3.37 Nuclear Data Information System for Nuclear Materials

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The conceptual system for nuclear material design is considered and some trials on WWW server with functions of the easily accessible simulation of nuclear reactions are introduced. Moreover, as an example of the simulation on the system using nuclear data, transmutation calculation was made for candidate first wall materials such as 9Cr-2W steel, V-5Cr-5Ti and SiC in SUS316/Li_2O/H_2O(SUS), 9Cr-2W/Li_2O/H_2O(RAF), V alloy/Li/Be(V), and SiC/Li_2ZrO_3/He(SiC) blanket/shield systems based on ITER design model. Neutron spectrum varies with different blanket/shield compositions. The flux of low energy neutrons decreases in order of V<SiC<RAF<SUS blanket/shield systems. Fair amounts of W depletion in 9Cr-2W steel and the increase of Cr content in V- 5Cr-5Ti were predicted in SUS or RAF systems. Concentration change in W and Cr is estimated to be suppressed if Li coolant is used in place of water. Helium and hydrogen production are not strongly affected by the different blanket/shield compositions.

1. Introduction

Many phenomena cased by neutron irradiation under thermal, fast and fusion reactors can be little understood except through the examination. Easily accessible material information system is required for design of nuclear materials and analyses or simulations of the phenomenon. In order to construct such a system, a project, "Data-Free-Way", has been under way from April in 1990 under the cooperation of National Institute for Metals (NRIM), Japan Atomic Energy Research Institute (JAERI) and Power Reactor and Nuclear Fuel Development Corporation (PNC) [1,2]. In NRIM besides the cooperated construction of the distributed database for nuclear materials, a simulation system of nuclear transmutation and radioactivation has been created.

On the other way, the new system is created on the basis of the substantial concept and data used in IRAC [3]. IRAC was developed in 1984, however the use of it is limited to the inside of NRIM. Therefore, the system as was improved to be easily used mutually through the network. The system consists of a nuclide database with several tables storing the data on nuclear reaction and two simulation processes on transmutation and radioactivation integrated under user-friendly interface. In the near future, the system will be combined with "Data-Free-Way".

Transmutation resulting in change of composition, helium and hydrogen production, and induced activity under neutron irradiation is considered as one of severe problems for first wall materials of fusion reactors. The compositional change and gaseous products lead the degradation of materials and induced activity should be lowered from the viewpoint of reactor and environmental safety. Since the degree of transmutation depends on the neutron spectrum[3], designs of fusion reactor structures such as blanket and shield must be considered to understand the transmutation behaviors of materials. Recently, high burn-up of some metals such as Mo, Re, W, Ta, V are predicted under fusion neutron irradiation conditions[3,4].

In the present paper, the outline of the new simulation system for nuclear transmutation is introduced. Then, the necessary functions of the system are discussed. Moreover, in order to verify the simulation using the system, the transmutation behaviors of several candidate first wall materials such as 9Cr-2W steels, V-5Cr-5Ti and SiC have been examined for various types of blanket and shields based on ITER design structures[5] using the simulation calculations[6].

2. Conceptual Material Information System for Nuclear Materials Design

In the system for nuclear materials, it has to be considered that irradiation in various reactors produces radiation damage as a consequence of the formation of impurity nuclide by transmutation and the displacement of atoms from their equilibrium lattice positions by high energetic neutron or atom collision. Moreover, induced radioactivity by transmutation is an important problem from the viewpoints of the reduction of radiological hazards such as contact maintenance, waste management and environmental safety. The calculation code for the simulation and various databases required for the system is as follows.

Code: a. Neutron spectrum calculation, b. Transmutation and Induced activity calculations, c. Damage calculation.

Database: a. Facts Material Database, b. Nuclear Database, c. Reactor Operation Database, d. Reactor Design Database, e. Safety criteria Database.

We are unable to employ readily all of them because these many database are now under construction. Thus, in the present situation, the conceptual flow diagram of a information system for the alloy design and selection of nuclear materials is shown in Fig.1. At the first, candidate materials are selected by using material database such as "Data-Free-Way"[1,2]. The properties of the materials under irradiation are checked by the three types of simulations and then the other properties will be evaluated.

