# 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

June 2014

Non-proprietary Version

# RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION 3-7443

**Date of RAI Issued: 03/25/2014**
**Response Date: 06/25/2014**

## Question 1

According to the KCE-1 CHF topical report (APR1400-F-C-TR-12002-P Rev.0), an overall heat balance was not performed for each CHF data point or for the entire range of the tested bundle power. Rather, the heat balance was typically tested at the beginning of each day of operation under sub-cooled conditions at the test section pressure (1500 psi), inlet temperature (400 $^oF$), mass velocity (1.5 M lbm/hr-ft$^2$), and bundle power 1.6 MW. These test conditions are expected to involve much smaller heat losses than the typical CHF measurements reported in the KCE-1 correlation database that involve inlet temperatures as high as 650 $^oF$ and 10 MW facility bundle power. The applicant should include the acceptable heat loss tolerance in the topical report, and justify the validity of the heat balance observed at low power and temperature conditions on the entire domain of KCE-1 CHF measurements.

## Response

*The [ ]$^{TS}$ heat loss acceptance criterion will be included in the appropriate subsection of the "A" version of the topical report upon approval.*

*The validity of the heat balance observed at low power and temperature conditions on the entire domain of KCE-1 CHF measurements is justified below.*

*Test condition for heat balance was determined per the condition tested for the previous rod bundle CHF test program performed by Westinghouse Electric Company. The acceptance criterion of [ ]$^{TS}$ was based on the HTRF standard procedure and acceptance criterion (Reference : KADF-01D-32, "Acceptance of Columbia University Test Prospectus for KNFC/WH Critical Heat Flux (CHF) Tests 101 and 102," April 2001).*

*The heat balance was automatically calculated by DAS (Data Acquisition System) using the [ ]$^{TS}$ as below (Reference : KAFD-01D-76, "Acceptance of Data from Columbia University HTRF for CHF Tests WH101, WH102 and WH102.1," August 2001).*

*Hloss =[ ]$^{TS}$ (equation 1-1)*

*where,*
*Hloss = heat loss (%)*
*[*

*]$^{TS}$*

*[ ]$^{TS}$ from the bundle power (Tspwr based on voltage measurement at the test section) as addressed in response to Question 5 of RAI 3-7443 (Class30). Thus, heat loss in HTRF was the total heat loss value which included the loses [ ]$^{TS}$, and*

*]$^{TS}$.*

*As discussed above, there were three (3) main heat loss sources based on measured flow condition as below.*

- *[ ]$^{TS}$*
- *[ ]$^{TS}$*
- *[ ]$^{TS}$*

*Table 1-1 shows the results of heat balance measurement for PLUS7 CHF tests. [ ]$^{TS}$. It is comparable to the estimated error based on measurement uncertainties at the tested heat balance condition as below.*

TS

*Uncertainty values of each variable in the error analysis are referred from the response to Question 14 of RAI 3-7443 (Class 90). Uncertainty of [ ]$^{TS}$ in power at 1.6MW is estimated by the 3-rd order poly-nominal equation based on values for power given in Table 14-1 of the response to Question 14 of RAI 3-7443 (Class 90).*

*Even though the amount of heat loss can be increased in high power and/or high temperature condition, the percent of heat loss is not increased as shown below at a [ ]$^{TS}$.*

TS

*Therefore, a heat balanced estimated at the tested condition for PLUS7 CHF tests is valid for the entire domain of KCE-1 CHF measurements.*

*Table 1-1 Heat Balance Measurements for PLUS7 CHF Tests (WH101 and WH102)*

TS

# Question 6

The CHF test data for the PLUS7 fuel geometry were obtained by using a non-uniform axial power distribution, a symmetric cosine power profile shape with a peak of 1.475. The applicant should explain the appropriateness of testing a single axial profile and why the inlet/bottom or outlet/top peaked power profiles were not included in the test matrix. The applicant should describe how well the tested power distribution represents the actual profile experienced during the operation of the PLUS7 fuel.

