RESPONSE FUNCTION OF A NEUTRON DOSE-RATE METER: UNFOLDING EVALUATION AND VERIFICATION

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I. Introduction

Many attempts have been done to achieve the response functions of neutron meters as a radiation protection guided curve (i.e. ICRP 74 neutron fluence-to-ambient dose equivalent conversion coefficients) to make the calibrations of neutron meters independent of incident neutron average energies.

In the present work, a computer code has been developed based on the Singular Value Decomposition (SVD) unfolding approach for determining the response function of a neutron dose rate meter (i.e. the Aloka TPS-451C neutron meter) as a function of various incident spectral neutron fluence rate average energies. In order to verify the method, the self-developed computer code was applied to determine the response functions of Bonner sphere spectrometer (BSS) system which were then compared with those published in IAEA technical report series No. 403. Since the reliability of the computer code is confirmed it has been used to determine the response function of the Aloka TPS-451C neutron meter.

II. Material and Method

II.1. Properties of neutron standard fields

Table 1: Dosimetric parameters of the neutron standard fields

Standard field	Distance (cm)	$\overline{E}$ (MeV)	$\widetilde{E}$ (MeV)	$\varphi_{(E)}^{\circledast}$ ($cm^{-2}.s^{-1}$)	$H^*(10)^{\circledast}$ ($\mu Sv/h$)
$^{241}Am-Be$	100	4.16	4.40	103.2	145.2
	150			45.9	64.5
	200			25.8	36.3
15PE ($^{241}Am-Be$)$^{\circledast}$	100	1.60	3.42	106.0	104.2
	150	1.57	2.97	68.3	53.2
	200	1.42	3.07	50.4	34.4
20PE ($^{241}Am-Be$)	100	1.60	2.93	104.5	83.8
	150	1.27	2.59	57.3	41.5
	200	1.06	2.58	44.6	26.9
25PE ($^{241}Am-Be$)	100	1.67	3.35	92.8	68.2
	150	1.26	2.95	53.9	33.5
	200	1.06	2.73	37.8	21.6
30PE ($^{241}Am-Be$)	100	1.50	3.01	69.7	51.2
	150	1.27	2.90	41.0	26.8
	200	1.07	2.81	30.4	17.1
35PE ($^{241}Am-Be$)	100	1.35	2.89	57.9	39.5
	150	1.25	3.04	33.5	20.3
	200	1.04	2.75	23.5	13.1

$\overline{E}$: neutron energy averaged over fluence spectrum
$\widetilde{E}$: neutron energy averaged over ambient dose equivalent spectrum
$\circledast$: $^{241}Am-Be$ source moderated by a polyethylene sphere with a diameter of 15 cm
$\circledast$: data normalized to October 1, 2019

This parameters (especially, the values of H*(10)' and the corresponding spectral neutron fluence rate caused those values of H*(10)') were used as input data for the computer code in order to determine the response function of the Aloka TPS-451C neutron meter.

II.2. Measurements of $H^*(10)'$ by Aloka TPS-451C neutron meter

Table 2: Specifications of Neutron Survey Meters and Measurements of H(10)'*

Neutron detector	^3He
Neutron energy range	Thermal – 15 MeV
Photon sensitivity	Non (in general)

Aloka – TPS 451C/ Hitachi

Seq. No	Incident spectral neutron fluence rate ($cm^{-2}.s^{-1}$)	Measured H*(10)' by Aloka TPS-451C (µSv/h)
1	$\phi_i(E_b)$	$H^*(10)_i'$
2		
....		
30	see (II.3)	see (II.3)

II.3. SVD approach for unfolding response function of neutron meter

$$H^*(10)_i' = \sum_{b=1}^{n} R_H(E_b) \times \phi_i(E_b)$$

see Tab. (2) — need to be calculated — see Tab. (2)

Units of quantities in this Eq. are dependent on the studied case - see (Fig.1) and (Fig.2).

