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Monte Carlo Evaluation of Fast Neutron Irradiation Damage of Al_2O_3/SS316L

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Hydrogen isotope permeation and neutron irradiation

- Hydrogen and hydrogen isotope (D, T) dissolves and penetrates into most metals, and the causes a embrittlement destroying the material without structural deformation.

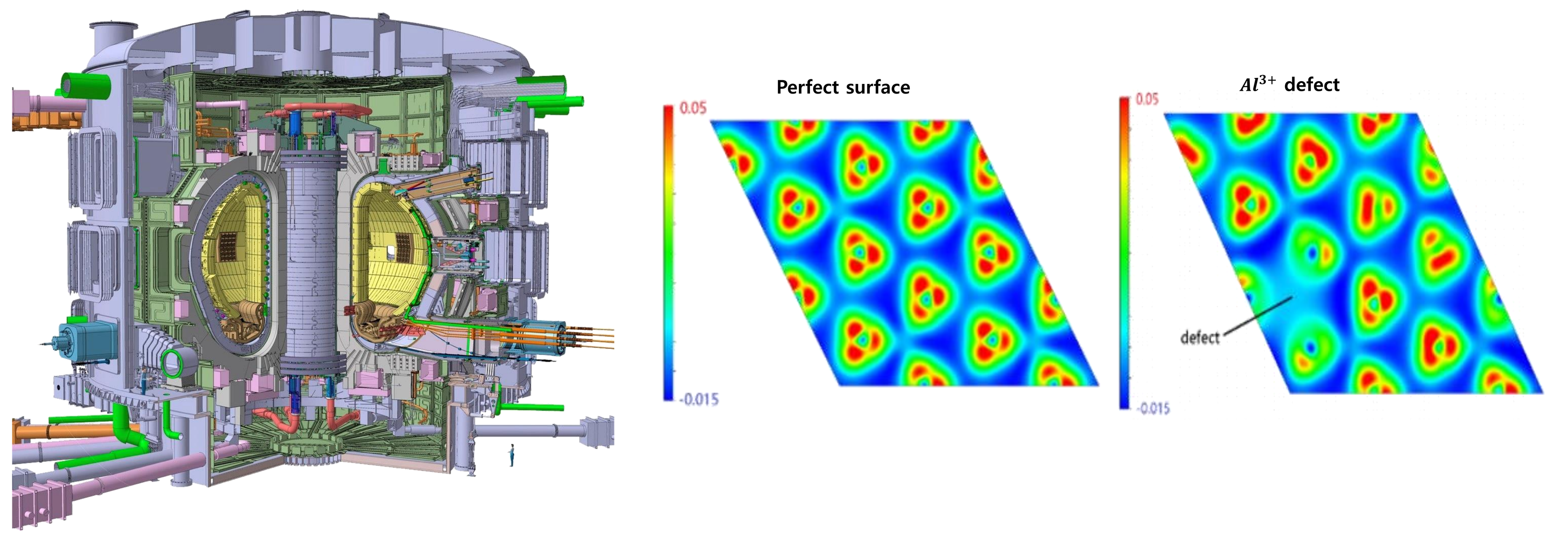

Fig. 1. A scheme of nuclear fusion reactor and DFT calculation scheme for point defect

- The structure materials of nuclear fusion reactor are exposed by fast neutron, which is generated by D-T reaction.
- A neutron irradiation makes point defect of materials and this defect improved the hydrogen retention, which is reported by DFT calculation.
- The application of hydrogen isotope permeation barriers of nuclear fusion reactor structural materials have been studied to reduce the hydrogen isotope permeability.
- The ceramic penetration barrier works as reducing the risk by hydrogen isotope due to its high temperature stability, high hardness and strong chemical bonding.
- Therefore, it is necessary to analyze the hydrogen isotope permeability of the Al_2O_3 depending on the neutron irradiation damage.
- In this study, we calculated the activity and neutron irradiation damage of the Al_2O_3/ SS316L as a pre-investigation.

Activity calculation of the neutron irradiated Al_2O_3/SS316L

- The activity of the radionuclide can be estimated by the equation as following,

$$A = N_0 \sigma_0 \emptyset \left(1 - e^{-\lambda t_i}\right)\left(e^{-\lambda t_c}\right)$$

where, N_0 is the number of mother nuclide, σ_0 is the neutron absorption cross section corresponding to 14.1 MeV of neutron, ϕ is the neutron flux calculated by MCNP6, λ is the decay constant, t_i is the neutron irradiation time, t_c is the cooling time, respectively.

