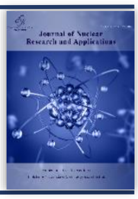
Journal of Nuclear Research and Applications

Research Paper
DOI: 1024200/jon.2022.1017



Cited in: https://jonra.nstri.ir
Received: 3 April 2022, Accepted: 19 April 2022

Analytical investigation on the shape of the response functions of Superheated Drop Detectors using Evaluated Nuclear Data

S. Badiei*

Radiation Application Research School, Nuclear Science and Technology Research Institute (NSTRI), Postcode: 14155-1339, Tehran, Iran

ABSTRACT
In this paper, the response matrix of Superheated Drop Detector was analyzed and investigated using Evaluated Nuclear Data. Elastic, nonelastic and total neutron cross sections were extracted and used for calculating the probability of the production of charged particles as a result of neutron interaction with superheated liquid nuclei. The values of the response functions in each energy are proportional to the probability of the production of charged particles. It was proposed that the response function can be represented as the multiplication of the total neutron cross sections by a monotonic probability function. The parameters associated with this function change with changing the physical properties of the detector such as temperature or external pressure. The growth rate of this function decreases when the temperature decreases or the external pressure on detectors increases due to increase in threshold energy for the generated charged particles. So the growth rate and shape of this function are set by parameters which are dependent on the physical properties of Superheated Drop Detectors.

Keywords: Response function, Superheated Drop Detector, Evaluated Nuclear Data File, Neutron cross section.

I. Introduction

Numerous devices and techniques such as Time-of-Flight method [1, 2], semiconductor solid state detectors [3] and capture gated neutron spectrometers [4] are generally utilized for neutron spectrometry. Regardless of many advantages of the aforementioned methods, there are as well, some complications in their uses and performances. For instance, low detection efficiency, complex detector design, intricate related electronics and problems in pulse processing methods.

A number of these difficulties can be resolved via using Superheated Drop Detectors (SDDs) which are frequently utilized for neutron spectrometry and dosimetry. These detectors that are developed based on a principle that was recognized in the 1950s [5], comprises tiny superheated drops distributed uniformly in a host gel medium [6-9]. If the charged particles generated due to neutron interactions with superheated liquid nuclei have sufficient stopping power and consequently sufficient energy (greater than a threshold value), cause the drop to evaporate and a visible bubble will be formed in the detector [6-9]. This detector can be seen in Fig.1 after irradiation in a neutron field.

Since SDDs are unresponsive to thermal neutrons, these detectors are a good choice for fast neutron spectrometry. They have numerous advantages, for example simple and fast fabrication, easy use procedure and low cost. Some of the disadvantages

**Corresponding Author name*: S. Badiei
E-mail address: shbadiei@aeoi.org.ir

Fig. 1 The SDD after irradiation in the field of ^{241}Am-Be neutron source.

are the production of spontaneous bubbles as the background and complications in counting the bubbles with the naked-eye.

Badiei et al (2019) developed and validated a Geant4 simulation application to calculate the response of SDDs (number of the formed bubbles) [6]. Also in 2021 this application was utilized for investigation of the processes and effective charged particles which are important for bubble formation in SDDs [10]. Moreover, in [6] this application was used to calculate the response matrix of a set of SDDs made from Freon-12 (CCl_2F_2) operating under different external pressures. One of these response functions at the external pressure of 1.32 atm is depicted in Fig. 2.

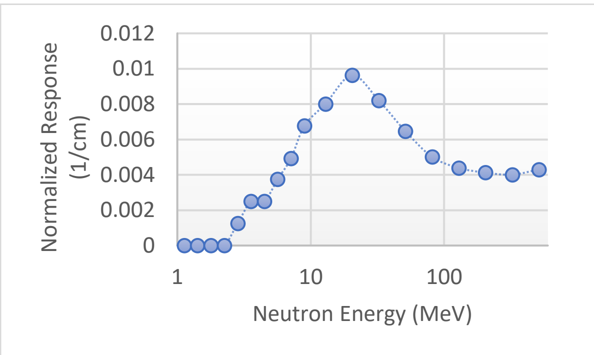


Fig. 2 The response function of an SDD made from Freon-12 (CCl2F2) operating under the external pressure of 1.32 atm as the number of bubbles per unit neutron fluence per unit superheated liquid volume.

