Enclosure 3

Docket No. PROJ 0782

Response to RAI 3-7443 on Topical Report
"KCE-1 Critical Heat Flux Correlation for PLUS7 Thermal Design"
APR1400-F-C-TR-12002-P, Rev. 0

May 2014

Non-Proprietary Version

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION 3-7443

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Question 4

The TR reports that the test section flow was measured by two (2) Venturi flow meters and a turbine meter prior to the entrance to the test section flow housing. However, Figure 2-2 shows only one Venturi flow meter, and not the two. Describe the logic behind using this flow rate measurement arrangement. Was there any parallel arrangement made to manually measure the pressure drops across the Venturi flow meter as well as the test section using manometers, as has been the methodology used in other CHF test programs?

Response

Figure 2-2 of topical report is not a detailed drawing but an overall schematic sketch of instrumentation arrangement. Thus, some components are not depicted in the sketch.

The flow rate was primarily measured by the first Venturi flow meter, and the second Venturi flow meter provided the redundancy in case of the primary flow meter failure. The turbine flow meter provided the diversity for flow measurement verification. The pressure drop at the throat of each Venturi flow meters was measured by two independent differential pressure transducers, and the measured pressure drops were automatically recorded by the data acquisition system. The differential pressure transducers were calibrated periodically/properly per corresponding Heat Transfer Research Facility (HTRF) of Columbia University procedure controlled by the HTRF QA system. Calibration records for differential pressure transducers were available on the QA report for PLUS7 CHF tests (Ref : KAFD-01D-111, "Acceptance of Columbia University HTRF Quality Assurance Report for KAFD Critical Heat Flux Tests 101, 102 and 102.1," December 10, 2001).

A manometer was not used in PLUS7 CHF test.

Note : KAFD was a project name of PLUS7 development (joint program between Westinghouse Electric Company and KEPCO Nuclear Fuel Company)

Question 10

The applicant should explain the technical basis for using 0.275 as the upper limit of the tested local quality range (-0.150~0.275) applicable to the PLUS7 fuel design. Other fuel bundle designs have used higher upper limits of quality range. Does the applicant envision exceeding the quality range in any circumstances, e.g., future power uprate, etc.? Please include the measured CHF vs. local quality data in the present topical report for the staff to ensure that there were no adverse trends in the data.

Response

The applicable range of local quality is determined based on the quality at the predicted MDNBR location by KCE-1 CHF correlation. All design/safety analysis activities will be limited to meet current applicable range of the quality of KCE-1 CHF correlation at the location of MDNBR.

The measured CHF vs. local quality data at the CHF location (where CHF indicated during the CHF test) were part of the initial data set to start KCE-1 CHF correlation development. Those are shown in Figure 10-1 for all data sets (including excluded data, tabulated in Table A-2 of topical report, from final database of KCE-1 correlation). The trend of measured CHF with respect to local quality is typical, meaning that [ ] ^{TS} without any adverse behavior. This information is listed in Table 10-1 below and will be included in the appropriate section of the "A" version of the topical report upon approval.

Note :

O MDNBR elevation/location

- where DNBR was minimum among all location of test sections
- DNBR = heat flux predicted by KCE-1 correlation / actual heat flux at the location of interest
- Table A-3 (KCE-1 correlation database) of topical report listed the information at the MDNBR elevation/location

O CHF elevation/location

- where CHF was indicated (measured) by temperature excursion on corresponding TC(s) of test sections
- Table A-1 (PLUS7 CHF Test Data) of topical report listed the information at the CHF elevation/location
- Table 10-1 listed corresponding information to Table A-3 of topical report at CHF location (including excluded data given in Table A-2 of topical report)

O Legend on Table 10-1 is the same as given in page A-1 of topical report

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Figure 10-1 Measured CHF vs. Local Quality (at CHF location)

Table 10-1 KCE-1 CHF Correlation Initial Dataset (1/7)

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Table 10-1 KCE-1 CHF Correlation Initial Dataset (2/7)

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Table 10-1 KCE-1 CHF Correlation Initial Dataset (3/7)

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Table 10-1 KCE-1 CHF Correlation Initial Dataset (4/7)

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Table 10-1 KCE-1 CHF Correlation Initial Dataset (5/7)

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Table 10-1 KCE-1 CHF Correlation Initial Dataset (6/7)

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Table 10-1 KCE-1 CHF Correlation Initial Dataset (7/7)

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Question 11

The ratios of measured-to-predicted CHF (M/Ps) of all test data were plotted for system pressure, local mass flux, local quality, and equivalent heated diameter ratio in Figure 5-3 through Figure 5-6, respectively. Figure 4-1 through Figure 4-3 provide similar plots for bundle average heat flux data. However, the topical report does not provide the corresponding plots of the measured CHF data that were used in the KCE-1 correlation coefficient development as well as for the M/P calculations.