## Response

*A symmetric cosine axial power distribution is a typical axial power shape resulted from two (2) dimensional neutron diffusion equation for finite cylinder geometry Table 6-2 of corresponding reference (Reference : J.R. Larmarsh & A.J. Baratta, "Introduction to Nuclear Engineering 3 e/d," Prentice-Hall 2001).*

*The effect of non-uniform axial power distribution on CHF was inherently included in KCE-1 correlation prediction, because KCE-1 CHF correlation was developed by using [ ]$^{TS}$. By applying Tong factor Fc in design analysis (it meant double-counting the effect of axial power distribution on CHF) [ ]$^{TS}$, KCE-1 prediction would be conservatively valid not only to tested axial power distribution but also to non-tested ones including top/bottom peaked. Non-tested ones include the actual axial power distribution expected to be experienced during the operation of PLUS7 fuel cores.*

*Background of above conclusion is as below.*

*[ ]$^{TS}$ defined as;*

*[ ]$^{TS}$ (equation 6-1)*

*where,*

*[ ]$^{TS}$*

*Physical basis and definition of Tong factor Fc implied that Tong factor Fc would be lower than one (1.0) for the upstream of peaked elevation. [ ]$^{TS}$, CHF prediction resulted in lower DNBR for region of interest than expected in real phenomenon.*

*By applying [ ]$^{TS}$ of Tong factor Fc,*

*conservatism given in Table 5-5 of topical report evaluated as an [ ]$^{TS}$. Figure 6-1 is a plot representing [ ]$^{TS}$. In actual design and safety analyses, an MDNBR prediction includes an application of Tong factor Fc. Thus, conservatism would be [ ]$^{TS}$ in design and safety analyses. And M/P trends are reasonable and/or conservative with respect to Tong factor Fc for all cases in Table 5-5 of topical report, as shown in Figures 6-2 to 6-4.*

*The applicability of standard Tong factor Fc with KCE-1 prediction is addressed in response to Question 7 of RAI 3-7443(Class 90).*

TS

*Figure 6-1 Comparison of M/P by [ ]$^{TS}$*

TS

*Figure 6-2 Distribution of M/P versus Tong Factor Fc [ ]* TS

TS

*Figure 6-3 Distribution of M/P versus Tong Factor Fc [ ]* TS

TS

*Figure 6-4 Distribution of M/P versus Tong Factor Fc [ ]* TS

# Question 7

As no testing was conducted with uniform axial power distribution, no "non-uniform axial power distribution correction factor, Tong factor *FC*," could be developed for the KCE-1 CHF correlation for the tested PLUS7 fuel geometry. Such an optimization of Tong factor for the PLUS7 fuel split vane mixing grid geometries would require testing both uniform and non-uniform axial power distributions with and without guide thimbles, but it was not done for the tested PLUS7 fuel geometry. However, the applicant plans to conservatively use the Tong factor along with the KCE-1 correlation to predict the CHF in the design analyses. The applicant should justify using the CE-1 Correlation Tong factor not developed for the tested PLUS7 fuel geometry. Other CHF correlations generally use Tong factor developed by the test data taken with both uniform and non-uniform axial power profiles.

## Response

*Applying standard Tong factor Fc to PLUS7 CHF data analysis with KCE-1 CHF correlation is conservative as discussed in response to question 6 of RAI 3-7443. It is applicable to design and safety analyses of PLUS7 cores with KCE-1 prediction based on the technical background of non-dependency to fuel design (note that : Tong factor Fc did not have any term related to geometric variables) and correlation under the assumption described in subsection 4.3 of topical report at the development stage.*

*The effect of Tong factor Fc application to design and safety analyses is addressed in response to Question 6 of RAI 3-7443 (Class90) including [*
*]TS.*

*Standard Tong factor Fc had applied successfully to various fuel designs and corresponding CHF correlations under the similar application environment with KCE-1 CHF correlation as below.*