The aim of the present research is to investigate and analyze the response functions and try to explain the main features of these curves by means of Evaluated Nuclear Data File (ENDF Database Version 2021-05-14) [11, 12].

This analysis also, can be considered as another validation of the response matrix of SDDs that ensures their uses in future researches.

II. Research Theories

An SDD made from Freon-12 with the chemical compound of CCl_2F_2 (superheated liquid nuclei are: ^{12}C, ^{19}F, ^{35}Cl: abundance 75%, ^{37}Cl: abundance 25%) was considered in this study. It was mentioned in [10] that one of the remarkable advantages of simulation of the superheated drop detectors in addition to practical experiments is that we can distinguish the nuclei and interactions that are more effective for bubble formation. It was observed that both elastic scattering and transmutation interactions [13-16] of neutrons with superheated liquid nuclei are important for bubble formation. Simulation results showed that the nuclei ^{19}F, ^{35}Cl, ^{37}Cl, ^{12}C, ^{32}P, ^{35}S, ^{16}N, ^{15}N, ^{8}Be and ^{16}O are mainly playing role in bubble formation. The results also, showed that ^{19}F, ^{35}Cl, ^{37}Cl and ^{12}C are generated due to elastic scattering of neutrons with superheated liquid drop nuclei and others are due to nonelastic (transmutation) interactions, such as ^{35}Cl (n,α) ^{32}P, ^{35}Cl (n, p) ^{35}S, ^{19}F (n,α)^{16}N and ^{19}F (n, nα)^{15}N.

Moreover, nonelastic interactions have the main contribution in the response of SDDs in high energy regions, so that at the energy of 40 MeV, that contribution is about 70%. This percentage increases when the energy of the neutron increases. Some of nonelastic cross section data are depicted in Figs. 3 and 4. Also, neutron elastic cross sections with ^{35}Cl is shown in Fig. 5.

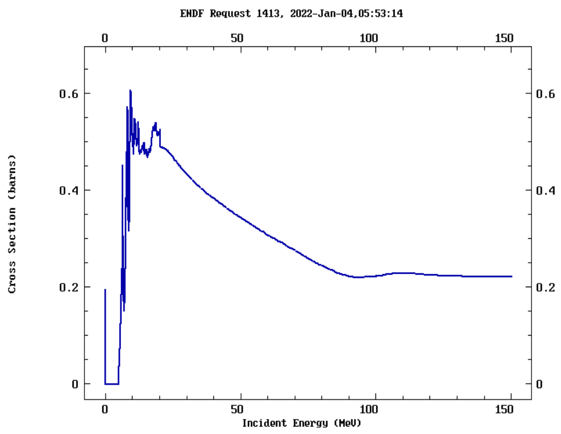


Fig. 3 Neutron non-elastic cross sections with ^{12}C [11].

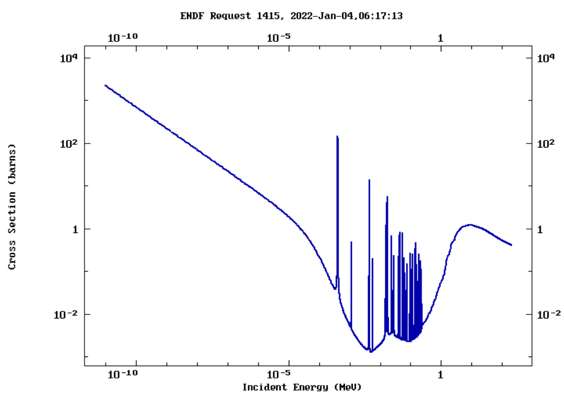


Fig. 4 Neutron non-elastic cross sections with ^{35}Cl [12].

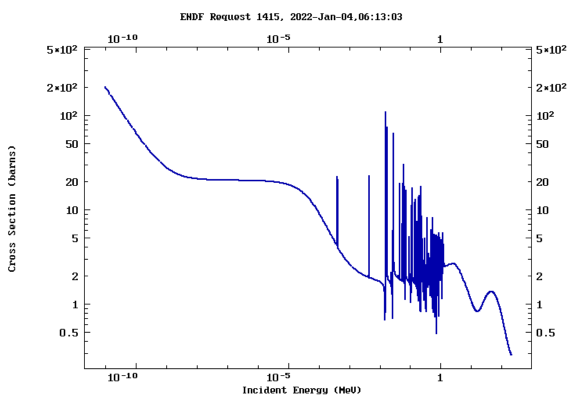


Fig. 5 Neutron elastic cross sections with ^{35}Cl [12].