In the data system, it is nec'ssary for the functions for analysis of data retrieved from database and the simulation of various phenomenon in material field. An example of the simulation of transmutation on WWW server is shown in Fig. 2. In this system, the results of simulation of the compositional change are easily obtained by the operation of mouse-click.

3. Effect of neutron spectra on the transmutation of first wall materials

3.1 Reactor designs and neutron spectra

The neutron spectrum calculation was made using ANISN for ITER inboard structure design[5]. Fig. 3 shows the one dimensional model of mid-plane of the reactor used for calculation. The main structures are composed of carbon armor of 2cm, first wall of 1.5cm, blanket/shield of around 150cm, SUS 316 vacuum vessel, super-conducting magnet, and liquid helium vessel. In the present study, the compositions of first wall and blanket/shield materials were changed. In Fig.3, several combinations of blanket/shield materials are shown. ITER originally adopts the blanket(SUS blanket) made of stainless steel, Li_2O with condensed ^6Li, Be and water, and the shield materials made of stainless steel and water, respectively. In the RAF blanket, SUS316 was replaced by 9Cr-2W steel. V blanket was one of options for ITER where V-5Cr-5Ti was considered as the first wall and liquid lithium is used as breeder and coolant. The composition of SiC blanket was taken from ARIES-1 blanket model[7]. The blanket is composed of SiC, Li_2ZrO_3, Be and He gas.

In the shield, B_4C is added to SiC and He gas to improve the shielding efficiency. Nuclear data library with respectively 42 and 21 energy groups of neutron and gamma ray used was FUSION- 40[8] based on JENDL-3. The calculation was made with scattering order of P5 and angular quadrature order of S8.

3.2 Transmutation calculation

Transmutation calculation of materials was conducted based on the neutron spectra obtained ANISN using IRAC[4] code considering several step reactions if reactions have large cross sections. Nuclear data with 42 energy groups used for the transmutation calculation were CROSSLIB[9], JENDL-3 and FENDL/GA-1.1[10]. The neutron wall loading was assumed to be $1MW/m^2$.

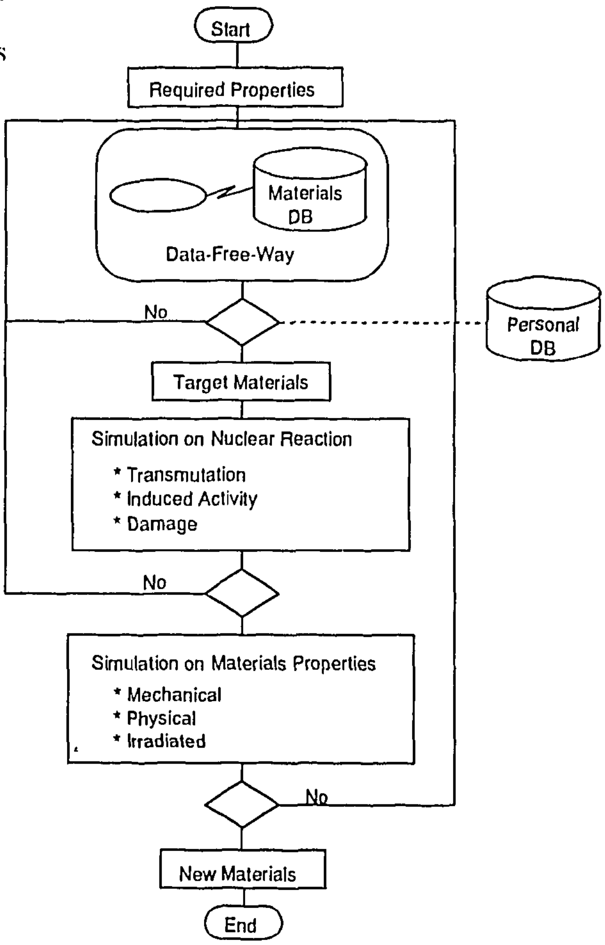


Fig. 1 Flow diagram on the concept of the ata system for nuclear material design and selection.

