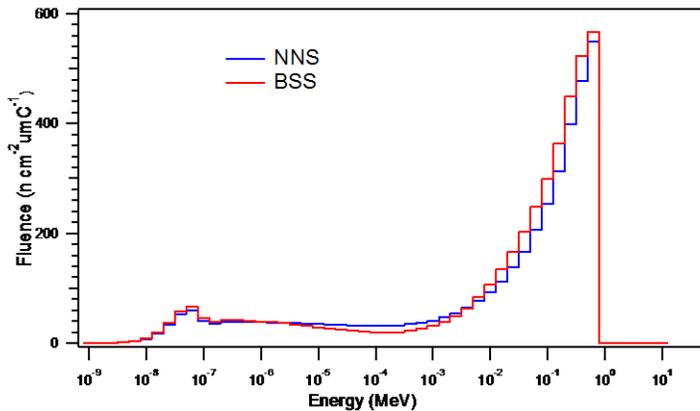


Figure 3: Neutron spectrum measured in the Van Dar Graaff accelerator facility at McMaster University in Hamilton, Canada [2].

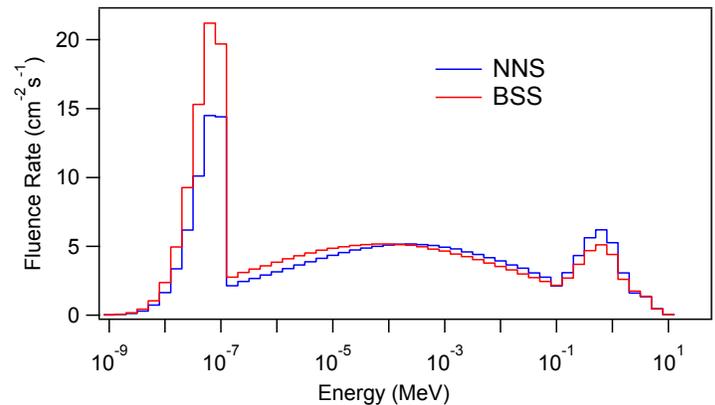


Figure 4: Neutron spectrum measured near the basement perimeter wall of a CANDU reactor at the Gentilly 2 power station in Bécancour, Canada [3].

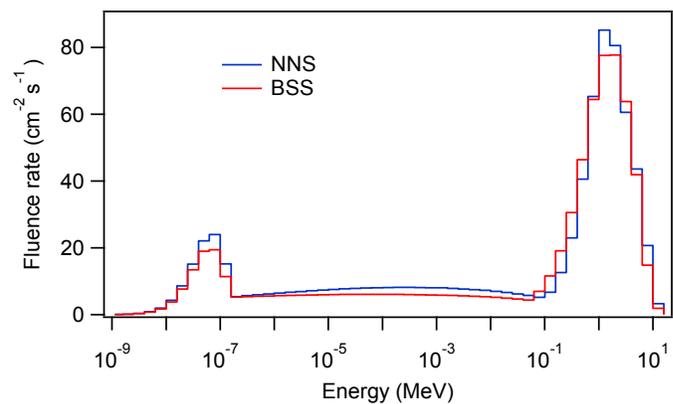
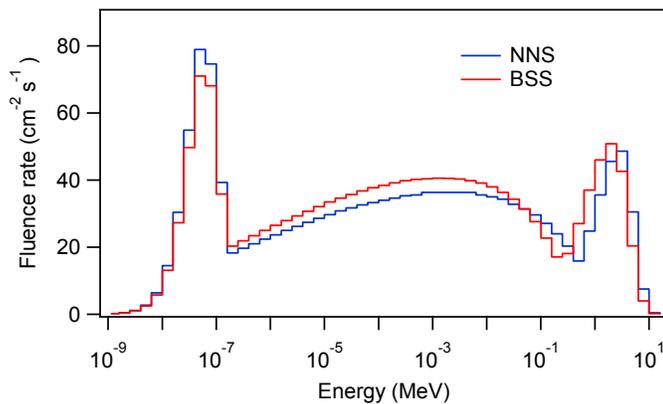


Figure 5: The neutron spectra, measured by the NNS and BSS, of bare (right) and moderated (left) Californium-252. Both tests were conducted at the Health Physics Neutron Generator facility in Chalk River, Canada [1].

3. References

1. J. Dubeau, et. al., A Field Portable Neutron Spectrometer, *Pending Pub. in IEEE Transactions on Nuclear Science*.
2. Atanackovic J., et. al., Measurements of Neutron Energy Spectra From $7\text{Li}(p,n)7\text{Be}$ Reaction with Bonner Sphere Spectrometer, Nested Neutron Spectrometer, and ROSPEC, *Nuclear 12 Conference Proceedings Aix-en-Provence, France 2012*. To be Submitted to *Radiation Protection Dosimetry (2013)*, Vol. 0, No. 0, pp. 1-5.
3. Atanackovic J., et. al. Neutron Spectrometry and Dosimetry Study at Two Research Nuclear Reactors Using Bonner Sphere Spectrometer (BSS), Rotational Spectrometer (ROSPEC) and Cylindrical Nested Neutron Spectrometer (NNS). *Radiation Protection Dosimetry*, Vol. 154(3), pp. 364-374, 2013.
4. J. Dubeau, et. al. A Neutron Spectrometer Using Nested Moderators. *Radiation Protection Dosimetry*, Vol. 15(2), pp. 217-22, 2012.