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.:	**431-8504**
SRP Section:	**15.00.02 – Review of Transient and Accident Analysis Methods**
Application Section:	**15.0.2**
Date of RAI Issue:	**03/08/2016**

Question No. 15.00.02-12

Have the computer codes used in the licensing basis calculations for APR1400 been qualified for core uncovery, peak cladding temperature (PCT), and the formation and clearing of the loop seal phenomena? If not, please justify using them for the APR1400 loop seal modeling and SBLOCA analysis for both the direct vessel injection (DVI) line and cold leg (CL) breaks.

Response

As described in TeR, the SBLOCA analysis computer codes (CEFLASH-4AS, COMPERC-II, STRIKIN-II, and PARCH) follow the methodology that is described in CENPD-137P, which is approved by NRC and it is the same conventional CENPD SBLOCA methodology used for US CE-fleet PWRs. The SBLOCA codes are well evaluated to predict core uncover, peak cladding temperature, etc. conservatively by conforming to 10CFR50.46 Appendix K.
The prediction of loop seal clearing model is appropriate. According to the CENPD-137P, the suction legs or loop seal are modeled with two vertical control volumes to preserve height and volume. Two volumes are connected to one flow path between the bottoms of each volume. This configuration delays the loop seal clearing until the level reaches the bottom of loop seal volume. The delayed loop seal clearing produces the more conservative peak cladding temperature.

In addition, CENPD SBLOCA methodology adopted a method to predict the PCT conservatively, that is the method to predict two-phase level by combining CEFLASH=4AS and COMPERC –II reflood two-phase levels conservatively.

Impact on DCD

There is no impact on the DCD.

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.

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Docket No. 52-046

RAI No.:	**431-8504**
SRP Section:	**15.00.02 - Review of Transient and Accident Analysis Methods 01/2006**
Application Section:	**15.0.2, "Review of Transient and Accident Analysis Methods"**
Date of RAI Issue:	**03/08/2016**

Question No. 15.00.02.13

Section 2 of the TeR gives a brief discussion of the computer codes (CEFLASH-4AS, STRIKINII, COMPERC-II, and PARCH) used in the SBLOCA methodology and an overview of the data transferred between the codes. However, no explanation is given about exactly what information is transferred between the codes and how it is transferred, automatically or manually. The staff therefore requests the applicant to demonstrate the methodology for a typical SBLOCA calculation in which all four codes are exercised. Identify the time intervals where each of the codes is being used.

Response

1. SBLOCA CENPD data transfer information between the codes is explained in Figure 1.
2. Data transfer types between the codes listed in Figure 1 are explained belows and summarized in Table 3.

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3. The time intervals for each of the codes are explained in Table 4 and Table 5.

Figure 1 provides the explanation about what information is transferred between the codes (CEFLASH-4AS, STRIKINII, COMPERC-II, and PARCH) used in the CENPD SBLOCA calculations.

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Figure 1 SBLOCA CENPD data transfer diagram between the codes

Figure 2 and Table 1 show the representative examples of MANUAL 1 type for data transfer. In Figure 2, Time vs. The containment pressure are extracted from the CEFLASH-4AS calculation by AWK script language (blue dots). And they are simplified by sampling manually for the PARCH input preparation (orange dots). In Table 1, Node vs. The initial average clad and fuel temperature are extracted from STRIKIN-II calculation by AWK script language. Then they are directly applied to PARCH input.

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Figure 2 The Containment Pressure from CEFLASH-4AS Code and Simplified Data

Table 1 The Initial Average clad and fuel Temperature from STRIKIN-II by AWK script

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In Table 2, The fuel clad gap conductance hot bundle is extracted from PARCH result and calculated automatically by AWK script language. It is the representative example of MANUAL 2 type for data transfer. It is directly applied to COMPERC-II input.

Table 2 The fuel clad gap conductance hot bundle from PARCH code by AWK script

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In Table 3, the first and second columns are the number and description of the data transfer items listed in Figure 1. And the third column is the data transfer type for each transferred data between codes. Table 3 provides the information about how data are transferred, automatically or manually between the codes.

Table 3 Data transfer type description

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Table 4 and Table 5 identify the time intervals where each of the codes is being used for a SBLOCA calculation. Table 4 shows the time intervals in CEFLASH-4AS code and Table 5 describes the time intervals of STRIKIN-II, PARCH, COMPERC-II codes.