III. Methods

Observing the response function of Fig. 2, the two main features of the function are observed as follows:

1. The response function has a peak in energies about 20 MeV.
2. It is nearly flat after 100 MeV.

For demonstrating these properties and analyzing the functions, the elastic and nonelastic cross sections of neutron interactions with superheated liquid nuclei (^{12}C, ^{19}F, ^{35}Cl : abundance 75%, ^{37}Cl : abundance 25%) were extracted from the ENDF database [11, 12], because the probability of the production of charged particles is proportional to neutron cross sections. This probability is the main component of the probability of bubble formation which is related to the response functions. Regarding the response function of Fig.2, calculated for energies beyond 100 MeV, the cross section data corresponding to higher energy region were selected.

For a more quantitative and precise analysis, the total neutron cross section (elastic + nonelastic) was calculated based on the number of elements in the chemical compound of Freon-12 and their natural abundance, in energies between 1 MeV to 200 MeV (the blue curve of Fig. 6). To do so, the total neutron cross section for each element was weighted by its abundance percentage and was multiplied by the number of that element in the chemical compound of Freon-12. Finally the neutron cross sections were summed for all the elements of Freon-12, as can be seen in Eq. (1) and is depicted by the blue curve of Fig. 6:

$$\sigma_{total}(E) = \sigma_{12_C}(E) + 2\left(0.75\sigma_{35_{Cl}}(E) + 0.25\sigma_{37_{Cl}}(E)\right) + 2\sigma_{19_F}(E) \quad (1)$$

III. Results and Discussion

As it is obvious, diagrams of the Figs. 3 and 4 have a peak about 20 MeV, and are nearly flat after 100 MeV which are similar in behavior with the response function of the Fig. 2. But the blue diagram of the Fig. 6 (the total cross section) does not show similarity with the response function.

One reason could be, that diagram (total cross section, p_1), is proportional to the probability of the generation of charged particles, and also, these charged particles should have enough energy (greater than a threshold value) for bubble formation. Our hypothesis to reflect this fact, is that the blue function of the Fig. 6 (total cross section) should be multiplied by another probability (p_2) which is the probability of bubble formation for the generated charged particles.

Since the bubble formation is unlikely for low energy particles and this probability increases with energy until reaching saturation, a monotonic probability function similar to the orange function of Fig. 6 can be considered for P_2. Here, this function has a simple form of $P(E) = 1-1/E$.

It is worth noting that this function (p_2) depends on the physical properties of SDDs such as temperature and external pressure because the growth rate of this function decreases when the temperature decreases or the external pressure on detectors increases due to increase in threshold energy for the generated charged particles. So the growth rate and shape of this function are set by parameters which are dependent on the physical properties of SDD. Determining these parameters and research on this function can be the subject of future research. The total probability for

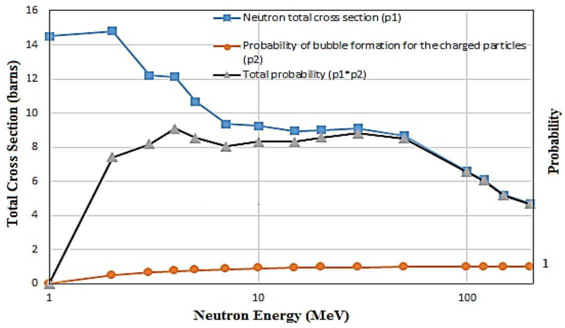


Fig. 6 Total neutron cross sections with superheated liquid nuclei (p_1), the probability of bubble formation for the charged particles (p_2) and total probability of bubble formation versus neutron energy ($p_1.p_2$).

bubble formation is the product of these two curves ($p_1.p_2$) which is depicted by the black curve in Fig.6 and is to some extent similar to the response function of SDDs. It is clear that this function must be multiplied by constants so that two functions have the same physical unit.

