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## RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

### APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.: 433-8363  
SRP Section: SRP 19  
Application Section: 19.1  
Date of RAI Issue: 03/08/2016

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### **Question No. 19-83**

All design certification applications under 10 CFR 52.47 shall satisfy the requirements of 10 CFR 52.47(a)(27) that a description and results of a design-specific PRA be provided as part of the application for design certification. The estimate of containment fragility as a function of pressure and associated temperature loads needs to be developed for use in the design-specific PRA.

APR1400 DCD Tier 2, Figure 19.1-47: Total Containment Fragility Curve shows the results of the containment fragility analysis, which includes the sum of the probability density functions for each failure mode considered. Section 19.1.4.1.2.2 and Table 19.1-28 provide the failure locations and failure modes considered for the containment ultimate pressure capacity and also for the containment fragility calculation.

- a. In Section 19.1.4, the applicant lacks a description of a specific analytical process used to determine the containment pressure fragility and associated failure modes. The staff reviewed the Ultimate Pressure Capacity Report (APR1400-K-P-NR-013605-P) and requests the applicant provide the following information in the DCD:
  - i An explanation of whether severe accident temperature effects on material properties were considered.
  - ii A clarification of the basis for the assumed temperature (400 F) and the relationship between that temperature and the temperature reduction factors in Section 5.6 of the report.
  - iii A description of the consideration of uncertainties
  - iv A description of how the uncertainty for the different parameters considered in the analysis is estimated and aggregated.

- b. In Section 19.1.4.2.1.2.2, the applicant lists the personnel emergency exit airlock as a failure location contributing to the containment pressure fragility. There are no corresponding failure modes included in Table 19.1-28 or Figure 19.1-47. Describe the basis for the selection of failure locations and failure modes considered and confirm whether the failure of the personnel emergency exit airlock was included in the analysis.

## **Response**

- a. Containment Ultimate Pressure Capacity Analysis (UPC) in DCD Section 19.1.4.2.1.2.2 is revised as shown in Attachment 1.
- i The bounding harsh environmental conditions are determined by simulating a broad spectrum of accident sequences including LBLOCA, MBLOCA, SBLOCA, TLOFW, and SBO, and dominant PRA sequences using the MAAP code. Long term atmospheric temperature after temperature spikes is enveloped by a temperature of 460 K (368 °F) (Reference 19.2.3.3.7.2.1). Based on long term temperature, 400°F is conservatively assumed for the strength properties of reinforcing and prestressing steels.
  - ii The relationship between the long term temperature 400°F and the temperature reduction factor is clarified based on The Structural Engineer, "The effect of elevated temperatures on the strength properties of reinforcing and prestressing steels", M. Holmes, R.D. Anchor, G.M.E.Cook & R.N.Cook, Vol. 60B, No. 1, March 1982. This report shows the typical strength properties of reinforcing and prestressing steels tested at room temperature after heating to an elevated temperature and gradually reduced under the conditions of concrete cracking and reinforcement yielding.
  - iii For controlling failure modes, the uncertainties associated with the median capacities are evaluated. The uncertainties,  $\beta_M$  and  $\beta_S$ , represent variability due to a lack of knowledge related to differences between the analytical model and the real structure. The modeling uncertainty ( $\beta_M$ ) such as internal force distribution, failure criteria, the use of empirical formulae in tendon and reinforcing steel placement, and variability in force-deformation relations is considered. The strength uncertainties ( $\beta_S$ ) are associated with variability related to the material resistance. The variability in concrete strength, tendon and reinforcing steel strength, steel liner strength, and the influence of elevated temperature on the material strengths are considered.
  - iv The random variable (uncertainty in the median pressure capacity) is assumed to be lognormally distributed with unity median and lognormal standard deviation ( $\beta_U$ ). This assumption is considered to be appropriate, since parameters that influence containment capacity, such as material strengths, are best represented by lognormal distributions. The uncertainty ( $\beta_U$ ) can be developed from combinations such as SRSS of the strength uncertainties ( $\beta_S$ ) and modeling uncertainty ( $\beta_M$ ).

