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SHIELDING DESIGN ANALYSES FOR SMART CORE WITH 49-CEDM

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Abstract - In Korea, an advanced reactor system of 330MWt power called SMART (System integrated Modular Advanced ReacTor) is being developed by KAERI to supply energy for seawater desalination as well as electricity generation. A shielding design of the SMART core with 49 CEDM is established by a two-dimensional discrete ordinates radiation transport analyses. The DORT two-dimensional discrete ordinates transport code is used to evaluate the SMART shielding designs. Three axial regions represent the SMART reactor assembly, each of which is modeled in the R-Z geometry. The BUGLE-96 library is used in the analyses, which consists of 47 neutron and 20 gamma energy groups. The results indicate that the maximum neutron fluence at the bottom of reactor vessel is 5.89×10^{17} n/cm^2 and that on the radial surface of reactor vessel is 4.49×10^{16} n/cm^2. These results meet the requirement, 1.0×10^{20} n/cm^2, in 10 CFR 50.61 and the integrity of SMART reactor vessel during the lifetime of the reactor is confirmed.

INTRODUCTION

The SMART[1] is a small-sized advanced integral PWR that produces thermal energy of 330 MWt under full power operating conditions. The primary components are integrated within a single pressure vessel, in which the arrangement of components differs from that of the conventional loop-type reactors. New, innovative and highly advanced features adopted in the SMART designs provide the reactor with noticeable characteristics of enhanced safety, reliability, performance, and operability. The SMART is composed of core, barrel, 6 side-screens, 3 bottom-screens, 12 steam generators, reactor vessel, and other internals as shown in Fig. 1.

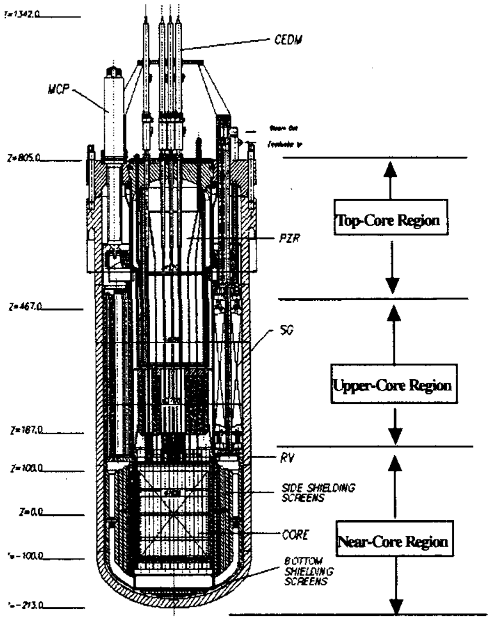
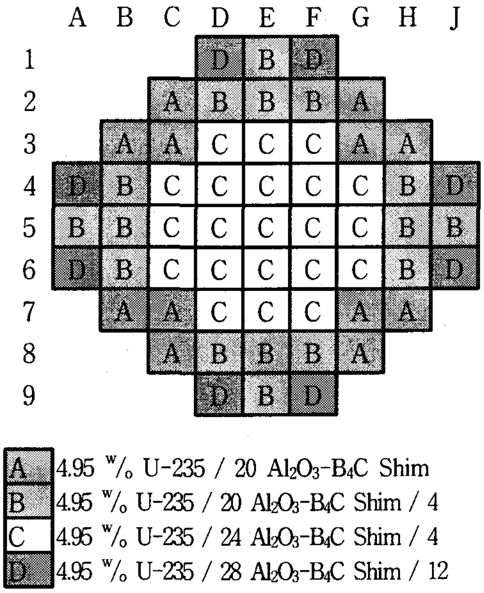


Fig. 1. Reactor Assembly of SMART.