The reason for the slight difference in the range of 8 to 20 MeV could be that the calculated total cross section may include processes that do not produce charged particles. To overcome this problem, the total cross-section should be replaced with charged particle generator interactions cross-section.

IV. Conclusions

In this research the response functions of SDDs were studied using Evaluated Nuclear Data. Elastic, nonelastic and total neutron cross sections were extracted and utilized for computing the likelihood of the liberation of charged particles as a result of neutron interaction with superheated liquid nuclei. It was proposed that the response functions of SDDs can be represented as the multiplication of the total neutron cross sections by a monotonic probability function. The growth rate of this function is determined by a set of parameters which are dependent on the physical properties of SDD. Working on these parameters and research on the function can be the subject of future research.

References

1. M. GATU JOHNSON et al. *The 2.5 MeV neutron time-of-flight spectrometer TOFOR for experiments* at JET, Nucl. Instrum. Meth. Phys. Res. A. **591**(2), 417 (2008).
2. J.R.D. Copley, T.J. Udovic, J. Res, *Neutron Time-of-Flight Spectroscopy*, Natl. Inst. Stand. Technol. **98**, 71 (1993).
3. R. Ciolini et al. *A feasibility study of a SiC sandwich neutron spectrometer*, Radiation Measurements**. 46** (12), 1634 (2011).
4. J.B. Czirr et al. *Capture-gated neutron spectrometry*, *Nucl. Instrum*. Meth. Phys. Res. A.**476** (1–2), 309 (2002).
5. F. Seitz, *On the theory of the Bubble Chamber*, The Physics of Fluids. **1** (1), 2 (1958).
6. S. Badiei et al. *Development and validation of a Geant4 application to calculate the response matrix of a set of superheated drop detectors under various external pressures*. *Nucl. Instrum.* Meth. Phys. Res. A. **939**, 55 (2019).
7. S. Badiei et al. *Unfolding of fast neutron spectra by superheated drop detectors using Adaptive Network-Based Fuzzy Inference System (ANFIS)*, *Nucl. Instrum*. Meth. Phys. Res. A. **944**, 162517 (2019).
8. S. Badiei et al. *Development and experimental validation of a fast neutron spectrometry system based on Superheated Drop Detectors (SDDs) operating under different external pressures*, *Nucl. Instrum.* Meth. Phys. Res. A. **1010**, 165569 (2021).
9. P. Rezaeian et al. *Development of a new pressure dependent threshold superheated drop detector for neutrons*, *Nucl. Instrum*. Meth. Phys. Res. A. **776**, 50 (2015).
10. S. Badiei et al. *Investigation of processes and effective charged particles for bubble formation in Superheated Drop Detectors using Geant4 simulation toolkit*, 27th Iran Nuclear Conference, Mashhad Ferdowsi University (2021).
11. G.M. Hale, P.G. Young, C.Y. Fu, *ENDF/B-VIII.0, U.S. Evaluated Nuclear* Data Library (2018).
12. A.J. Koning and D. Rochman, *TENDL-2019 TALYS-based Evaluated Nuclear* Data Library (2019).
13. V. McLane, C. L. Dunford, P. F. Rose, *Neutron Cross Sections. Elsevier. ISBN 978-0-323-14222-9.* OCLC 1044711235 (2012).
14. J. R. Lamarsh, *Introduction to nuclear reactor theory*, Addison-Wesley Reading, MA, 1966.
15. H. L. Taylor, O. Lönsjö, and T. W. Bonner, *Nonelastic Scattering Cross Sections for Fast Neutrons*, Phys. Rev. **101**, 1835 (1956).
16. M. Ibaraki et al. *Measurement of Neutron Non-elastic Cross Sections of C, Si, Fe, Zr and Pb in 40 - 80 MeV Region*, Journal of Nuclear Science and Technology, **39** :sup2, 405 (2002).

How to cite this article
S. Badiei, Analytical investigation on the shape of the response functions of Superheated Drop Detectors using Evaluated Nuclear Data, *Journal of Nuclear Science and Applications,* Vol. **3,** No. **2, (2022),** P **25-29,**
Url: https://jonra.nstri.ir/article_1468.html **, DOI**:1024200/jon.2022.1017