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Radiation Shielding Analysis for CFVS Operation

Min Hwa Kim, Young Suk Bang, Doo Yong Lee
FNC Technology Co. Ltd.
minhya@fnctech.com

1. Introduction

Containment can be damaged by over-pressurization due to steam and non condensable gas generation during severe accidents. Because containment failure results in release of a large amount of radioactive materials to the environment, Containment Filtered Vent System (CFVS) has been considered as the effective measure to depressurize the containment and prevent the late containment failure. The filtered contaminants like aerosols are retained in the filter system which makes the filter system as a radiation source. In order to properly protect the field workers conducting recovery actions, the radiation shielding is required to make the radiation dose rate from the CFVS to be low which the regulatory recommends dose of 100 mSv for the workers conducting recovery action [1]. In this study, the shielding calculation for CFVS is presented. Especially, since the clear guideline for the appropriately conservative CFVS opening pressure, where the venting to the CFVS is started, is not established although the radioactivity of CFVS is affected by CFVS operation conditions, shielding calculations are performed with various opening pressures. The radioactivity of the deposited materials in the containment filtered venting system is estimated. Then, the shielding concrete wall thickness to satisfy the regulatory requirements and resulting dose rate are calculated. Consequently the required radiation shielding with respect to the CFVS opening pressure can be presented.

2. Method

Shielding calculation was performed using ORIGEN-ARP [2], MAAP5 [3], and MICROSHIELD [5] codes. ORIGEN-ARP analyzes decay of radioactive nuclides. MAAP5 simulates the severe accident and transporting behavior of materials from the core to the CFVS [4]. MICROSHIELD, which is based on point-kernel method, calculates the dose rate caused by gamma ray source.

Reference plant is selected as OPR1000 and Station Blackout (SBO) is chosen as representative accident [4]. Three simulations are performed with different opening pressures which are assumed as 5, 7 and 9 bar(a) respectively considering the containment failure pressure. The deposited mass fractions of each element to the CFVS against initial mass in core are examined with the release of elements from the core and its natural removal in the containment such as gravitational deposition are considered within.

Table I: MICROSHIELD modeling of CFVS shielding problem

Component	Geometry	Size [m]	Material	Density [g/cm^3]
Filter	Cylinder	I.D.: 2 O.D.:2.015	Iron	8
Wall	Slab	0.3 ~	Concrete	2.3

Since radioactive physics is not considered in MAAP5, the transformation of elements depend on time is calculated by ORIGEN-ARP in parallel to take into account time-dependent variation of radioactive elements composition in the CFVS. Decay of important fission products in the initial core inventory is calculated during the accident. Nuclide with half-life longer than years or element with small quantity is ignored in the calculation. These decayed fission product quantities for each element and the obtained mass fraction against initial mass of elements in core [4] and are combined by multiplying to estimate the radioactivity inventory in CFVS considering releasing from the core, natural removal in the containment, mass transfer from the containment to the CFVS and decay of nuclides. The daughter elements are assumed that they are released to CFVS with same fraction of mother elements in this study.

Estimated time-dependent radiation sources are used for dose rate calculation in MICROSHIELD. Radioactive information for each nuclide is introduced from the ICRP 107 library. The modeling of CFVS is assumed as table I. Radiation source needed to be modeled in the CFVS is the filtering part which contains the radioactive materials. The filter is assumed as 1.5 cm thick iron cylinder filled with air and all incoming radioactive materials retained. Concrete wall is located at 1 m away from the filter wall and the dose rate at the 100 m away from the wall is calculated based on ICRP 74 and antero-posterior geometry. Necessary concrete wall thickness is obtained by increasing the thickness with 10 cm step until the dose rate is reduced as the 10 mSv/hr assuming 10 hr of recovery conducting time and 1 mSv/hr assuming 100 hr of recovery conducting time for considering conservativeness.

3. Results

The simulation results from the MAAP5 are shown in Figure 1 and Table II [4]. The change of containment pressure is shown in Figure 1. Detailed CFVS operation time is shown in Table II. Radiation activity in the CFVS is estimated for the time points described in

Table II to see the evolution of activity during the venting to the CFVS and the 100 hrs after accident occurs.

