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Our ref: LTR-NRC-08-27
June 25, 2008

Subject: Response to the Second Round of NRC's Request for Additional Information by the Office of Nuclear Reactor Regulation for Topical Report (TR) WCAP-16747-P, "POLCA-T: System Analysis Code with Three-Dimensional Core Model" (TAC No. MD5258) (Proprietary/Non-proprietary)

Enclosed are copies of the Proprietary and Non-Proprietary versions of the " Response to the Second Round of NRC's Request for Additional Information by the Office of Nuclear Reactor Regulation for Topical Report (TR) WCAP-16747-P, "POLCA-T: System Analysis Code with Three-Dimensional Core Model" (TAC No. MD5258) (Proprietary/Non-proprietary)

Also enclosed is:

1. One (1) copy of the Application for Withholding, AW-08-2432 (Non-proprietary) with Proprietary Information Notice.
2. One (1) copy of Affidavit (Non-proprietary).

This submittal contains proprietary information of Westinghouse Electric Company, LLC. In conformance with the requirements of 10 CFR Section 2.390, as amended, of the Commission's regulations, we are enclosing with this submittal an Application for Withholding from Public Disclosure and an affidavit. The affidavit sets forth the basis on which the information identified as proprietary may be withheld from public disclosure by the Commission.

Correspondence with respect to the affidavit or Application for Withholding should reference AW-08-27 and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

R. M. [signature] /FOR

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Enclosures
cc: A. Mendiola, NRR
J. Thompson, NRR

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Our ref: AW-08- 2432
June 25, 2008

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: LTR-NRC-08-27 P-Enclosure, Response to the Second Round of NRC's Request for Additional Information by the Office of Nuclear Reactor Regulation for Topical Report (TR) WCAP-16747-P, "POLCA-T: System Analysis Code with Three-Dimensional Core Model" (TAC No. MD5258) (Proprietary)

Reference: Letter from J. A. Gresham to Document Control Desk, LTR-NRC-08-27, dated June 25, 2008

The application for withholding is submitted by Westinghouse Electric Company LLC (Westinghouse) pursuant to the provisions of paragraph (b)(1) of Section 2.390 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10 CFR Section 2.390, Affidavit AW-08-2432 accompanies this application for withholding, setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.390 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-08-2432 and should be addressed to J. A. Gresham, Manager of Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P. O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

R. M. Span / FOR

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Cc: A. Mendiola, NRR
J. Thompson, NRR

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared T. Rodack, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse) and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

Thomas Rodack

T. Rodack, Director
Quality Licensing Programs

Sworn to and subscribed
before me this 27th day
of June, 2008.

Sharon L. Markle
Notary Public

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Sharon L. Markle, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Jan. 29, 2011
Member, Pennsylvania Association of Notaries

(1) I am Director, Quality Licensing Programs, in Nuclear Fuel, Westinghouse Electric Company LLC (Westinghouse) and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Commission's regulations and in conjunction with the Westinghouse "Application for Withholding" accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.390, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked LTR-NRC-08-27 P-Enclosure, "Response to NRC's Request for Additional Information by the Office of Nuclear Reactor Regulation for Topical Report (TR) WCAP-16747-P, 'POLCA-T: System Analysis Code with Three-Dimensional Core Model'" (TAC No MD5258)(Proprietary), for submittal to the Commission, being transmitted by Westinghouse letter (LTR-NRC-08-27) and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by Westinghouse Electric Company is responses to NRC's Request for Additional Information.

This information is part of that which will enable Westinghouse to:

(a) Obtain generic NRC licensed approval for use of the advanced dynamic system analysis code POLCA-T in performing BWR licensing analysis.

(b) Specific applications using the POLCA-T computer code will include Control Rod Drop Accident (CRDA) analysis and BWR stability analysis

Further this information has substantial commercial value as follows:

(a) Future applications of the POLCA-T computer code will include BWR Transient Analysis and Anticipated Transient Without Scram (ATWS) analysis.

(b) Assist customers to obtain license changes.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar fuel design and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for developing the enclosed improved core thermal performance methodology.

Further the deponent sayeth not.