- *Standard Tong factor Fc for rod bundle applied to W-3 CHF correlation (Reference : Rosal, E.R.. et al.,"High Pressure Rod Bundle DNB Data with Axially Non-Uniform Heat Flux," Nuclear Engineering and Design 31, pp 1-20, 1975)*

  *Effects on CHF due to non-uniform axial power distribution had investigated for the spacer grid design (with and without mixing vane), grid spacing, heated length and pitch to rod diameter ratio. Applying standard Tong factor Fc to W-3 CHF correlation with spacer factor had predicted CHF accurately in axially non-uniformly heated rod bundles.*

- *Standard Tong factor Fc for rod bundle applied to CE-1 CHF correlation (Reference : CENPD-162-P-A & CENPD-207-P-A, references 4 & 5 of topical report)*

  *Applying standard Tong factor Fc to CE-1 CHF correlation had predicted CHF conservatively in axially non-uniformly heated rod bundles. CE-1 CHF correlation had developed with CHF data from axially uniformly heated rod bundles for various spacer grid designs and pitch to rod diameter ratio.*

- *Standard Tong factor Fc for rod bundles applied to WRB-1 CHF correlation (Reference : WCAP-8763-A, "New Westinghouse Correlation WRB-1 for Predicting Critical Heat Flux in Rod Bundles with Mixing Vane Grids," July 1984 )*

  *Confirmation process to existing non-uniform F factor (standard Tong factor Fc) had been performed with respect to the CHF correlation developed with CHF data from axially uniformly heated rod bundles. Applying standard Tong factor Fc to WRB-1 prediction for non-uniform data had resulted that no modification to either the constant or the form of F factor had been necessary for application.*

- *The geometries of CHF test data for above included design characteristics of PLUS7 fuel. Data for CE-1 correlation (2-nd circle above) included data with a rod pitch (0.506 inch) and a guide tube diameter (0.980 inch) of PLUS7 fuel. Data for W-3 and/or WRB-1 correlation (1-st and/or 3-rd circle above) included data with a mixing vane design (R-type split vane) and a grid spacing (15.72 inch), and a rod diameter (0.374 inch) of PLUS7 fuel.*

# Question 8

SRP Section 4.4 outlines the DNB acceptance criterion to provide assurance that there be at least a 95-percent probability at a 95-percent confidence level that the hot fuel rod in the core does not experience a DNB or transition condition during normal operation or AOOs. The use of a single 95/95 DNBR limit to bound the uncertainty of the KCE-1 correlation is predicated on the assumption that the correlation behaves consistently and its uncertainty is independent of location throughout the application domain. Figure 5-3 of the topical report suggests that this assumption may not be true. The five (5) pressure datasets in the figure used in the correlation development seem to be from four different populations. Additionally, there is a trend of decreasing predictive capability with pressures from 2200 to 1750 psia. While that trend has clearly reversed by the low pressures around 1400 psia, it is not apparent how far the trend would continue in the empty region of pressures between 1400–1750 psia before reversing, and what causes the reversal. Provide justification for the use of a single uncertainty to bound the KCE-1 correlation over its intended application domain, focusing specifically on the regions which demonstrated a trend in decreasing predictive capability. Further provide justification for the application of the uncertainty in the empty region around pressures between 1400–1750 psia. To a less extent, a similar concern pertains to Figure 5-4, where a more conservative dataset of local mass flux at about 0.85 Mlbm/hr-ft2 is included in the correlation development after a similar reversal in the predictive capability of the KCE-1 correlation.