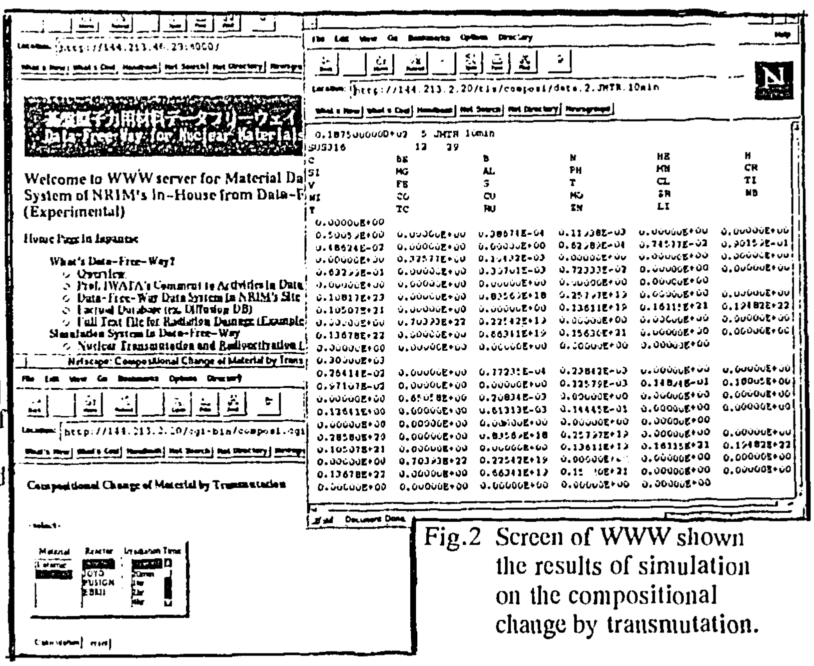
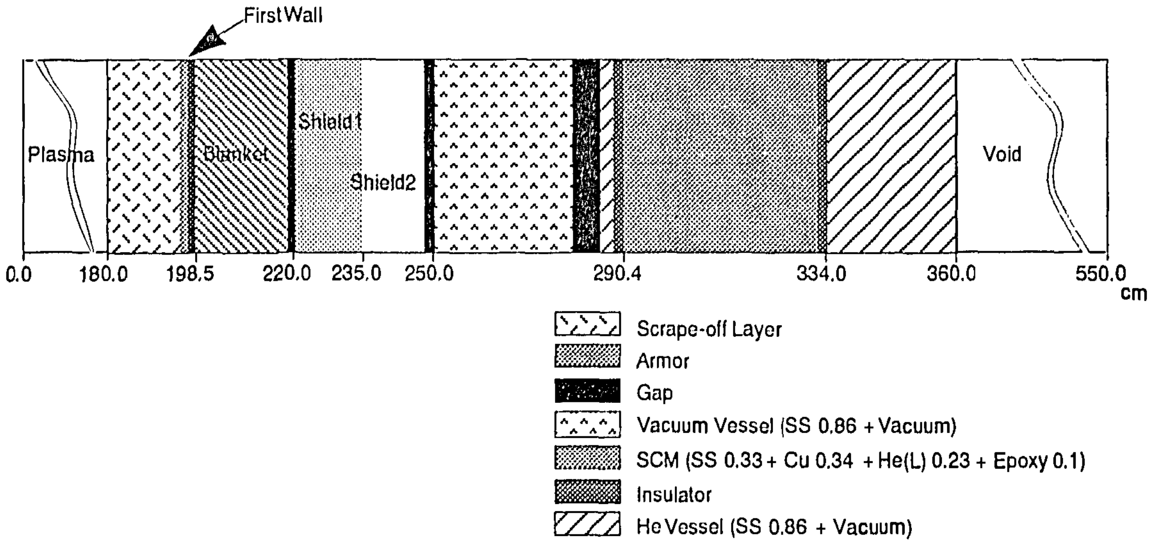


Fig.2 Screen of WWW shown the results of simulation on the compositional change by transmutation.

