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RESEARCH ARTICLE

CALCULATION OF FISSION PRODUCT CONCENTRATIONS FOR TIME FOLLOWING A FISSION BURST

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ABSTRACT

Precise information of the variation of fission product concentration for time after a fission burst is necessary for safety designs and operations of nuclear power reactors, fuel storage, transport flasks, and for spent fuel management and processing. In this study, an efficient computation procedure has been introduced for exact analysis of the buildup and decay of fission products for time following a fission burst. The analytical data of fission product concentrations was applied to calculate aggregate fission product decay heat from neutron fission of ^{235}U, ^{238}U, ^{239}Pu and ^{232}Th.

INTRODUCTION

In a fission reaction, fission products (FPs) are formed with initial concentration known as fission yield, but this data still change following time after the end of fission event. This is mainly because of the natural decay of radioactive fission products. In nuclear science and technology, the distribution of concentrations of fission products as functions of cooling time are the key nuclear data (Oyamatsu, 1999; Nichols, 2002) required in aggregate decay heat calculations for designs and operations of nuclear power reactors, fuel storage, transport flasks, and for spent fuel management and processing. In this study, a computation procedure has been developed for calculating the decay and buildup of FPs following time after a fission burst or a fission process. The method used in this calculation is numerical analysis, in which the buildup and decay of FP nuclides are analyzed by exactly analysis of the general solutions of the Bateman's Equations (Tobias, 1980) for every full complex decay chain. Based upon the input data of nuclear decay and fission yield data from JENDL3.3, the concentration of each FP nuclide as a function of cooling time is determined. The present computational algorithm can be applied to solve the difficulty of the solutions for a complex decay-chain system.

Analysis of Decay and Build-up Numbers

The number of the nuclide i^{th} at cooling time t after a fission burst can be calculated from the following formula:

$$N_i(t) = N_i(0)\exp(-\lambda_i t) + \sum_{j \neq i}^{M} N_{j \to i}(t), \qquad (1)$$

in which, $N_i(0)$ is equal to the independent fission yield of the nuclide i^{th}, and the part of $N_{j\to i}(t)$ is the buildup number of nuclide i^{th} at cooling time t, that was formed in the system of decay chains originated from the nuclide j^{th}. This term of buildup 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 $N_{j\to i}(t)$ in equation (2) directly by using the decay data file and fission yield data from JENDL3.3 and/or ENSDF libraries. The procedure is generalized as the following steps:

a. For every nuclide j^{th}, the decay net that started from the nuclide j^{th} is separated to form equivalent linear decay chains.
b. For each linear decay chain, if nuclide i^{th} is a daughter nuclide in the decay chain, apply the general solution of Bateman's equation (Tobias, 1980) to calculate the buildup number of nuclide i^{th} duce to the decay of nuclide j^{th} through the present linear decay chain, at the cooling time t.
c. The amount of $N_{j\to i}(t)$ can be obtained by summing all of the buildup numbers of nuclide i^{th} from all of the linear decay chains.

In general case for a linear decay chain, the quantity of $N_{j\to i}(t)$ is calculated by using the solution of Bateman's equation as following expression.

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$$N_{j\to i}(t)=\sum_{l=1}^{i}\prod_{k=l}^{i-1}N_l(0)\left(\sum_{m=l}^{i}\frac{e^{-\lambda_m t}}{\prod_{\substack{j=l\\ j\neq m}}^{i}(\lambda_j-\lambda_m)}\right) \tag{2}$$

The computer program called DHP (Decay Heat Power) (Pham Ngoc Son and Jun-Ichi Katakura, 2007) 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 block diagram of the present improved computational algorithm is shown in Figure 1.

Application

One of the important significance of the present code is application to prepare input data for FP decay heat power prediction. In this study, the data of FP concentrations as a function of cooling time after a fission burst of ^{235}U, ^{238}U, ^{239}Pu and ^{232}Th have been calculated using the FP Decay Data File 2000 from JENDL3.3 (Katakura *et al.*, 2001). Accordingly, the basis data of FP concentrations have been used to perform the decay heat summation calculation for the above mentioned fissile nuclides. The formula for decay heat summation calculation is as follow:

$$f(t)=\sum_{i=1}^{M}E_i\lambda_i N_i(t), \tag{3}$$

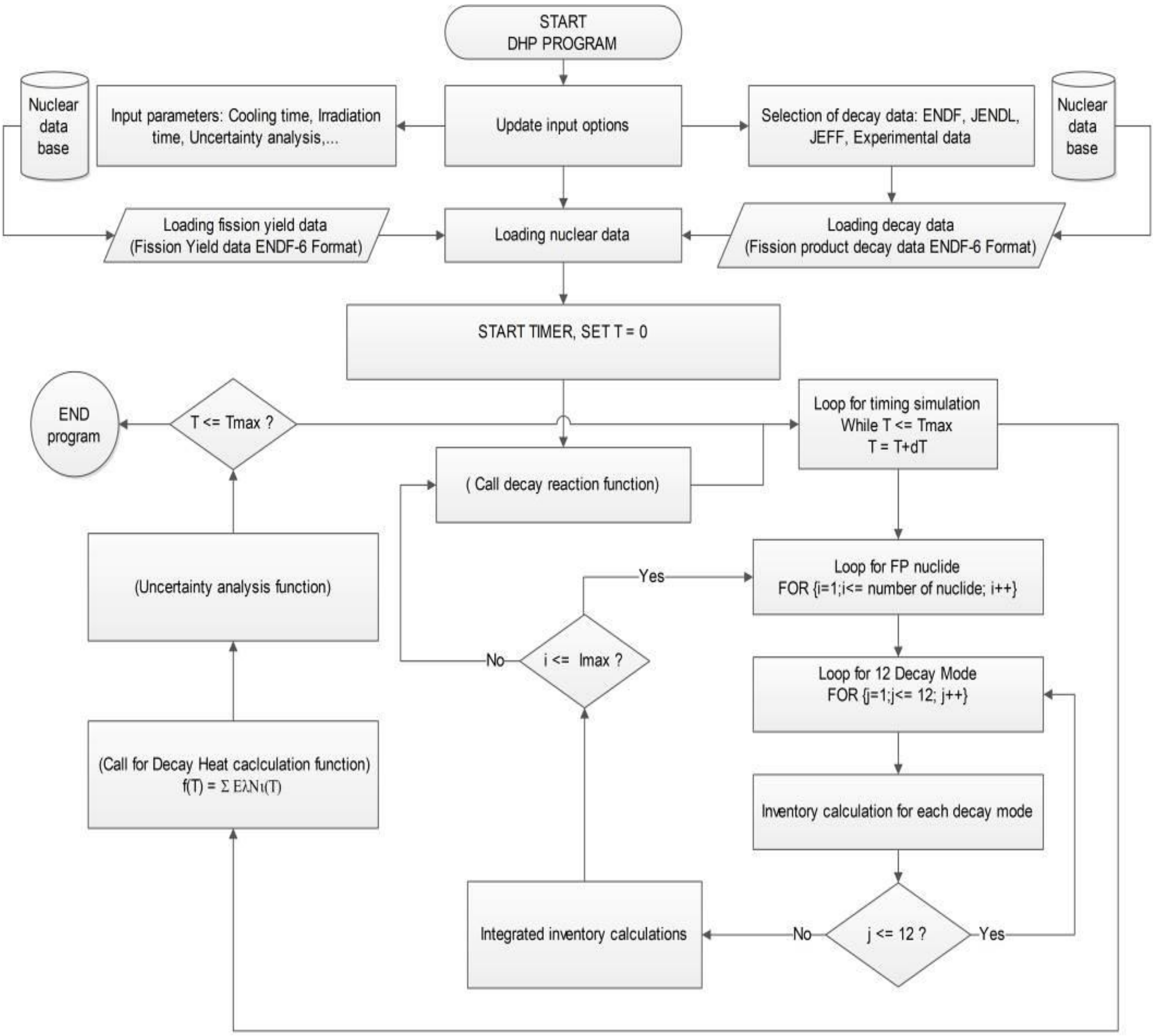

Fig. 1. The block diagram of computational algorithm

where

M The maximum number of FP nuclides,
E_i Mean decay energy per decay of the nuclide I; $E_{i\ total} = E_{i\beta} + E_{i\gamma}$,
λ_i Decay constant of the nuclide i,
$N_i(t)$ Number of the nuclide i at cooling time t (s),
f(t) The burst function (MeV/fission/s).

The physical quantity equal to t*f(t) is called decay heat power (MeV/fission). The results of calculation for t*f(t) as a function of cooling time are shown in Figures 2-5.

