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SUBJECT: Forwards response to NRC 910726 request for addl info re Topical Rept WPPSS-FTS-127, "Qualification of Core Physics Methods for BWR Design & Analysis."

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January 30, 1992
G02-92-029

Docket No. 50-397

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
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Gentlemen:

Subject: **NUCLEAR PLANT NO. 2, OPERATING LICENSE NPF-21
RESPONSE TO THE REQUEST FOR ADDITIONAL INFORMATION REGARDING TOPICAL REPORT WPPSS-FTS-127, "QUALIFICATION OF CORE PHYSICS METHODS FOR BWR DESIGN AND ANALYSIS" (TAC NO. 76783)**

Reference:
1) Letter dated 7/26/91, PL Eng, NRC to Supply System, "Request for Additional Information Regarding Topical Report WPPSS-FTS-127 - Qualification of Core Physics Methods for BWR Design and Analysis (TAC NO. 76783)"

2) G02-90-061, 3/29/90, GC Sorensen, Supply System to NRC, "Notification of Request for NRC Review of Topical Report WPPSS-FTS-127 - Qualification of Core Physics Methods for BWR Design and Analysis"

Reference 1 requested additional information regarding Topical Report WPPSS-FTS-127 (Reference 2). This letter provides the additional information required to complete review of this topical report.

A001

If you have any questions or require additional information, please do not hesitate to contact us.

Very truly yours,

G. C. Sorensen
Manager, Regulatory Programs

GCS:BMM:bw

Attachment: Additional Information Regarding Topical Report WPPSS-FTS-127

cc: JB Martin - NRC RV
NS Reynolds - Winston & Strawn
PL Eng - US NRC
DL Williams - BPA/399
NRC Site Inspector - 901A

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION ON TOPICAL REPORT WPPSS-FTS-127

1. *Do the albedos used in SIMULATE-E vary from cycle to cycle? Is there any adjustment made to the albedos during the cycle? Are the albedos used in the cold calculation different from those used in the hot calculations?*

   The horizontal albedos and related radial thermal leakage correction factors (TLC's) used in the SIMULATE calculations for WNP-2 were evaluated initially at the beginning of Cycle 1 and were changed at the beginning of Cycle 3 and again at the beginning of Cycle 5. (For additional details see the response to Question 4, below). The change from Cycle 3 to Cycle 5 produced changes in the hot model horizontal albedos of only 0.1 to 0.2%, and the impact of those changes on SIMULATE-E calculations is insignificant. The Supply System plans to look at the change in albedos again when a significant number of the new 9x9-9X assemblies, with large central water channels, are placed on the periphery.

   The top and bottom albedos used in the SIMULATE calculations for WNP-2 have been fixed at 0.40 (top) and 0.80 (bottom) for all cycles to date. (For additional details, see the response to Question 4, below).

   No adjustments are made to the hot or cold albedos during the cycle since they change very little with exposure.

   The albedos and TLC's are changed when going from hot to cold conditions. The top and bottom albedos for the cold model are set equal to the hot model bottom albedo. Cold horizontal albedos are calculated using the ABLE code with cold cross sections as input. The change in the horizontal albedos when going from hot to cold conditions is approximately 8 percent.

2. *What adjustments are made to the FIBWR input in order to match plant data?*

   In the reported calculations, adjustments were made to the form loss coefficients for the lower tie plate and for the orifice to reproduce the curves of active flow vs. pressure drop from plant data or fuel vendor data. Also, the calculated pressure drop over the core support plate and the bypass fraction were matched to plant data or fuel vendor data. These computations utilized the spacer and upper tie plate loss coefficients derived in Reference 16 of WPPSS-FTS-127. In future calculations, adjustments may be made to spacer and upper tie plate loss coefficients to match vendor or plant data.

3. *Describe the ABLE albedo and boundary evaluation program. How are the effects of temperature, exposure, voids, rod pattern and core loading accounted for in determining the albedos for a given statepoint?*

The ABLE code has been adopted as part of the EPRI ARMP-02 code package and is described in Appendix D of the SIMULATE-E (Mod 3) Code Manual (Reference 14 of WPPSS-FTS-127).

The ABLE code uses two group diffusion theory to calculate albedos and parameters related to the reflector thermal leakage correction factors. The calculation assumes an infinite reflector and a finite critical fuel region. Corrections are made for regions that have outside corners, inside corners, or both inside and outside corners.