4 Results

Fig. 4 shows the typical neutron spectra at the first wall, the first shield and the vacuum wall for SUS blanket system. The flux of 14 MeV neutron remarkably decreases with the distance from plasma. The relations between 14 MeV neutron flux and the distance from the plasma center for various blanket systems are shown in Fig. 5



	Region	Thickness (cm)	Outer Radius (cm)	Composition
SUS	First Wall	1.5	198.5	SS 0.7+H_2O 0.3
	Blanket	19.5	218.0	SS 0.05+ Li_2O 0.1575+ Be 0.4725+ H_2O 0.05+ He 0.1
	Shield1	15.0	235.0	SS 0.9 + H_2O 0.1
	Shield2	13.0	248.0	SS 0.95 + H_2O 0.05
RAF	First Wall	1.5	198.5	9Cr2W 0.7+H_2O 0.3
	Blanket	19.5	218.0	9Cr2W 0.05 + Li_2O 0.1575+ Be 0.4725 + H_2O 0.05 + He 0.1
	Shield1	15.0	235.0	9Cr2W 0.9 + H_2O 0.1
	Shield2	13.0	248.0	9Cr2W 0.9 + H_2O 0.1
V	First Wall	1.5	198.5	V Alloy (V5 Cr5 Ti)
	Blanket	19.5	218.0	Li + Be
	Shield1	15.0	235.0	V Alloy + Li
	Shield2	13.0	248.0	V Alloy+ Li
SiC	First Wall	1.5	198.5	SiC
	Blanket	19.5	218.0	SiC 0.25 + Li_2ZrO_3 0.14 + Be 0.56+ He 0.05
	Shield1	15.0	235.0	SiC 0.56 + B_4C 0.24 + He 0.20
	Shield2	13.0	248.0	SiC 0.665 + B_4C 0.285 + He 0.05

Fig.3 One dimensional inboard model of a fusion wall reactor based on ITER design and aterial compositions of several first wall, blanket and shield models.

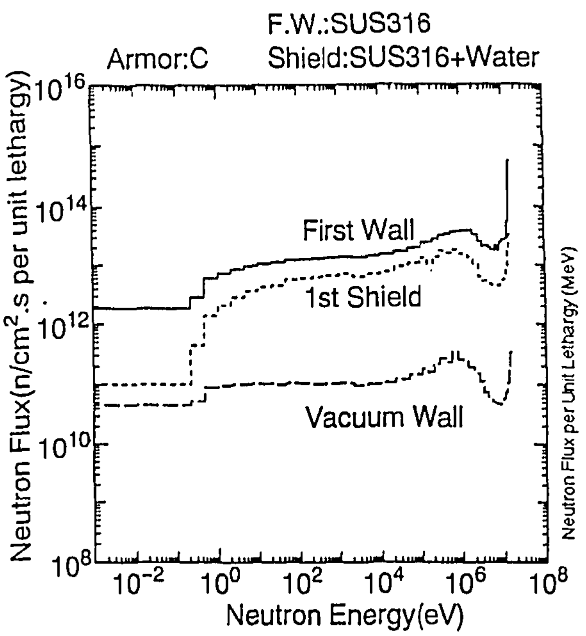


Fig.4 Neutron spectra at first wall, shield and vacuum position under 1 MW/m^2 wall loading.