- The information of the radionuclides, which can be generate from Al_2O_3/SS316L, by neutron irradiation are shown in table1.

Table 1. Radionuclides for Al_2O_3/SS316L

Nuclide	at. %	Reaction	Radionuclide
Fe-54	5.845	(n,p)	Mn-54
		(n,g)	Fe-55
Fe-56	91.754	(n,p)	Mn-56
Fe-58	0.282	(n,g)	Fe-59
Cr-50	4345	(n,g)	Cr-51
Cr-52	83.789	(n,2n)	Cr-51
Cr-53	9.501	(n,2n)	Cr-52
		(n,p)	V-53
		(n,α)	Sc-49
Cr-54	2.365	(n,g)	Cr-55
Ni-58	68.077	(n,g)	N-59
		(n,p)	Co-58
Ni-60	26.223	(n,p)	Co-60
Ni-62	3.635	(n,p)	Ni-63
Ni-64	0.9255	(n,g)	Ni-65
Al-27	100	(n,g)	Al-28
		(n,p)	Mg-27
		(n,2n)	Al-26
O-16	99.757	(n,p)	N-16
O-17	0.038	(n,p)	N-17

- The neutron cross section for each materials are shown in Fig.

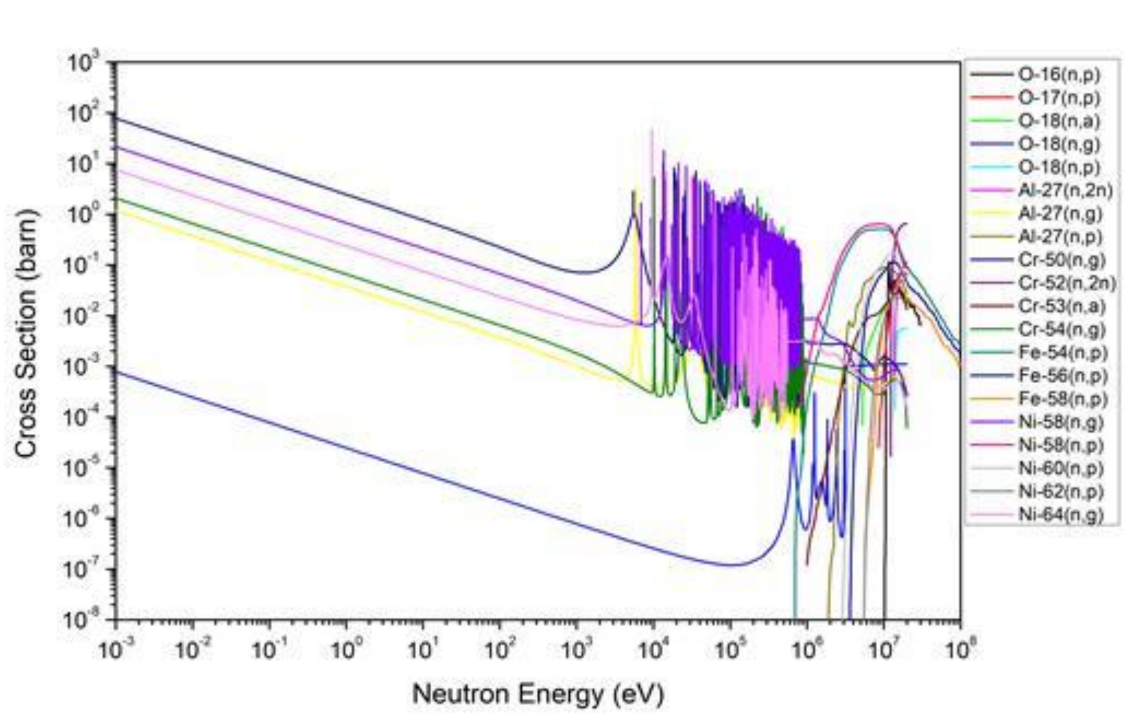

Fig.2. Neutron cross section of the radionuclides of Al_2O_3/SS316L

Specific activity of Al_2O_3/SS316L

- Al_2O_3/SS316L were irradiated by neutron for 3,000 sec.
- A total activity of the Al_2O_3/SS316L was 3.27 x 10^7 Bq and a specific activity as a function of the time is shown in Fig.
- The radionuclides, which generated from Al_2O_3/SS316L, were almost decayed in 2.5 hours. For the SS316L, long lived radionuclides, like a ^{51}Cr, ^{55}CR, ^{56}Fe, ^{59}Fe, ^{59}Ni, ^{64}Ni, were created and take long time for the decay.