The input to the ABLE code includes two group cross sections for both the fuel and the reflector. It is through these cross sections that the effects of temperature, exposure, voids and rod pattern are accounted for. The core loading is modeled assuming that the assemblies on the periphery control the characteristics of the fuel for the albedo calculation. The reactor core edge geometry is described as part of the input.

The albedos change only slightly with changes in core conditions, except for the swing from hot to cold, or from cold to hot conditions. Therefore, albedos are not changed from statepoint to statepoint but are only changed when there are major changes in the design of peripheral assemblies.

4. *How were the albedos determined for WNP-2 Cycles 1 and 2? Why wasn't the ABLE code used to determine the horizontal albedos for Cycle 1?*

At the time input data was prepared for the core simulations of WNP-2 Cycles 1 and 2 (1981) the ABLE code was not yet available. Thus, the Supply System evaluated the horizontal albedos for those two cycles by a method presented by D. VerPlanck (Yankee Atomic) at the 1980 and 1981 EPRI ARMP (Advanced Recycle Methodology Program) meetings. The resulting albedos were found to provide a good fit to data provided to the Supply System by General Electric (GE).

By the time input data was prepared for the core simulation of WNP-2 Cycle 3 the ABLE code had become available and had been adopted as part of the Supply System's core physics code package. Thus, ABLE was used to evaluate the horizontal albedos for WNP-2 Cycle 3, and for each subsequent cycle at WNP-2. ABLE was also used to provide the horizontal albedos for the Supply System's Peach Bottom and Quad Cities core simulations.

The top and bottom albedos for WNP-2 Cycles 1 and 2 were evaluated by comparing core simulation results generated by the Supply System to an axial power shape provided to the Supply System by GE. The resulting top and bottom hot albedos (0.40 and 0.80, respectively) were used in the Supply System's core simulations for all WNP-2 cycles, for Peach Bottom Cycles 1 and 2, and for Quad Cities Cycle 1. (For comments on the bottom albedo used in the core simulation for Quad Cities Cycle 2, see the response to Question 20 below).

5. *What error is introduced by using a single typical power distribution as input for FIBWR? How is consistency between plant thermal hydraulic parameters and the FIBWR/SIMULATE-E data ensured for non-typical conditions?*

Use of a single typical power distribution in FIBWR has been investigated pametrically for the Supply System Core Physics model. Computations were performed for power distributions that include the most limiting rod patterns. These include a rod pattern that pushes the bounding high power region to the top of the core, an all rods out pattern that generates the bounding bottom of the core power shape, and a typical operating statepoint early in the cycle. Core support plate pressure drop varies by +2.3% to -1.7% over this spectrum of bounding power shapes. The percentage change in percent bypass flow plus water rod flow varies from +2.2% to -1.9%. These results indicate that significant changes in the FIBWR core average axial power shape produce small effects on the core flow distribution and core pressure drop. This confirms that a generic set of power distributions can be used for all FIBWR calculational purposes.

6. *Do the cold critical eigenvalues listed in Table 3.2 correspond to in-sequence or local critical rod patterns? Has any difference been observed between the calculation to measurement agreement for the in-sequence and local critical eigenvalues? If so, explain.*

The WNP-2 cold criticals listed in Table 3.2 are all in-sequence criticals. The performance of SIMULATE-E and the Supply System calculational methods for local criticals was tested by performing calculations of the Quad Cities Cycle 1 local criticals as summarized in Table 3.7. The local criticals in Table 3-7 are those with identification numbers 02, 03, 06-11, 14-20, 25, 26, 28, 30, 31 and 36. Analysis of the data shows that the local criticals fall within the uncertainty of the in-sequence criticals.

7. *Have the cold critical eigenvalues for WNP-2 and Quad Cities (Tables 3.2 and 3.7) been corrected for temperature and period?*

The effects of temperature and reactor period are modeled in the calculations.

The core temperature measured at the time of the cold critical is included as part of the input to SIMULATE-E. The cross section tables generated by CASMO-2 and NORGE-B for use by SIMULATE-E provide fits to the temperature dependence of the cross sections. Thus, the core simulation uses cross sections evaluated at the actual temperature of the cold critical.