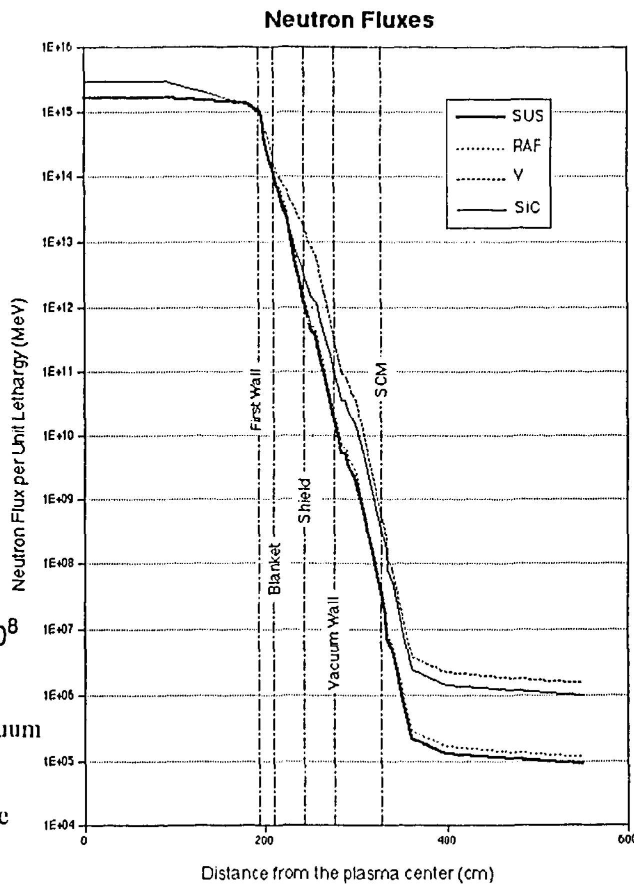


Fig.5 Neutron flux of 14 MeV as a function of the distance from the plasma center.

The flux almost linearly decreases with the distance from the armor. The decay slope is around one order magnitude per 15-17cm independently on the blanket/shield compositions.

Figure 6 shows the neutron spectra at the position of first wall for various blanket/shield compositions. There is a large difference in neutron flux at low energy region between blanket/shield materials. Especially, in the V blanket/shield system where liquid Li is used as a coolant, the sharp decrease of the neutron flux is observed with decreasing neutron energy.

Compositional changes of 9Cr-2W steel, V-5Cr-5Ti and SiC for the respective blanket/shield systems with neutron fluence are shown in Fig.7. The concentration of main constituents does not change remarkably for V-5Cr-5Ti and SiC except helium and hydrogen production. On the other hand, tungsten content in 9Cr-2W steels decreases with the neutron fluence. Next the effect of neutron spectrum on the compositional change of 9Cr-2W steel, V-5Cr-5Ti and SiC were examined for various blanket/shield systems by changing the first wall materials.

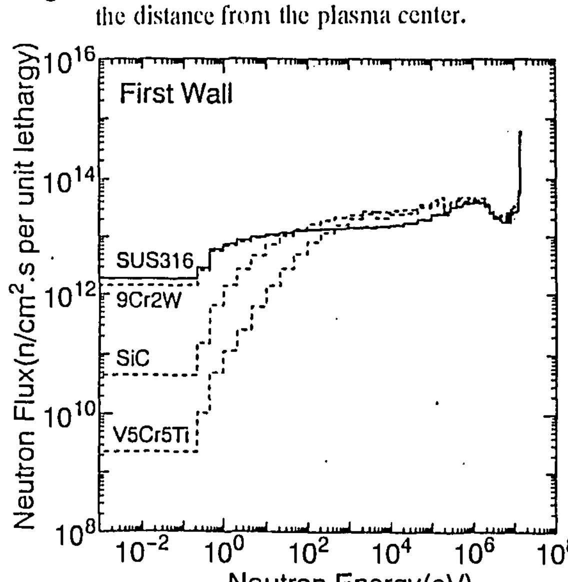


Fig.6 Comparison of neutron spectra at first wall for various blanket/shield compositions.

Table 1 and 2 show the concentration change of some elements in 9Cr-2W steel, V-5Cr-5Ti, and SiC for different blanket/shield systems after 10MW.y/m^2 irradiation. In 9Cr-2W steel, W is transmuted to Re and Os and reduces the concentration below half of an initial value in SUS and RAF systems, while the transmutation is suppressed in V blanket/shield system. Chromium, another main alloying element, is hardly affected in concentration by neutron spectrum, though it is slightly transmuted to Mn.

If V-5Cr-5Ti is used as a first wall in SUS or RAF blanket/shield system, Cr content increases by about 40% in contrast to V blanket/shield system where only several % of the increase is predicted. Titanium concentration is not affected by the neutron spectrum as seen in table 1.

