Fission Product Behavior during Ex-Vessel Phase of the LB-LOCA Severe Accident in Westinghouse 2 loops PWR

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Abstract

The purpose of this research is to estimate the magnitude of fission product and aerosol release from the PWR NPP containment during Large Break Loss of Coolant Accident (LB-LOCA) up to 24 hr as severe accident scenario without considering the safety injection systems(SIS) using MELCOR1.8.6. The results show that, 174kg radioactive materials are discharged into the containment and 118 kg of this amount are related to the airborne material including aerosols and vapors.

Keywords: MELCOR Code, LOCA, Radionuclide

Introduction

To estimate source terms in severe accident conditions, integral codes such as MELCOR (Methods for Estimation of Leakages and Consequences Of Releases) can be used for analysis [1] and severe accident analyses are performed to help in understanding the behavior of plant and containment systems during postulated accident conditions.

The "in-vessel release phase" of a severe accident refers to that period of time during which the reactor core is damaged and begins to melt, but is still retained within the Reactor Cooling System (RCS). LBLOCA is investigated in this research. Due to LBLOCA and failure of RCS integrity, only ex-vessel release phase presented.

Severe accident modeling

In this research, LB-LOCA without actuation of active safety systems (accumulator tank injection and passive autocatalytic recombiners actuate as passive safety system) considered as severe accident. LBLOCA accident sequence begins as a complete guillotine break of the RCS cold leg recirculation piping. The break is located between Reactor Coolant Pump (RCP) and Reactor Pressure Vessel (RPV) that due to the lack of cooling fluid inventory to the core is one of the most important accidents.

Severe accident MELCOR code is used in this study. MELCOR is an integrated computer code in the field of calculation of nuclear engineering severe events, covering all serious phenomena related to light water reactors. In this research, the release 1.8.6 of this code developed by USA Nuclear Regulation Adjustment Commission in Sandia National Laboratory in 2005 has been used [2].

In this research, all system of nuclear power plant is modeled in MELCOR code. To perform a hydrodynamic modeling for the reactor pressure vessel, primary and secondary circuit and NPP containment, control volume package (CVH) and flow path (FL) packages of the code have been employed. Core itself is modeled in a separate package named COR which calculates thermal response of the core structures and lower plenum and internal structures of each of them.

For development of the model, the severe accident packages of the MELCOR code are added to the steady state model described in reference [3]. Also, by RadioNuclide (RN) package the behavior of fission product aerosols and vapors and other trace species, including release from fuel and debris, aerosol dynamics with vapor condensation and revaporization, deposition on structure surfaces, transport through flow paths for all control volumes of primary, secondary and containment are modeled. In this research 16 groups of radionuclides elements (with similar properties [2]) are modeled and CORSOR-M model with surface-to-volume ratio option is considered as core release model. Figure 1 shows the overall nodalization of the plant.

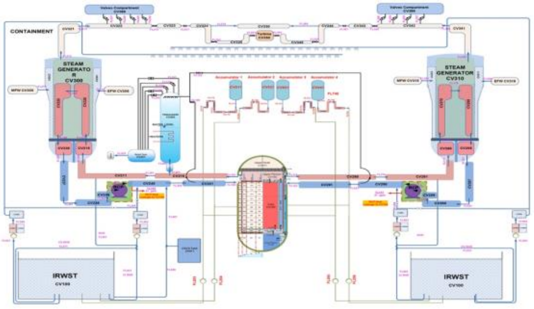

Figure 1. Plant nodalizationsin MELCOR model

Results and discussion

The more volatile fission products would tend to enter the RCS as gases, while the less volatile elements would tend to condense (RPV structures). The released fission product gases could absorb or condense onto particulates and RCS surfaces, react chemically with other species in the RCS atmosphere or with RCS surfaces, or dissolve in or otherwise react with any water present in the dominant pathway(s) through the system. The aerosols released from the core would tend to increase in size by the agglomeration process. As time passes, some aerosols would be removed by settling or be transported to surfaces by diffusiophoresis, thermophoresis, or other processes. Some removed material could subsequently be resuspended, revaporized, or otherwise entrained in the RCS fluids and subsequently transported out of the RCS[5].

A timeline summarizing the major event timing for large break loss of coolant accident is provided in Table1. The first hydrogen explosion (Burn) occurred in control volume 400 during 4.548 hours after accident initiation.

Table 1. Key event timing for LBLOCA

Key Event	time
Double-Ended Guillotine Break (DEGB) in Cold Leg Pipe (LBLOCA)	0.0 sec
Water Level at Top of Active Fuel	0.0 sec
Reactor Trip & SIS Fail to Start	0.5 sec
Accumulators Discharge	0.0-66.0 sec
Start of Fuel Cladding damage (gap release due to crack creation 1170 K)	0.658 hr
First PARs actation	1.110 hr
First Support Plate Failure	1.398 hr
Debris Relocation to Lower Head	3.297 hr
Vessel Failure	4.547 hr
First Hydrogen Burn in Containment (CV400)	4.548 hr
First Hydrogen Burn in RCS	Not Occur

Table 2 identifies the radionuclide class mass inventories in core at NPP steady state condition that is output from MELGEN calculation (MELGENOUT). In addition to, the inventory masses for 3412 MWth reactor at shutdown state according to NUREG-1465 calculation [6] represent in this table.