## Response

*The 95/95 DNBR limit of KCE-1 CHF correlation, 1.124, is the most limiting value among cases considered in Table 5-3 of topical report with the assumption described in subsection 4.2 of topical report. Corresponding M/P plots to 95/95 DNBR limit of 1.124 were given in Figures 5-3 and 5-4 of topical report for pressure and mass flux, respectively. However the assumption to consider type of subchannel would not be applied to design and safety analyses with KCE-1 CHF correlation. M/P statistics without the assumption led a lower value of 95/95 limit value as given in Table 5-4 of topical report. Corresponding M/P plots without the assumption are given in Figures 8-1 and 8-2 for pressure and mass flux, respectively. Even though M/Ps of [*

*][TS]. For pressure, design analysis range (AOO) of APR1400 is 1785 ~ 2415 psia, as addressed in response to Question 18 of RAI 3-7443 (Class 60). [ ][TS].*

*A new tentative 95/95 DNBR limit of [ ][TS] , less than 1.124 as shown in Table 8-1, was determined based on M/P data without the assumption of interest, [*

*][TS].*

*Therefore, 1.124 is conservatively applicable to design and safety analyses for PLUS7 fuel in APR1400 cores as the 95/95 DNBR limit of KCE-1 CHF correlation within applicable ranges of parameters given in section 7 of topical report.*

*Below is the detail of statistical assessment to determine a tentative 95/95 limit with respect to [ ][TS]. SPSS commercial package was applied to statistical assessment.*

*[*

*]TS.*

*[ ]TS.*

*Table 8-1 Tentative 95/95 DNBR Limit for KCE-1 CHF Correlation*

TS

*Table 8-2 [ ]TS*

TS

*Table 8-3 [ ]TS*

TS

*Table 8-4 [ ]TS*

TS

TS

*Figure 8-1 Distribution of M/P versus System Pressure (without the assumption : relaxation)*

TS

*Figure 8-2 Distribution of M/P versus Local Mass Flux (without the assumption : relaxation)*

# Question 9

Detailed investigation of the test data, conducted by the staff, has revealed a potentially nonconservative subregion at pressures near 1750 psia, qualities near 0.1, and local mass fluxes near 2 Mlbm/hr-ft2. This subregion contains a higher than expected number of M/P values which were below the 95/95 statistic than can be explained by random chance. Provide justification for the use of the KCE-1 correlation in this subregion, and the surrounding empty subregions.

## Response

*As pointed out in Question 9 of RAI 3-7443, there was relatively a large number of M/P points fell below 95/95 DNBR limit in pressure near 1750 psia, but it would not be critical for applying KCE-1 CHF correlation to APR1400 cores within applicable ranges of parameters given in Section 7 of topical report because;*

- *A number of M/P less than 95/95 DNBR limit were small and randomly distributed over the range of variables except for the pressure.*

  *Seven (7) out of 321 M/P in database of KCE-1 CHF correlation fell below 95/95 DNBR limit, 1.124. In case of pressure, six (6) out of 7 were in near 1750 psia and one (1) out of 7 was in near 2200 psia. In case of local mass flux, four (4) out of 7 were in near 1.5 Mlbm/hr-ft$^2$, two (2) out of seven 7 were in near 2.0 Mlbm/hr-ft$^2$, and one (1) out of 7 was in near 2.5 Mlbm/hr-ft$^2$. In case of local quality, one (1) out of 7 was in below 0.0, one (1) out of 7 was in near/below 0.05, two (2) out of 7 were in near/above 0.05, one (1) out of 7 was in near 0.15 and two (2) out of 7 were in near 0.17.*

- *A number of M/P fell below 95/95 DNBR limit was reduced when the assumption described in subsection 4.2 of topical report is not considered.*

  *As addressed in response to Question 8 of RAI 3-7443 (Class 90), M/P statistics was improved. And it resulted that only three (3) out of [ ]$^{TS}$ M/P fell below 95/95 DNBR limit. In case of pressure, two (2) out of 3 were in near 1750 psia, one (1) out of 3 was in near 2000 psia, as shown in Figure 8-1 of response to Question 8 of RAI 3-7443.*

- *No M/P fell below 95/95 DNBR limit with standard Tong factor Fc application*

  *As shown in Table 5-5 of topical report, M/P mean of KCE-1 CHF correlation increased over [ ]$^{TS}$ with Tong factor Fc application. Any of M/P did not fall below 95/95 DNBR limit of 1.124 with [ ]$^{TS}$ for pressure, mass flux and quality as shown in Figures 9-1 to 9-3, respectively.*