- b. The selection of emergency exit airlock failure location was based on the review of research results such as “Containment Integrity Research at Sandia National Laboratories”, NUREG/CR-6906 and design UPC outputs (structural drawings, containment penetration detail). These results show that the unhomogeneous part of containment is relatively more vulnerable than other parts and the failure modes are listed based on such results.

The personnel emergency exit airlock was included in the analysis and Table 19.1-28 of DCD Section 19.1 is replaced as shown in Attachment 2.

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### **Impact on DCD**

Table 19.1.4.2.1.2.2 is revised as shown in Attachment 1 and Table 19.1-28 is replaced as shown in Attachment 2.

### **Impact on PRA**

There is no impact on the PRA.

### **Impact on Technical Specifications**

There is no impact on the Technical Specifications.

### **Impact on Technical/Topical/Environmental Reports**

There is no impact on any Technical, Topical, or Environment Report.

**APR1400 DCD TIER 2**

~~A plant-specific containment structural analysis was performed to determine the ultimate pressure capacity of the APR1400 containment building, and to identify the failure modes. Potential modes considered include:~~

- ← Insert A on next page
- a. Membrane failure
  - b. Cylindrical wall at the basemat
  - c. Failure of the basemat
  - d. Failure of the equipment hatch
  - e. Failure of the personnel access airlock
  - f. Failure of the personnel emergency exit airlock
  - g. Failure of the fuel transfer tube

~~In this analysis, the several failure modes that are identified in the containment structural analysis can be classified by their failure sizes into two groups, which are defined in NUREG-1150 and NUREG/CR-6906 (Reference 35).~~

- ← Insert B on next page
- a. A leak is defined as a containment breach that would arrest a gradual pressure buildup, but would not result in containment depressurization in less than 2 hours. The typical leak size is evaluated to be on the order of  $9.29 \times 10^{-3} \text{ m}^2$  (0.1 ft<sup>2</sup>).
  - b. A rupture is defined as a containment breach that would arrest a gradual pressure buildup and would depressurize the containment within 2 hours. The typical rupture size is evaluated to be on the order of approximately  $9.29 \times 10^{-2} \text{ m}^2$  (1.0 ft<sup>2</sup>).

The failure modes and their results are as presented in Table 19.1-28.

A probability density function was calculated for each potential failure mode, and summed together to estimate a total fragility curve. The results of this analysis are presented in Figure 19.1-47. These results were used in the Level 2 phenomenological evaluations for leak and rupture failure pressures of the containment.

**A**

A plant-specific containment structural analysis was performed to determine the ultimate pressure capacity (UPC) of the APR1400 containment building, and to identify the failure modes. The selection of failure modes was based on the review of research results from NUREG/CR-6906 (Reference 35) and design UPC outputs (structural drawings, containment penetration detail). These results show that the unhomogeneous part of containment is relatively more vulnerable than other parts and the failure modes are listed based on such results. Potential modes considered include:

**B**

The bounding harsh environmental conditions are determined by simulating a broad spectrum of accident sequences including LBLOCA, MBLOCA, SBLOCA, TLOFW, and SBO, and dominant PRA sequences using the MAAP code. Long term atmospheric temperature after temperature spikes is enveloped by a temperature of 460 K (368 °F) (Reference 19.2.3.3.7.2.1). Based on long term temperature, 400°F is conservatively assumed for the strength properties of reinforcing and prestressing steels. The relationship between the long term temperature 400°F and the temperature reduction factor is clarified based on reference 59. This report shows that the typical strength properties of reinforcing and prestressing steels tested at room temperature after heating to an elevated temperature and gradually reduced under the conditions of concrete cracking and reinforcement yielding.

For controlling failure modes, the uncertainties associated with the median capacities are evaluated. The uncertainties,  $\beta_M$  and  $\beta_S$ , represent variability due to a lack of knowledge related to differences between the analytical model and the real structure. The modeling uncertainty ( $\beta_M$ ) such as internal force distribution, failure criteria, the use of empirical formulae in tendon and reinforcing steel placement, and variability in force-deformation relations is considered. The strength uncertainties ( $\beta_S$ ) are associated with variability related to the material resistance. The variability in concrete strength, tendon and reinforcing steel strength, steel liner strength, and the influence of elevated temperature on the material strengths are considered. The random variable (uncertainty in the median pressure capacity) is assumed to be lognormally distributed with unity median and lognormal standard deviation ( $\beta_U$ ). This assumption is considered to be appropriate, since parameters that influence containment capacity, such as material strengths, are best represented by lognormal distributions. The uncertainty ( $\beta_U$ ) can be developed from combinations such as SRSS of the strength uncertainties ( $\beta_S$ ) and modeling uncertainty ( $\beta_M$ ).