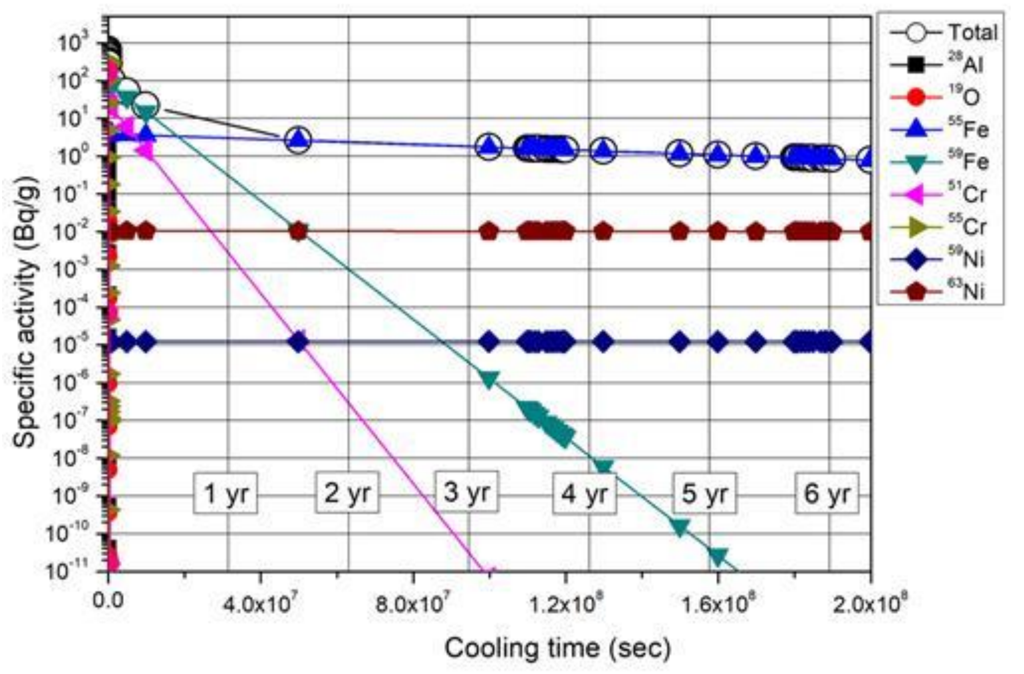

Fig. 3. A specific activity of neutron irradiated Al_2O_3/SS316L as a function of the cooling time

Collision heating calculation by neutron irradiation

- Collision heating was calculated to evaluate the possible damage of the Al_2O_3/ SS316L by temperature increasing due to the neutron irradiation.
- For the fast neutron irradiation, MC-50 cyclotron at KIRAMS was employed]

