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Evaluation of Atmospheric Source Term Release from Fukushima Daiichi with ORIGEN-MELCOR Code Frames

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1. Introduction

After the Fukushima Daiichi accident on March 11, 2011, NERHQ [1], TEPCO [2] and MEXT [3] provided dose rate monitoring data at the site from March 11 to March 21 and radioactivity concentrations in ground in Japan land.

The objective of this study is to identify from which unit the radiation monitoring peaks come and which radionuclide is a biggest contributor to the peaks in Fukushima accident during first one week.

Source term release during first one week to environment are evaluated from three cores of Fukushima Daiichi using ORIGEN-MELCOR code frames. Comparison is made with monitoring data at the site to check the reasonability of the severe accident analysis code results. It is confirmed that there is a reasonable agreement in the timing of release to atmosphere between estimated peaks by simulation and site monitoring data.

2. Methods

Initial fission product inventory at core is obtained from JAEA-Data/Code 2012-018 [4] for three units of Fukushima Daiichi at shutdown. MELCOR code [5] is used to simulate the thermal hydraulic, the core degradation, and the transport, deposition in plant compartments (RPV and PCV), and finally release to environment of fission products. External water injection to core is not assumed in these simulations. But, suppression chamber venting to reactor building is assumed. The timings of venting follows the plant record.

Initial operation of safety systems to cool the reactor core such as isolation condenser (IC) in Unit 1 (about initial one hour), the RCIC/HPCI operation in Unit 3 (about 36 hours), RCIC operation in Unit 2 (about 72 hours) is assumed in the simulation. Fission products in fuel pellet are released to reactor coolant system as the core temperature increases. Fission products in RCS move to suppression chamber and drywell by cyclic opening of safety relief valve. Pressure of primary containment vessel (PCV) reaches to drywell hatch flange failure pressure (0.75 MPa) by the movement of the steam and non-condensable gases from RPV to PCV.

Fresh water and sea water injection were attempted at the site, however, it is difficult to judge if that external water injection were effective in cooling the core. (OECD/NEA BSAF) [6]

Radioactivity release from the core to atmosphere from the volatile radionuclides such as ^{85}Kr, ^{133}Xe, ^{131}I, ^{134}Cs, ^{137}Cs, and ^{132}Te is estimated (Table 1).

Table 1. Radionuclide (RN) class in MELCOR

Class No.	Name	Elements	Radionuclides considered in this study
1	Noble Gas	Xe, Kr	^{85}Kr, ^{133}Xe
2	Alkali Metals	Cs	^{134}Cs, ^{136}Cs, ^{137}Cs
3	Alkaline Earths	Ba, Sr	^{89}Sr, ^{90}Sr
4	Halogens	I	^{131}I, ^{133}I
5	Chalcogen	Te	^{129m}Te, ^{132}Te
6	Platinoids	Ru	-
7	Early Transition Elements	Mo, Tc	^{99}Mo, ^{99m}Tc
8	Tetravalent	Ce	^{144}Ce
9	Trivalent	La	-
10	Uranium	U	-
11	More Volatile Main Group	Cd, Sb	^{125}Sb
12	Less Volatile Main Group	Sn, Ag	^{110m}Ag

Table 2. Released fraction to environment calculated by MELCOR code at time 186 h

Class	1F1	1F2	1F3	1F123
1	1.00E+00	9.10E-01	9.00E-01	9.30E-01
2	1.16E-01	4.51E-02	4.58E-02	6.41E-02
3	2.30E-02	1.10E-02	1.50E-02	1.53E-02
4	1.38E-01	2.52E-01	1.39E-01	1.83E-01
5	6.20E-02	1.70E-01	1.40E-01	1.30E-01
7	3.20E-02	1.20E-01	2.50E-03	5.50E-02
8	1.10E-04	2.10E-04	2.10E-04	1.90E-04
9	5.50E-05	2.80E-05	4.20E-05	4.30E-05
11	1.10E-01	7.50E-02	4.20E-02	7.20E-02
12	5.50E-02	8.60E-02	1.70E-02	5.30E-02

3. Results and Discussions

Table 2 shows the released fraction to environment at 186 h which is calculated by MELCOR code. Table 3 shows the initial inventory of Fukushima Daiichi Units 1, 2, 3 cores [4]. Table 4 shows the accumulated released activity to environment at 186 h after the reactor trip. Source term estimated by this paper is very compatible with other results estimated by reverse or inverse method as indicated at the end of Table 4.