"Response to the Second Round of NRC's Request for Additional Information by the Office of Nuclear Reactor Regulation for Topical Report (TR) WCAP-16747-P, "POLCA-T: System Analysis Code with Three-Dimensional Core Model" (TAC No. MD5258) (Non-Proprietary)

Westinghouse Electric Company
P.O. Box 355
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NRC RAI 3-5

Provide the staff with qualification of the extension of the constitutive models (i.e. closure relationships) and heat transfer correlations to bundle power and flow conditions that bound those experienced in expanded operating domains. These bounding values should consider exit quality, mass flux, boiling length, exit and average void fraction, and axial power shapes. Confirm that historically reported uncertainties are valid using a statistically significant sample of the population of data used to generate the constitutive correlations.

Westinghouse Response to NRC RAI 3-5

POLCA-T constitutive models and heat transfer correlations have been validated to the [ ]^{a,c} The heat transfer regions that have been verified cover heat transfer regimes from single phase liquid, nucleate boiling, two-phase forced convection to boiling transition with rewetting. The comparison also validates the momentum equation, pressure drop calculation and the drift flux correlation for different flow regimes spanning from single phase flow to the different types of two phase flow. An illustration of the POLCA-T test section model is provided in Figure 1. The model consists of four main parts:

- Upper plenum: sets the boundary conditions for the outlet pressure versus time.
- Test section (fuel bundle): nodalized into [ ]^{a,c} boundary conditions are used to describe the bundle power versus time.
- Lower plenum: connected by a flow path to the bottom of the test section. This flow path is then used to describe the inlet mass flow rate versus time as a boundary condition.
- Bottom of test section: sets the boundary conditions for the inlet pressure, inlet liquid temperature versus time and is only used to calculate the enthalpy of the inlet water.

a,b,c

[ ]

Figure 1: POLCA-T test section model

The results of POLCA-T simulations are shown below. These results compare measured steady state cladding temperatures along the fuel rods (pink dots) with the average rod temperatures simulated by POLCA-T (blue dots).

a,b,c

[ ]

Figure 2: Steady state cladding temperature along the test section

The results in Figure 2 demonstrate that POLCA-T predicts [ ][a,c] It is a challenging task to measure the surface temperature using thermocouples; therefore, the agreement is good considering the [ ][a,c] and the fact that an [ ][a,c] one thermal-hydraulic environment is simulated. It can be concluded that the heat transfer coefficients can be predicted well along the bundle using the heat transfer map in POLCA-T when the heat transfer regime changes from single phase liquid via nucleate boiling to two phase forced convection.

The comparison of POLCA-T predicted cladding temperatures with measured data is shown for a [ ][a,c] in the following.

Figure 3 shows the cladding temperature at cells eight, thirteen and fourteen, which are located around the middle of the test section.

Figure 4 shows the cladding temperature in the upper quarter of the test section (i.e. nodes eighteen, nineteen and twenty).

a,b,c

Figure 3: Cladding temperature versus time, comparisons test data with POLCA-T predictions

a,b,c

[ ]

Figure 4: Cladding temperature versus time, comparisons test data with POLCA-T predictions

From [ ]^{a,c} it can be observed that
[ ]^{a,c} are well predicted:

It can be also observed that the [ ]^{a,c} is well predicted independently of the axial location. The [ ]^{a,c} is better predicted in the upper quarter than in the middle of the bundle.

NRC RAI 5-1

Provide additional descriptive details of the database used to develop the void-quality correlations. Specifically provide as a separate table the nature of any transient tests performed, the range of pressures, mass flow rates, and heat fluxes tested

Westinghouse Response to NRC RAI 5-1

The behavior of the void–quality correlation via the drift flux correlation can be shown by different comparisons of POLCA-T results against the test data.

For example the drift flux correlation has been verified as a part of the simulation of the [ ][a,c] experiments (see the answer to RAI 3-5).

A second case where the result from the drift flux correlation has been checked and validated is from the Pump trip test 406 (Ref.1).

The predicted results obtained with the POLCA-T code are compared to measurement data from an all recirculation pump trip test performed at the Nuclear Power Plant Olkiluoto 1 during its commissioning in 1978. The plant is owned and operated by the electrical power company Teollisuuden Voima OY, TVO, in Finland.