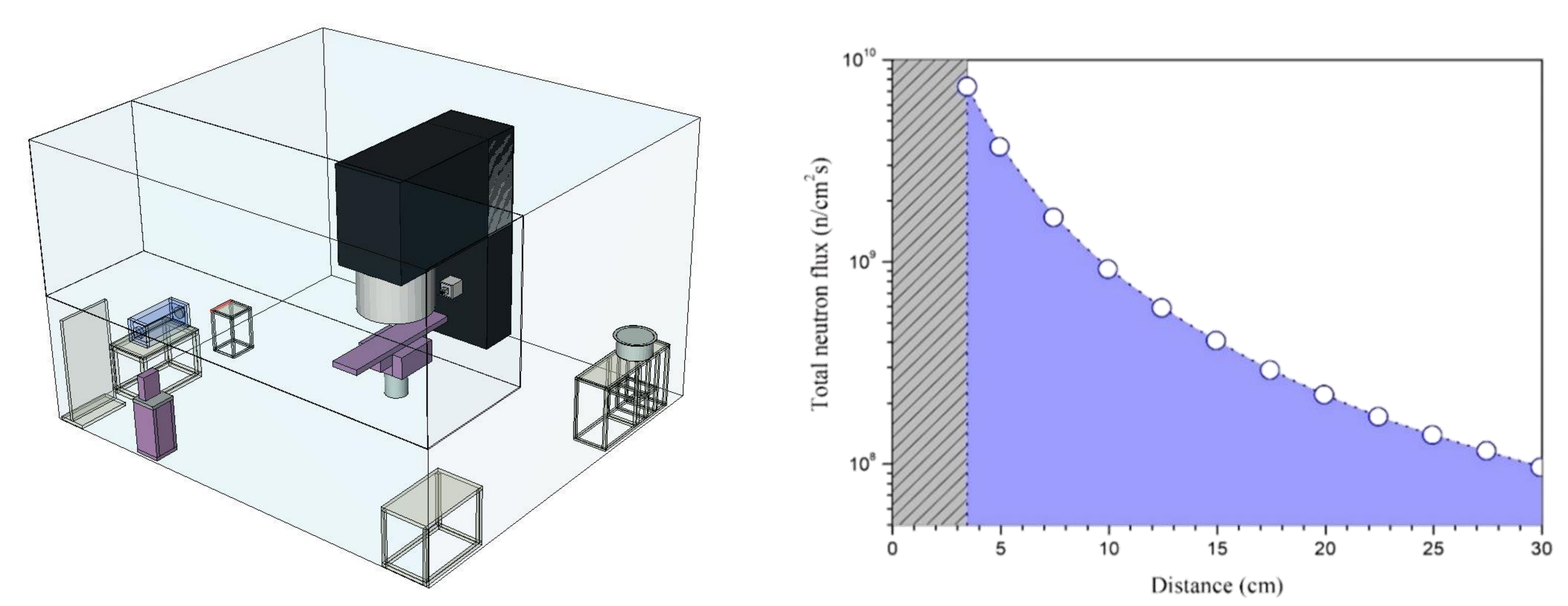

Fig. 4 A specific activity of neutron irradiated Al_2O_3/SS316L as a function of the cooling time

- Through the quantification of the collision heat, the thermal expansion of the Al_2O_3 and SS316L can be estimated as calculating the temperature increasing.
- To calculate the collision heating according to the different neutron fluences, the +F6 tally was calculated by varying the distance to the Be target, and the results are shown in table.2.
- It is assumed that all collision heating is used for the temperature increasing of the samples, As the results, the damage of the sample by temperature increasing is negligible.

Table 2. Temperature increasing of Al_2O_3/SS316L by neutron irradiation

Distance (cm)	Φ (n/cm²s)	MeV/g	material	ΔT (℃)
3.45	6.07E9	2.63E-5	Al_2O_3	3.41E-5
			SS316L	5.71E-5
12.75	5.50E8	3.25E-7	Al_2O_3	4.22E-7
			SS316L	7.06E-7
32.25	9.00E7	1.57E-8	Al_2O_3	2.03E-8
			SS316L	1.00E-9

DPA calculation of Al_2O_3/SS316L

- The neutron irradiation damage of the sample can be quantified by DPA (Displacement Per Atom) and its equation is as following

$$DPA_{total} = \int_0^t \int_0^\infty \sigma_{dpa}(E)\phi(E)\,dE\,dt$$

where, σ_{dpa} is the DPA cross section depending on the neutron spectrum, $\phi(E)$ is the differential neutron flux, respectively.

- The DPA values of the Al_2O_3 and SS316L with neutron flux of 6.07E9 were 1.38E-28 and 1.75E-25, and these DPA values decrease as increasing the distance.
- Consequently, the DPA rate of the Al_2O_3/ SS316L by fast neutron irradiation is very low.

Table 3. DPA of neutron irradiated Al_2O_3/SS316L

Distance (cm)	Φ (n/cm²s)	material	DPA/sec
3.45	6.07E9	Al_2O_3	1.38E-28
		SS316L	1.75E-25
12.75	5.50E8	Al_2O_3	1.01E-29
		SS316L	1.7E-26
32.25	9.00E7	Al_2O_3	3.59E-27
		SS316L	2.38E-31