ENCLOSURE 2

M220112

Response to Requests for Additional Information

Non-Proprietary Information

IMPORTANT NOTICE

This is a non-proprietary version of Enclosure 1, from which the proprietary information has been removed. Portions of the enclosure that have been removed are indicated by an open and closed bracket as shown here [[ ]].

NEDC-33935P, Revision 0, "LANCR02/PANAC11 Application Methodology"

NRC RAI #1

Table A-1 and A-2 list spacer tests results for GNF2 and GNF3 fuel designs, respectively. Please provide details of how the spacer test for GNF2 (Table A-1) and spacer test for GNF3 (Table A-2) were done.

GNF Response

Details on the process by which experimental pressure drop data was obtained and compared against calculated results can be found in the following locations:

- GNF2 - Section 3.5 of NEDC-33270 Revision 11 and Section 2.2.1.2 (subsection "Pressure Drop") of NEDC-33173 Supplement 3P-A Revision 1
- GNF3 - Section 3.5 of NEDC-33879 Revision 4 and Section 2.2.1.2 (subsection "Pressure Drop") of NEDC-33173 Supplement 5P-A Revision 1

NRC RAI #2

In Section 3.2.2.2.3, "Manufacturing" of NEDC-33935P, Revision 0, there is a list of items that justify continued adequacy of values in Table 3-3 of the TR ("The continued adequacy of values in Table 3-3 is justified by the following items…"). The NRC staff requests justification for the items on that list for higher fuel enrichment beyond 5 percent, especially bullets 2, 3, 4 and 5.

GNF Response

Justification is provided on a bullet specific basis as follows:

(a) Enrichment and density manufacturing tolerances are expected to remain consistent for the expanded enrichment range allowed by this report.

Justification - [[

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(b) The one-for-one relationship between variation in pellet enrichment and power has been demonstrated to be conservative, with higher enrichments observing less variation in power for the same percent change in enrichment compared to lower enriched pins.

Justification – [[

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(c) The one-for-one relationship between variation in pellet density and power has been demonstrated to be conservative. Note that target pellet density is not a function of enrichment.

Justification – [[

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(d) Process performance continues to be significantly tighter than the tolerances allow for enrichment and density in the GNF manufacturing process.

Justification – [[

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[[ ]]

Figure 2-1 – Pin Power Deviation vs Enrichment Deviation

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Figure 2-2 – Pin Power Deviation vs Density Deviation

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Figure 2-3 – Enrichment Manufacturing Process Capability

NRC RAI #3

Please explain how the following uncertainties are evaluated: (1) gradient uncertainty for critical power ratio, (2) gradient uncertainty for linear heat generation rate, and (3) channel bow uncertainty (Section 3.2.4 of the TR).

GNF Response

Responses are provided on an uncertainty specific basis as follows:

1) Gradient Uncertainties – A description of the calculation process for gradient uncertainties, including the rationale for quantifying them differently for application in critical power ratio evaluations and linear heat generation rate evaluations, is provided in Section 3.2.2.2 of NEDC-33935.

   To further clarify this description, it is noted that the purpose of this pin power uncertainty is to account for influences of flux gradients across bundles in the core. These gradients are driven by two core characteristics. First, the core radial flux profile will generally produce a gradient as one traverses the core from the center to the periphery such that the interior facing edge of the bundle has a higher flux than the edge that faces the core periphery. Second, there is an influence on flux shape across a given individual bundle due to the presence of neighboring bundles, as these neighboring bundles will have different enrichment, burnup, and/or control characteristics. Because the influence of these flux gradients is not inherently a part of the pin power peaking distribution that is calculated by LANCR02 (i.e. the infinite lattice pin peaking), their impact must be treated as an independent uncertainty when assessing thermal limits.

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2) Channel Bow Uncertainties – The uncertainty on pin peaking due to channel bow is evaluated differently in NEDC-33935 compared to historical precedent. [[

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NRC RAI #4

(a) Explain the relationship of NEDC-33173 Limitations and Conditions in Appendix C to the TR under review, NEDC-33935P.

(b) Which of these Limitations and Conditions are applicable to NEDC-33935P, and which of them are not applicable to NEDC-33935P.

(c) NEDC-33173 Limitation Number 9.13 titled "Application of 10 Weight Percent Gd" is for the application of 10 weight percent Gadolinium. Please explain how this limitation is satisfied for fuel enrichment beyond 5 percent.

