WG6 IPNDV Experimental Technology Data Sheet

November 14, 2019, A. Rozite and H. Tagziria; EC JRC-Ispra; Italy

Name of Experimental Campaign:

Belgium exercise to investigate performance of measurement methods

Technology Name: Nested Neutron Spectrometer

Physical Principle/Methodology of Technology:

Nested Neutron Spectrometer (NNS, a Bonner sphere type device)

The instrument contains a He-3 detector, a set of cylindrical polyethylene (PE) moderators of different thicknesses, an electronic chain to measure neutron count-rate versus moderator thickness and post-processing software to determine the neutron energy spectrum, fluence, and dose-rates.

Figure 1. Principal components of the nested neutron spectrometer

What Does the Method Determine/Measure (e.g., presence of nuclear material, isotopics, mass):

The instrument measures:

(a) Neutron energy spectrum;
(b) Neutron fluence;
(c) Neutron dose-rate.

What Is the Applicability to IPNDV:

Determination of the presence of neutron radiation, measurement of neutron energy spectra (thermal to tens of MeV), neutron fluence, and dose rates. Unaffected by large gamma-ray fields.

Type of Data Collected by the Technology:

Neutron count-rate versus moderator thickness

Constraints (e.g., time to install the equipment, measurement times including distance from object, dose rate required, required Cd shielding to limit the count rate):

A complete measurement is made of eight separate measurements (corresponding to each PE thickness).

For the 61-pin assembly, with the neutron fluence being about 40 n/s/cm^2 at the position of the detector (taking into account the scattering) the duration of each measurement was three to five minutes (depending on the number moderators), which allowed to achieve an error of 2 to 3%.

With a manual change of moderators requiring about one to two minutes, the total time to complete a full measurement at a distance of 125 cm from the NNS was about 30 minutes.

For unknown active length of the object, it is essential to measure at larger distances as to achieve quasi-point-source geometry.

Monte Carlo modeling is required to account for neutron scattering in the room.

Physical Description/Diagram/Photos of the Experimental Setup/Layout:

Figure 2. 61-pin assembly with HDPE/Cd shield (on the left); Nested neutron spectrometer with all moderators (on the table) at SCK●CEN (Be)

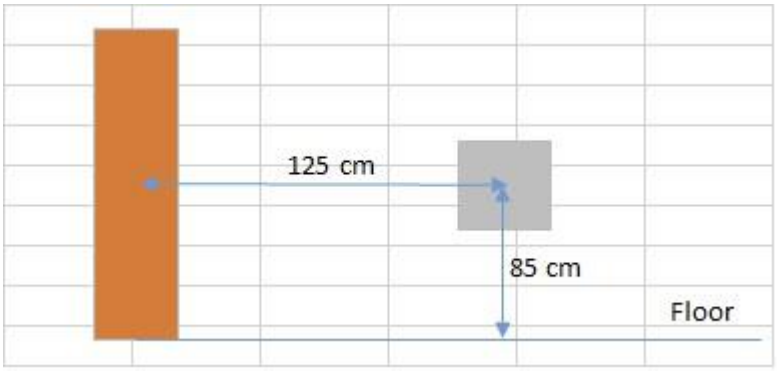

Figure 3. Distance between fuel assembly and nested neutron spectrometer (midpoints)—125 cm

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Specific Objects Measured (which of the experimental objects were measured; if not described elsewhere, describe experimental objects here):

61-pin fuel assembly:

(a) without shield;
(b) with Cd shield;
(c) with HDPE + Cd (2 sides) shield;
(d) with Pb shield.

Process Required to Analyze the Data (include any software used):

Neutron count-rate measuring software.

Neutron energy spectrum deconvolution software that includes processing of the measured neutron count-rate versus moderator thickness, guess (or a priori) spectrum, and detector response functions.

Preliminary Results (qualitative, not quantitative; e.g., did the method perform as expected, if not how was it different):

The measured neutron flux was about twice higher than expected (from calculations), mostly due to the high neutron scattering environment.

Final Results (if available; if not, estimate of when final results will be available):

See Appendix.

