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Preliminary Mass and Energy Release Analysis for Postulated MSLB Accidents on APR1400 Using SPACE-ME Methodology

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1. Introduction

The release of coolant mass and energy (M/E) resulting from postulated loss of coolant accidents (LOCAs) and main steam line break accidents (MSLBs) must be performed for the functional design of light water reactor containment. This assessment involves calculating containment pressure and temperature (P/T) behavior. In 2007, Korea Electric Power Corporation Engineering and Construction Company Inc. (KEPCO E&C) developed an advanced M/E release analysis method known as KEPCO E&C Improved Mass and Energy Release Analysis (KIMERA). This method utilizes RELAP5-ME computer code, which links RELAP5K with CONTEMPT4/MOD5 [1]. KIMERA methodology was applied to the M/E analysis of Advanced Power Reactor 1400 (APR1400) and received approval from Korea Institute of Nuclear Safety (KINS) in 2012 [2].

A novel methodology for M/E release analysis, known as SPACE-ME methodology, is currently being developed by KEPCO E&C [3,4]. This methodology utilizes Safety and Performance Analysis CodE for nuclear power plants (SPACE) and nuclear Containment Analysis Package (CAP) codes [5]. SPACE code was originally developed for thermal-hydraulic safety analysis of pressurized water reactors. In junction with SPACE, CAP code, designed to calculate thermal-hydraulic behavior within containment, is employed to determine containment back pressure [6].

This paper presents the preliminary study on M/E release analysis using SPACE-ME methodology for postulated MSLB accidents on APR1400. The M/E release data resulting from the steam line ruptures in various postulated MSLB accidents were analyzed utilizing the SPACE and CAP codes. Using the M/E release data obtained through SPACE-ME methodology for MSLB accidents, assessments of containment P/T behavior were performed using stand-alone CONTEMPT4 code. This was done to validate the peak containment P/T and to compare these values with results obtained from previous methodologies.

2. Methodology

2.1 Description of Modeling

We used the modeling of APR1400 nuclear steam supply system (NSSS) in SPACE code. It was assumed that the break of steam line is located at the front-end of a Main Steam Isolation Valve (MSIV). Figure 1 shows the node configuration for steam line break to simulate the release of M/E during the postulated MSLB accidents on the APR1400.

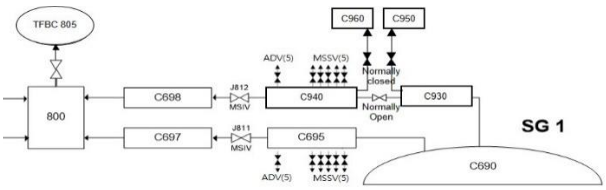

Fig. 1. SPACE node configuration of steam line break

2.2 Major Assumptions and Initial Conditions

Some conservative assumptions and initial conditions were introduced to maximize the release of M/E from the rupture of steam line into the containment. Major assumptions of the postulated MSLB accidents on APR1400 for the M/E release analysis were from basically the same with those of KIMERA methodology [1,2]. Table I explains the major assumptions used in this study.

Table I: Major assumptions of the postulated MSLB accidents on APR1400

Parameters	Assumptions
Evaluation time	30 min. from the accident initiation
Turbine trip	At the accident initiation
Loss of offsite power (LOOP)	Available (Non-LOOP)
Feedwater flow to steam generator (SG)	Maximum total flow only to broken side
Feedwater enthalpy	Maximum
Volume of reactor coolant system (RCS)	Maximum without tube plugging
Volume of feed and steam line	Maximum without tube plugging

The initial conditions were basically based on the limiting conditions for operation (LCO) in Final Safety Analysis Report (FSAR) of Shin-Kori Units 3&4 nuclear power plants (SKN3&4), which employ APR1400. Table II describes the initial conditions assumed for this study.

Table II. Initial conditions of the postulated MSLB accidents on APR1400

Parameters	Values
Core power	102%, 75%, 50%, 20%, and 0% of full power (FP, 3983 MWt)
Pressurizer (PZR) pressure	16.03 MPa (2325 psia)
Core inlet temperature	568.15 K (563 °F)
RCS flow rate	95%
PZR water level	60% (102%FP), 55% (75%FP), 50% (50%FP) , 40% (20 and 0%FP)
SG water level	52% narrow range (77.75% wide range)
Break type	Double-ended (guillotine)
Break size	Discharge coefficient (Cd) 0.1, 0.2, 0.3, 0.4, 0.5, and 1.0
Single failures	MSIV failure and loss of containment cooling (LCC)

3. Results

The M/E release of the postulated MSLB accidents on APR1400 was investigated for the various initial core power conditions, such as 102%, 75%, 50%, 20%, and 0% of full power. For each core power, the spectrum analysis of break sizes, such as discharge coefficient of 0.1, 0.2, 0.3, 0.4, 0.5, and 1.0, was conducted. Subsequently, the containment P/T behaviors were analyzed by each core power and each break size. Furthermore, based on the peak containment P/T, the most limiting break size of each core power with MSIV failure and LCC was compared, respectively. Finally, the most limiting case of each single failure was compared with that of the previous methodologies.