Where, H'(10)' (unit can be converted into $pSv.s^{-1}$) measured by the Aloka TPS-451C neutron meter, corresponding to the i[th] incident spectrum $\Phi_i(E_b)$ (unit of $cm^{-2}.s^{-1}$); $R_H(E_b)$ (unit can be deduced as $pSv.cm^2$) is the response function of the Aloka TPS-451C neutron meter needed to be calculated

Main sequence steps of SVD unfolding method

- ***Initialization***: Define the bin number of $H^*(10)_i'$ and $R_H(E_b)$; Define the covariance matrix of $H^*(10)_i'$; Prepare an initial guess of the response function $R_H(E_b)$ based on Monte Carlo simulation or published data.
- ***Mathematic transformation***: Perform the mathematic transformation (i.e., rescaling, rotating, matrix eigen and inversion, etc.).
- ***Unfolding and uncertainty estimation***: Determine the effective rank of related matrices to obtain the final solution; Based on the mathematic transformations, finally the solution of $R_H(E_b)$ and its uncertainty are achieved.

III. Result and Discussion

III.1. Response functions of BSS system

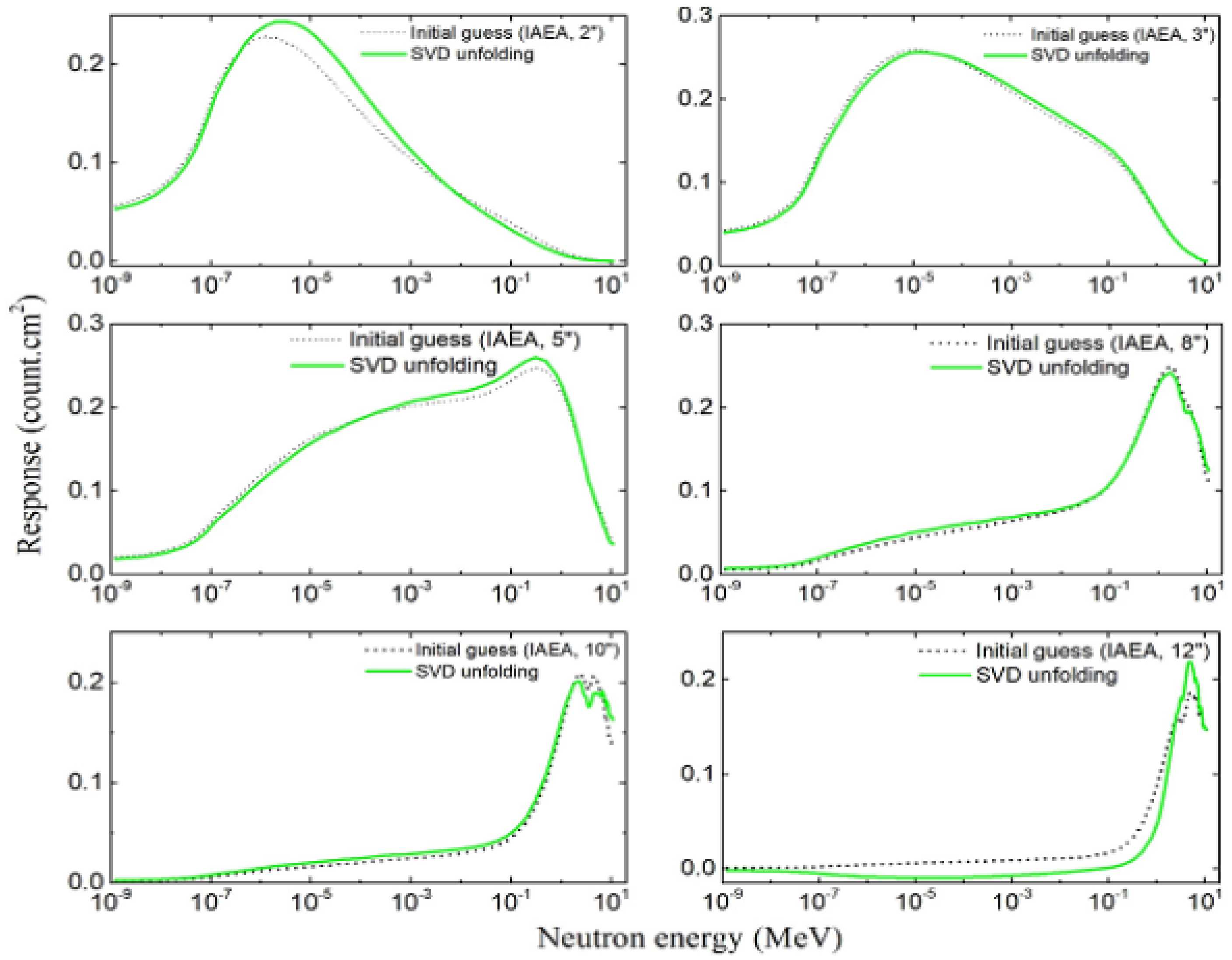

Fig.1: Response functions of all BSS system obtained from the SVD unfolding approach in comparisons with the initial guesses taken from IAEA Techical report series No. 403

Ones can figure out the good agreement of $R_H(E_b)$ between calculated and published data. That means the self-developed computer code is applicable to estimate the response functions of neutron meters.

III.2. Response function of the Aloka TPS-451C neutron meter