Lesson Learned (e.g., what went well, what went wrong or not as expected, do the results confirm what we said in the technology tables?):

Appendix. Results of the Nested Neutron Spectrometer at SCK●CEN

1. Summary of Measured Data

Table 1. Summary of Measurement Parameters		
Parameter	**Value, cm**	
	Sep. 13	Sep.11
Distance to the floor (spectrometer midpoint)	85	46
Distance to the wall (spectrometer midpoint)	110	26
Distance between source and spectrometer (midpoints)	125	125
Distance to the wall (source)	110	110
Distance to the graphite box	163	350
Wall thickness	25,4	25,4
Floor thickness	40	40
Graphite box height	400	400
Room height	700	700

Figure 1. Summary of Measured Count Rates

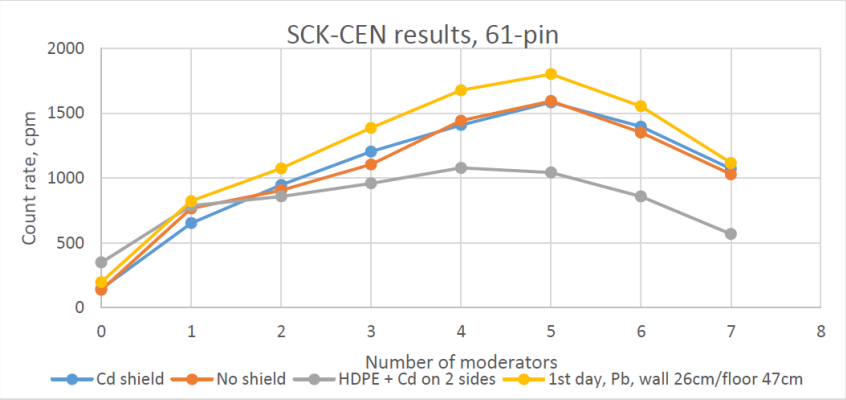


Table 2. Summary of the Measurement Results				
Parameter/Value	Sep. 13			Sep. 11
	Cd 1.1 mm	**No shield**	**HDPE 5 cm, Cd 2-sides**	**Pb 10 mm**
Expected fluence rate, n/s/cm2	17.3			
Measured fluence rate, n/s/cm2	38	37.5	30.6	43
Mean energy (fluence), MeV	1.18	1.15	0.69	0.98
Dose-rate, uSv/h	33.3	32.3	17.5	35.4

2. Detailed Results

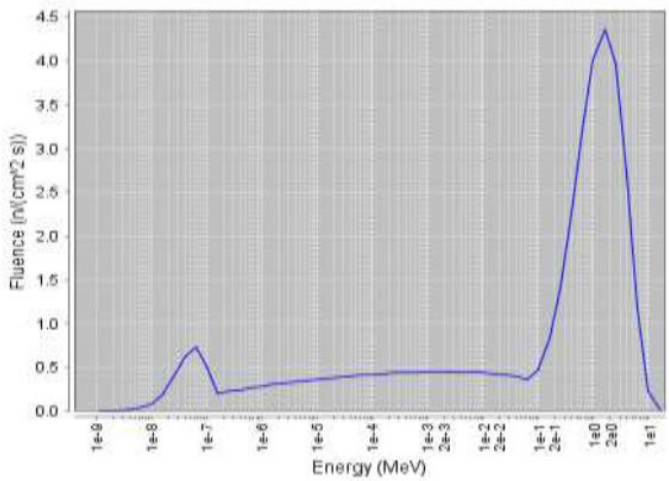
Friday, September 13, 2019: Set of Measurements No. 1

61 pin, Cd shield		

Number of moderators	Count rate, cpm	Error, %
0	147.7	3.00
1	652	1.90
2	946.4	1.90
3	1203.6	1.90
4	1408.3	1.90
5	1583.1	1.90
6	1396.4	1.60
7	1071.3	2.00

Results	
Expected, n/s	3400000
Measured, n/s	7460000
Fluence rate, n/s/cm2	38
Mean energy (fluence), MeV	1.18
Mean energy (dose), MeV	1.98
Dose-rate, uSv/h	33.3
Iterations	100
Guess spectrum	Cf252
Fit	MLEM

Figure 2. Obtained Neutron Spectrum (Set of Measurements No. 1)



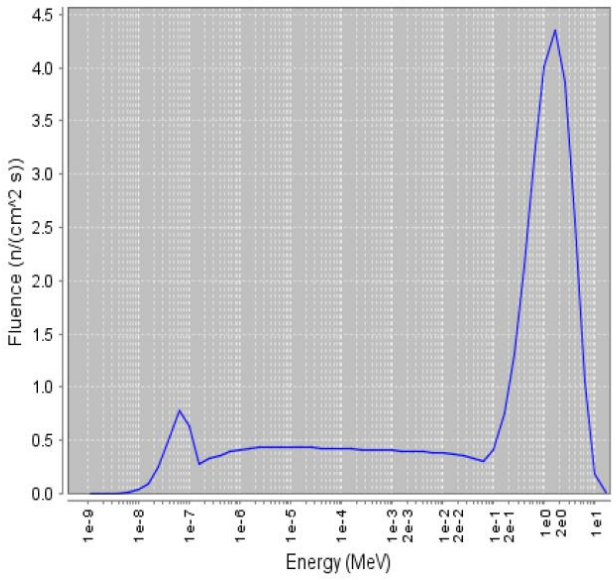
Friday, September 13, 2019: Set of Measurements No. 2