Table 2. Radionuclide Class Masses at Shutdown

CLASS	Rep. element	NUREG1465 Calculation(kg)	MELGENOUT for PWR(kg)
1	(Xe) Noble Gases	3.421E+02	1.13339E+02
2	(Cs) Alkali Metals	1.907E+02	6.31670E+01
3	(Ba)AlkalineEarths	1.501E+02	4.97200E+01
4	(I)Halogens	1.470E+01	4.88160E+00
5	(Te)Chalcogens	3.002E+01	9.94400E+00
6	(Ru)Platinoids	2.111E+02	6.99470E+0
7	(Mo)EarlyTransition	2.490E+02	8.24900E+01
8	(Ce)Tetravalents	4.393E+02	1.45544E+02
9	(La) Trivalents	4.076E+02	1.35035E+02
10	(U) Uranium	8.458E+04	2.82500E+04
11	(Cd)More Volatile	9.970E-01	3.30299E-01
12	(Sn)Less Volatile	5.662E+00	1.87580E+00
13	(B)Boron	0.0	0.0
14	H_2O	0.0	0.0
15	Concrete	0.0	0.0
16	(CsI)Cesium Iodide	0.0	0.0

Conclusions

MELCOR Severe accident analysis code can be used to estimate the radioactive release from which reactor core and from which radionuclide the peaks in monitoring points can be generated.

The fuel elements normally fail through cladding rupture. When the cladding ruptures, much of the noble gas inventory is released (about 113.3 kg that related to gap release of radionuclide gases). The molybdenum is released to the containment about 4 kg during 24 hr in LBLOCA.

The iodine will predominantly be released into the containment as aerosol iodide ions (I- or as combined ionic species such as CsI). The amount of this radioactive material is about 4.8 kg during LBLOCA severe accident. About 6.4 kg Tellurium release into the containment that will be delayed (compared with iodine and cesium), because it remains chemically bound with zircalloy cladding in the vessel. Radioactive airborne mass of 16 classes of radionuclides in all volumes of containment , including aerosols and vapors are shown in figure 2. The sum of these radioactive masses is about 118 kg. Also, the sum of radioactive masses of radionuclides in all control volumes of RCS and containment (0.092 kg and 164.21 kg, respectively). Includes mass in pool and atmosphere, but not that deposited on heat structures, are represented in figure3.

Radioactive mass of each class (core inventory percentage) in all control volumes of RCS and containment after 24 hours, including mass deposited on heat structures associated with the control volumes, tabulated in table3.

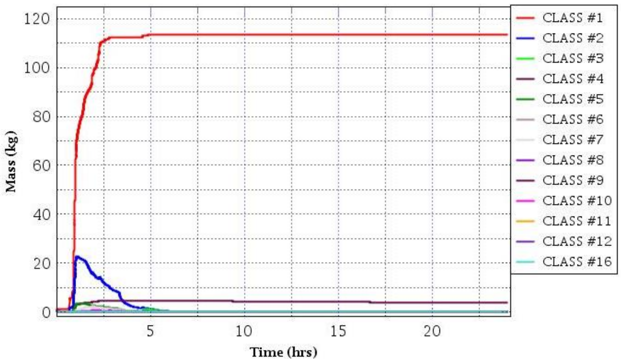

Figure 2. Radioactive airborne masses in Containment

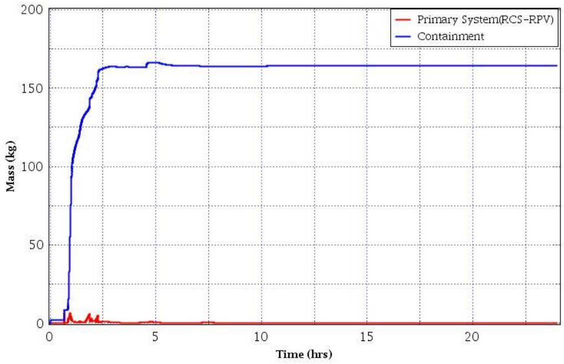

Figure 3. total radioactive materials in RCS and containment

Table 3. Realese Radionuclide Class Masses in Containment and RCS during LBLOCA

CLASS	Rep. element	RCS(kg)	Containment(kg)
1	(Xe) Noble Gases	0.03	113.3 (99.96%)
2	(Cs) Alkali Metals	22.3	40.9 (64.71%)
3	(Ba)AlkalineEarths	0.15	2.2 (4.44%)
4	(I)Halogens	~0.0	4.8 (99.13%)
5	(Te)Chalcogens	3.5	6.4 (64.38%)
6	(Ru)Platinoids	~0.0	~0.0 (0.0%)
7	(Mo)EarlyTransition	2.1	4.0 (4.81%)
8	(Ce)Tetravalents	2.9	0.6 (6.48%)
9	(La) Trivalents	~0.0	0.03 (0.02%)
10	(U) Uranium	0.8	1.9 (~0.0%)
11	(Cd)More Volatile	0.01	0.03 (0.1%)
12	(Sn)Less Volatile	0.05	0.1 (5.17%)
13	(B)Boron	0.0	0.0
14	H_2O	0.0	0.0
15	Concrete	0.0	0.0
16	(CsI)Cesium Iodide	~0.0	0.08
	Total	31.84	174.34

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