Other cases when the drift flux correlation has been validated are all cases of POLCA-T stability and transients validation.

Pumptrip test 406

The bundle flow is measured and compared for the following assemblies shown in Figure 3 below.

Eight individual channel flows are reconstructed using the pressure drop measurements over the bundle inlet orifice. The bundles are evenly distributed in the central throttling zone. The throttling map and the positions of the pressure drop measurement for the individual channel flow are shown in Figure 1. The flow measurement positions are named 211K301 through 211K304 and 211K311 through 211K314, and are in green colour, and flows predicted by POLCA-T are named FLOW ch xxx, and are in red colour in Figures 2 and 3.

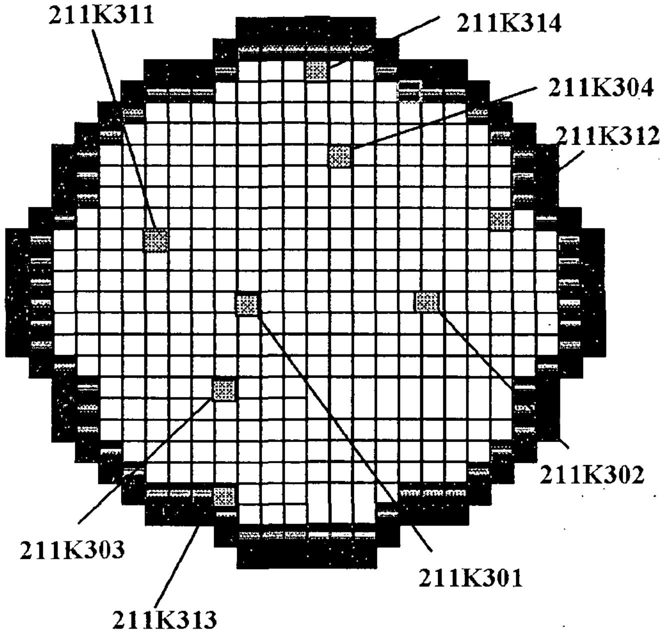


Figure 3: Core outline showing location of bundle flow measurement

a,b,c

Figure 2: Channel Mass Flow Rates, predicted and measured, channel 211K301-211K304

a,b,c

Figure 3. Channel Mass Flow Rates, predicted and measured, channel 211K311-211K314

The following conclusions are made based on the simulations with POLCA-T of the Olkiluoto 1 commissioning test of tripping all recirculation pumps :

- POLCA-T predicts the event accurately, the flow coast down and the power decay is in good agreement with measured data.
- The drift flux correlation does a good job during the pump coast down, from forced circulation down to natural circulation.
- The accuracy of the predicted channel flow is independent of its location in the core.

Reference:

1) U. Bredolt, POLCA-T – Validation of transient bundle flow predictions during an all recirculation pumptrip in a BWR Proceedings of ICONE 14 International Conference on Nuclear Engineering, paper ICONE 14-89134, July 17-20, 2006, Miami, Florida, USA

NRC RAI 7-1

Provide specific details regarding the qualification of PHOENIX4 in regards to determining the Doppler worth attributed to plutonium absorption during CRDA at the EOC. First, describe specific qualifications of the PHOENIX4/POLCA7 code suite to determine the buildup of plutonium under voided depletion in the upper regions of a BWR code. Provide any sensitivity in the code's capability to conditions affecting spectrum hardness (control state, bypass voiding, high power density operation, and low flow conditions). Provide comparisons of the plutonium Doppler worth contribution against benchmarks or more sophisticated transport methods to demonstrate adequate cross section collapsing.

Westinghouse Response to NRC RAI 7-1

In its depletion calculations, PHOENIX4 applies a relatively detailed representation of the isotopic transformations occurring during fuel burnup. The burnup chains of heavy metals include [ ][a,c] isotopes, among them five [ ][a,c]. The depletion calculations are done in the library group structure [ ][a,c] using the predictor-corrector method [ ][a,c]. No condensation is involved and the local neutron spectrum is applied for each burnable region. Thus, individual conditions in fuel pins are accounted for depending on the fuel state parameters (burnup, channel/bypass void, burnable absorber remaining fraction, control rod insertion, etc.).