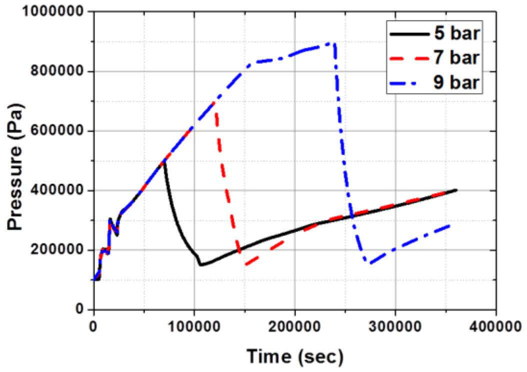

Fig. 1. Pressure of containment building for different CFVS opening pressure [4]

Table II: Detailed CFVS operation time point for different CFVS opening pressure [4]

Pressure	Opening time	1/3 operation time	2/3 operation time	Closing Time
5 bar(a)	19.4 hr	22.8 hr	26.1 hr	29.4 hr
7 bar(a)	33.6 hr	36.3 hr	39.0 hr	41.7 hr
9 bar(a)	66.4 hr	69.5 hr	72.7 hr	75.8 hr

Table III is estimated gamma source for 5 bar(a) of opening pressure. The level of total activity is 10^{18} Bq during the accident. Activity of CFVS increased until the CFVS is closed. Table IV is estimated gamma source for 7 bar(a) of opening pressure. The variation of activity during the accident is similar with that of 5 bar(a) of opening pressure case. The level of total activity is decreased to 10^{16} ~ 10^{18} Bq. However, this is increased to the level of 10^{18} Bq when the opening pressure is 9 bar(a) as shown in Table V. Clear difference in total activity is not found although different opening pressure.

Table III: Estimated gamma source activity for 5 bar(a) of CFVS opening pressure

Energy [MeV]	1/3 operation time	2/3 operation time	Closing Time	100 hr
0.015	4.53E+12	3.70E+12	7.40E+11	7.43E+11
0.02	2.33E+17	3.12E+17	3.36E+17	1.64E+17
0.03	1.29E+18	1.83E+18	2.11E+18	1.45E+18
0.04	7.22E+16	1.00E+17	1.11E+17	6.94E+16
0.05	1.40E+15	2.27E+15	9.47E+15	5.34E+15
0.06	8.12E+13	1.27E+14	3.88E+14	2.93E+14
0.08	1.01E+18	1.43E+18	1.62E+18	1.12E+18
0.1	4.69E+14	7.39E+14	2.87E+15	1.47E+15
0.15	1.91E+18	2.58E+18	2.79E+18	1.38E+18
0.2	1.46E+17	1.95E+17	2.50E+17	1.24E+17
0.3	1.28E+16	1.76E+16	3.02E+16	1.97E+16
0.4	9.50E+16	1.38E+17	2.36E+17	1.73E+17
0.5	8.24E+16	1.13E+17	2.04E+17	3.62E+16
0.6	2.06E+16	3.19E+16	1.09E+17	6.43E+16
0.8	3.98E+17	5.28E+17	6.23E+17	2.99E+17
1	9.31E+15	1.35E+16	3.25E+16	1.64E+16
1.5	1.08E+16	1.35E+16	2.58E+16	1.52E+16
2	1.44E+15	1.24E+15	2.84E+15	1.54E+15
3	2.81E+14	3.72E+14	4.30E+14	3.56E+14
Total	5.29E+18	7.31E+18	8.49E+18	4.94E+18

Table IV: Estimated gamma source activity for 7 bar(a) of CFVS opening pressure

Energy [MeV]	1/3 operation time	2/3 operation time	Closing Time	100 hr
0.015	1.77E+11	2.50E+11	2.73E+11	1.26E+11
0.02	1.50E+12	2.60E+13	6.14E+13	5.82E+13
0.03	3.59E+15	8.77E+16	1.71E+17	1.26E+17
0.04	8.59E+13	8.95E+14	1.74E+15	1.73E+15
0.05	1.96E+14	9.97E+15	1.93E+16	1.15E+16
0.06	1.81E+13	3.76E+14	7.48E+14	5.59E+14
0.08	1.49E+15	2.17E+16	4.28E+16	4.08E+16
0.1	6.46E+13	2.94E+15	5.67E+15	3.10E+15
0.15	1.74E+14	1.19E+15	2.16E+15	1.37E+15
0.2	1.28E+15	6.13E+16	1.18E+17	7.01E+16
0.3	1.46E+15	1.93E+16	3.68E+16	2.70E+16
0.4	1.08E+16	1.54E+17	2.95E+17	2.37E+17
0.5	9.17E+15	1.25E+17	2.25E+17	5.30E+16
0.6	2.90E+15	1.09E+17	2.11E+17	1.30E+17
0.8	3.04E+15	8.80E+16	1.69E+17	9.32E+16
1	1.02E+15	2.59E+16	4.98E+16	2.79E+16
1.5	1.68E+15	1.58E+16	2.87E+16	1.53E+16
2	6.85E+13	2.86E+15	5.53E+15	3.16E+15
3	4.85E+13	1.10E+14	1.56E+14	1.14E+14
Total	3.71E+16	7.26E+17	1.38E+18	8.43E+17