Table 4 Time steps in CEFLASH-4AS code

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Table 5 Time step in codes of STRIKIN-II, PARCH, COMPERC-II

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Application Section:	**15.0.2**
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Question No. 15.00.02-14

The applicant is requested to justify the applicability of various heat transfer correlations used in the licensing basis codes for the range of thermal-hydraulic conditions encountered in the APR1400 SBLOCA analysis. Were these correlations used within their prescribed correlation limits? If not, please justify their out-of-bound usage to be conservative. The staff is especially interested in the FLECHT heat transfer correlations used in COMPERC-II, and the various pool boiling, film boiling, and critical heat flux (CHF) correlations used in the STRIKIN-II and PARCH codes.

Response

FLECHT in COMPERC:

The PERC code, which calculates the reflood rate, was written and developed at CE. During this development, other codes were written to calculate inputs for the PERC code and to calculate reflood heat transfer coefficients using the FLECHT correlation. COMPERC-II calculates FLECHT-based reflood heat transfer coefficients, which are used in the STRIKIN-II hot rod heatup computer code, and the core steam flow rate, which is used in the PARCH computer code to calculate steam cooling heat transfer coefficients. The COMPERC-II computer program evaluates the thermal-hydraulic responses of a pressurized water reactor during the refill and reflood periods of a loss-of-coolant accident (LOCA). COMPERC-II is only applied in evaluating large break LOCAs and calculates the core coolant recovery reflood rates. From the analyzed reflood rates, COMPERC-II also calculates FLECHT –based reflood heat transfer coefficients used for core rod heatup calculations.

The following heat transfer descriptions and equations were gathered from CENPD-135, CENPD-138P.

Pool boiling:

PARCH is a pool boiling axial rod and coolant heatup code developed at CE for use in the small break loss of coolant accident (LOCA) analysis.

Heat transfer below the two-phase level is assumed to be through pool boiling to saturated water. The transient two-phase level in the core is input in tabular form. (See Item 3-1 in Figure 1 and Table in the response of Question No. 15.00.02.13) The transient core pressure is input to PARCH in tabular form. Pool boiling correlations for nucleate, transition, and stable film boiling, along with the critical heat flux, are used to define the heat transfer regime at each axial position below the two-phase level.

Heat transfer regimes.
The PARCH code considers all of the possible boiling heat transfer regimes for nodes below the two-phase level. In nucleate boiling, the Rohsenow correlation for saturated pool boiling is employed.

$$\frac{C_l}{h_{lV}}\Delta T_{wall} = C_{sf}\left\{\frac{q''_{surf}}{\mu_l h_{lV}}\left[\frac{g_c^{\sigma}}{g(\rho_l-\rho_V)}\right]^{1/2}\right\}^{0.33} Pr_l^{\,1.7}$$

This correlation defines the wall superheat T_{wall} in terms of the surface heat flux. The Rohsenow correlation has been compared to the saturated pool boiling data of several investigators and correlates this data within ± 20 %. This data covers a variety of fluids including water from 14 to 2400 psia.

Film boiling:

A modified Bromley heat transfer coefficient is used in the stable film boiling regime. The analysis of film pool boiling on vertical surfaces given by Hsu and Westwater is used in defining this coefficient. In their paper, Hsu and Westwater consider two regimes in the vapor film, laminar and turbulent flow. In the laminar flow regime the Bromley heat transfer coefficient for vertical rods is valid.

$$\mathrm{h}_{surf} = 0.707\left[\frac{k_v^3\rho_V(\rho_l-\rho_V)g\,\lambda'(3600)^2}{Z\mu_V\,\Delta T}\right]^{1/4}$$

CHF correlation:

The Zuber correlation for the critical heat flux is used in PARCH.

$$\mathrm{q''}_{CHF} = 0.13\rho_V\,h_{lV}\left[\frac{g_c g\sigma(\rho_l-\rho_V)}{{\rho_V}^2}\right]^{\frac{1}{4}}\left[\frac{\rho_l}{\rho_l+\rho_V}\right]^{\frac{1}{2}}(3600\ \mathrm{sec/hr})$$

This expression was theoretically derived based on the incipience of the Helmholtz instability. A nearly identical correlation was obtained by Kulateladze based on a dimensional analysis. He found a coefficient of 0.16 better fit his data, however, Rohsenow compared the pool boiling data of several investigators with this correlation and recommends a value of 0.18 for the coefficient. Again this data included pool boiling data of water from 14 to 2400 psia. The use of the 0.16 coefficient in PARCH in considered conservative.

Critical Heat Flux Correlations in STRIKIN-II

In the subcooled and two-phase flow regimes the critical heat flux is calculated by the W-3 and Macbeth correlations. The modified Levy correlation is used to set a lower limit on the calculated critical heat fluxes.

