Estimation of Source Term Release to Environment in Three Severe Accident Scenarios in Typical PWR and Comparison with Other Research or Accidents

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1. Introduction

Severe accident source term estimation is needed for the establishment of emergency response preparedness. This paper provides insights into the radiological impacts of three typical severe accident scenarios of OPR-1000 nuclear power plants. Three severe accident scenarios analyzed are (1) Station Blackout (SBO) without recovery of AC and DC powers longer than a few days as occurred in Fukushima accident, (2) Steam generator tube rupture (SGTR), and (3) Interfacing systems Loss of coolant accident (ISLOCA). Fission products released from core are released to containment by cyclic opening and closure of PORV after the fuel cladding damage occurs and then released to environment by overpressure of the containment in SBO accident sequence. SGTR and ISLOCA accidents are bypass sequences where the fission products released from the core to RCS released directly to the environment bypassing containment.

MELCOR code [9] is used for this analysis. Radioactivity released to environment for 12 radionuclide classes are analyzed.

The objective of this study is to gain insights on the radiological impacts of hypothetical severe accident scenarios which can be occurred in PWR type of nuclear power plants. Maximum values of radioactivity which can be release to environment are compared with previous actual accidents which happened in Kyshtym, Windscale Piles, TMI-2, Chernobyl and Fukushima. The purpose of comparison with real accident is to check the reasonability of our estimation.

1. Kyshtym, Russia, 1957: Chemical explosion of containment tank of liquid radioactive wastes at military installation
2. Windscale Piles, UK, 1957: Fire of nuclear reactor at military installation designed to produce plutonium
3. Three Mile Island, USA, 1979: Partial core melt at civilian nuclear reactor
4. Chernobyl, Ukraine (then USSR), 1986: Core explosion and fire at civilian nuclear reactor
5. Fukushima, Japan, 2011: Core melt-through; three reactor cores damaged; three reactor buildings hydrogen explosions

The released fraction and radioactivity values estimated in this study are also compared with results of previous PSA studies such as WASH-1400 [14], HANUL 3&4 PSA [15], MAANSHAN PSA [16], and Surry SOARCA study. They are summarized in Table 1 and Figure 1 for radionuclides of ^{137}Cs and ^{131}I.

2. Methods

Initial inventory in core is estimated by ORIGEN code at first [5]. ORIGEN code estimates the fission product inventory (mass or radioactivity) based on the burnup history and shutdown history for about thousand radionuclides. And then MELCOR code is used to estimate the deposition fractions in plant compartment i.e. RCS and Containment and release fraction to environment by virtue of aerosol dynamics. 12 radionuclide classes are defined in MELCOR code. It is assumed that each class has the same volatility and chemical properties between different radionuclides. Class 1 (noble gas) and Class 4 (I) has gaseous forms but other classes are all in particulate forms (i.e. aerosols), such as Class 2 (Cs), Class 3 (Sr), Class 5 (Te)…. Typical isotopes are maybe ^{137}Cs in Class 2 and ^{131}I in Class 4 on which we should focus in emergency preparedness, because they can cause the biggest impacts on the early and long-term health effects.

3. Results and Discussions

Initial inventory of radionuclides are shown in Table 1. Released radioactivity to environment is summarized in Table 2. Table 3 shows the released fractions to environment from this study and other research or real accident (Fukushima). Figure 1 shows the release timings and magnitudes (fractions of initial inventory) of ^{131}I and ^{137}Cs for three severe accident scenarios (SBO, SGTR and ISLOCA) from this study (OPR-1000)

Figure 2 shows the comparisons of environmentally released radioactivity (Unit : PBq) of ^{131}I and ^{137}Cs among this study, Fukushima, and Chernobyl accidents. The released radioactivity for OPR-1000 is obtained by multiplying the initial core inventory of fission products obtained by ORIGEN code [6] by the release fraction to environment obtained by MELCOR code [4]. Iodine has gaseous state that many percent of inventory are released to environment while cesium has particulate form (aerosol), many percent of which is retained in RPV. In case of ISLOCA scenario, however, many

percent of cesium is not retained in RCS but released through auxiliary building to environment via low elevation shutdown cooling system (SCS) piping.

The released radioactivity (PBq) to atmosphere and to stagnant water in building from Fukushima accident in Figure 2 are obtained from the book of Povinec et al [3]. Total amounts of released radionuclides from reactor cores of FNPP1 into the atmosphere were estimated and reported by Japanese Government for Cores 1, 2 and 3 (Japanese Government, 2011) [7]. After the severe accident in the FNPP1, a large amount of contaminated stagnant water was produced in turbine buildings and surrounding areas. Nishihara et al. (2012) [18] reported activities of radionuclides in stagnant waters in turbine buildings and surrounding areas, and they also estimated inventories of radionuclides in stagnant water. It was revealed that the release ratios of iodine and cesium were several tens of percent, while those of strontium and barium were smaller by one or two orders of magnitude. These release ratios observed at the Fukushima accident were similar to those observed during the Three Miles Island 2 accident which occurred in USA in March 1979.

The released radioactivity (PBq) to environment from Chernobyl accident in Figure 2 is obtained from UNSCEAR-2008 report [1]. More detailed information on source term research and real accident results can be found in ref [4] and [5].