The values of k-effective produced by SIMULATE-E are corrected manually for the reactivity associated with the measured reactor period. In Table 3.2, the column labeled "Xenon-Free Critical Eigenvalue" lists the values of k-effective produced by SIMULATE-E and corrected for reactor period. In Table 3.7, the column labeled "SIMULATE-E keffective" lists the values of k-effective as calculated by SIMULATE-E

while the column labeled "kcritical" lists the values of k-effective corrected for reactor period.

8. *Explain the large discrepancies between the calculated and measured string and core average axial power distributions for WNP-2 Cycle 1 at 4579 MWD/MT as shown in Figure 3.5.*

The Supply System's interpretation of discrepancies such as the one mentioned in the question is that the core physics model based on MICBURN-E/CASMO-2/SIMULATE-E does not deplete gadolinium fast enough. As a result, at exposures at which the gadolinium near the bottom of the core actually burns out, the model predicts that some gadolinium still remains, resulting in an underprediction of the flux near the core bottom. This problem is especially significant for WNP-2 Cycle 1 because most of the initial core assemblies had gadolinium concentrations of 4 and 5 weight percent. At lower exposures, when most of the gadolinium is still present, and at higher exposures, when most has been depleted, the discrepancies between calculated and measured axial power distributions are generally smaller.

The Supply System's interpretation that current core physics models underpredict the rate of gadolinium burn out is shared by a number of other users of the same or related code packages. For examples, see a number of papers presented at recent EPRI RPSUG (Reactor Physics Software Users Group) meetings, e.g. J.R. Fisher (URA), May, 1988; K.R. Medved (Cleveland Electric), Nov., 1988; R.L. Grow (URA), May, 1990 and Nov., 1990; D. Knott, (Penn. State. U.), Nov., 1990.

9. *Have data for all the measured axial locations (including the top and bottom nodes) been used in the evaluation of the TIP prediction errors for WNP-2 Cycles 1 through 4 listed in Table 3.3? Have any measured TIP data been left out in the benchmarking of WNP-2 Cycles 1 through 4?*

Yes, all measured axial locations (including the top and bottom nodes) were included in the evaluation of the TIP prediction errors for WNP-2 Cycles 1 through 4 listed in Table 3.3. No measured TIP data was purposely left out in the benchmarking of WNP-2 Cycles 1 through 4.

10. *Are there any significant differences in the core loading for WNP Cycle 1 and those of Cycles 2, 3, and 4 which may account for the observed increase in the cold eigenvalue with increasing core exposure?*

There are two significant differences in the core loading for Cycle 1 compared to the core loading for the following cycles. Cycle 1 had all natural uranium assemblies on the core periphery and the interior assemblies had higher gadolinia loadings than any of the fresh reload fuel assemblies loaded in later cycles. However, these differences are not believed to be the cause of the increase in eigenvalue with increasing core exposure. The

increase in eigenvalue with exposure after the first cycle has been noted by other users of the CASMO-2/SIMULATE-E code combination. The slope in the eigenvalue with exposure is accounted for when projecting cold critical statepoints.

11. *Comparisons of calculated and measured TIP data for most statepoints show significant SIMULATE-E underpredictions in the bottom of the core for WNP-2, most of Cycle 1 and Cycle 2; Peach Bottom 2, Cycles 1 and 2; and Quad Cities 1, most of Cycle 1. Explain this systematic underprediction.*

Significant TIP underpredictions near the bottom of the core are shown in WPPSS-FTS-127 for WNP-2 Cycle 1 (but not Cycle 2), Peach Bottom Cycles 1 and 2, and Quad Cities Cycle 1. The Supply System's interpretation of these results is that they are due to an underprediction of the rate at which gadolinium burns out, as discussed in the response to Question 8, above.

The data provided in WPPSS-FTS-127 was selected at random from the complete data base for WNP-2, Peach Bottom, and Quad Cities. Review of the entire data base reveals that TIPs are underpredicted in the bottom of the core about 20% of the time and agree closely, or are slightly high, the remainder of the time. Thus, the data sets presented in WPPSS-FTS-127 inadvertently overemphasize the frequency of underprediction.

12. *In the benchmarking comparisons, what determined when a half core and a quarter core calculation was required? Was the calculation and/or measurement data processed or adjusted to account for a measurement asymmetry?*

In the benchmarking comparisons, no calculations used half core geometry. Either quarter core or full core geometry was used depending on the degree of asymmetry in the loading pattern and rod pattern.

