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Preliminary Evaluation of Radiation Shielding for Fluid System Equipment Design of Small Modular Reactor

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After commercial nuclear power plants (NPP) had been developed, the development of large scale NPP was dominated due to economic advantages, but interest in small and medium-sized NPP has been increasing in recent years due to various reasons.

Small and medium-sized NPP have several advantages such as low market risk due to low investment scale, greater safety margin than large-capacity NPP, ability to provide power source in remote locations, and possible entry into markets with small power demand. Despite these advantages, it failed to appear in the energy market due to difficulties in economic and technical feasibility, but the possibility of commercial success of a small reactor is increasing due to recent technological advances and changes in the energy market environment [1].

In the domestic industrial and academic fields, the research and development of the 10-110 MWe small modular reactor (SMR) are actively being conducted.

In this study, as to provide the basic data for shielding deign of fluid system equipment of the SMR, dose rate of the major equipment (purification filter, drainage filter and purification ion exchanger) was evaluated, and the thickness required to satisfy design standards and dose limits is presented.

2. Materials and Methods

To conduct shielding evaluation, the radiation source terms for each of the equipment were derived. Then, MCNP 6 code was used to model each of the equipment and shielding materials. Furthermore, evaluation criteria were established to confirm satisfaction by comparing evaluation results.

2.1 Source term

The drain and purification filters have functions to purify primary coolant, which is leaked out from the primary coolant system, by removing the insoluble impurities. The purification ion-exchanger contains mixed-phase ion exchange resin within the exchanger, so its function is to remove impurities or radionuclides from the primary coolant.

Currently, the radiation source term information of the SMR equipment is unpublished, so in this evaluation, source term, as presented in table I, of the drain filter, purification filter and purification ion exchanger of light water NPP was used [2].

2.2 Assumptions of evaluation

Following assumptions were applied for the shielding evaluation.

- The filter and ion exchanger were assumed to be cylindrical.
- As filter and spent resin contain system water, their densities were assumed to be same as density of water (1 g/cc).
- For conservative evaluation, the filter housing and the outer wall of the ion exchanger are assumed to have no shielding functions.
- The radiation dose is based on a point 2.54 cm away from the surface of the shielding material.

2.3 Geometry modeling

Lead (11.35 g/cm3), metal (carbon steel, 7.82 g/cm3) and concrete (2.25 g/cm3), which are commonly used for shielding gamma rays, were selected for shielding material, and according to each material's shielding performance, evaluation thickness for each material was selected as follows.

- Lead: 3 cm, 6 cm, 9 cm
- Carbon Steel: 5 cm, 10 cm, 15 cm
- Concrete: 15 cm, 30 cm, 45 cm

Using the MCNP 6 code [3], each of the equipment was modelled to be surrounded by cylindrical shields as shown in the Figure 1. In addition, purification ion exchanger was modelled to be filled 2/3 with spent resin.

2.4 Evaluation criteria

To prevent unnecessary radiation exposure to workers and related personnel in NPP, radiation-controlled zones are dedicated, and the zones are further subdivided and managed according to the radiation dose rate. The equipment is in the high radiation zone with dose rate greater 10 mSv/hr. Therefore, in this evaluation, dose rate limit is selected to be 10 mSv/hr and below for a conservative evaluation.

Table I: Source term of Equipment (Bq)

Nuclide	Purification Filter	Drain Filter	Purification Ion exchanger
H-3	1.60E+09	2.00E+09	1.50E+11
Kr-85	4.70E+08	5.80E+08	4.30E+10
Xe-133	1.90E+10	4.10E+10	3.10E+12
I-133	1.40E+08	4.30E+08	1.50E+13

Cs-134	2.60E+07	3.20E+07	2.00E+14
Cs-137	3.40E+07	4.10E+07	3.10E+14
Cr-51	1.40E+10	8.80E+12	9.60E+12
Mn-54	9.60E+09	5.20E+12	5.60E+12
Fe-55	1.00E+10	5.30E+12	5.80E+12
Co-58	1.20E+10	7.10E+12	7.80E+12
Co-60	4.80E+09	2.50E+12	2.80E+12
Ba-137m	3.40E+07	4.10E+07	3.10E+14

