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A Preliminary Study on the Activation Analysis for a Conceptual K-DEMO Fusion Reactor

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1. Introduction

It is known that the radioactive materials of nuclear fusion reactor have a low radioactivity in comparison with fission reactors. However, in the case of a specific module which is directly facing the fusion plasma, its radioactivity is so high that the module is needed to control and decommission by the legal regulation. The typical modules which have such a characteristic are Blanket Module (BM) and Divertor (Dv). These modules are regularly substituted with new module when irradiated sufficiently, so an accurate assessment of neutron activation is mandatory for those components of the fusion reactors because of the environmental effect and safety advantages. In order to reduce the neutron activation effect, two primary considerations are required. One is the use of the materials which abate the radioactive effects, and the other is the development of effective designs for low neutron activation. Various research groups of the ITER member countries have been performing the researches to satisfy these requirements. As part of the international research trends on neutron activation fields, the Korean research group has been designing the demonstration fusion reactor, which is named K-DEMO [1].

In this study, the activation calculations of K-DEMO were carried out, and then those calculation results were compared with the calculation results of ITER model. In addition to two main modules, the activation calculations for Vacuum Vessel (VV) were performed, because that component represents the containment integrity of the fusion reactor. Neutron flux distributions in the fusion reactor were provided by a MCNP [2] calculation. The activation calculations were performed by FISPACT 2007 code [3]. The calculated fluxes were employed to FISPACT for the activation calculation.

2. Method

2.1 MCNP Simulation for Conceptual K-DEMO Design

The conceptual design of K-DEMO and the result of MCNP modeling are shown in Figure 1, respectively. The structural characteristics to reduce the neutron activation were adopted in the design of K-DEMO. For BM, various structures such as First Wall (Tungsten, W), tritium breeder (Li4SiO4), neutron multiplier (Be), etc., were arranged in consecutive order to minimize the neutron activation. Among these structures, the RAFM (Reduced Activation Ferritic Martensitic) steel but not an ordinary stainless steel was used for the water pipe and VV. In this study, EUROFER steel [4] is employed as RAFM steel. The designs of outboard BM are shown in Figure 2. According to K-DEMO design, Dv (W) was located in both sides of the BM, and VV (Eurofer) surrounded the BM.

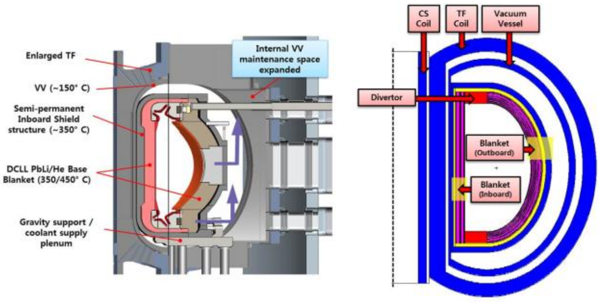

Figure 1. Design of K-DEMO (left) and MCNP Modeling for K-DEMO (right)

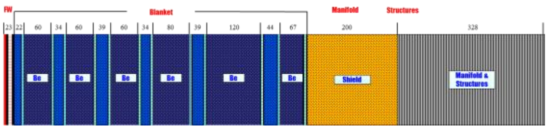

Figure 2. Designs of Outboard Blanket Module

In order to calculate the neutron distribution at each structure, all parts of K-DEMO from the first wall to TF coil were simulated in detail using MCNP code. The used nuclear library was FENDL 3.0.

2.2 Activation Calculation for Main Module of K-DEMO Fusion Reactor

Using the obtained neutron distributions, the activation calculation for each module of K-DEMO was performed by FISPACT 2007 code. Various parameters and decay time step after shutdown are shown in Table 1.Using these values, the total activity and decay heat of each structure were calculated. Then, the results were compared with the ITER data which had are given in the former studies [5].

Table 1. Parameters for Activation Calculation of K-DEMO

Fusion Power	1763 MW		Effective Full Power Day	300
Decay Time	1sec, 1hour, 10hours, 1day, 3days, 1week, 1month, 3 months, 6months, 1year, 3years, 10years, 30 years, 50years, 100years, 1000years			
Total Flux (#/cm^3)	First Wall	1.7688E15	Inner Pipe	1.7705E15
	2^{nd} Breeder	5.1476E11	Vacuum Vessel	1.5230E05
	Low Divertor	3.2970E14		

3. Results

By performing MCNP simulations for K-DEMO, the source distribution and total flux at each structure were obtained. Using the obtained source information, the activation inventory and activity of each structure were calculated at each time intervals. The neutron distribution at the 'First Wall' is shown in Figure 3.