For WNP-2, all core simulations except cold criticals have been done in quarter core geometry because of the high degree of symmetry present in the WNP-2 fuel loading patterns. Cold critical simulations require full core geometry because the actual rod pattern at the time of a cold critical is generally asymmetric. The core properties for each WNP-2 cold critical were obtained by expanding quarter core results calculated with SIMULATE to the full core by using mirror symmetry. The actual (asymmetric) rod pattern was then used in a full core SIMULATE calculation of the cold critical.

For Peach Bottom, all Cycle 1 and Cycle 2 core simulations (depletions, TIPs, cold criticals) were done in full core geometry because of the higher degree of asymmetry present in the fuel loading patterns.

For Quad Cities, the depletions for both cycles were done in quarter core geometry. The Quad Cities Cycle 1 depletions modelled the SE quadrant, those for Cycle 2 the NW quadrant. (The NW quadrant was chosen for Cycle 2 because the EOC2 gamma scan

data is primarily from assemblies in that quadrant). The choice of quarter core geometry for Quad Cities was made primarily for economic reasons since the SIMULATE depletions at that time (1988-early 1989) were being done offsite at Boeing Computer Services.

The Quad Cities Cycle 1 quarter core depletions necessarily used symmetric rod patterns for each statepoint. At four of the Cycle 1 statepoints the actual rod patterns were asymmetric with one or two pairs of rods differing by one or two notches. The effects of this low level asymmetry were estimated by rerunning the most asymmetric of the statepoints with the asymmetric rod shifted by two notches. The resulting changes in k-effective (less than 1 mk) and TIP RMS (less than 0.2%) were judged to be minor. Analogous rod asymmetries occurred during Cycle 2, with comparable effects.

The results of the Quad Cities quarter core depletions were used as input for the TIP comparisons. In Cycle 1, where loading pattern asymmetry was minor, data from all forty-one TIP strings was retained. In Cycle 2, where asymmetry in the loading pattern was more severe, six of the TIP strings were located adjacent to fuel bundles that differed from their symmetrically located counterparts in the NW quadrant. (The differences were due to differing fuel types, gadolinium loadings, or dished versus undished fuel pellets). These six asymmetric TIP strings were omitted from the Cycle 2 TIP comparisons.

For each of the Quad Cities cold criticals, an attempt was made to model the full asymmetry of the core loading pattern. First, the core properties calculated in quarter core geometry were expanded to the full core. Then, the asymmetrically loaded assemblies (one in Cycle 1, thirty in Cycle 2) were inserted in the SIMULATE input and the actual critical rod pattern was used in a full core calculation. For Cycle 2, the exposure distributions of the thirty asymmetrically loaded assemblies were estimated by combining axial exposure shapes from EOC1 with assembly average exposures obtained from similar NW quadrant assemblies at the time of the cold critical.

13. *Was the plugging of the bypass flow holes modelled in the Peach Bottom 2 calculation? If so, describe how it was represented in the calculation?*

Yes, the Supply System modelled the plugging of the bypass flow holes between data sets 21 and 22 by adjusting the input to the FIBWR model in SIMULATE-E. Specifically, the coefficient for calculating the bypass flow in the FIBWR model was changed to match the bypass flow to the data provided in Ref. 20 of WPPSS-FTS-127. No attempt was made to model possible bypass voiding that may have resulted when the holes were plugged.

14. *Comparisons of the Peach Bottom 2 calculated and measured TIP data show poor agreement particularly for Cycle 1. Also, in both Cycles 1 and 2, SIMULATE-E underpredicts the power in the bottom of the core. How does this affect the WPPSS licensing calculations.*

The results of the Supply System's TIP comparisons for WNP-2, Peach Bottom, and Quad Cities are summarized on pages 49, 51, and 54, respectively, of WPPSS-FTS-127. These comparisons cover four cycles at WNP-2 and two cycles each at Peach Bottom and Quad Cities. Of these comparisons, the results for Peach Bottom, Cycle 1, are the least successful. The higher overall TIP residual for this cycle is due to large contributions from Statepoints 8, 9, 12, and 20 (WPPSS-FTS-127, p. 51). The first three of these statepoints occur at exposures near the time of peak k-effective values associated with the burnout of gadolinium. The fourth, Statepoint 20, is a low-flow point. The remaining seven statepoints modeled in Cycle 1 show much lower TIP residuals comparable to those obtained for Cycle 2 of Peach Bottom and for WNP-2 and Quad Cities.