  *Technical bases of Tong factor Fc application KCE-1 CHF correlation were addressed in response to Questions 6 and 7 of RAI 3-7443 (Class 90).*

- *For the application of KCE-1 CHF correlation to design and safety analyses of reactor cores, DNBRs are calculated to all location of cores with Tong factor Fc, and MDNBR is*

*determined regardless of [ ]TS among all DNBRs, which are consistency with last two cases above.*

TS

*Figure 9-1 Distribution of M/P versus Pressure with Tong factor Fc*

TS

*Figure 9-2 Distribution of M/P versus System Mass Flux with Tong factor Fc*

TS

*Figure 9-3 Distribution of M/P versus Quality with Tong factor Fc*

## Question 13

The second paragraph of Section 6 (Correlation Application) of the topical report implies that meeting the 95/95 DNBR limit would also mean meeting the DNB acceptance criterion in SRP Sections 4.2 and 4.4 to provide 95/95 assurance that the hot fuel rod in the core would not experience a DNB or transition condition during AOOs (Anticipated Operational Occurrences). This is not correct. The approval of the topical report for a given 95/95 DNBR limit would not imply its applicability to AOOs that would be separately reviewed under the DCD review of the thermal design and safety analysis. The applicant should either document in the topical report that the applicability of the KCE-1 correlation to AAOs to meet the DNB acceptance criterion will be reviewed separately under the DCD review, or take out the reference to AOOs.

### Response

*From the second paragraph of Section 6 of the topical report, the statement of*

*"The acceptance criterion is met in thermal design and safety analysis when the MDNBR of the hot rod in the hot channel is above 95/95 DNBR limit of the correlation."*

*would be changed to*

*"The acceptance criterion is met in thermal design and safety analysis when the MDNBR of the hot rod in the hot channel is above appropriate DNBR limit (Specified Acceptable Fuel Design Limit, SAFDL) which includes 95/95 DNBR limit of the KCE-1 correlation. The results of KCE-1 CHF correlation applying to AOO analysis of APR1400 would be included corresponding subsection of the APR1400 Design Control Document (DCD) Section 4.4."*

*This modification will be included in the corresponding section of the "A" version of the topical report upon approval.*

*Supporting information will be included in an updated version of technical report APR1400-F-C-NR-12001, "Thermal Design Methodology." Technical report will be submitted with docketing of APR1400 Design Control Document (DCD).*

# Question 14

SRP Section 4.4 Acceptance Criterion#1 deals with experimental uncertainties involved in the CHF measurement. Even though the use of the 95/95 limit for DNBR adequately captures the uncertainty in the prediction of the measured values using the CHF correlation, the origin of each uncertainty parameter, such as fabrication uncertainty, computational uncertainty, or measurement uncertainty have not been identified in the topical report, nor classified as statistical or deterministic, following the acceptance criterion. The topical report should include information about the overall experimental uncertainty, and demonstrate that all the uncertainties in the measured CHF data have been appropriately captured in the 95/95 DNBR limit of the KCE-1 correlation.

## Response

*[*

*]$^{TS}$.*

*[*

*]$^{TS}$.*

*Uncertainties of each measured variables of CHF test, listed in Table 14-1, as well as a statement that those [ ]$^{TS}$, will be included corresponding section of the "A" version of topical report upon approval.*

*Table 14-1 Measurement Uncertainties for PLUS7 CHF Tests*

| *Variable* | *Unit* | *Range* | *Uncertainty* |
|---|---|---|---|
| *Pressure* | *psi* | | TS |
| *Mass flux* | *Mlbm/hr-ft$^2$* | | |
| *Inlet Temperature* | *℉* | | |
| *Power* | *MW* | | |

** Reference of Table 14-1: KAFD-01D-78, "DNB Test Results Report (Final) for the KAFD 16x16 Fuel Assembly Design : Tests WH101, WH 102 and WH 102.1," October 2001.*