Figure 1 shows the comparison between the radioactivity release rate (PBq/h) peaks estimated by ORIGEN-MELCOR code frames (upper panel) and site monitoring peaks in dose rate (μSv/h) provided by TEPCO (lower panel) [2]. The timings of peaks have very good agreement. The estimated result by MELCOR code explains that the peaks in March 13 and 14 are the same as March 15 and 16. But, the magnitude of peaks in March 12 to 14 are lower than those of March 15 and 16 in monitoring result. This explains that the earlier release (March 12-14, which comes from Unit 1) is mostly blow out to Pacific Ocean due to the wind direction (from west to east). Most of late release in March 15 and 16 are from Units 3 and 2, which blew out to North-West direction. There was a rain at this time that most of hot spots are made in North-West direction from the Fukushima site [3].

Even though the units used in radioactivity rate (Bq/h) and in dose rate (Sv/h) are different each other in Figure 1, the timings of peaks estimated by ORIGEN-MELCOR are well matched with those of dose rate measured at monitoring posts in the site (MP) during the first week of the Fukushima accident.

To be accurately compared between simulation and monitoring results, it is needed to investigate on the conversion factors from radioactivity rate (PBq/h) to dose rate (μSv/h).

REFERENCES

[1] NERHQ, Nuclear Emergency Response Headquarters, Government of Japan, Report of the Japanese Government to the IAEA Ministerial Conference on Nuclear Safety, The Accident at TEPCO's Fukushima Nuclear Power Stations, 7 June, 2012. available at: http://www.iaea.org/newscenter/focus/fukushima/japanreport

[2] TEPCO, Fukushima Nuclear Accident Analysis Report, Tokyo Electric Power Company (TEPCO), June 2012.

[3] MEXT (Ministry of Education, Culture, Sports, Science & Technology) in Japan. Dose Readings at various locations and Readings of integrated Dose at Monitoring Post out of 20 Km Zone of Fukushima Dai-ichi NPP, 2011.

[4] K. Nishihara, H. Iwamoto, K. Suyama, Estimation of fuel compositions in Fukushima-Daiichi nuclear power plant, JAEA-Data/Code 2012-018, (2012)

[5] R. O. Gauntt et al., "MELCOR Computer Code Manuals, Vol. 1: Primer and Users Guide and Vol. 2: Reference Manual, Version 1.8.6 September 2005," SAND 2005-5713, Sandia National Laboratories (2005).

[6] OECD/NEA, Phase-I Final Report on the OECD/ NEA BSAF Project, IAE, Japan, March 2015 (Draft)

Table 3. Initial inventory of Fukushima Daiichi Units 1, 2 and 3 Cores (PBq)

RN Class No.	RN	Product	Half	Life	1F1 (PBq)	1F2 (PBq)	1F3 (PBq)	SUM (PBq)
1	85Kr	Fission	10.756	years	23.1	31.1	29.5	83.7
1	133Xe	Fission	5.24	days	2710	4670	4670	12000
2	134Cs	Fission	2.065	years	190	277	252	719
2	136Cs	Fission	13.16	days	54.2	81.7	81.8	218
2	137Cs	Fission	30.04	years	203	256	241	700
3	89Sr	Fission	50.53	days	1360	2210	2350	5930
3	90Sr	Fission	28.74	years	150	191	181	522
4	131I	Fission	8.02	days	1350	2340	2330	6010
4	133I	Fission	20.8	days	118	204	204	527
5	129mTe	Fission	33.6	days	44	70.6	74.8	189
5	132Te	Fission	3.2	days	1950	3360	3370	8690
7	54Mn	Activation	312.12	days	0.0647	0.11	0.108	0.283
7	60Co	Activation	5.271	years	2.5E-03	3.6E-03	3.3E-03	9.4E-03