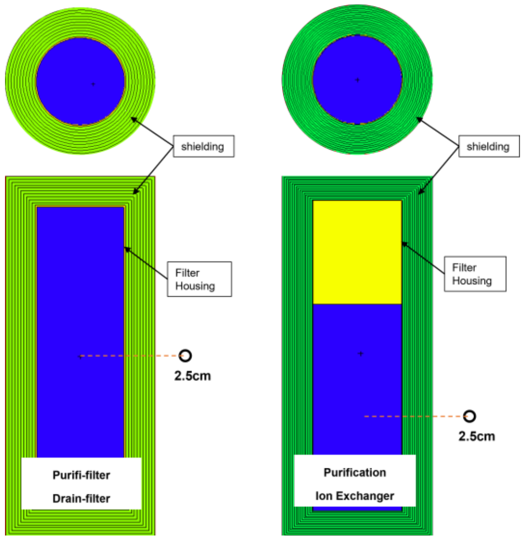

Fig. 1. Equipment modeling in MCNP 6.

3. Results

The evaluated dose rate of the drain filter, the purification filter and the purification ion exchanger are presented in Table II~IV. As per the results, for the drain filter to satisfy the evaluation standard, 11.5 cm thick metal shield, 33.0 cm thick concrete shield, or 5.5 cm thick lead shield is required. Then, for the purification filter to satisfy the evaluation standard, 9.0 cm thick metal shield, 28.0 cm thick concrete shield, or 4.5 cm thick lead shield is required. Lastly, for the purification ion exchanger to satisfy the evaluation standard, 9.0 cm thick metal shield, 28.0 cm thick concrete shield, or 4.5 cm thick lead shield is required.

Table II: Dose Rate – Darin Filter

Material	Thickness	Dose Rate (mSv/hr)
Unshielded	-	1,392.0
Metal	5cm	120.0
	10cm	18.4
	15cm	3.9
Concrete	15cm	119.0
	30cm	20.4
	45cm	4.6
Lead	3cm	68.0
	6cm	9.6
	9cm	1.9

Table III: Dose Rate – Purification Filter

Material	Thickness	Dose Rate (mSv/hr)
Unshielded	-	1,271.0
Metal	5cm	80.8
	10cm	7.6
	15cm	0.8
Concrete	15cm	87.1
	30cm	8.7
	45cm	1.0
Lead	3cm	37.3
	6cm	3.4
	9cm	0.4

Table IV: Dose Rate – Purification Ion-Exchanger

Material	Thickness	Dose Rate (mSv/hr)
Unshielded	-	12,416.0
Metal	5cm	644.0
	10cm	50.4
	15cm	4.8
Concrete	15cm	799.0
	30cm	70.8
	45cm	7.0
Lead	3cm	190.7
	6cm	14.3
	9cm	1.8

4. Conclusions

In this study, dose rate evaluation was conducted for the major high radiation equipment of the fluid system of the NPP and shielding material and its thickness required to satisfy the safety requirements were presented.

To conduct evaluation, specification and radionuclide information of the major equipment were investigated and analyzed, and the requirements and standards related to the shielding design were reviewed to establish the evaluation criteria. Furthermore, MCNP 6 code was used to model the equipment, and the shielding body.

According to the evaluation results, the thickness of the shielding material required to satisfy the evaluation standard (10 mSv/hr) was evaluated to be 4.5~6.5 cm for lead, 9.0~14.0 cm for carbon steel and for 28.0~43.0 cm concrete.

The results of this study can be used as basic data for the shielding design of the purification filter, drain filter, and purification ion exchanger, which are the major equipment of the fluid system of SMR.

REFERENCES

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[3] MCNP 6, A general monte carlo n-particle transport code, Los Alamos National Laboratory, http://mcnp.lanl.gov