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

# Question 15

The coefficients of the KCE-1 CHF correlation were determined by a non-linear multiple regression analysis of the measured CHF data along with the local fluid conditions calculated by using Westinghouse's subchannel analysis code TORC. The main input data used for TORC are summarized in Table 4-1. However, no discussion of the selection of inputs is provided in the topical report. As using TORC plays an important role in reducing the measured CHF data and generating the KCE-1 correlation coefficients, the applicant is requested to provide justifications and sources for their TORC input selections. For example, the single-phase friction factor that is used in the TORC model is valid for fully-developed turbulent internal flow through a smooth tube for Reynolds numbers greater than 20,000. The applicant needs to demonstrate that using the same friction factor correlation would be valid throughout the application domain of the TORC based CHF data reduction, as a different single-phase friction factor correlation would have to be used for Reynolds number less than 20,000.

# Response

*The TORC input parameters, given in Table 4-1 of the topical report, were [ ]$^{TS}$.*

*Among them, [ ]$^{TS}$, as shown in Table 15-1.*

*TDC of [ ]$^{TS}$ or inverse Peclet number of [ ]$^{TS}$ was applied to PLUS7 CHF data analysis. Assessment to the applicability had performed based on [ ]$^{TS}$. Generally, [ ]$^{TS}$. TDC of [ ]$^{TS}$ was the value for grid spacing of 26 inches. It would be conservatively applicable to PLUS7 CHF data analysis. Mid grid of PLUS7 fuel is R-type split mixing vane design and grid spacing of PLUS7 fuel and CHF test section is 15.7 inches as described in Figure 2-9 of topical report. A lower value of TDC or inverse Peclet number would be applied to design applications as described in Section 6 of topical report.*

*$K_{Grid}$'s were determined by the analytical prediction method for 6x6 CHF test grids (mid grid with mixing vane and non-mixing vane grid, MV and NMV in Figure 2-9 of topical report) [ ]$^{TS}$. Figure 15-1 shows analytically derived $K_{Grid}$ for mid grid with mixing vane of test sections 101 and 102 (102.0 and 102.1 were the test sections with same geometry as described in Subsection 2.2 of topical report).*

*The turbulent momentum factor is the weighting factor that allows the user to account for uncertainties associated with the formulation of the axial momentum carried by the turbulent interchange. For PLUS7 CHF data analysis value of [ ]$^{TS}$ was used rather than [ ]$^{TS}$. The deviation induced from turbulent momentum factor is implicitly included in M/P statistics. In design application, the momentum factor of [ ]$^{TS}$ would be consistently applied to APR1400 design and safety analyses.*

*Corresponding statements based on above four (4) paragraphs will be included in Subsection 4.2 of topical report. Updated version of a topical report will be prepared after submitting all response to RAI 3-7443.*

*For the applicable range of design constitutive relations, corresponding information for TORC analyses was listed in Table 15-2 with ranges of CHF data. Ranges of CHF data were within the applicable range of TORC design constitutive relations. As noted in footnote of Table 15-2, ranges of some parameters were calculated based on inlet condition or MDNBR location. However, it is not expected to exceed drastically beyond the applicable ranges of TORC design constitutive relations, even for the case to calculate parameter range of CHF data at the outlet condition. Moreover, [*

*]$^{TS}$.*

*Table 15-1 TORC Input data consistency with design constitutive relations*

| *Parameter* | *Used input data* | *Consistency with design constitutive relations* | *Justification* |
|---|---|---|---|
| *Single Phase friction factor* | | | |
| *Two-phase pressure drop* | | | |
| *Forced flow diversion* | | | |
| *Axial power distribution* | | | |
| *Crossflow resistance relationship* | | | |
| *Diversion crossflow resistance factor($K_{ij}$)* | | | |
| *Turbulent momentum factor* | | | |
| *Traverse momentum factor(s/l)* | | | |
| *Number of axial nodes* | | | |
| *Allowable fractional error in flow convergence* | | | |
| *Flow damping factor* | | | |
| *Thermal conduction in the coolant* | | | |
| *Inlet flow option* | | | |
| *Thermal diffusion coefficient* | | | |
| *Tong Factor Fc* | | | |
| *Loss Coefficient* | | | |