7	99Mo	Fission	65.94	hour	2570	4430	4420	11400
7	99mTc	Fission	6.01	hour	2240	3880	3860	9980
8	144Ce	Fission	284.9	days	1330	2310	2280	5920
8	238Pu	Actinide	87.74	years	4.63	4.58	5.54	14.7
8	239Pu	Actinide	24100	years	0.7	0.883	1.04	2.62
8	240Pu	Actinide	6570	years	0.883	1.03	1.35	3.27
8	241Pu	Actinide	13.2	years	3.5E-05	1.2E-03	1.6E-05	1.3E-03
9	241Am	Actinide	433	years	0.561	0.434	0.558	1.55
9	242Cm	Actinide	162.8	days	89.4	89.7	104	283
9	244Cm	Actinide	18.11	years	2.71	3.22	2.71	8.64
11	125Sb	Fission	2.758	years	10.9	16.5	15.7	43.1
12	110mAg	Fission	249.8	days	4.04	6.41	5.99	16.4

Table 4. Radioactivity released to environment up to 186 h from Fukushima Daiichi Units 1, 2 and 3 Cores (PBq)

Radionuclide		Environmental Radioactivity (PBq)					Reverse Method*		
Class	RN	1F1	1F2	1F3	SUM	Decay corrected	Min	-	Max
1	85Kr	23	28	27	78	78	44.1	-	83.7
1	133Xe	2710	4250	4203	11163	7630	6000	-	22000
2	134Cs	22	12	12	46	46	11.8	-	18
2	136Cs	6	4	4	14	11		-	
2	137Cs	24	12	11	46	46	5.5	-	62.5
3	89Sr	31	24	35	91	82		-	
3	90Sr	3	2	3	8	8	0.02	-	0.14
4	131I	186	590	324	1100	753	65.3	-	500
4	133I	16	51	28	96	92	42.2	-	146
5	129mTe	3	12	10	25	23	3.33	-	15
5	132Te	121	571	472	1164	509	88	-	180
7	54Mn	2.10E-03	1.30E-02	2.70E-04	1.60E-02	1.60E-02		-	
7	60Co	8.10E-05	4.30E-04	8.20E-06	5.20E-04	5.20E-04		-	
7	99Mo	82	532	11	625	122		-	
7	99mTc	72	466	10	547	9.28E-02		-	
8	144Ce	0.15	0.49	0.48	1.11	1.11		-	
8	238Pu	5.10E-04	9.60E-04	1.20E-03	2.60E-03	2.60E-03	2.00E-06	-	5.00E-06
8	239Pu	7.70E-05	1.90E-04	2.20E-04	4.80E-04	4.80E-04	1.00E-06	-	3.50E-06
8	240Pu	9.70E-05	2.20E-04	2.80E-04	6.00E-04	6.00E-04	1.00E-06	-	3.50E-06
8	241Pu	3.90E-09	2.50E-07	3.40E-09	2.60E-07	2.60E-07	1.10E-04	-	2.60E-04
9	241Am	3.10E-05	1.20E-05	2.30E-05	6.60E-05	6.60E-05	5.00E-07	-	1.30E-06
9	242Cm	4.90E-03	2.50E-03	4.40E-03	1.20E-02	1.20E-02	2.70E-05	-	6.50E-05
9	244Cm	1.50E-04	9.00E-05	1.10E-04	3.50E-04	3.50E-04	1.00E-06	-	2.60E-06
11	125Sb	1.2	1.24	0.66	3.1	3.1		-	
12	110mAg	0.22	0.55	0.1	0.88	0.88	0.015	-	0.03