In PHOENIX4 the ability to predict the evolution of the isotopic composition over time has been qualified in the OECD/NEA Isotopic Depletion Benchmark (References [1], [2]) placing the code in-between the 21 codes participating in the benchmark. The following are the results for Pu isotopes which are generally in good agreement with the benchmark average.

a,b,c

[ ]

Only the concentration of]^{a,c} by an amount that is noticeably outside the standard deviation of the benchmark average. The [ ]^{a,c} is mostly attributed to the neglecting of [ ]^{a,c} , and as it is proved by a distinctively higher standard deviation of the NEA average for the isotope, the uncertainty for [ ]^{a,c} was generally much higher among the participating codes. This higher uncertainty of calculated [ ]^{a,c} concentration has no larger practical implication in reactor calculations because of its small reactivity contribution [ ]^{a,c}.

PHOENIX4 results of a typical BWR pin cell calculations were validated against the more advanced HELIOS code to further qualify the capability of PHOENIX4 to predict build-up of Pu isotopes in various core conditions. The validation was performed over a wide range of (increasingly harder) neutron spectrum conditions, achieved by modeling:

[ ]a,c

Observe that a 40% void in the pin cell calculations corresponds to much higher void, in the range of 70-80 %, in a BWR assembly where channel bypass remains essentially non-boiling.
The summary of the observed deviations [%], presented below, confirms the capability of PHOENIX4 in determining Pu build-up over the whole neutron spectrum variation of a LWR reactor.

a,b,c

[ ]

The temperature dependence of nuclear data is an inherent feature of the PHOENIX4 cross section library. Fuel isotopes have their nuclear data (both cross sections and resonance integrals) tabulated for several temperatures covering the range from [ ]^{a,c}, so PHOENIX4 can interpolate for the actual temperature. Only less important isotopes [ ][a,c] have data for a single temperature.

The ability of PHOENIX4 to handle the temperature effects for plutonium has been verified against HELIOS by comparing Pu reactivity worth and its change with the temperature (the Pu Doppler effect) at several burnups in pin cell calculations. The table below shows the results for a pin cell with [ ][a,c]. The Pu reactivity worth is defined here as the difference in the infinite multiplication factor with and without the plutonium isotopes. For the temperature change of the Pu reactivity worth, both codes agree within [ ][a,c]

a,b,c

[ ]

Another proof that PHOENIX4 and its cross section library are capable tools to accurately compute plutonium reactivity worth is comparison against the MCNP5 results for a [ ][a,c] to assess PHOENIX4 performance for application in criticality analyses. In this exercise, where the purpose was to verify the PHOENIX4 library data rather than burnup, the PHOENIX4 computed [ ][a,c], since MCNP5 cannot perform burnup calculations. As shown in the following table with the results for a fuel pin cell [ ][a,c], there is very good agreement between the two codes.

a,b,c

[ ]

The cross-section representation model utilized by POLCA-7 incorporates Doppler corrections in both macroscopic and microscopic (for all actinides of importance) cross sections. These correction terms employ PHEOENIX4-calculated cross-section Doppler coefficients tabulated as a function of [ ][a,c].

REFERENCES

1) M. C. Brady, "Burnup Credit Criticality Benchmark, Part I-B. Isotopic Prediction (Problem Specification)", Sandia National Laboratories, NEA/NSC/DOC(92)10/REV (1992)

2) M. D. DeHart, M. C. Brady, C. V. Parks, "OECD/NEA Burnup Credit Calculational Benchmark Phase I-B Results", NEA/NSC/DOC(96)-06, ORNL-6901 (1996)

NRC RAI 7-3

Towards the EOC some BWRs have a positive moderator temperature coefficient at cold zero power conditions. Does the POLCA-T method account for this effect?