TS

*Table 15-2 TORC Design Constitutive Relations and Applicable Ranges*

| *Parameter* | *Constitutive Relation* | *Applicable Range* | *CHF Data* |
|---|---|---|---|
| *Single phase friction factor* | *McAdams* | | TS |
| *Two-phase pressure drop* | *Sher-Green & modified Martinelli-Nelson* | | |
| *Two-phase flow model* | *Homogeneous model* | | |
| *Quality* | *Thermodynamic equilibrium quality* | | |
| *Void fraction* | *Modified Martinelli-Nelson* | | |
| *Heat transfer model* | *Dittus-Boelter (Single-phase forced convection)* | | |
| | *Jens-Lottes (Two-phase flow)* | | |

* *based on bare-bundle flow area*
** *based on inlet condition*
*** *at the MDNBR location*

TS

*Figure 15-1 Grid loss coefficients (mid grids) for CHF tests 101, 102*

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

# Question 16

As a TORC model was used to analyze the CHF test data, it is logical that the resulting KCE-1 CHF correlation can be implemented in TORC to perform the PLUS7 fuels thermal design and safety analyses, as it would use the same fluid properties database and compute the same local fluid conditions. However, the topical report mentions that the correlation can also be used in the CETOP-D code. The applicant should justify it by relating it to how the two codes calculate the local fluid conditions and whether they use the same fluid properties database. At a minimum, the use of the KCE-1 correlation in the CETOP-D code should be dependent on CETOP-D being an approved methodology for the OPR-1000 and APR1400 designs. It is not clear from the topical report what CETOP-D methodology is being referenced. Please submit the topical report for the CETOP-D methodology which will be used with OPR-1000 and APR1400, otherwise take out the reference to CETOP-D.

## Response

*Reference for CETOP-D computer code, CEN-139(A)-P (reference 8 of topical report) included as the enclosure 4 of response to RAI 3-7443.*

*CETOP-D computer code would be applied to hot subchannel thermal and safety analyses of CE-PWRs operated with COLSS/CPCS. APR1400 is CE-PWR with COLSS/CPCS (Reference : Section 7.7 of APR1400 Design Control Documents Tier 2, to be issued). The theoretical bases and design constitutive relations of CETOP-D computer code are the same to TORC computer code. CETOP-D code uses the [ ]$^{TS}$ to obtain the diversion crossflow and turbulent mixing between adjoining channels with a less detailed calculation modeling. Furthermore, a predictor-corrector method is used to solve the conservation equations, rather the iterative method used in the TORC code, and thereby reduce execution time. Application of CETOP-D code to design and safety analyses requires an assurance that a MDNBR calculated by CETOP-D code should be lower than or equal to a MDNBR calculated by TORC code at the same inlet boundary condition.*

*A detail of CETOP-D computer code applicability to PLUS7 fuel and APR1400 reactor cores will be addressed in an updated version of technical report APR1400-F-C-NR-12001, "Thermal Design Methodology." Technical report will be submitted with docketing of APR1400 Design Control Document (DCD).*

## Question 17

In the development of a correlation, the potential for overfitting exists in which the correlation can predict the data used to develop the correlation well, but lacks in predictive capability on other data not used in the development of the correlation. It is not clear from the topical report whether some test data were initially excluded from the KCE-1 correlation coefficient generation and were used later as additional points for independent correlation validation. The applicant should address the potential for overfitting in the KCE-1 correlation.

The applicant should also resolve the inconsistencies among the number of data points reported in various parts of the report. During the PLUS7 fuel CHF tests, [ ]TS test data for the thimble subchannel test section TS101 and [ ]TS data for the matrix subchannel test section TS102 were collected, respectively. The [ ]TS test data points are listed in Table A-1 of APPENDIX A. Table A-2 lists [ ]TS test data points that were rejected during the correlation development process. The applicant needs to explain how this data processing has led to an overall KCE-1 CHF correlation database of [ ]TS." The two hundred and twenty-five (225) data points cited in the abstract as well as in Section 5.2 of the report are also confusing.

