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

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Abstract

In this paper the response matrix of Superheated Drop Detector was analyzed and investigated using Evaluated Nuclear Data. Elastic, non-elastic and total neutron cross sections were extracted and used for calculating the probability of the production of charged particles as the result of neutron interaction with superheated liquid nuclei. It was shown that the response function can be represented as the multiplication of the total neutron cross sections by a monotonic probability function which depends on the physical properties of SDDs.

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

Introduction

Among neutron detectors, Superheated Drop Detectors (SDDs) are frequently used for neutron spectrometry and dosimetry, which comprises tiny superheated drops distributed uniformly in a host gel medium [1-3]. 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 [1-3].
Badiei et al (2019) developed and validated a Geant4 simulation application to calculate the response of SDDs (number of the formed bubbles). Also, Badiei et al (2021) utilized this application for investigation of the processes and effective charged particles which are important for bubble formation in SDDs. Moreover, in [1] 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 (see Fig. 1).

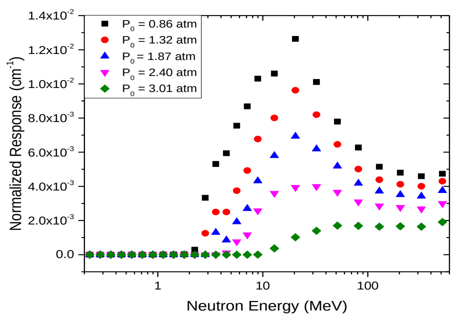

Figure 1. The response matrix of a set of SDDs made from Freon-12 (CCl_2F_2) operating under different external pressures [1].

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

Experimental

Observing the response functions of Fig. 1, the two main features of the functions are observed as follows:

1. All functions have a peak in energies about 20 MeV.
2. They are nearly flat after 100 MeV.

For demonstrating these properties and analyzing the functions, the elastic and non-elastic 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 [5,6], 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 functions of Fig.1, calculated for energies beyond 100 MeV, the cross section data corresponding to higher energy region were selected.
It was mentioned in [4] that non-elastic 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 non-elastic cross section data are depicted in Figs. 2 and 3. Also, neutron elastic cross sections with ^{35}Cl is shown in Fig. 4.
For a more quantitative and precise analysis, the neutron total cross section (elastic + non-elastic) 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. 5).

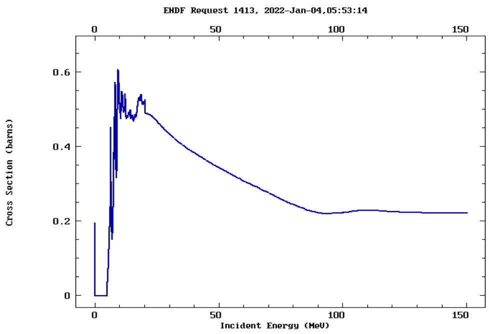

Figure 2. Neutron non-elastic cross sections with ^{12}C [5].

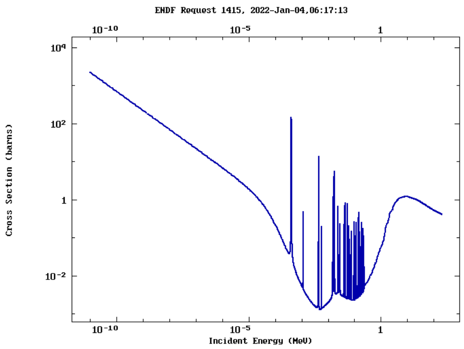

Figure 3. Neutron non-elastic cross sections with ^{35}Cl [6].

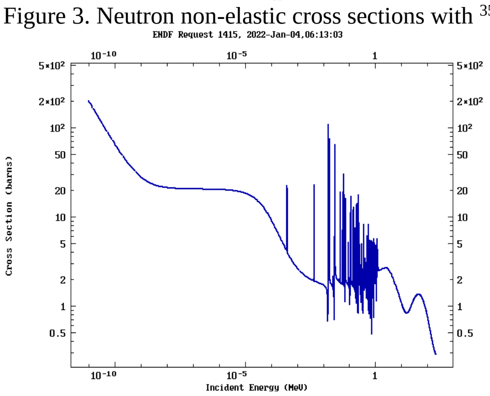

Figure 4. Neutron elastic cross sections with ^{35}Cl [6].

Results and discussion

As it is obvious, diagrams of the Figs. 2 and 3 have a peak about 20 MeV, and are nearly flat after 100 MeV which are similar in behavior with the response functions of the Fig. 1. But the blue diagram of the Fig. 5 does not show similarity with the response functions. One reason could be, that diagram (total cross section), shows 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 propose to reflect this fact, is that the blue function of the Fig. 5 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, the orange function of Fig. 5 is proposed. 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. 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. The total probability for bubble formation is the product of these two curves which is depicted by the black curve in Fig.5 and is to some extent similar to the response function of SDDs. The reason for the slight difference could be that the calculated total cross section may include processes that do not produce charged particles.

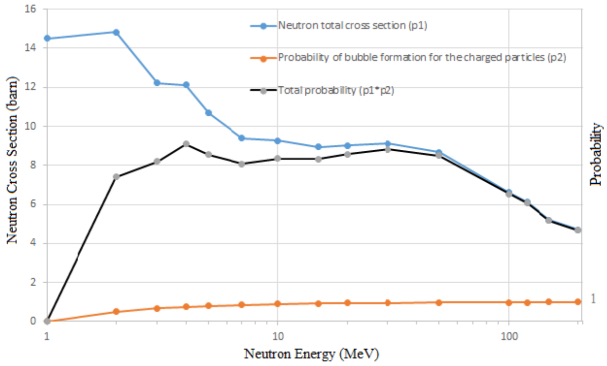

Figure 5. Total neutron cross sections with superheated liquid nuclei, the probability of bubble formation for the charged particles and total probability of bubble formation versus neutron energy.

Conclusions

This research studied the response functions of SDDs using Evaluated Nuclear Data. It was shown that these response functions could be represented as the multiplication of the total neutron cross sections by a monotonic probability function.

References

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