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Effects of Neutron Spectrum and Cross-section Library on Displacements per Atom (dpa)

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Abstract

Effect of cross-section libraries on displacements per atom (dpa) was investigated under the spectrum which is calculated in the outer and inner of capsule in the JMTR fuel region. The variation of dpa value of iron was calculated by TENJIN2 code using several cross section libraries (ENDFB-IV, JENDL 3.1 and JENDL 3.2). The dependency of input spectrum on total damage (dpa) is more clearly appeared in case of ENDFB-IV in JENDL 3.2 and JENDL 3.1 libraries. The gas production rate calculated by ENDFB-IV library showed slightly larger value than that by JENDL library, and it responded more sensitively in neutron spectrum.

Introduction

The value of dpa is very important in the study of radiation damage of reactor pressure vessel. Since the value of dpa depends on the neutron spectrum and cross section library, it is necessary to calculate the neutron spectrum at the sample position and to compile cross section libraries. In the present study, the variation of dpa value of iron was calculated by TENJIN2 code [1] using several cross section libraries (ENDFB-IV, JENDL 3.1 and JENDL 3.2) under the spectrum which is calculated on the outer and inner position of capsule in the JMTR fuel region. The neutron spectrum at the center of capsule was calculated using MCNP code [2]. The production rates of helium and hydrogen were also obtained under different spectrum and cross section libraries.

Procedure

The capsule which was used in this study was positioned in the JMTR fuel region. It is assumed that the neutron source was distributed isotropically around the capsule. The neutron spectrum around the capsule in the position of irradiation hole was calculated with a slab model for JMTR core as shown in Fig. 1, by using the one-dimensional discrete ordinate ANISN code [3], and this was used as an input source data of MCNP code. It is known that ANISN results are well accord with real spectrum within the range of 10 % in the fuel region [4]. The calculation were performed using one dimensional cylindrical model and the neutron spectrum at the center of capsule was calculated by MCNP, this spectrum was used in the calculation of dpa and gas production rate. MCNP calculation was carried out with 1,500,000 histories which were chosen considering the calculation time and statistical error.

The compilation of cross section library for damage calculation was performed by SUPERTOG-J3 code with MGCL (137 group) structure [5], and the calculations of dpa and gas production rates were performed by TENINN2 code. This study was performed with respect to iron element, because it was the dominant element of nuclear structural materials and the contents of other elements could be neglected in the dpa calculation of nuclear pressure vessel materials. When materials were irradiated in the fission reactor, most of damages come from the elastic and inelastic collision rather than from a fission reaction. TENJIN code considers several nuclear reactions, ie (n,n), (n,n'), (n,2n), (n,γ), (n,p), (n,α) and Charged Particles. Among these reactions, hydrogen and helum are produced from the (n,p) and (n,α) reaction, respectively.

Three kinds of cross section libraries, JENDL3.2, JENDL3.1 and ENDFB-IV were used for the calculation of TENJIN code. TENJIN use the ENDFB-IV format of cross section library, but JENDL3.2, and JENDL3.1 make use of ENDFB-V format. Therefore, auxiliary processing code is necessary, which convert ENDFB-V to ENDFB-IV format. The conversion of cross section library format was performed with the help of processing code B6TO5 (ENDFB-VI $\rightarrow$ ENDFB-V) and CRECT-J5 (ENDFB-V $\rightarrow$ ENDFB-IV)

Results and Discussion

The deviation calculated in spectrum capsule of center and outer position is small as shown in Fig. 2. A large fluctuation at around intermediate region seems to be attributed to resonance absorption. The variation of dpa as a function of neutron energy with JENDL 3.2 cross section library under the spectrum at the sample position are shown in Fig. 3. The calculated results of total dpa due to the difference of neutron energy spectrum are shown in Table 1.

The figure shows that most of the damages are come from the elastic and inelastic collision. The damage due to (n,γ) reaction extends from thermal to fast energy region, but the contribution to total damage is less than 0.1 % of the damage by fast neutron. Therefore, the damage of iron due to (n, γ) reaction under the spectrum of JMTR fuel region can be neglected.

The displacement damage by elastic and inelastic reaction under the JENDL 3.2 is shown in Fig. 4. The effect of elastic collision on total dpa is larger than that of inelastic collision. In the intermediate energy region, somewhat large disturbance of damage due to (n, γ) is attributed to the resonance absorpion of iron.