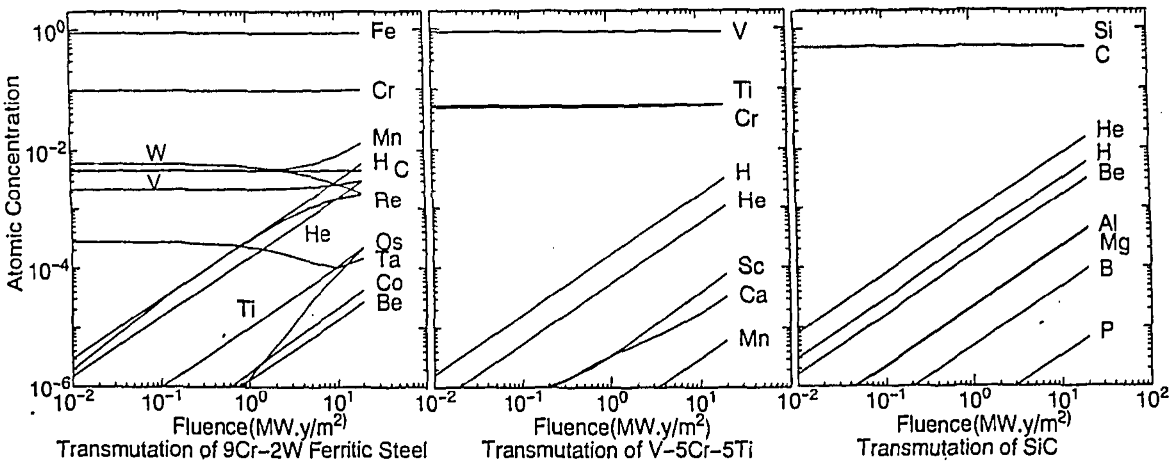


Fig.7 Compositional change of 9Cr-2W steel for RAF , V-5Cr-5Ti for V and SiC for SiC blanket/shield system as a function of neutron fluence.

Table.1 Concentration change of some elements for candidate first wall materials after 10MW.y/m^2 irradiation in various blanket/shield systems (at %)).

Material	Blanket / shield				
	Before	SUS	RAF	V	SiC
9Cr2W steel					
W	0.61	0.27	0.27	0.48	0.32
Re+Os	0	0.17	0.16	0.06	0.14
Cr	9.71	9.80	9.80	9.81	9.81
Mn	0.46	0.81	0.81	0.84	0.81
V5Cr5Ti					
Cr	4.89	6.77	6.47	5.13	5.35
Ti	5.31	5.36	5.36	5.40	5.39
SiC					
Si	50.0	49.6	49.6	49.5	49.5
C	50.0	49.2	49.2	49.1	49.2

Table.2 Helium and hydrogen production for candidate first wall materials after 10MW.y/m^2 irradiation in various blanket/shield systems (appm).

Material	Blanket / shield			
	SUS	RAF	V	SiC
9Cr2W steel				
He	1510	1510	1710	1630
H	3020	3020	3440	3300
V5Cr5Ti				
He	476	475	509	537
H	1420	1420	1620	1550
SiC				
He	7310	7310	8250	7800
H	2740	2740	5970	3130

Regarding SiC, compositional change except gaseous products is not obvious. However substantial He formation occurs in SiC for any blanket/shield systems. Helium of about 0.7-0.8 at % is produced after 10 MW.y/m^2 irradiation.

The results in table 2 indicates that the amounts of He and H are produced in V and SiC blanket/shield systems where fluxes with energies of 100 keV-1 MeV are rather higher than other systems.

5. Discussion

The concentration change of W in 9Cr-2W steel and Cr in V-5Cr- 5Ti due to the transmutation is affected by the neutron spectrum. Especially significant transmutation of W and V occurs when the neutron flux with low energy is considerably high in such case of SUS blanket/shield system.