(A) The corresponding plots of the measured CHF data would be needed by the staff to observe any adverse and non-linear trends in the data. Provide these plots and include them in the topical report for future reference.

(B) Describe in the report the key parameters tabulated in Tables A-1 and A-3; whether and how they were measured, tagged, or computed. This needs describing the data populated on a typical row of these tables and how they are linked with one another or across the tables. For example, explain how HFX is computed from BAP in Table A-1 and how is it linked with TC within the same table and with CHFM in Table A-3.

(C) Include the outlet temperature test data in the topical report to demonstrate their fidelity and facilitate a staff assessment of the heat losses.

Response

(A) Corresponding plots of the measured CHF data are given in Figures 11-1 to 11-3 for system pressure, local mass velocity (local mass flux), and equivalent heated diameter ratio, respectively. The plot for local quality is presented in response to Question 10 (Figure 10-1).

This information will be included in the appropriate section of the "A" version of the topical report upon approval.

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]^{TS}.

The trend of measured CHF with respect to system pressure and mass flux is typical, meaning that [

]^{TS} without any adverse behavior. The trend of measured CHF with respect to equivalent heated diameter ratio shows no adverse behavior.

Note : Figures 11-1 to 11-3 include all data, as described in response to question 10 (the same data listed in Table 10-1).

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Figure 11-1 Measured CHF vs. Pressure (at CHF location)

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Figure 11-2 Measured CHF vs. Local Mass Velocity (at CHF location)

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Figure 11-3 Measured CHF vs. Equivalent Heated Diameter Ratio (at CHF location)

(B) Measured values at each CHF data point are tabulated in Appendix Table A-1 of topical report. Otherwise, the local fluid conditions at MDNBR location are tabulated in Appendix Table A-3 of topical report. These data were calculated by subchannel code TORC using measured CHF data, presented in Table A-1, as an input with the assumptions described in sections 4.2 and 4.3 of the topical report.

The variables in Table A-1 and A-3 of topical report are explained in page A-1 of the topical report.

In Table A-1, the description of each abbreviation is as follows;

- *TS : CHF test section*
- *RUN : individual data identification number*
- *PR/TIN/GIN/BAP : Pressure/Inlet Temperature/Inlet Mass flux/Bundle Power (measured values for each RUN)*
- *HFX : average heat flux (BAP divided by heat transfer area and multiplied by corresponding unit conversion factor)*
- *TC : CHF indicated location at each RUN with the convention of XX.x (XX represents the rod identification number as given in Figure 2-5 to 2-7, and x represents the T/C identification number as given in Figure 2-9 of the topical report)*

As an example for a datum from TS101;

- *BAP :* [ ]TS
- *Bundle heat transfer area : 39.1652 ft*^{2} $(32 \times \pi \times 0.374/12 \times 150/12)$
- *Conversion factor : 3.413 (MBtu/hr)/(MW)*

- *HFX* : [ ]^{TS} *MBtu/hr-ft*^{2} ([ ]^{TS} $\times 3.413/39.1652$)
- *TC : 23.3 (radially rod 23 depicted in Figure 2-5 and axially T/C #3 depicted in Figure 2-9 of topical report)*
  - ✓ *Rod Power Factor : 1.125 (rod 23)*
  - ✓ *Axial power Factor : approximately* [ ]^{TS} *(at axial elevation of 109.5 inch from BOHL)*
- *CHFM* : [ ]^{TS} *MBtu/hr-ft*^{2} ([ ]^{TS} $\times 1.125 \times$ [ ]^{TS})

In Table A-3, the description of each abbreviation is as follows;

- *GL/XL : calculated value in MDNBR location by subchannel code TORC using measured values given in Table A-1 and assumptions described in sections 4.2 and 4.3 of topical report*
- *CT : the type of subchannel, M/C/S correspond to subchannel such as 12/19/18 in Figure 2-5 of topical report*
- *CHFM : local heat flux at MDNBR location calculated by HFX multiplying corresponding rod power factor and axial power factor as shown in Figures 2-5 to 2-7 and Figure 2-9 of topical report*

Following information will be updated in the "A" version of the topical report upon approval.