61 pin, without shield		

Number of moderators	Count rate, cpm	Error, %
0	137.8	3.00
1	765.6	2.00
2	906	2.00
3	1104.8	1.80
4	1442.2	1.90
5	1592.9	1.90
6	1350.8	1.60
7	1028.8	2.00

Results	
Expected fluence, n/s	3400000
Measured, n/s	7360000
Fluence rate, n/s/cm2	37.5
Mean energy (fluence), MeV	1.15
Mean energy (dose), MeV	1.94
Dose-rate, uSv/h	32.3
Iterations	100
Guess spectrum	Cf-252
Fit	MLEM

Figure 3. Obtained Neutron Spectrum (Set of Measurements No. 2)



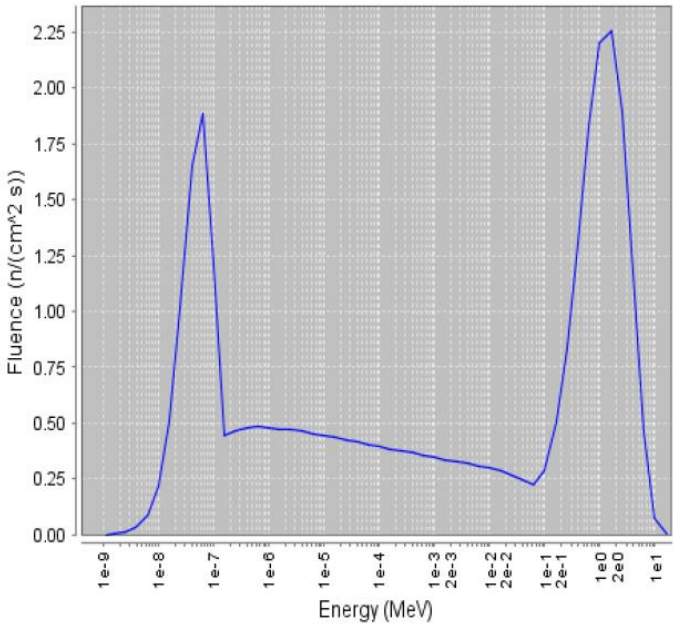
Friday, September 13, 2019: Set of Measurements No. 3

61 pin, with HDPE, 50 mm, with 2 sides Cd, 1.1 mm

Number of moderators	Count rate, cpm	Error, %
0	349.5	2.20
1	786.8	1.90
2	857.7	1.90
3	959.2	2.00
4	1078	1.90
5	1042.5	2.00
6	858.3	2.00
7	568.6	2.90

Results	
Expected fluence, n/s	3400000
Measured, n/s	6000000
Fluence rate, n/s/cm2	30.6
Mean energy (fluence), MeV	0.69
Mean energy (dose), MeV	1.74
Dose-rate, uSv/h	17.5
Iterations	100
Guess spectrum	Cf-252
Fit	MLEM

Figure 4. Obtained Neutron Spectrum (Set of Measurements No. 3)



Wednesday, September 11, 2019: Set of Measurements No. 4

61 pin, Pb shield, 10mm		
Number of moderators	**Count rate, cpm**	**Error, %**
0	197.7	3.00
1	822.5	1.80
2	1074	2.00
3	1386.8	2.00
4	1676.3	1.40
5	1801	0.25
6	1553.4	1.80
7	1116.1	2.00

Results	
Target fluence, n/s	3400000
Measured, n/s	8439000
Fluence rate, n/s/cm2	43
Mean energy (fluence), MeV	0.98
Mean energy (dose), MeV	1.73
Dose-rate, uSv/h	35.4
Iterations	100
Guess spectrum	Cf-252
Fit	MLEM

Berthold Dose-Rate Results for Comparison

		Normalized to distance*
Distance from fuel assembly surface and center of Berthold, cm	50	125
Distance to the floor, cm	56	56
Number of pins	61	61
Shield	Cd	Cd
Neutron dose-rate, uSv/h	128	20.5**

*Solid angle correction cannot be easily applied as fuel not a point source at such small distance

**Compared to 33.3 uSv/h measured with the NSS