The damage due to inelastic reaction under JENDL 3.2 library gives different result from that of JENDL 3.1 and ENDFB-IV libraries. In contrast to the result by JENDL 3.2, the damage calculation under JENDL3.1 and ENDFB-IV gives similar result as shown in Table 1.

In contrast to the deviation of damage by inelastic collision, the value of total dpa gives similar results. The total dpa value calculated by JENDL 3.1 library gives larger value in comparision with what is calculated by other cross section libraries irrespective of input spectrum.

The deviation of total dpa due to the difference of input spectrum, which is the ratio of sample outer position to center of sample, are 4 %, 5 % and 9 % for the JENDL 3.2, JENDL 3.1 and ENDFB-IV cross section library, respectively. Therefore, the dependency of input spectrum of ENDFB-IV on total damage (dpa) is higher than that of JENDL 3.2 and JENDL 3.1 library.

Table 2 represents the relative ratio of elastic and inelastic collision to total dpa under the spectrum obtained at the sample outer position and center of sample. The contribution of elastic collision to total reaction is estimated 94 %, 83 % and 77% under the spectrum at the center of sample, respectively. It seems that the elastic cross section of JENDL 3.2 library is overestimated in comparison with JENDL 3.1 and ENDF B-IV library.

The gas production rate as a function of neutron energy at each cross section library and total gas production rate is also shown in Table 1. As shown in Table 1, there is no difference of total gas production between JENDL 3.2 and JENDL 3.1 library under same neutron spectrum, and the gas production rate calculated by ENDFB-IV library shows slightly larger value than that by JENDL library. Since hydrogen and helium are produced from (n,p) and (n,γ) reaction, JENDL 3.2 and 3.1 seem to have same reaction cross section. Hydrogen production rate due to JENDL library is evaluated larger than that of ENDF B-IV, but it was appeared conversely in case of He production.

The hydrogen production rate was estimated 32 % larger in the center of sample than in sample outer position irrespective of cross section library, but helium production rate at the corresponding position was estimated 15.2 % and 39 % for the JENDL and ENDFB-IV library, respectively. This result represents that gas production rate seems to respond more sensitively in neutron spectrum rather than in neutron cross section library

Conclusions

Present investigation of the effect of neutron spectrum and cross section libraries on displacement damage (dpa) yielded following conclusions.

1) Most of the damages in fission neutron environments are attributed to elastic collisions.
2) The damage (dpa) due to inelastic collision from JENDL 3.2 library gives different results in comparison with the results of corresponding JENDL 3.1 and ENDFB-IV.
3) The dependency of input spectrum to total damage (dpa) is appeared more clearly in case of ENDFB-IV than JENDL 3.2 and JENDL 3.1 library.
4) There is no difference of total gas production between JENDL 3.2 and JENDL 3.1 library under same neutron spectrum, and the gas production rate calculated by ENDFB-IV library shows slightly larger value than that by JENDL library.
5) The gas production rates are responded more sensitively in neutron spectrum rather than neutron cross section library

Referencs

1. JAERI-6103 (1975) TENJIN code Manual
2. MCNP-4A, Monte Carlo N-Particle Transport Code System, ORNL
3. K. KOYAMA, et al, ANISN-JR, A One Dimensional Discrete Ordinate Code for Neutron and Gamma Ray Transport Calculation, JAERI-M6954 (1977)
4. JAERI-Tech 90-023
5. Y, TAJI et al, SUPERTOG-JR, A Code Generating Transport Group Constants with ENDF JAERI-M6935 (1987)

Table 1. DPA and gas production due to different cross section library and neutron spectrum.

Library	Elastic Collision (dpa/sec)		Inelastic Collsion (dpa/sec)		Total DPA (dpa/sec)		H Production (appm/s)		He Production (appm/sec)	
	Capsule Out	Capsule Center	Capsule Out	Capsule Center	Capsule Out	Capsule Center	Capsule Out	Capsule Center	Capsule Out	Capsule Center
JENDL 3.2	1.422-8	1.396-8	1.203-9	8.788-10	1.549-8	1.489-8	1.309	1.728	0.0724	0.1016
JENDL 3.1	1.434-8	1.405-8	3.443-9	2.860-9	1.786-8	1.696-8	1.309	1.728	0.0724	0.1016
ENDF B4	1.096-8	1.044-8	3.794-9	3.121-9	1.483-8	1.362-8	1.357	1.787	0.0632	0.0876

Table 2. Relative ratio of DPA and gas production due to different cross section libraries and neutron spectrum.