GNF Response

(d) As noted in the 3rd bullet on page 1-2 of NEDC-33935 Revision 0, Appendix C provides dispositions for, or continued commitments to comply with, limitations and conditions that have historically been associated with the use of TGBLA06/PANAC11 in expanded operating domains (i.e., in NEDC-33173). These limitations and conditions are carried forward from the earlier topical report to apply to LANCR02/PANAC11 when evaluating expanded operating domains on a limitation specific basis. The continued applicability of these limitations for expanded operating domains is considered appropriate for those limitations which are not impacted by the methods changes implemented in NEDC-33935 compared to NEDC-33173 (e.g., limitations that are unrelated to neutronic methods). They are included for completeness such that NEDC-33173 need not be referenced going forward when NEDC-33935 is adopted as a licensing basis for a specific application.

(e) The applicability of each limitation is addressed explicitly in the columns "Disposition" and "Comments" in Appendix C. This approach is consistent with the one adopted in NEDC-33173 Supplement 3P-A Revision 1 and NEDC-33173 Supplement 5P-A Revision 1.

(f) Limitation Number 9.13 has two components. The first component indicates that compliance with Thermal Mechanical (T-M) acceptance criteria must be confirmed before fuel with up to 10 weight percent Gd can be applied in licensing applications. Since the initial issuance of this limitation, PRIME03 has been approved for use through topical reports NEDC-33256P-A, NEDC-33257P-A, and NEDC-33258P-A. PRIME03 is approved to evaluate up to 10 weight percent Gd. This enables the evaluation of compliance with T-M acceptance criteria to proceed with a method that is approved for use in this application range.

    The second component of the limitation is related to nuclear methods, specifically noting that TGBLA06 is not approved to evaluate 10 weight percent Gd. As discussed in Appendix C, this limitation is no longer applicable because LANCR02 has no explicit limitation on Gd concentration. It is noted for completeness that Test Suite 7 of NEDC-33377 Revision 4 shows that LANCR02 has excellent and consistent predictive performance for Gd concentrations up to at least 12 weight percent.

Based on the approved application range of both of these methodologies, licensing applications with up to 10 weight percent Gd can now be performed. This is independent of limitations related to fuel enrichment, which require their own approved application range.

NRC RAI 5

In section E.1.1, “Coarse-Mesh Nodal, One-Group Diffusion Theory,” of Appendix E three-group neutron diffusion equations are listed. Please specify the energy ranges for the three groups of neutron energy.

GNF Response

The three group energy boundaries for use with LANCR02/PANAC11 are specified in the text following Table A-4 in NEDC-33376.

NRC RAI #6

Section 4.3.3, "Thermal Margin Bias Comparisons" of the TR briefly describes how to calculate thermal margin bias comparisons. Please describe how to obtain (1) Thermal $Margin_{adapted}$ and (2) Thermal $Margin_{non\text{-}adapted}$.

GNF Response

Thermal $Margin_{Adapted}$ values are calculated based on power shapes that have been adjusted to better match in-core instrument signals that were measured during operation. The process to adjust (i.e., "adapt") nodal power shapes which are subsequently used to define thermal margins (e.g., MFLPD, MFLCPR) is specified in Appendix F of NEDC-33935.

Thermal $Margin_{non\text{-}adapted}$ values are calculated based on power shapes calculated by LANCR02/PANAC11 that are not adjusted based on in-core instrument signals.

NEDC-33376P, Revision 4, "LANCR02 Lattice Physics Model Description"

NRC RAI-7

(a) [[

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GNF Response

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NRC RAI 8

Appendix C to the NEDC-33376P, Revision 4, lists GNF responses to RAIs on NEDC-33376P, Revision 1. Please state whether each of these RAIs and their responses are applicable to the current Revision 4 of the TR. Identify if any of the RAIs and their responses are not applicable to Revision 4 of the TR. In case any of them is not directly applicable to Revision 4, please modify the response(s) suitable for Revision 4 of NEDC-33376P.

GNF Response

Responses to all RAIs in Appendix C remain applicable to Revision 4 of NEDC-33376, with the following noted for completeness:

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NRC RAI-9

In Section 2.2.3 of the TR there is a brief description of "final background cross sections." Describe how the background cross sections are used in creating the resonance table. Also explain how the appropriate cross sections for each resonance absorber isotope is determined.

GNF Response

The response to RAI 4-2 included in NEDC-33376 Revision 3 clarified the manner in which background cross sections are used to generate f-tables from NJOY data. This clarification was included in Section 2.1 of the same document. These f-tables must subsequently be entered with the appropriate background cross section for each isotope in each fuel mixture. The method for calculating an accurate background cross section for this purpose is described in Section 2.2.1 of NEDC-33376.

NRC RAI 10

Provide details of the "Bickley-Nayler function." That accounts for the motion of neutrons in connect with Equation 19 (A journal paper would be sufficient).