The primary purpose of the Peach Bottom depletions was to provide initial conditions for modeling the turbine trip tests at the end of Cycle 2. The TIP comparisons for Cycle 2 show general improvement as the Cycle progresses and at Statepoints 35 and 37 near the end of Cycle 2 the agreement is quite good (RMS = 7.8% and 7.4%, respectively). Thus, the Supply System judged that possible inaccuracies at four statepoints in Cycle 1 did not significantly impact results at the end of Cycle 2. This conclusion is confirmed by the very good results obtained in modeling the turbine trip tests (see Transient Analysis Topical Report, WPPSS-FTS-129, Rev. 1).

The Supply System's interpretation of the higher overall TIP residuals seen at Statepoints 8, 9, and 12 of Peach Bottom Cycle 1, and elsewhere, is that they are due to underprediction of the rate of gadolinium burnup, as discussed in the response to Question 8, above. It is possible that these TIP residuals could have been reduced by using a more sophisticated modeling of the gadolinium fuel rod buffer zones in the MICBURN analysis. Similarly, the results at Statepoint 20 might have been improved by making further adjustments to the FIBWR model for low flow conditions. In the end, neither of these options was pursued because the primary aim of the Peach Bottom depletions, providing realistic initial conditions for the EOC2 turbine trip tests, had been achieved, and because generally better agreement had been found for the TIP comparisons for Quad Cities and for later cycles at WNP-2, where the initial gadolinium content was 3% or lower.

Because the Peach Bottom core loadings included fuel that differs substantially (7x7 with no water rods, 4% Gd) from that currently in use at WNP-2, estimates of computational uncertainty in the Supply System core physics model should be based on TIP comparisons for WNP-2 itself, and Quad Cities.

15. *How was the experimental error of 4.9% determined for the Peachbottom 2 cycle 1 TIPS?*

As part of the detailed methodology developed by the Supply System for the analysis of the Quad Cities and Peach Bottom data sets, the following results were derived:

(1) $\langle(\text{delta E})^2\rangle_s = \langle(\text{delta M})^2\rangle_s - \langle(\text{delta C})^2\rangle_s$

where

delta M = Difference between measured TIP responses for a symmetric pair of TIPs

delta C = Difference between calculated TIP responses for a symmetric pair of TIPs

delta E = Difference between true measurement errors for a symmetric pair of TIPs

Also,

(2) $\langle E^2\rangle = (1/2)\langle(\text{delta E})^2\rangle_s$

where

$\langle E^2\rangle^{1/2}$ = RMS true measurement error

In the above expressions,

$\langle\ \rangle_s$ denotes averaging over <u>symmetric pairs</u> of TIPs

$\langle\ \rangle$ denotes averaging over <u>all</u> TIPs

An additional derived result is

$$(3) \quad \langle R^2 \rangle = \langle T^2 \rangle - \langle E^2 \rangle$$

where

$\langle R^2 \rangle^{1/2}$ = RMS calculational error

$\langle T^2 \rangle^{1/2}$ = total RMS difference (calculated - measured)

The analysis leading to the above results does not require the core properties actually to be symmetric. In fact, some physical asymmetry is generally present due to asymmetries in the loading pattern, rod pattern, and depletion history. This physical asymmetry is estimated by the calculated asymmetry and Eq. (1) is then used to reduce the measured asymmetry by this amount to obtain an estimate of the "true" measurement asymmetry.

The CALTIP code provides as output values of the following:

$\langle T^2 \rangle^{1/2}$

$\langle (\text{delta M})^2 \rangle^{1/2}$

$\langle (\text{delta C})^2 \rangle^{1/2}$

The RMS measurement error $\langle E^2 \rangle$ for the statepoint is then obtained by using (1) and (2) while the RMS calculational error for the statepoint is obtained by using (3). The overall results reported in WPPSS-FTS-127 are RMS values over all TIP statepoints of the cycle.