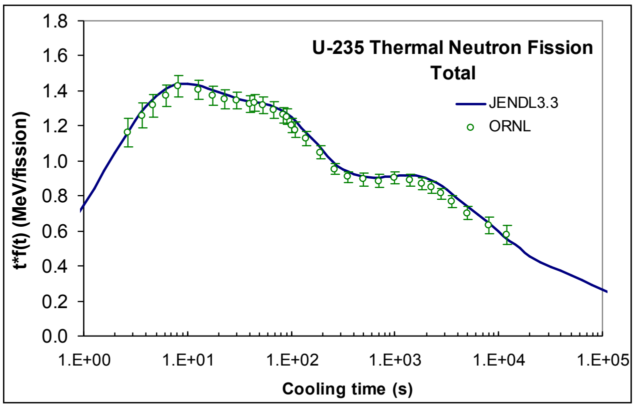

Figure 2. Calculated total decay heat from FPs after a thermal neutron fission burst of ^{235}U, experimental data (Dickens et al., 1981)

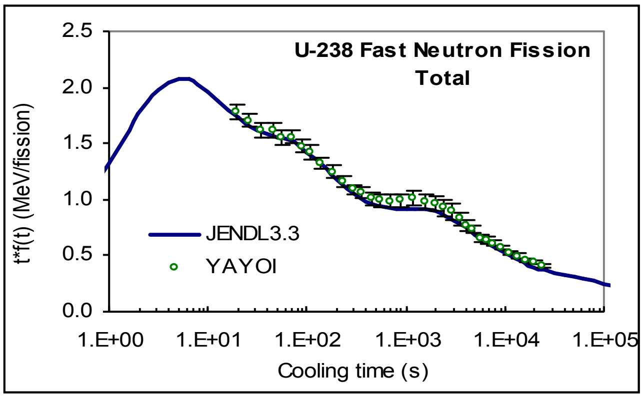

Figure 3. Calculated total decay heat from FPs after fast neutron fission burst of ^{238}U, experimental data (Akiyama and S. An, 1982; Dickens et al., 1980)

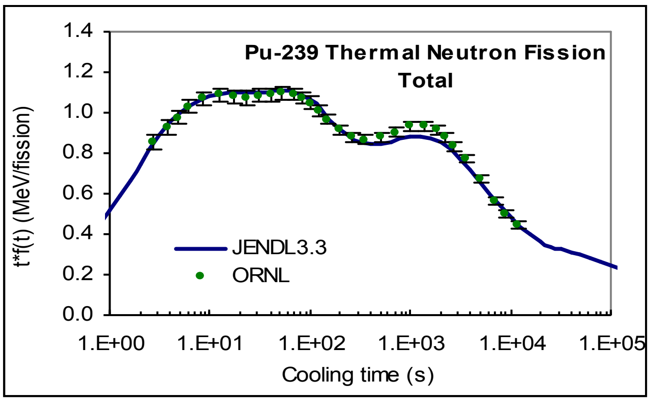

Figure 4. Calculated total decay heat from FPs after a thermal neutron fission burst of ^{239}Pu, experimental data (Dickens et al., 1978)

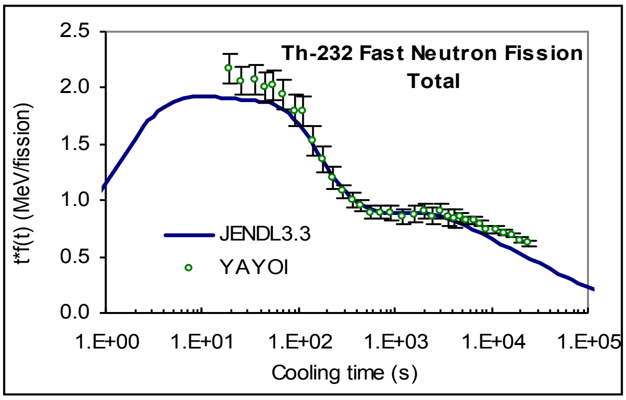

Figure 5. Calculated total decay heat from FPs after fast neutron fission burst of ^{232}Th, experimental data (Akiyama and S. An, 1982; Dickens et al., 1980)

Conclusion

In the present work a computer code has been developed for calculation the decay and growth of FP concentrations. The data calculated from this program have been introduce into summation calculation of FP total decay heat for several fissile nuclides such as ^{235}U, ^{238}U, ^{239}Pu and ^{232}Th, using the decay data and fission yield from JENDL3.3 (Katakura *et al*., 2001). The present results are shown in Figures 2-5, in comparison with the experimental values measured by the University of Tokyo (YAYOI) (Akiyama and S. An, 1982; Dickens *et al*., 1980) and the Oak Ridge National Laboratory (ORNL) (Dickens *et al*., 1981; Dickens *et al*., 1978). As shown in the Figures 2-5, the agreements between the present calculation results and measured data say that the present computational algorithm updated in the DHP program is qualify for precise calculations of fission product concentrations and its inventory data.

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