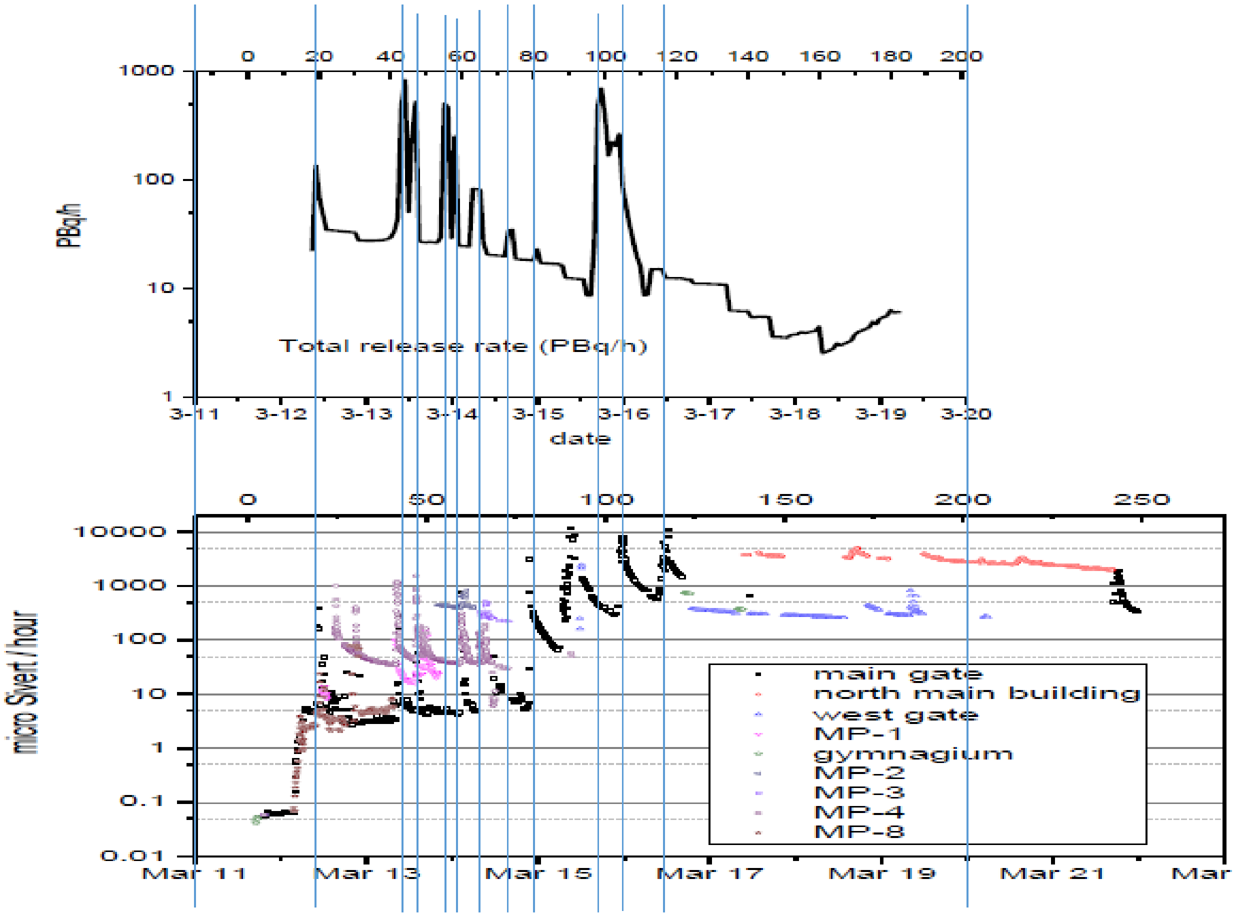

Figure 1. Comparison between the radioactivity release rate (PBq/h) peaks estimated by ORIGEN-MELCOR code frames (upper panel) and site monitoring peaks in dose rate (μSv/h) provided by TEPCO (lower panel)