3.1 M/E Release of MSLB Accidents with MSIV Failure

Table III shows the peak containment P/T of the postulated MSLB accidents with MSIV failure by break size. the bolded and underlined values are the maximum peak containment P/T at each core power condition. The most limiting peak pressure of the containment was predicted to be 62.30 psia in the case with core power 102% and discharge coefficient of 0.3. The case with core power 102% and discharge coefficient of 1.0 was the most limiting case in terms of the peak temperature of the containment, as shown to be 366.9 °F.

Figures 2 and 3, respectively, illustrate the integrated release of M/E from the postulated MSLB accidents with MSIV failure in the most limiting case of each core power in terms of the containment peak pressure. The case of core power 102%, which has the highest peak containment pressure, released the largest amount of the M/E from the accident initiation to the end of the accident.

Table III: The peak containment P/T of the postulated MSLB accidents with MSIV failure

Core power (% of full power)	Discharge coefficient (Cd)	Peak cont. pressure (psia)	Peak cont. temperature (°F)
102	1.0	60.58	**366.9**
	0.5	60.11	362.3
	0.4	60.90	358.3
	0.3	**62.30**	359.3
	0.2	60.87	341.7
	0.1	54.50	317.1
75	1.0	58.71	**366.5**
	0.5	58.22	357.4
	0.4	58.89	354.5
	0.3	**60.25**	356.2
	0.2	58.65	339.9
	0.1	52.44	316.8
50	1.0	56.27	**363.7**
	0.5	55.38	357.2
	0.4	55.73	349.6
	0.3	**56.69**	351.4
	0.2	54.71	337.8
	0.1	49.00	314.3
20	1.0	**56.49**	**366.6**
	0.5	53.46	352.1
	0.4	53.72	348.1
	0.3	54.52	349.7
	0.2	51.18	336.5
	0.1	43.83	311.1
0	1.0	55.33	**352.5**
	0.5	54.86	347.0
	0.4	55.25	348.2
	0.3	**56.11**	348.6
	0.2	52.96	333.9
	0.1	44.84	309.5

The pressure behavior of the containment for each case is shown in Figure 4. After accident initiation, the containment pressure gradually increases and then sharply decreases in about 100 seconds in response to the containment spray actuation. Afterwards, the pressure rises again to create the secondary peak. The maximum peak pressure of the containment is observed at 62.30 psia for the case of core power 102% and discharge coefficient of 0.3.

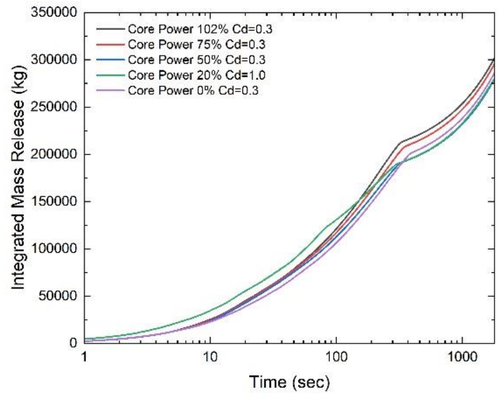

Fig. 2. The integrated mass release of the postulated MSLBs with MSIV failure by the most limiting break size, based on the containment peak pressure, of each core power.

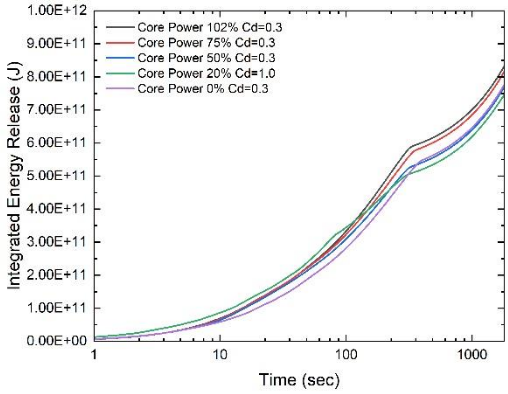

Fig. 3. The integrated energy release of the postulated MSLBs with MSIV failure by the most limiting break size, based on the containment peak pressure, of each core power.