Westinghouse Response to RAI 7-3:

The existence of less negative or even positive moderator temperature coefficients at zero power conditions during the cycle is a well-known fact in cores loaded with modern fuel due to the presence of part-length rods. In order to properly deal with this effect, which is strongly dependent on the core loading and the core conditions (xenon state, control rod sequence, etc.), the standard nuclear data tables include cross sections at [ ]^{a,c}. As seen from Table 1, these [ ]^{a,c} cover the whole range from [ ]^{a,c} providing, together with the data at [ ]^{a,c} conditions, full coverage for the whole start-up process of the plant. It should also be noted that these [ ]^{a,c} have been specifically chosen to minimize the error in reactivity prediction and, thereby in computing the isothermal temperature coefficient (ITC) by comparing POLCA7 predictions against corresponding PHOENIX4 reference results for simple single-assembly test cases representing core conditions encountered during reactor startup.

Table 1: Recommended nuclear heating state points below rated power for cell data generation

a,b,c

[ ]

NRC RAI 7-5

Considering that a reactor may experience an unplanned shutdown and subsequent startup from a mid-cycle core exposure condition, describe those aspects of the determination of the limiting initial conditions and candidate limiting control rods that accounts for core cycle exposure.

Westinghouse Response to RAI 7-5:

In the first step of the methodology we do select the control rod (CR) candidates at several core cycle exposures [ ]^{a,c}, so if the CR has a high reactivity worth it will be selected as a potential candidate for transient evaluation. In the provided demonstration of step 1 in the topical report it was observed that both the CR worth and power peaking factor (PPF) at MOC are [ ]^{a,c} those obtained at EOC conditions (see Figures A.4-2 and A.4-3). Given the sensitivity of the peak fuel enthalpy to the CR worth (see Figure A.5-1) the control rod worth will dominate and MOC exposures will not result in more limiting conditions. The choice of limiting initial conditions considers only instantaneous effects, consistent with the separation of historical and instantaneous effects in steps 1 and 2 of the methodology.

If the [ ]^{a,c} in the cycle were to provide CR candidates with highest reactivity worth or PPF (for example because of fuel design), both the choice of limiting initial conditions and transient evaluation will be performed according to the methodology steps 1 through 3 described in section A.4.6 Cycle-Specific Evaluation Methodology.

NRC RAI 7-6

CENPD-390-P-A includes several cold critical eigenvalue calculations for various plants over several cycles. Using the cold critical eigenvalues and associated plant data, quantitatively justify the use of a 5% uncertainty value (at the 95% confidence level) for the control rod worth uncertainty in the subject uncertainty analysis.

Westinghouse Response to NRC RAI 7-6

The following table shows a summary of the (local) cold critical eigenvalue evaluations over 16 cycles for one of the plants included in CENPD-390-P-A. These evaluations are performed by taking a sub-critical reactor at cold conditions with all of its control rods inserted to a critical level by fully withdrawing a control rod and partially withdrawing a neighboring control rod at different locations in the core. The following table contains the average calculated cold reference level (based on 5 to 10 individual measurements) and its associated standard deviation for every cycle. In addition, the average cold reference level and the total standard deviation (of all the individual measurements performed over those 16 cycles) around this average level are provided.

a,b,c

[ ]

As shown above, the cold critical level is predicted with an uncertainty of [ ]^{a,c}. Assuming this value is representative of the ability of PHOENIX/POLCA to predict core eigenvalues (keff) and the control rod reactivity worth is expressed as a relative difference between eigenvalues (before and after the control rod withdrawal/insertion), the following uncertainty propagation can be performed in the case of a rod withdrawal.

a,c

[ ]

Where k is the multiplication factor of the reactor after the rod withdrawal.

The associated uncertainty to the control rod reactivity worth estimate will be:

[ ]$^{a, c}$

Since the core after the rod withdrawal will be very close to critical ($1/k^2 \approx 1$), the uncertainty in control rod worth will basically be equivalent to [ ]^{a,c}. The estimated uncertainty of [ ]^{a,c} would lead to about a [ ]^{a,c} eigenvalue uncertainty with 95% confidence, which is clearly lower than [ ]^{a,c}.

NRC RAI 7-7

Specify those aspects of the POLCA-T methodology that conservatively account for the negative reactivity during a SCRAM. Specifically address any assumptions regarding the rate of negative reactivity insertion. If a linear approximation is used, justify the use of this approximation.