The shielding design is concentrated around the core to prevent reactor components such as the reactor pressure vessel and steam generators from fast neutron damage and to protect the workers from the radiation exposure by reduction of the radiation dose equivalent rate. The flux distributions, radiation dose rates, and fast neutron fluence distributions in the reactor assembly around the SMART core with 49-CEDM is evaluated by using conventional method, which is SN transport code such as DORT[2]. And the time-averaged radial and axial power distributions in the SMART core are evaluated using MASTER code [3], which is a nuclear design code system developed by KAERI.

SOURCE TERM

The SMART core consists of 57 fuel assemblies of a rectangular cross-section based on Korean optimized fuel assembly (KOFA) design technology[4]. The cross-sectional view of SMART core with 49-CEDM is shown in Fig. 2. 17×17 KOFA design is chosen as the basis of the SMART fuel assembly. The height of the fuel region of KOFA is 365.8 cm, but the reduced active height of 200 cm is to be applied in the SMART reactor. The radial and axial power distributions of the SMART core with 49-CEDM are calculated using MASTER code as shown in Table 1.



	A	B	C	D	E	F	G	H	J
1				D	B	D			
2			A	B	B	B	A		
3		A	A	C	C	C	A	A	
4	D	B	C	C	C	C	C	B	D
5	B	B	C	C	C	C	C	B	B
6	D	B	C	C	C	C	C	B	D
7		A	A	C	C	C	A	A	
8			A	B	B	B	A		
9				D	B	D			

A 4.95 $^{w}/_{o}$ U-235 / 20 Al_2O_3-B_4C Shim

B 4.95 $^{w}/_{o}$ U-235 / 20 Al_2O_3-B_4C Shim / 4

C 4.95 $^{w}/_{o}$ U-235 / 24 Al_2O_3-B_4C Shim / 4

D 4.95 $^{w}/_{o}$ U-235 / 28 Al_2O_3-B_4C Shim / 12

Fig. 2. 49CEDM Core Loading Pattern

Table 1. Normalized Power Distribution resulted from MASTER code Calculation

Radius [cm]	Normalized Power Distribution	Height [cm]	Normalized Power Distribution
2.25	0.2247	5.0	1.0426
6.75	0.4053	15.0	1.5370
11.25	0.4100	25.0	1.9540
15.75	0.4610	35.0	2.1823
20.25	0.5451	45.0	2.1758
24.75	0.5391	55.0	2.1223
29.25	0.6379	65.0	1.9791
33.75	0.8802	75.0	1.7562
38.25	0.6549	85.0	1.4450
42.75	0.9132	95.0	1.1051
47.25	1.1785	105.0	0.8615
51.75	1.2599	115.0	0.6573
56.25	1.3966	125.0	0.4840
60.75	1.4279	135.0	0.3357
65.25	1.4119	145.0	0.1968
69.75	1.3265	155.0	0.0853
74.25	1.2933	165.0	0.0412
78.75	1.1903	175.0	0.0197
83.25	1.0731	185.0	0.0103
87.75	0.8638	195.0	0.0081

TRANSPORT CALCULATION

The DORT code is selected for the shielding design of SMART because it has been used extensively for the shielding design of power reactors over the years and it has been proven to be reliable for the reactor shielding design. Two-dimensional R-Z geometry models are used in DORT transport analyses. The R-Z models include most of the reactor components with consideration of the azimuthally homogeneous core configuration. The geometrical model extends axially from the bottom of reactor pressure vessel to the top of the reactor assembly cover and radially from the core centerline to the outer surface of reactor vessel. Three axial regions divide the reactor assembly because of a limitation of memory space, which are near-core, upper-core, and top-core models as shown in Fig. 1. The boundary surface source was used for upper-core and top-core models because of the absence of the fission neutron source in the regions.

The 181 radial and 253 axial meshes, the 181 radial and 221 axial meshes, and the 181 radial and 428 axial meshes are applied to the near-core model, upper-core model, and top-core model, respectively. The P5 scattering expansion and S8 angular quadrature set are used for the DORT calculation. For the energy spectrum, the Watt fission spectrum normalized to the thermal power density is used. BUGLE-96[5] library is used for 67 group coupled neutron and gamma-ray cross-section data of DORT calculation, which consists of 47 neutron and 20 gamma energy groups. The fluence level is derived based on 60 years lifetime with 90% capacity factor from the fast neutron flux for energy more than 1.0 MeV.