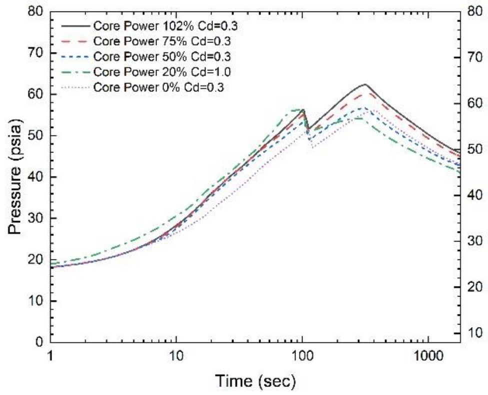

Fig. 4. The containment pressure during the postulated MSLBs with MSIV failure by the most limiting break size, based on the containment peak pressure, of each core power.

The integrated M/E release from the postulated MSLB accidents with MSIV failure are shown in Figures 5 and 6 by the most limiting peak temperature of the containment of each core power.

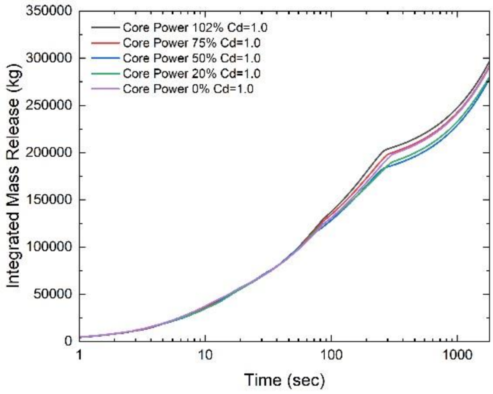

Fig. 5. The integrated mass release of the postulated MSLBs with MSIV failure by the most limiting break size, based on the containment peak temperature, of each power.

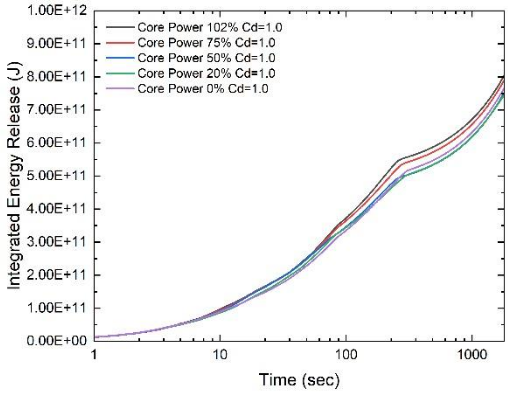

Fig. 6. The integrated energy release of the postulated MSLBs with MSIV failure by the most limiting break size, based on the containment peak temperature, of each power.

Figure 7 shows the containment temperature behavior of the limiting cases for each core power. The containment temperature tends to rise during 100 seconds. and rapidly drop immediately after the actuation of the containment spray. The peak temperature of the containment for the case of core power 102% and discharge coefficient of 1.0, which is the most limiting case, is 366.9 ^{o}F observed at 69 seconds.

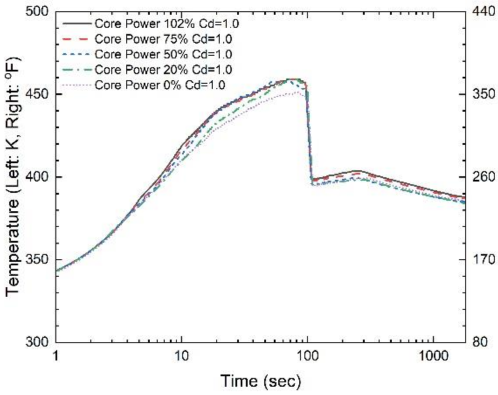

Fig. 7. The containment temperature during the postulated MSLBs with MSIV failure by the most limiting break size, based on the containment peak temperature, of each power.

3.2 M/E Release of MSLB Accidents with LCC

The peak containment P/T of the postulated MSLB accidents with LCC by break size are summarized in Table IV. The maximum peak P/T of the containment by each initial core power are highlighted. From the viewpoint of the containment peak pressure, the case with core power 102% and discharge coefficient of 0.1, which peak pressure is at 62.23 psia, was investigated as the most limiting case. The most limiting peak temperature of the containment was observed at 366.8 ^{o}F in the case with core power 50% and discharge coefficient of 1.0.