For example, for Peach Bottom, Cycle 1, the CALTIP code provided the following RMS values:

$\langle T^2 \rangle^{1/2}$ = 11.33%

$\langle (\text{delta M})^2 \rangle^{1/2}$ = 11.15%

$\langle (\text{delta C})^2 \rangle^{1/2}$ = 8.75%

Thus, from (1),

$$\langle(\text{delta } E)^2\rangle = (11.15)^2 - (8.75)^2 = 47.76$$

and from (2)

$$\langle E^2\rangle^{1/2} = (47.76/2)^{1/2} = 4.89\%$$

The rounded value, 4.9%, was reported in WPPSS-FTS-127.

16. *Do the experimental or measurement uncertainties of 4.9%, 7.6% and 6.3% for Peachbottom 2, cycle 1 and Quad Cities 1, Cycles 1 and 2, respectively, account for TIP asymmetry only? Please explain.*

The measurement uncertainties reported in WPPSS-FTS-127 were estimated as described in the response to Question 15, above. As outlined there, the calculated asymmetry was used as an estimate of the physical asymmetry actually present in the core. The observed measurement asymmetry was then corrected by that amount to obtain an estimate of the "true" measurement asymmetry. It is the corrected values that are reported in WPPSS-FTS-127. Thus, the reported values account both for the observed measurement asymmetry and for the actual physical asymmetry present in the core.

17. *Will the CASMO-2/SIMULATE-E code system be applied to new fuel designs, for which the lattice geometry, water holes, rod arrays, enrichment or gadolinium zoning, differ significantly from those represented in the benchmark data base? If so, please provide justification for such applications.*

The core physics benchmarks reported in WPPSS-FTS-127 consist of comparisons of calculated and measured data from Peach Bottom, Quad Cities, and WNP-2. These comparisons are all for cores loaded with GE 7x7 or 8x8 assemblies, or SNP 8x8 assemblies. It is lattices of this type that CASMO-2 was designed to model.

Fuel designs have evolved, and will no doubt continue to do so in the future. Thus, there will be a continuing need to upgrade reactor analysis codes to handle major changes in lattice design. In response to the marketing of new fuels such as the ANF (now SNP) 9x9-9X, the ABB Atom SVEA-96 and the General Electric GE11, Studsvik has upgraded CASMO to model designs that have more fuel pins and have features such as large water rods, a water cross, a central water channel, or an outer channel of varying thickness.

The best-known of the Studsvik upgrades is CASMO-3, which uses different numerics and references a different cross section library than CASMO-2. Thus, immediate adoption of CASMO-3 by the Supply System would require that the benchmarks be recalculated. As an interim measure, the Supply System has obtained from Studsvik an

alternative extended version of CASMO-2 termed CASMO-2E/SS. This code uses the same numerics and references the same cross section library as CASMO-2. In applications to 7x7 and 8x8 fuel designs, CASMO-2E/SS produces results identical to those of CASMO-2. Thus, rebenchmarking is not required. The extended capabilities of CASMO-2E/SS allow the Supply System to model new fuel designs such as those mentioned above.

Clearly, a new fuel design cannot have the extensive accumulation of measured data characteristic of an established design. Thus, the Supply System must rely initially on comparisons to results generated with NRC-approved methods by the fuel vendor.

As an example, the Supply System's Cycle 7 reload consisted of SNP 9x9-9X+ assemblies. The Supply System has used CASMO-2E/SS to generate cross sections, local peaking factors, and thermal limits parameters for those assemblies. The results compare favorably to those reported in the vendor's fuel design report. Small differences are attributed to differences in cross section libraries, code numerics, and modeling techniques.

Changes in lattice geometry, water holes, and rod arrays referred to in Question 17 impact the lattice physics and are handled by the extended capabilities of the Supply System's lattice physics code CASMO-2E/SS. These changes have no direct impact on the core simulation model itself. Fuel designs having two or three axial gadolinium zones are included in the present Supply System core physics benchmarks. Thus, the Supply System believes that continued use of SIMULATE-E as the primary core simulation code is amply justified.

The Supply System may, in the future, adopt a different core analysis code system (e.g., CASMO-3/SIMULATE-3, or a fuel vendor code system), as required to model evolving fuel designs. At such times, the Supply System will recalculate applicable benchmarks and apply for NRC approval for the proposed code change.

18. *Describe the CALTIP instrument response code.*

The CALTIP code was developed by the Supply System to calculate TIP responses, to compare them to measured TIP data, and to calculate statistical measures of the differences.