Overall of 30% uncertainty is applied to the fluence at the vessel so that uncertainty due to dimensional tolerance, representation of source distribution and cross-section can be supplemented.

RESULTS AND DISCUSSION

The reactor assembly of SMART has been analyzed by using the DORT transport code.

The total neutron flux distributions are shown in Figs. 3, 4 and 5. The total neutron fluxes on the axial bottom of reactor pressure vessel and on the outer surface of reactor vessel of the core centerline are less than 5.0×10^{8} n/cm2s and that on the reactor cover is less than 5.0×10^{-7} n/cm^{2}s. The fast neutron fluence distributions are shown in Figs. 6, 7 and 8.

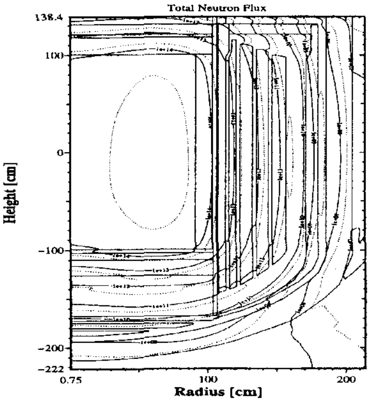


Fig. 3. Total Neutron Flux Distribution for Near-Core Model [n/cm^{2}s]

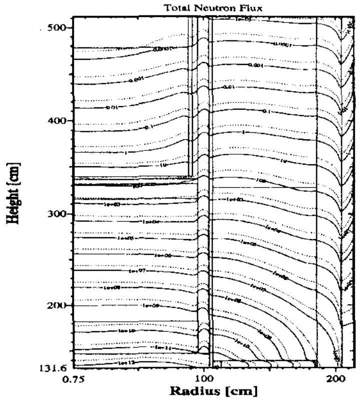


Fig. 4. Total Neutron Flux Distribution for Upper-Core Model [n/cm^{2}s]

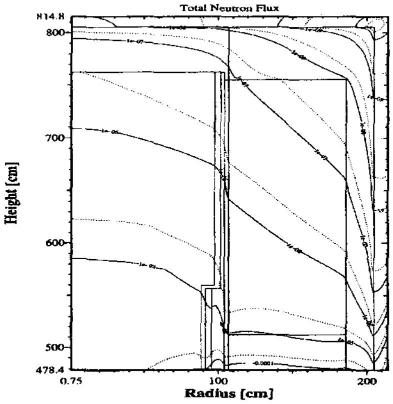


Fig. 5. Total Neutron Flux Distribution for Top-Core Model [n/cm^{2}s]

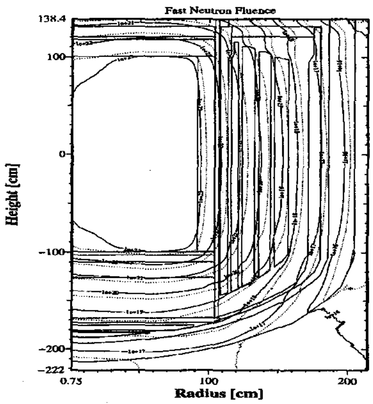


Fig. 6. Fast Neutron Fluence Distribution for Near-Core Model [n/cm^2]

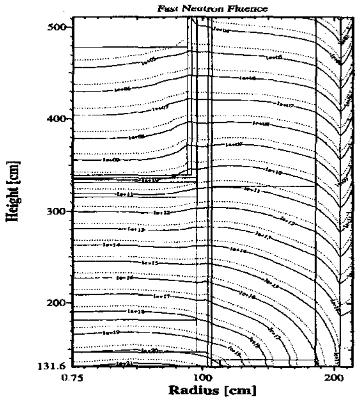


Fig. 7. Fast Neutron Fluence Distribution for Upper-Core Model [n/cm^2]