- *HFX = BAP / bundle heat transfer area * unit conversion factor*
- *DH = 4 * flow area / heated perimeter of the subchannel of interest*
- *DHM = 4 * flow area / heated perimeter of the matrix subchannel*
- *CHFM = HFX * rod power factor * axial power factor at the elevation of interest*

(C) A value of thermodynamic equilibrium quality based on inlet fluid condition (inlet mass flux and inlet temperature) and bundle power for PLUS7 CHF data was [

]^{TS}. Further concerns related to heat loss will be addressed in response to Question 1.

Question 12

The testing was conducted with a constant heated length (150 inch) and a constant grid spacing (15.7 inch). During the testing conducted for some other CHF correlations, heated length and grid spacing were also varied and duly accounted for in the resulting correlation using additional terms. The applicant should explain whether the lack of heated length and grid spacing in the KCE-1 correlation would impact its applicability to the actual PLUS7 fuel bundle safety analyses.

Response

KCE-1 correlation was developed by using the CHF data from test sections with the same axial geometry as PLUS7 fuel as described in Table 2-1 and Figure 2-9 of topical report.

The effect of grid spacing on CHF was included in the measured data, and thus it was reflected inherently to the KCE-1 correlation prediction. As for the heated length, the same as grid spacing, the effect was reflected in both of measured data and the KCE-1 correlation prediction. KCE-1 correlation is applied to PLUS7 geometry (grid spacing and heated length) only.

Even though there is a variation, KCE-1 correlation gives reasonable prediction with respect to the MDNBR elevation as shown in Figures 12-1 and 12-2 for all [ ] TS data sets in the database (Table A-3 of topical report) and for data without assumption described in section 4.2 of topical report (relaxation of assumption), [ ] TS data sets, respectively.

Note : Corresponding M/P statistics for all data and relaxed assumption were given in Table 5-4 of topical report.

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Figure 12-1 M/P Trend with respect to Axial Elevation
(all data listed in Table A-3 of topical report)

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Figure 12-2 M/P with respect to MDNBR Elevation
(all data without assumption in section 4.2 of topical report : relaxation)

Question 18

As identified in Figure 4-1, [

]TS. This has effectively reduced the application domain of the KCE-1 correlation to a maximum 2415 psia pressure and 3.15 Mlbm/hr-ft^2 inlet mass flux. The applicant should explain the technical bases for selecting the upper limits on the tested system pressure and inlet mass flux ranges, and whether the applicant envisions the actual PLUS7 design exceeding these ranges in any circumstances.

Response

The design analysis range of APR1400 is shown in Table 18-1 with applicable range of KCE-1 correlation. All design/safety analyses perform within applicable range of the KCE-1 correlation at the MDNBR location. The process of checking variable range would be applied to APR1400 design analyses with respect to applicable range of KCE-1 correlation. Therefore, data with higher value of variable beyond the Table 18-1 were excluded along with the fact of [

] TS discussed.

Among the variables included in Table 18-1, the inlet temperature is not an issue for applicable range of KCE-1 correlation because it is not the variable in the functional form of correlation. For pressure and local quality, the APR1400 design analysis range is within the applicable range of KCE-1 correlation. For inlet mass flux, the upper limit of KCE-1 correlation range is slightly lower than APR1400 design analysis range. However, the local mass flux at the location of MDNBR in actual core analyses is a value within the applicable range of KCE-1 correlation. It is generally true because higher pressure drop due to higher power and higher quality of hot subchannel force to redistribute flow from hot subchannel to surrounding subchannels. Redistribution of flow reduces the flowrate of hot subchannel where calculated DNBR is the minimum.

Even though those data were [

] TS, the M/P behavior is comparable/conservative to data within the applicable range, as shown in Figures 18-1 and 18-2 for pressure and mass flux, respectively.

Table 18-1 Range of AOO Design Analysis for APR1400

Parameter	*Design Analysis Range (AOO)*	*KCE-1 Correlation Applicable Range*
Core Inlet Temperature, ^oF	*500 ~ 595*	*N/A*
Pressurizer Pressure, psia	*1785 ~ 2415*	*1395 ~ 2415*
Mass Flux, Mlbm/hr-ft^2	*1.91 ~ 3.20 (inlet)*	*0.85 ~ 3.15 (local)*
Local Quality	*-0.150 ~ 0.275*	*-0.150 ~ 0.275*

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Figure 18-1 M/P Trend vs. System Pressure
(with Excluded Data due to [ ]TS)

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Figure 18-2 M/P Trend vs. Local Mass Flux
(with Excluded Data due to [ ]TS)