1) W-3 Correlation

The W-3 correlation is employed in the following range of system variables:

P > 1000 psia, G > 10^6 lb/hr-ft^2, X < 0.15

The critical heat flux (Btu/hr-ft^2) is calculated from the following expression:

$$\frac{\Phi_{DNB}}{10^6} = \left[(2.022 - 0.0004302P) + (0.1722 - 0.0000984P)e^{(18.177 - 0.004129P)X}\right]$$
$$* \left[(0.1484 - 1.596X + 0.1729X^2)\frac{G}{10} + 1.037\right]$$
$$* \ [1.157 - 0.869X]$$
$$* \ [0.2664 + 0.8357e^{-151.248R}]$$
$$* \ [0.8258 + 0.000794(H_{sat} - H_{in})]$$

where G is the mass velocity (lb/hr-ft^2)
X is the nodal quality
P is the pressure (psia)
R is the hydraulic radius (ft)
H_{sat} is the saturated liquid enthalpy (Btu/lb)
H_{in} is the channel inlet enthalpy (Btu/lb)

2) Macbeth Correlation

The Macbeth correlation for a uniformly heated tube is used to calculate the critical heat flux for conditions outside of the range of the W-3 correlation. The equations for calculating the heat flux in the low and high velocity regimes using the local fluid properties are given as follow:

Low velocity regime

$$\mathrm{DNB}_L = \frac{G^{0.51}H_{fg}}{158D^{0.1}}\{1 - \mathrm{x}\}$$

High velocity regime

$$\mathrm{DNB} = \frac{4(Y_0)D^{(Y_1 - Y_4)}G^{(Y_2 - Y_5)} - D^{(1 - Y_4)}G^{(1 - Y_5)}H_{fg}X}{4Y_3}$$

Where H_{fg} is the latent heat at system pressure, Btu/lb
D is the heated equivalent diameter, ($4A/P_h$), in
X is the nodal quality
G is the mass velocity (lb/hr-ft^2)

3) Modified Levy Correlation (Optional)
The modified Levy correlation is used to determine a quality and pressure dependent critical heat flux. The critical heat flux as calculated by the W-3 or the Macbeth correlation is compared to the modified Levy correlation critical heat flux and the maximum value is selected. The modified Levy critical heat flux is calculated from the following expressions:

P < 1000 psia

$$\frac{\phi_{DNB}}{10^6} = 0.705 \quad \text{for } x < 0.10$$

$$\frac{\phi_{DNB}}{10^6} = (0.605 - 0.653x) \quad \text{for } x \geq 0.10$$

P ≥ 1000 psia

$$\phi_{DNB} = 0.705 \cdot 1.0 \cdot 10^6 + 440(1000 - P) \quad \text{for } x < 0.10$$

$$\phi_{DNB} = (0.605 - 0.653X) \cdot 1.0 \cdot 10^6 + 440(1000 - P) \quad \text{for } x \geq 0.10$$

Impact on DCD

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Question No. 15.00.02-15

According to Section 3.2, “Reflood Hydraulics,” of the TeR, the reflood period of an SBLOCA is defined as the period of time following initiation of emergency core cooling (ECC) injection by the safety injection tanks (SITs). It is the staff’s understanding that the COMPERC-II code is used only for the reflood phase. Please explain why a computer code different from CEFLASH-
4AS is needed to analyze this phase of the transient. Why was CEFLASH-4AS not run for the entire transient to generate the hydraulic input parameters for PARCH and STRIKIN-II, and why was COMPERC used?

Response

The general method of data transfer between the four computer codes employed for analysis of a small break LOCA is illustrated schematically in figure 15.00.02-15-1. The sequence of the calculation using the various codes is as follows. CEFLASH-4AS calculation of blowdown and reflood thermal hydraulic transient, STRIKIN-II temperature calculation, PARCH calculation of temperature up to the initiation of reflood, COMPERC-II calculation of reflood hydraulics, and PARCH calculation of reflood temperatures.

The calculation procedure as described above is the CENPD-SBLOCA methodology. And also, this methodology calculates the conservative PCT by combining CEFLASH-4AS and COMPER-II reflood two-phase levels. When the SIT is on, COMPERC-II code calculates the two-phase levels instead of CEFLASH-4AS as is shown Figure 15.00.02-15-2. COMPERC-II code calculates the collapsed two-phase and the results of level transfer to the PARCH code. For this reason, the most conservative PCT mainly occurs at the large break size that SIT is injected in the CENPD-SBLOCA methodology.

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Figure 15.00.02-15-1. Data interface among codes

Figure 15.00.02-15-2. Combining CEFLASH-4AS and COMPERC-II reflood two-phase levels

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