Table IV: The containment peak P/T of the postulated MSLB accidents with LCC

Core power (% of full power)	Discharge coefficient (Cd)	Peak cont. pressure (psia)	Peak cont. temperature (ºF)
102	1.0	59.81	**363.6**
	0.5	59.42	353.7
	0.4	60.36	354.1
	0.3	61.75	355.6
	0.2	62.01	337.8
	0.1	**62.23**	308.9
75	1.0	57.81	**357.3**
	0.5	57.76	349.5
	0.4	58.51	350.1
	0.3	59.98	350.8
	0.2	**59.98**	335.2
	0.1	58.60	309.9
50	1.0	55.53	**366.8**
	0.5	54.75	345.9
	0.4	55.16	344.6
	0.3	**56.13**	347.3
	0.2	55.48	333.0
	0.1	53.95	308.0
20	1.0	53.75	**349.7**
	0.5	53.38	341.2
	0.4	53.75	340.3
	0.3	**54.82**	344.2
	0.2	53.65	331.0
	0.1	46.90	306.5
0	1.0	55.15	**346.7**
	0.5	54.90	339.0
	0.4	55.38	343.9
	0.3	**56.43**	345.7
	0.2	55.37	329.8
	0.1	50.00	305.3

The integrated M/E release and the containment temperature behavior of the postulated MSLB accidents with LCC are shown in Figures 8, 9, and 10. The pressure behavior of the MSLB accidents with LCC is generally similar to those of the MSLB with MSIV failure. However, after depressurization following the secondary peak, the containment pressure slightly increases again in the LCC cases. The maximum peak pressure of the containment is shown at 62.23 psia for the case of core power 102% and discharge coefficient of 0.1.

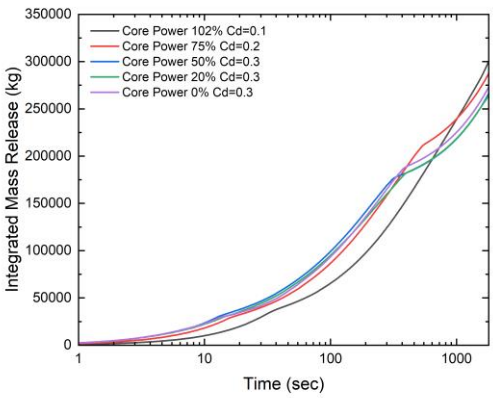

Fig. 8. The integrated mass release of the postulated MSLBs with LCC by the most limiting break size, based on the containment peak pressure, of each power.

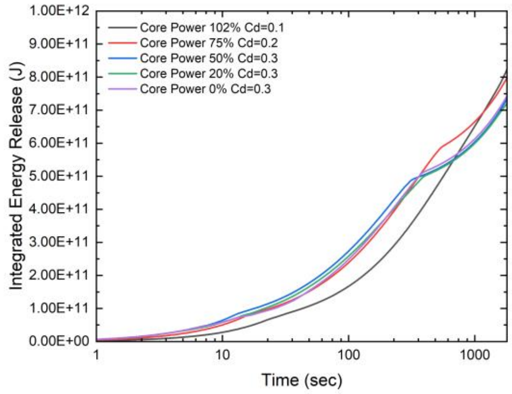

Fig. 9. The integrated energy release of the postulated MSLBs with LCC by the most limiting break size, based on the containment peak pressure, of each power.

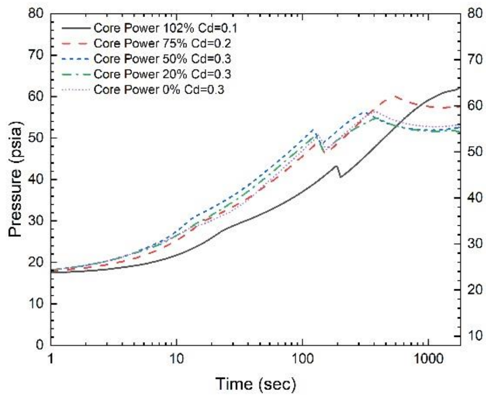

Fig. 10. The containment pressure during the postulated MSLBs with LCC by the most limiting break size, based on the containment peak pressure, of each power

The integrated M/E release and the containment temperature behavior of the postulated MSLB accidents with LCC are shown in Figures 11, 12, and 13. The maximum peak temperature of the containment appears at 366.8 ºF in the case of core power 50% and discharge coefficient of 1.0.