Also provide clear descriptions identifying the following:

(A) The total number of test points for each test
(B) The total number of test points which were used for generating the coefficients of the correlation for each test.
(C) The total number of test points which were excluded from calculating the coefficients of the correlation for each test.
(D) The validation statistics (similar to that provided in the first table of Table 5-4) for both (B) and (C) above. Statistics should be provided for each test.

## Response

*Potential for overfitting is not expected in KCE-1 CHF correlation prediction because ;*

- *Four (4) variables for flow condition, pressure, local mass flux, local quality, and latent heat of vaporization are the minimum essential basic variables to characterize CHF phenomena in flowing water. One (1) variable, equivalent heated diameter ratio is to characterize the effect of the unheated guide tube on CHF.*
- *Corresponding eight (8) coefficients represented by five (5) basic variables and combination of them make simple functional formula.*
- *The functional form and the variables in the KCE-1 correlation are not the brand new ones, but the same as the CE-1 correlation (Reference : CENPD-162-P-A, reference 4 of topical report). CE-1 correlation is proven technology.*

- *[*

  *]$^{TS}$ due to higher CHF performance of PLUS7 fuel with mixing vane (KCE-1 correlation prediction) than Guardian fuel without mixing vane (CE-1 correlation prediction).*

  *Prediction trend of both correlations is compared in Figures 17-1 to 17-3 for quality, pressure and mass flux, respectively. [*

  *]$^{TS}$.*

*To provide clear description identifying the number of data, corresponding information is listed as requested below.*

(A) The total number of test points for each test :

- *[ ]$^{TS}$ test points for test section 101 (or [ ]$^{TS}$)*
- *[ ]$^{TS}$ test points for test section 102*

*and*

- *[ ]$^{TS}$ test points : listed in Table A-1 of topical report*
- *[ ]$^{TS}$ test points : listed in Table 10-1 of response to RAI 3-7443 Question 10*

(B) The total number of test points which were used for generating the coefficients of the correlation for each test :

- *[ ]$^{TS}$ test points for test section 101 (or [ ]$^{TS}$)*
- *[ ]$^{TS}$ test points for test section 102*

(C) The total number of test points which were excluded from calculating the coefficients of the correlation for each test :

- *[ ]$^{TS}$ test points for test section 101 (or [ ]$^{TS}$) : excluded due to [ ]$^{TS}$)*
- *[ ]$^{TS}$ test points for test section 102 : excluded due to [ ]$^{TS}$*
- *Excluded data listed in Table A-2 of topical report per the types of subchannel. Out of [ ]$^{TS}$ listed in Table A-2 of topical report,[*
- *]$^{TS}$.*

(D) The validation statistics (similar to that provided in the first table of Table 5-4) for both (B) and (C) above. Statistics should be provided for each test :

- *Corresponding M/P statistics for above (B) and (C) are given in Tables 17-1 and 17-*

*2, respectively.*

*Table 17-1 M/P Statistics for (B)*

| *Test Section* | *n* | $\bar{x}_{(M/P)}$ | $s_{(M/P)}$ |
|---|---|---|---|
| *101* | | | TS |
| *102* | | | |

*Table 17-2 M/P Statistics for (C)*

| *Test Section* | *n* | $\bar{x}_{(M/P)}$ | $s_{(M/P)}$ |
|---|---|---|---|
| *101* | | | TS |
| *102* | | | |

TS

*Figure 17-1. Comparison of CHF Prediction : KCE-1 and CE-1 Correlations (for Local Quality)*

TS

*Figure 17-2. Comparison of CHF Prediction : KCE-1 and CE-1 Correlations (for Pressure)*

TS

*Figure 17-3. Comparison of CHF Prediction : KCE-1 and CE-1 Correlations (for Mass Velocity)*