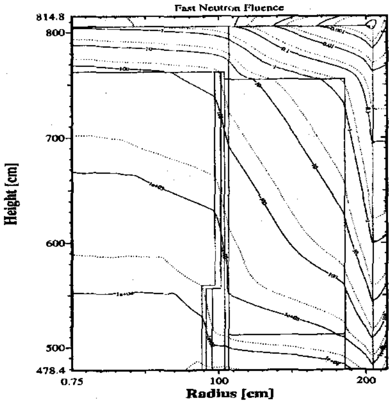


Fig. 8. Fast Neutron Fluence Distribution for Top-Core Model [n/cm^2]

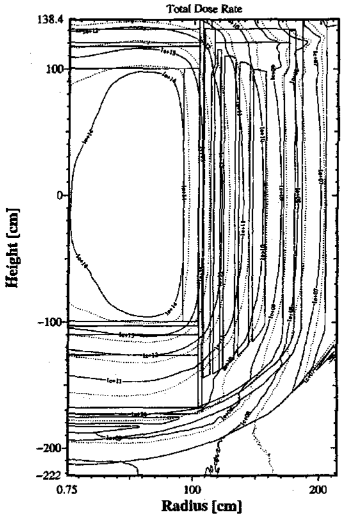


Fig. 9. Total Dose Rate Distribution for Near-Core Model [μ Sv/h]

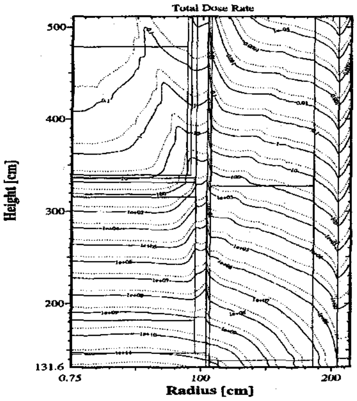


Fig. 10. Total Dose Rate Distribution for Upper -Core Model [μ Sv/h]

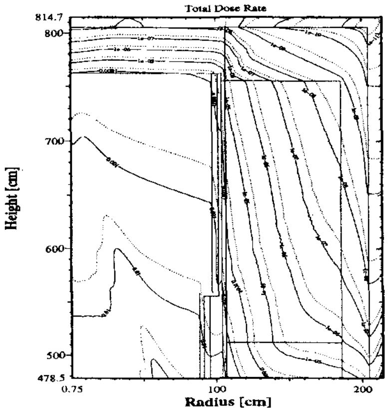


Fig. 11. Total Dose Rate Distribution for Top-Core Model [μ Sv/h]

The maximum neutron fluence at the bottom of reactor vessel is 5.89×10^{17} n/cm^2 and that on the radial inner surface of reactor vessel is 4.49×10^{16} n/cm^2. These results meet the requirement, 1.0×10^{20} n/cm2, in 10 CFR 50.61[6] and U.S. SRP[7] and the integrity of SMART reactor vessel during the lifetime of reactor is confirmed. The total dose equivalent rate distributions are shown in Figures 9, 10 and 11. The total neutron dose equivalent rate on the outer surface of reactor pressure vessel is less than 5.0×10^{6} (Sv/h and that on the reactor cover is less than 5.0×10^{-8} (Sv/h. The total dose equivalent rate around the reactor cover is far less than 1.0 (Sv/h, design target of accessible area. However, the additional shielding such as the internal shielding tank is considered to reduce the dose equivalent rate on the outside reactor pressure vessel.

CONCLUSIONS

The shielding design analyses were performed for SMART with 49-CEDM loading pattern by using DORT two-dimensional transport code. It is concluded that the integrity of the SMART vessel is preserved throughout the lifetime of SMART and the total dose equivalent rate on the reactor cover region is far less than 0.5 (Sv/h, design target of accessible area.

In the near future, the additional shielding analyses using the three-dimensional SN transport code and the Monte Carlo transport code will be performed to verify the results from this work.

ACKNOWLEDGMENT

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