Table V: Estimated gamma source activity for 9 bar(a) of CFVS opening pressure

Energy [MeV]	1/3 operation time	2/3 operation time	Closing Time	100 hr
0.015	1.12E+10	2.32E+09	2.56E+09	2.26E+09
0.02	9.45E+12	1.45E+13	1.69E+13	1.63E+13
0.03	8.91E+17	1.39E+18	1.58E+18	1.39E+18
0.04	3.31E+16	5.17E+16	5.89E+16	5.17E+16
0.05	2.09E+15	3.08E+15	3.39E+15	2.74E+15
0.06	1.07E+14	1.73E+14	2.23E+14	2.00E+14
0.08	6.95E+17	1.09E+18	1.24E+18	1.09E+18
0.1	5.84E+14	8.56E+14	9.48E+14	7.39E+14
0.15	1.43E+15	2.25E+15	2.81E+15	2.29E+15
0.2	1.28E+16	1.89E+16	2.09E+16	1.68E+16
0.3	4.73E+15	7.19E+15	9.02E+15	7.43E+15
0.4	3.88E+16	5.80E+16	6.47E+16	5.90E+16
0.5	1.51E+16	2.11E+16	2.40E+16	1.27E+16
0.6	2.34E+16	3.44E+16	3.79E+16	3.13E+16
0.8	1.77E+16	2.62E+16	3.03E+16	2.35E+16
1	5.53E+15	8.34E+15	1.00E+16	8.04E+15
1.5	2.67E+15	3.90E+15	7.00E+15	3.32E+15
2	5.82E+14	8.53E+14	9.65E+14	7.48E+14
3	9.81E+12	1.49E+13	1.22E+14	1.44E+13
Total	1.75E+18	2.71E+18	3.09E+18	2.69E+18

Table VI: Dose rate at the 100 m away from the 60 cm concrete shielding wall

Pressure	1/3 operation time [mSv/h]	2/3 operation time [mSv/h]	Closing Time [mSv/h]	100 hr [mSv/h]
5 bar(a)	2.42	3.17	4.56	2.39
7 bar(a)	0.131	1.86	3.47	1.91
9 bar(a)	0.348	0.513	0.741	0.455

Table VII: Required concrete shielding wall thicknesses

Pressure	10 mSv/h limitation	1 mSv/h limitation
5 bar(a)	60 cm	80 cm
7 bar(a)	60 cm	80 cm
9 bar(a)	40 cm	60 cm

Table VI shows the effective dose rate calculated with estimated radiation source when the concrete shielding wall is 60 cm. The calculated dose rate is decreased as the opening pressure increases unlike total activity of estimated gamma source except for the 1/3 operation time point. Necessary concrete shielding wall thicknesses of 2 case of dose rate limitation are presented in Table VII. More than 40 cm of shielding wall was required for the CFVS. As shown in the table VI, 9 bar(a) of opening pressure needed the thinnest wall which is 40 cm for the dose rate less than 10 mSv/h and 60 cm for the dose rate less than 1 mSv/h.

4. Conclusion

The radiation source of CFVS and necessary shielding wall thickness are estimated in this study for the case of OPR1000 with SBO with respect to the CFVS opening pressure. As the CFVS opening pressure increases, the maximum dose rate during the accident is decreases so that the required shielding also decreases. 40 cm of shielding wall was required for the dose rate less than 10 mSv/h and 60 cm for the dose rate less than 1 mSv/h at least. Increasing the opening pressure as 9 bar was effective for reducing dose rate and shielding cost.

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