As have pointed out in the previous works[1,2], stable isotopes of W have a large cross section for (n,γ) reaction in low energy region of neutrons. W is composed of 0.135% ^{180}W, 26.4% ^{182}W, 14.4% ^{183}W, 30.6% ^{184}W and 28.4% ^{186}W. Re and Os productions mainly occur through following paths:

$^{184}W (n, \gamma)^{185}W$ (75.1days)->$^{185}Re (n, \gamma)^{186}Re$ (90.64h)->^{186}Os (1)

$^{184}W (n, \gamma)^{185}W$->$^{185}Re (n, \gamma)^{186}Re (n, \gamma)^{187}Re (n, \gamma)^{188}Re$(16.98h)->$^{186}Os$ (2)

$^{186}W (n, \gamma)^{187}W$ (23.9h)->$^{187}Re (n, \gamma)^{188}Re$->$^{188}Os$ (3)

Most Os is produced through reaction of (3). Neutron capture is also significant for the transmutation of vanadium. Chromium is formed according to the following reaction:

$^{51}V (n, \gamma)^{52}V$(3.75min)->^{52}Cr (4)

As have seen in table 2, W depletion and Cr accumulation caused by the transmutation are much affected by the neutron spectrum. Especially neutron fluxes with energies below around 100eV determine the degree of concentration change of these elements. Returning to the neutron spectra of various blanket/shield compositions, it is necessary to examine the factors controlling spectrum changes. In the present study, V blanket/shield system showed the lowest flux at low energies of neutrons. In order to clarify the compositional dependence of the spectrum, V-5Cr-5Ti, structural material of V blanket/shield system, was replaced by 9Cr-2W steel and the neutron spectrum was calculated.

Figure 8 shows the comparison of neutron spectra for RAF blanket/shield systems with different coolant and breeder. It is clear that H_2O softens the neutron spectrum resulting the production of more neutrons with low energies than Li. The neutron spectra in this figure suggest that W depletion in 9Cr-2W steel is minimized if Li coolant is used.

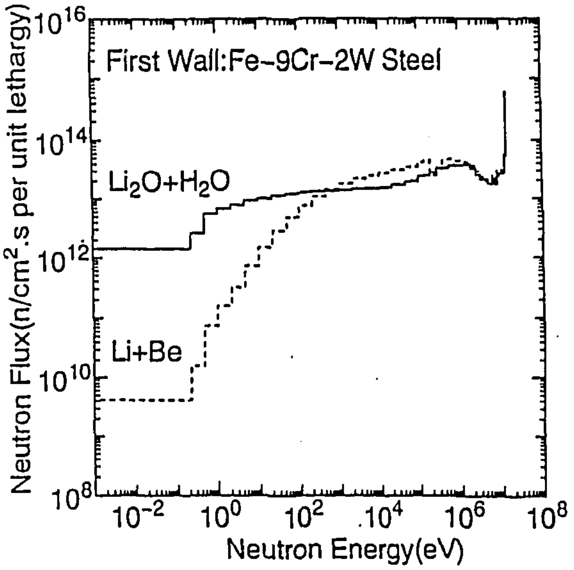


Fig.8 Neutron spectra at the first wall of 9Cr-2W/Li_2O H_2O nd 9Cr-2W/Li/Be blanket/shield systems.

Considering the real first wall/blanket/shield system, the combination of V alloy/Li_2O/H_2O is not necessary realistic because vanadium is not stable in water. Therefore Cr accumulation in V alloys will not be significant so far as V alloy/Li/Be system is considered.

6. Conclusion

Concept of data system for nuclear material design was considered. It is necessary that the system consists of a nuclide database storing the data on nuclear reaction and two calculating processes for the simulation of transmutation and radio activation.

The transmutation of 9Cr-2W steel, V-5Cr-5Ti and SiC for SUS316/Li_2O/H_2O(SUS), 9Cr-2W/Li_2O/H_2O(RAF), V-5Cr-5Ti/Li/Be(V), and SiC/Li_2ZrO_3/He(SIC) blanket/shield systems were examined by using the simulation calculation code. Conclusions are as follows:

1. Neutron spectrum depends on the composition of blanket/shield materials.
2. The flux of neutrons with energies lower than around 100 eV decreases in order of V<SiC<RAF<SUS blanket/shield system.
3. Fair amounts of W depletion in 9Cr-2W steel and Cr accumulation in V-5Cr-5Ti were predicted for H_2O coolant system.
4. Transmutation of W and V is suppressed if Li coolant is used.
5 .Helium and hydrogen production are not strongly affected by the different blanket/shield systems.

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