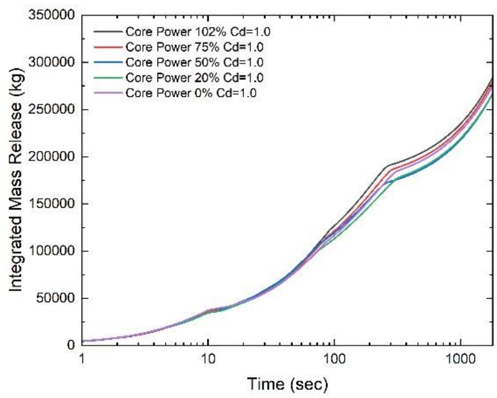

Fig. 11. The integrated mass release of the postulated MSLBs with LCC by the most limiting break size, based on the containment peak temperature, of each power.

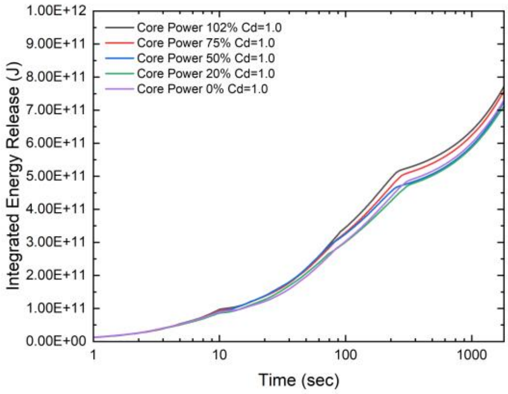

Fig. 12. The integrated energy release of the postulated MSLBs with LCC by the most limiting break size, based on the containment peak temperature, of each power.

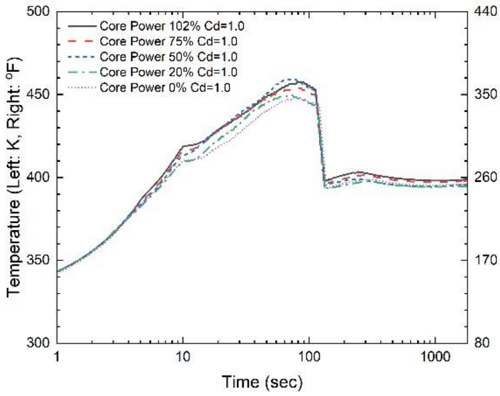

Fig. 13. The containment temperature during the postulated MSLBs with LCC by the most limiting break size, based on the containment peak pressure, of each power.

3.3 Comparison with the Previous Methodologies

Table V summarizes the most limiting case of each single failure, based on the containment P/T, analyzed by the previous methodology included in SKN 3&4 FSAR, KIMERA methodology [2], and SPACE-ME methodology used in this study. The maximum peak containment pressure of the postulated MSLB accidents, analyzed by SPACE-ME, appear at 62.30 psia in the case of core power 102% and discharge coefficient of 0.3. The maximum peak containment temperature of SPACE-ME methodology observed at 366.9 °F in the case of core power 102% and discharge coefficient of 1.0. Compared to other methodologies, the maximum peak pressure of the containment obtained by SPACE-ME methodology tends to be lower. In contrast, the maximum peak temperature of the containment is relatively inclined to be higher than that of others.

Table V: The summary of the most limiting MSLB accident for the containment peak P/T depending on the single failure analyzed by the various M/E release analysis methodologies

Comparison of methodology		MSIV failure		LCC	
		Press. (psia)	Temp. (°F)	Press. (psia)	Temp. (°F)
APR1400 (SKN3&4) FSAR	Peak	63.1 at 378 sec	328.6 at 112 sec	**64.6 at 428 sec**	**336.2 at 125 sec**
	Power /Size	75% Cd 1.0	102% Cd 1.0	75% Cd 1.0	102% Cd 1.0
APR1400 KIMERA [2]	Peak	60.86 at 500 sec	**329.8 at 102 sec**	**65.84 at 1,040 sec**	329.5 at 130 sec
	Power /Size	50% Cd 0.4	102% Cd 0.3	50% Cd 0.2	20% Cd 0.3
SPACE-ME APR1400 (This study)	Peak	**62.3at 315 sec**	**366.9 at 69 sec**	62.23at 1,800 sec	366.8 at 63 sec
	Power /Size	102% Cd 0.3	102% Cd 1.0	102% Cd 0.1	50% Cd 1.0

4. Conclusions

In this paper, the preliminary study of the M/E release from the postulated MSLB accidents on APR1400 with MSIV failure and LCC was performed using SPACE-ME methodology. The maximum peak pressure of the containment appears at 62.34 psia, which is less conservative than that of previous methodologies. More conservative maximum peak temperature of the containment is obtained at 366.9 °F. In the future, further studies for the establishment of SPACE-ME methodology are required.

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