Cross section Library	Elastic/Tot. dpa		Inelastic/Tot. dpa		Hydrogen Production	Helium Production.
	Capsule Out	Capsule Center	Capsule Out	Capsule Center	Capsule Cen/Out	Capsule Cen/Out
JENDL3.2	0.918	0.938	0.078	0.059	1.32	1.15
JENDL 3.1	0.803	0.828	0.193	0.169	1.32	1.15
ENDFB4	0.739	0.767	0.256	0.229	1.32	1.39

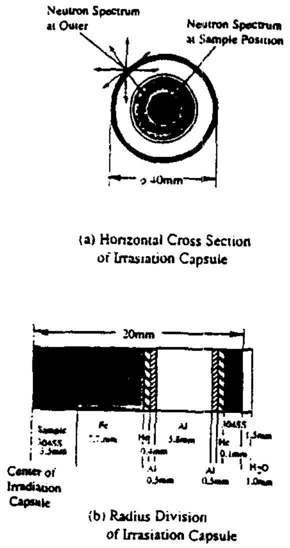

Fig. 1. Neutron Spectrum Calculation Model used in MCNP Code

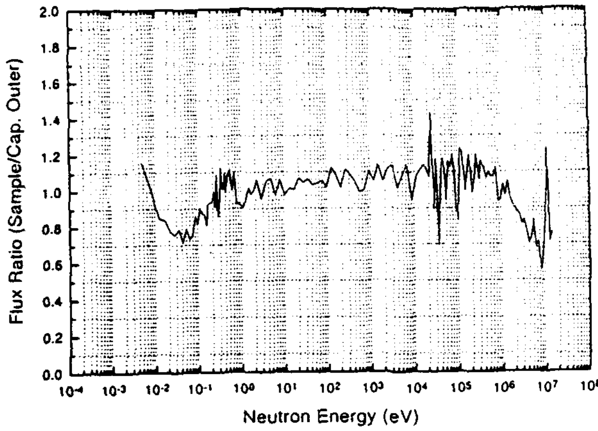

Fig. 2. The neutron flux ratio between capsule center and sample position

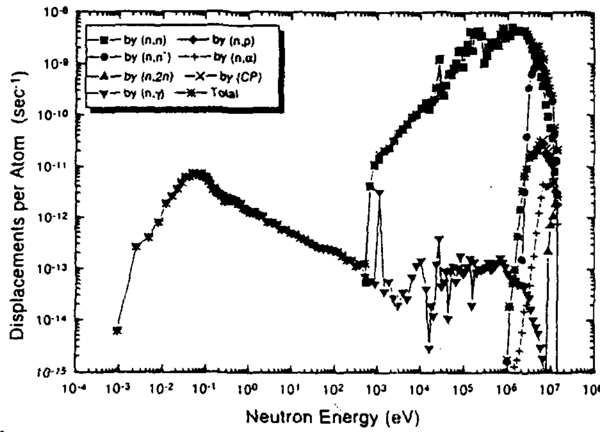

Fig. 3. DPA variation of Fe using JENDL3.2 C.X Lib. under the spectrum at sample position

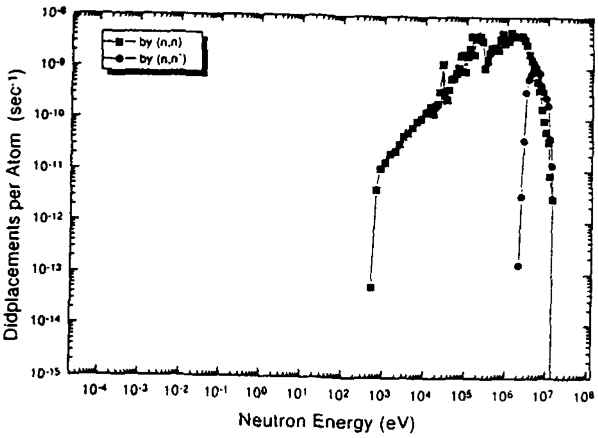

Fig. 4. DPA variation of Fe due to (n,n) and (n,n') using JENDL3.2 C.X Lib. under the spectrum at sample position