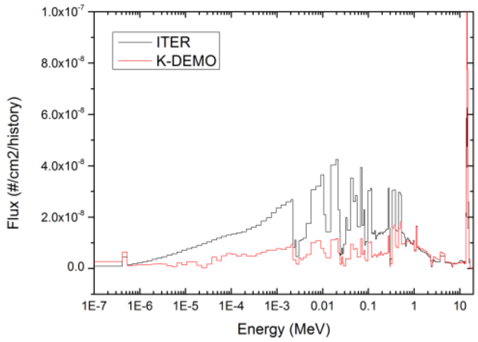

Figure 3. Simulated Neutron Distribution at the First Wall

In the case of total activity, all structures except VV showed that their activities were very high at each time step. However, after 100 years cooling time, the total activities of all modules converged below 1~6 Ci/kg. Various activation results of each module are shown in Figure 4.

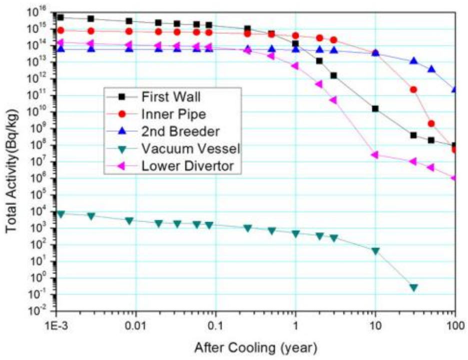

Figure 4. Activation Analysis of K-DEMO Modules

For the decay heat, the obtained results showed similar trends to the activation results. The obtained results for the decay heat of each module are shown in Figure 5.

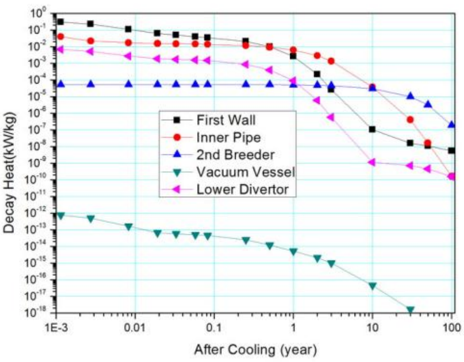

Figure 5. Decay Heat Analysis of K-DEMO Modules

Finally, calculated results for BM, Dv, and VV on out board structure were compared with results of ITER model.

The comparison results are shown in Table 2.

Table 2. Activation Comparison between K-DEMO and ITER

	K-DEMO (Bq/kg)			ITER (Bq/kg)		
	BM	Dv	VV	TBM	Dv	VV
1 sec	1.32E15	1.92E14	1.08E4	2.19E13	9.19E14	4.25E12
7days	6.77E14	1.02E14	2.13E3	1.98E13	8.39E14	3.69E12
3mons	5.20E14	4.98E13	1.10E3	1.12E13	3.92E14	1.42E12
1year	3.87E14	5.96E12	5.13E2	6.50E12	3.45E13	7.42E11
10year	3.48E13	2.65E07	4.57E1	1.11E11	1.82E09	2.56E10
50year	1.97E09	4.65E06	0.00	1.70E10	7.55E07	7.68E09
100year	5.11E07	1.04E06	0.00	1.14E10	2.96E07	5.32E09

As a result about comparison studies, because of the conceptual design of K-DEMO to reduce activations, activities of Dv and VV were far less than that of ITER module through each time interval. In the case of BM, activities of K-DEMO were slightly higher than that of ITER. However, activities after 50 years cooling time were less than that of ITER after all. Finally, the results show that the total activity of BM at 100 years cooling time after shutdown was 5.11×10^{7} Bq/kg and that of ITER was 1.14×10^{10} Bq/kg.

4. Conclusions

In this study, the activation calculations for three main modules of K-DEMO and the comparison studies with ITER results were carried out. Through all time intervals after shutdown, the total activities and decay heats were less than ITER results except BM module. Furthermore, in the case of BM, activities were slightly higher than that of ITER until only 50 years cooling time. Therefore, these results leaded us to the conclusion that the decrease in activities of main modules for the fusion reactor resulted from the new developed K-DEMO design and the use of RAFM.

Acknowledgment

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