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Table 1. Initial inventory (radioactivity) of OPR-1000, Chernobyl and Fukushima at reactor shutdown (PBq)

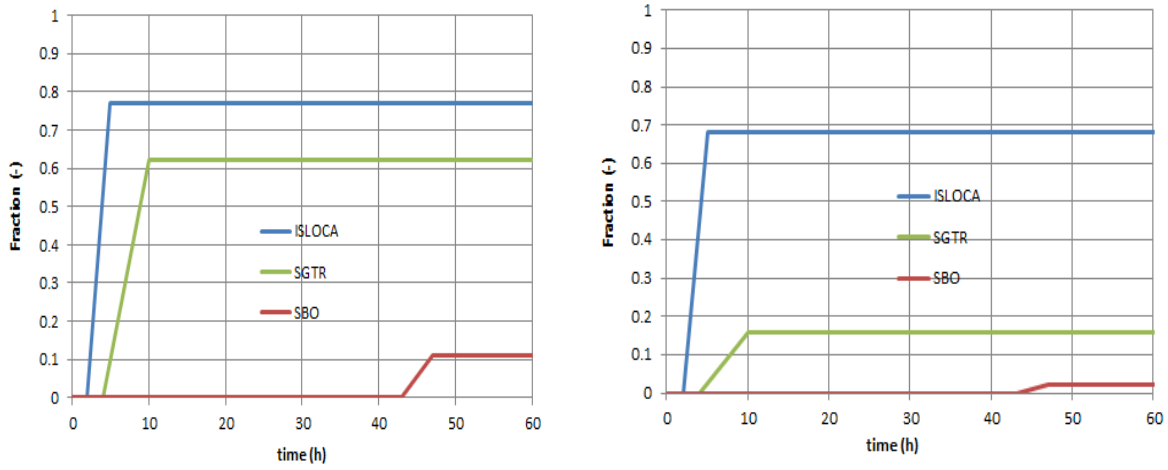
RN	Half-life	OPR-1000 [6]	Fukushima [3]	Chernobyl [12]	TMI-2	Windscale	Kyshtym
^{85}Kr	10.72 years	19	83.7	33	24		
^{133}Xe	5.24 days	5820	14,000	6500	3700		
^{131}I	8.02 days	2807	6010	3200	4660		
^{133}I	20.8 days	5965	527		1797		
^{134}Cs	2.065 years	135	719	180	463		
^{137}Cs	30.04 years	176	700	280	32		
^{132}Te	3.2 days	4060	8690	2700	19,712		
^{89}Sr	50.53 days	3290	5930	2300	5540		
^{90}Sr	28.74 days	148	522	200	27		
^{95}Zr	64.032 days						
^{106}Ru	368 days						
^{144}Ce	284.9 days		5920				

Table 2. Released radioactivity to environment from this study and other accident (PBq)

RN	This study (OPR-1000)			Windscale [10]	Kyshtym [10]	TMI-2 [13]	Chernobyl [1]	Fukushima [3]		
	SBO	SGTR	ISLOCA					Atmos-phere	Building Stagnant Water	Sum
^{85}Kr				0.045		2.4	33	44	-	44
^{133}Xe				26	-	370	6500	14,000	-	14,000
^{131}I	317	1786	2218	1.8	-	0.0005	1760	159	1940	2099
^{133}I							910	42.2	-	42.2
^{134}Cs							47	17.5	147	164.5
^{137}Cs	7	55	236	0.18	0.027	-	85	15.3	141	156.3
^{132}Te				1.3			1150	88.4	-	88.4
^{89}Sr							115	1.96	70.6	72.56
^{90}Sr				0.0015	4		10	0.139	8.6	8.739
^{95}Zr				0.016	18		84			
^{106}Ru				0.006	2.7		73			
^{144}Ce				0.026	49		50	0.00115		

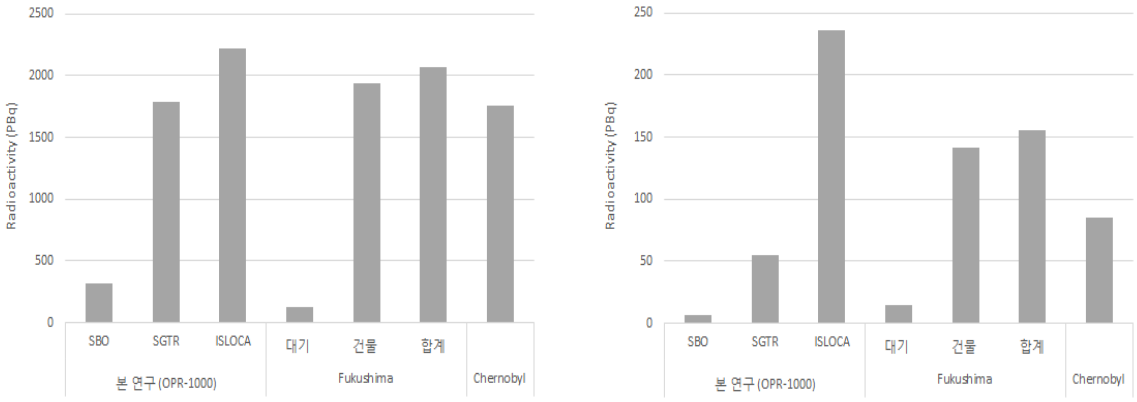
Table 3. Released fractions to environment from this study and other research or accident

RN	This study (OPR-1000)			WASH -1400 [14]	Surry SOARCA [17]	Hanul 3,4 PSA [15]	Maanshan PSA [16]	Fukushima [3]		
	SBO	SGTR	ISLOCA					Atmos-phere	Building Stagnant Water	Sum
^{131}I	11%	79%	77%	70%	16%	40%	99%	2.6%	32%	35%
^{137}Cs	2%	21%	68%	50%	2%	32%	99%	2.2%	20%	22%



^{131}I ^{137}Cs

Figure 1. Release timings and magnitudes (fractions of initial inventory) of ^{131}I and ^{137}Cs from this study (OPR-1000)



^{131}I ^{137}Cs

Figure 2. Comparisons of environmentally released radioactivity (PBq) of ^{131}I and ^{137}Cs from this study (OPR-1000), Fukushima, and Chernobyl Accident