CALTIP reads nodal detector responses calculated for each lattice type by the lattice physics code (CASMO-2) as a function of nodal exposure, void history, and control rod presence. At each of the four nodes surrounding a detector, CALTIP obtains the lattice type, exposure, void history, and control history by reading a restart file produced by the core simulation code (SIMULATE-E). CALTIP then interpolates the nodal detector responses to the appropriate values of exposure, void history, and control history. The

estimated TIP response is then calculated by summing the contributions from the four nodes surrounding the TIP.

The specific expression used by CALTIP to evaluate the nodal detector response is given below:

$$T_R=P_R*[D_S(N_{FT},E,V_H)*(1-C_F)+D_{Sc}(N_{FT},E,V_H)*C_F]$$

where:

T_R - Calculated TIP response

P_R - Relative Power (corewide) in the fuel node (from SIMULATE-E)

D_S - Detector response rate for an uncontrolled node (from CASMO-2)

C_F - Nodal control fraction (from SIMULATE-E) (1=controlled, 0=uncontrolled)

D_{Sc} - Detector response rate for a controlled node (from CASMO-2)

N_{FT} - Nodal fuel material type (from SIMULATE-E)

E - Nodal exposure (from SIMULATE-E)

V_H - Nodal void history (from SIMULATE-E)

CALTIP normalizes the calculated and measured results both for each individual TIP string, and over the entire core. Axial power shapes are compared by using results normalized for each TIP string. Radial power shapes are compared by using results normalized over the entire core.

19. *Are the CASMO-2/SIMULATE-E calculation procedures, such as code options, numerical convergence, geometrical modelling and TIP response evaluation, the same for all the cores analyzed in the topical? If not, explain the differences.*

Yes, however, this does not mean that all input numbers were the same, but rather that the procedures were consistent and were not modified from statepoint to statepoint to make the results come out better. The code options were the same for each core but did vary as required for each type of calculation. The numerical convergence was the same for all hot cases, but for cold cases the outer source convergence was tightened by a

factor of five, and the number of outer source iterations per feedback iteration was greatly increased. Also, the top albedo was set equal to the bottom albedo for the cold cases. The geometry was changed only to reflect plant differences in the number and placement of assemblies and in the locations of control rods and detector strings. The TIP responses were modeled using the same procedures to account for fuel type differences in each respective core.

20. *Have any adjustments to input data in either CASMO-2 or SIMULATE-E been made to improve comparisons with the measured data?*

Adjustments were made to the FIBWR model in SIMULATE-E. Also, the bottom albedo was changed for Cycle 2 of Quad Cities. These changes are discussed below.

The FIBWR model was adjusted to agree with core design and operating data at the beginning of each cycle. For Peach Bottom Cycle 1, the FIBWR model was adjusted again to agree with operating data when the core support plate holes were plugged. However, no additional changes were made in the FIBWR model to improve results for individual statepoints.

In Cycle 2 of Quad Cities, it was necessary to adjust the bottom albedo (from 0.80 to 0.65) to obtain good agreement between calculated and measured axial power shapes. This change was necessary because the power shapes for Quad Cities Cycle 2 exhibit extreme bottom peaking, at least early in the cycle. As a result of the very steep flux gradients near the core bottom, the calculated power shapes, including the peak power, are unusually sensitive to the value of the bottom albedo.

In order to show that the albedo change was not necessary under more typical power shape conditions, Statepoint 10 of Cycle 1 was recalculated using a bottom albedo of 0.65. The resulting power shape and k-effective value were only slightly different from those obtained in the original calculation that used a value of 0.80. Thus, only under extreme power shape conditions is a change in the bottom albedo required.

Because of the geometric complexity of the material immediately above and below the core, it is difficult to calculate top and bottom albedos accurately from first principles. Thus, some adjustments based on TIP comparisons are generally in order. The values of top and bottom albedo (0.40 and 0.80) developed for WNP-2 were used for all reported benchmarks except for Cycle 2 of Quad Cities.

All present and contemplated fuel designs in use at WNP-2 feature natural uranium top and bottom blankets. These blankets reduce the sensitivity of the axial power shape to the values of top and bottom albedo, so no changes in these albedos are anticipated in future simulations of WNP-2.