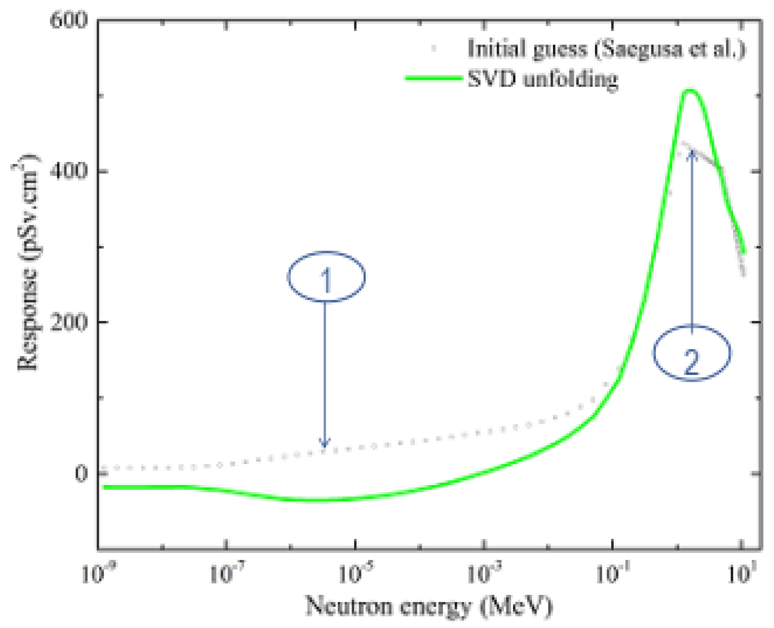

Fig.2: Response function of the Aloka TPS-451C neutron meter determined by SVD approach with the initial guess from published data (i.e. Saegusa et al). The responses were normalized at the energy of 4.16 MeV.

The difference between these two response functions (at energy smaller than 0.1 MeV) can be acceptable for radiation protection purpose because the fluence to dose conversion coefficients are small in this region.

For energy greater than 0.1 MeV, ones can see the good agreement between these two response functions at most of energies (except the region 2 which was interpolated from published data of Saegusa et al.). That means the Aloka TPS-451C neutron meter is suitable for radiation safety assessment and protection purposes.

IV. Conclusion

The response function of the Aloka TPS-451C neutron meter was investigated and compared with a published initial guess using a self-developed computer code. The reliability of the computer code was confirmed in calculations of Bonner sphere spectrometer response functions which were then compared with those in published data. The consistence between the calculated response functions and their initial guesses taken from published data means that the self-developed computer code is applicable for determining response functions of neutron meters and the Aloka TPS-451C neutron meter is suitable for neutron safety assessment and radiation protection purposes.

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