**APR1400 DCD TIER 2**

42. NUREG-1921, "EPRI/NRC-RES Fire Human Reliability Analysis Guidelines," U.S. Nuclear Regulatory Commission, November 2009.
43. EPRI 1016735, "Fire PRA Methods Enhancements: Additions, Clarifications, and Refinements to EPRI 1019189," Electric Power Research Institute, December 2008.
44. NUREG/CR-4527, "An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets, Part II: Room Effects Tests," U.S. Nuclear Regulatory Commission, April 1987.
45. Regulatory Guide 1.102, "Flood Protection for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, September 1976.
46. EPRI 1021086, "Pipe Rupture Frequencies for Internal Flooding Probabilistic Risk Assessments (PRAs)," Electric Power Research Institute, October 2010.
47. NUREG/CR-6144 (BNL-NUREG-52399), "Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Surry, Unit 1," U.S. Nuclear Regulatory Commission, June 1994.
48. Inspection Manual Chapter 0609, Appendix G, "Shutdown Operations Significance Determination Process," U.S. Nuclear Regulatory Commission, February 2005.
49. NUMARC 93-01, "Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants," Nuclear Energy Institute, July 2000.
50. NEI 00-04, "10 CFR 50.69 SSC Categorization Guideline," Rev. 0, Nuclear Energy Institute, July 2005.
51. CAFTA 6.0b, Software Manual, EPRI, Palo Alto, CA, 2014.
52. NUREG/CR-7114, "A Framework for Low Power/Shutdown Fire PRA," U.S. Nuclear Regulatory Commission, September 2013.
53. NUREG/CR-7150, "Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE)," May 2014.
59. The Structural Engineer, "The effect of elevated temperatures on the strength properties of reinforcing and prestressing steels", M. Holmes, R.D. Anchor, G.M.E.Cook & R.N.Cook, Vol. 60B, No. 1, March 1982.

**APR1400 DCD TIER 2**

Table 19.1-28

Containment Failure Modes and Results

Failure Mode		Force	Median Pressure (psi)	Logarithmic Standard Deviation	Failure Size Category
Cylinder Wall	Hoop Direction	Membrane	204.79	0.20	Rupture
	Meridional Dire.	Membrane	257.66	0.19	Rupture
Dome	Hoop Dire. (above 45 deg.)	Membrane	221.90	0.23	Rupture
	Meridional Dire. (under 45deg.)	Membrane	237.31	0.18	Rupture
Basemat -Cylinder Wall Junction	Radial Dire.	Shear	214.80	0.29	Rupture
	Meridional Dire.	Moment	224.28	0.16	Rupture
Basemat	Screen out	-	-	-	Rupture
Equipment Hatch	Spherical Hatch Cover	Buckling	225.71	0.15	Rupture
	Welded Stud	Shear	251.69	0.11	Rupture
	Wall-Hatch Junction	Shear	459.10	0.29	Rupture
Personnel Air lock	Spherical Hatch Cover (Bulkhead plate)	Buckling	222.18	0.15	Rupture
	Welded Stud	Shear	253.03	0.11	Rupture
	Wall-Hatch Junction	Shear	443.92	0.24	Rupture
Fuel Transfer Tube	Blind Flange	-	223.08	0.15	Rupture
	Sleeve	-	281.03	0.15	Rupture
Fuel Transfer Tube	Welded Stud	Shear	420.55	0.15	Rupture
	Wall-Hatch Junction	Shear	752.43	0.24	Rupture
Liner Tearing of Equipment Hatch	-	-	188.0	0.15	Leak

Personnel emergency exit air lock	Spherical Hatch Cover (Bulkhead plate)	Buckling	222.18	0.15	Rupture
	Welded Stud	Shear	253.03	0.11	Rupture
	Wall-Hatch Junction	Shear	443.92	0.24	Rupture