Filtered thermal neutron captured cross sections measurements and decay heat calculations

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Abstract

Recently, a pure thermal neutron beam has been developed for neutron capture measurements based on the horizontal channel No.2 of the research reactor at the Nuclear Research Institute, Dalat. The original reactor neutron spectrum is transmitted through an optimal composition of Bi and Si single crystals for delivering a thermal neutron beam with Cadmium ratio (R_{cd}) of 420 and neutron flux (Φ_{th}) of 1.6×10^6 n/cm^2.s. This thermal neutron beam has been applied for measurements of capture cross sections for nuclide of ^{51}V, by the activation method relative to the standard reaction ^{197}Au(n,γ)^{198}Au. In addition to the activities of neutron capture cross sections measurements, the study on nuclear decay heat calculations has been also considered to be developed at the Institute. Some results on calculation procedure and decay heat values calculated with update nuclear database for ^{235}U are introduced in this report.

I. Introduction

The first object of this works is to measure the thermal neutron capture cross sections on the new thermal filtered neutron beam at the channel No.2 of Dalat research reactor. The measurements were carried out by the activation method, relative to the standard capture cross section of ^{197}Au. The thermal filtered neutron is tailored by using a combination of 80cm Si and 6cm Bi single crystals. The second object is to calculate decay heat data for fission products from a thermal neutron fission reaction of ^{235}U. In this study, a computation procedure has been improved for calculating the decay and buildup of fission products following time after a fission reaction or a fission process. The method used in this calculation is numerical analysis, in which the buildup and decay of fission product nuclides are analyzed by exactly analysis of the general solutions of the Bateman's Equations [1] for every full complex decay chain. Based upon the input data of nuclear decay and fission yield data from JENDL4.0 [2], the concentration of each nuclide as a function of cooling time is determined.

II. Filtered Thermal Neutron Capture Cross Section Measurements

The measurements for neutron capture cross sections of ^{51}V(n,γ)^{52}V reaction were performed on the thermal filtered neutron beams at the Dalat reactor. The neutron beams were collimated to 3cm in diameter with neutron flux of 1.6×10^6n/cm^2.s, and the value of Cadmium ratio R_{Cd}(Au) is 420. The thermal neutron capture cross sections, $<\sigma_0>^x$, for nuclide x can be determined relative to that of ^{197}Au(n,γ)^{198}Au standard reaction by the following relations:

$$<\sigma_a> = \frac{C^x f(\lambda,t)^x f_c^x I_\gamma^{Au} \varepsilon_\gamma^{Au} N^{Au} <\sigma_a>^{Au}}{C^{Au} f(\lambda,t)^{Au} f_c^{Au} I_\gamma^x \varepsilon_\gamma^x N^x} \quad (1)$$

$$f(\lambda,t) = \frac{\lambda}{(1-e^{-\lambda t_1})e^{-\lambda t_2}(1-e^{-\lambda t_3})} \quad (2)$$

where C is the net counts of the corresponding gamma peak; the superscript 'x' denotes the nucleus of sample; t_1, t_2 and t_3 are irradiating, cooling and measuring times, respectively. The symbol λ denotes the decay constant of the product nucleus, ε_γ the detection efficiency of detector, I_γ the intensity of interesting γ-ray. f_c is the correction factor which is account for self-shielding and multiple scattering of neutron in the irradiated sample and standard. The standard thermal neutron capture cross section of ^{197}Au is adopted from the reference [3]. The correction factors for the neutron self-shielding, multi-scattering were calculated by Monte-Carlo method using MCNP5 code [4].

The result of measurement in this work for thermal neutron capture reaction of $^{51}V(n,\gamma)^{52}V$ is σ_0 = 5076 ± 151 (mb), and the comparison with previous experimental data extracted from EXFOR data base [5] is shown in Fig.1.

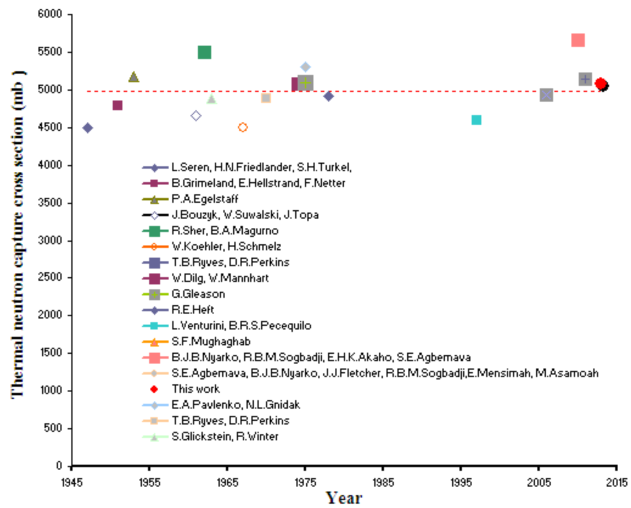

Fig. 1. The experimental thermal neutron capture cross section of ^{51}V

III. Decay Heat Calculations

The number of the nuclide ith at cooling time t after a fission burst can be calculated from the following formula:

$$N_i(t) = N_i(0)\exp(-\lambda_i t) + \sum_{j\neq i}^{M} N_{j\rightarrow i}(t)\,, \qquad (3)$$

in which, $N_i(0)$ is equal to the independent fission yield of the nuclide ith, and the part of $N_{j\rightarrow i}(t)$ is the build-up number of nuclide ith at cooling time t, that was formed in the system of decay chains originated from the nuclide jth. This term of build-up number can be obtained by analysis the general solutions of the Bateman's equation for every particular linear decay chain. In this work, we developed a numerical algorithm to calculate the term of $N_{j\rightarrow i}(t)$ in equation (3) directly by using the decay data file and fission yield data from evaluated nuclear structure data libraries. In general case for a linear decay chain, the quantity of $N_{j\rightarrow i}(t)$ is calculated by using the solution of Bateman's equation as following expression.

$$N_{j\rightarrow i}(t) = \sum_{l=1}^{i}\prod_{k=l}^{i-1} N_l(0)\left(\sum_{m=l}^{i}\frac{e^{-\lambda_m t}}{\prod\limits_{\substack{j=l\\ j\neq m}}^{i}(\lambda_j-\lambda_m)}\right) \qquad (4)$$

The computer program called DHP (Decay Heat Power) [6] was applied with the present procedure to perform the above mentioned calculation tasks. In this calculations, all of decay chains and decay modes including β^- decay to ground, fist and second isomer states, double β^- decay, electron capture decay to ground and isomer states, alpha and proton decay, delay neutron β^- decay, and internal transitions in the fission product system are taken into consider in the calculated procedure. The summation model for decay heat calculations is as the following function:

$$f(t) = \sum_{i=1}^{M} \overline{E_i} \lambda_i N_i(t), \qquad (5)$$

where: M denotes the maximum number of FP nuclides; $E_i = E_{i\beta} + E_{i\gamma}$ stands for the mean energy per decay of the ith nuclide, λ_i the decay constant, $N_i(t)$ the corresponding concentration function for cooling time t. f(t) is the burst function of decay heat (MeV/Fission/s). The physical quantity equal to t*f(t) is called decay heat power function (MeV/Fission). In this work, the JENDL FP Decay Data File 2011 [7] and fission yield data file from JENDL 4.0 [2] have been applied for calculations of fission product concentrations as functions of cooling time after thermal neutron fission reactions of ^{235}U. The results of calculations for t*f(t) as a function of times after fission burst are shown in Figure 2 in comparison with measured values by Dicken [8], and Akizama [9].

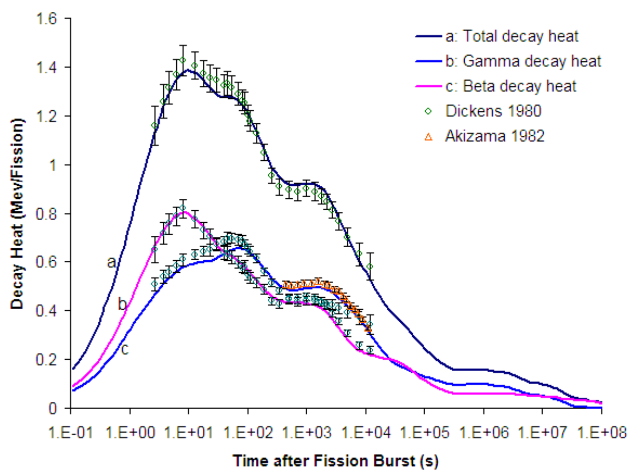

Fig. 2. Decay heat of fission products from thermal neutron fission reaction of ^{235}U

IV. Summary

In this report, we present the activities of thermal neutron capture cross section measurements and decay heat calculations at the Nuclear Research Institute of VINATOM. The thermal neutron capture cross section of $^{51}V(n,\gamma)^{52}V$ reaction has been measured by using the filtered neutron beam at the Dalat research reactor. The decay heat calculation for fission products from thermal neutron fission of U-235 was performed with the DHP code based on the fission yield and decay data files from JENDL-4.0.

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