GNF Response

Appendix 1 of Reference 11 of NEDC-33376 provides one source of details. Additional discussion can be found in Appendix B of the NRC Document ML032160628. Information from this appendix is extracted below, for convenience:

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Appendix B

PROPERTIES OF THE BICKLEY NAYLER FUNCTIONS

B.1 Definition

The Bickley Nayler functions are defined as:[12,32]

$$\mathrm{Ki}_n(x) = \int_0^{\frac{\pi}{2}} d\theta\,(\sin\theta)^{n-1} \exp\left[\frac{-x}{\sin\theta}\right]$$
$$= \int_0^1 du\left(\sqrt{1-u^2}\right)^{n-2} \exp\left(\frac{-x}{\sqrt{1-u^2}}\right),$$

for all n. Here, $\mathrm{Ki}_0(x)$ and $\mathrm{Ki}_{-1}(x)$ are the modified Bessel functions of the second kind of order 0 and 1 respectively. They satisfy the following recurrence relations:

$$\mathrm{Ki}_n(x) = \left(\frac{n-2}{n-1}\right)\mathrm{Ki}_{n-2}(x) + \left(\frac{x}{n-1}\right)\left[\mathrm{Ki}_{n-3}(x) - \mathrm{Ki}_{n-1}(x)\right]$$

B.2 Differentiation and Integration Formulas

The derivative of a Bickley Nayler function is given by

$$\frac{d}{dx}\mathrm{Ki}_n(x) = -\mathrm{Ki}_{n-1}(x).$$

This equation can be inverted to yield:[12]

$$\mathrm{Ki}_n(x) = \int_x^\infty \mathrm{Ki}_{n-1}(y)dy$$

B.3 Series Expansion

The power series expansion for the Bickley Nayler functions are of the form:

$$\mathrm{Ki}_n(x) = \mathrm{Ki}_n(0) - x\mathrm{Ki}_{n-1}(0) + \frac{x^2}{2}\mathrm{Ki}_{n-2}(0) + \ldots$$

They also have asymptotic expansions of the form:

$$\mathrm{Ki}_n(x) = e^{-x}\sqrt{\frac{\pi}{2x}}\left\{1 - \frac{4n+1}{8x} + \frac{3(16n^2+24n+3)}{2!(8x)^2}\ldots\right\}$$

B.4 Numerical Values

In DRAGON the numerical value of the Bickley Nayler functions are evaluated using the subroutine `AKIN10` which is adapted from the `KIN` routine written by P. Christie for AELIB. It uses rational Chebyshev approximations for $\mathrm{Ki}_8(x)$, $\mathrm{Ki}_9(x)$ and $\mathrm{Ki}_{10}(x)$ with a backward recursion formula when $x > 6$ and rational Chebyshev approximations for $\mathrm{Ki}_1(x)$, $\mathrm{Ki}_2(x)$ and $\mathrm{Ki}_3(x)$ with a forward recursion formula when $0 \leq x \leq 6$.

NEDC-33377P, Revision 4, "LANCR02 Lattice Physics Model Qualification Report"

NRC RAI-11

For critical experiments using Monte Carlo N-Particle (MCNP), provide the details of the geometry used in the MCNP model.

GNF Response

The geometries of the critical experiments that were modeled in MCNP are described at a relatively high level in Section 4 of NEDC-33377. More detailed descriptions can be found in references 7, 8, 9, and 10 of the same report.

The MCNP models developed to represent these configurations used limited modeling approximations that are entirely consistent with the benchmark inputs recommended by the benchmark references. Providing the detailed model specifications for each experimental configuration would be too voluminous to be practical in this response; however, it is noted that near exact geometry was implemented to the extent possible. Approximations that were made are consistent with recommendations made in the International Criticality Safety Benchmark Evaluation Project (ICSBEP) handbook for each experiment. Examples of typical MCNP inputs used in these studies can be found in appendices of experimental reports provided in the ICSBEP.

Errata for NEDC-33935P, Revision 0

Two typographical errors have been identified in NEDC-33935 Revision 0. Note that neither error impacts calculations or results presented in the any other section of this report. It is proposed that these errors be reconciled by updating the topical report when creating the final approved version (i.e., the “-A” revision). The following should be updated:

- Equation E.2.19 – There is a typographical error in how this equation is defined: the second term in the parenthesis should be squared to match the method it is describing. The correct equation reads as follows:
    - [[ ]]

Appendix E, Second Paragraph – Both References should be “Reference 26”. The second is incorrectly listed as “Reference 27” in Revision 0 of NEDC-33935 Revision 0.