Westinghouse Response to RAI 7-7:

The SCRAM insertion positions used in the POLCA-T Control Rod Drop Accident (CRDA) analyses are taken from the plant technical specifications which place limits on the scram insertion rate in the form of maximum times for control rods reaching [ ][a,c] . This is as discussed on page A-47 of the topical report. These plant SCRAM specifications are conservative and are used as input to the safety analyses performed for example by BISON or RAMONA3 codes. POLCA-T utilizes this SCRAM data in the CRDA analyses and thus the same SCRAM conservatism is assumed as well.

NRC RAI 7-8

It is the staff's understanding that the PHOENIX4/POLCA7 cross section library is based on ENDF/B-VI. How does the value of the delayed neutron fraction for the principle nuclides compare with what used in RAMONA-3B SCP2?

Westinghouse Response to RAI 7-8:

The delayed neutron data in the PHOENIX4 library is currently based on a compilation of [ ]^{a,c}. The ENDF/B-VI delayed neutron data is known to be erroneous and is not recommended for general use and, [ ]^{a,c}. The RAMONA-3B SCP2 delayed neutron data was based on the PHOENIX2 data set. These two data sets are provided in the following tables. As seen, these two data sets show [ ]^{a,c}.

a,b,c

[ ]

<u>NRC RAI 7-11</u>

As part of the screening for potentially limiting control rods for CRDA does the methodology allow for analyzing an off-center control rod as a representative central control rod?

<u>Westinghouse Response to RAI 7-11</u>:

The methodology [ ]^{a,c} the consideration of an off-center control rod as a representative central control rod. [ ]^{a,c}.

NRC RAI 7-15

Provide additional descriptive details regarding the determination of the initial conditions. Specifically address what process is used to determine the worst single operator failure or which rods are bypassed.

Westinghouse Response to NRC RAI 7-15

Westinghouse methodology for a complete analysis of CRDA is fundamentally a two-step approach.

The first step involves the [ ]^{a,c} resulting from CRDA. These candidates are selected based on the [ ]^{a,c} with the following assumptions: the dropped control rod in the final withdrawn position within the constraints of [ ]^{a,c} and the plant licensing basis [ ]^{a,c}. As required in the actual application, calculations may be needed for both cold and hot standby conditions to determine the [ ]^{a,c}.

An NRC approved three-dimensional static nodal code, such as POLCA7, in conjunction with the cross-section generator code PHOENIX4, are utilized for this evaluation.

The second step is the analysis of the [ ]^{a,c} to the dropped control rods and the subsequent consequences to the fuel. This evaluation is performed with POLCA-T. The dynamic evaluation is performed to calculate [ ]^{a,c}.

For a particular plant, consideration must be given to the [ ]^{a,c} for rod sequence control and the Technical Specifications concerning inoperable rods.The maximum number of inoperable rods allowed by the plant Technical Specifications is assumed [ ]^{a,c}.

These [ ]^{a,c} are assumed to be [ ]^{a,c} for the three- dimensional nodal simulator calculations utilized to select candidates for the most limiting control rod configuration. They are [ ]^{a,c} assumed to be [ ]^{a,c} for POLCA-T calculations used to evaluate the dynamic response resulting from dropping the control rods and the subsequent consequences for the fuel.

The existing plant-specific [ ]^{a,c} and [ ]^{a,c} are utilized by Westinghouse in the CRDA evaluation. Since these limiting assumptions are [ ]^{a,c}, substantial revisions are [ ]^{a,c} for most applications when Westinghouse reload fuel is installed in a particular plant.

In fact, the utilization of POLCA-T code, which allows [ ]^{a,c}, may allow a more precise description of [ ]^{a,c} than the plant's licensed existing analysis.

The assumed [ ]^{a,c} will depend on the control rod withdrawal system utilized for a given plant. For example, [ ]^{a,c} are assumed to be [ ]^{a,c} of the dropped control rod; thus, [ ]^{a,c}.

The following text will be added after the first paragraph on page A-43:

[

]^{a,c}

NRC RAI 7-16

Explain the differences between a power and flux SCRAM. Specifically explain what calculation in POLCA-T yields the core power. Is the power based on the integrated total of the rod heat fluxes? Does power refer to simulated thermal power?

Westinghouse Response to NRC RAI 7-16

"Power SCRAM" generally assumes that the process to initiate a SCRAM is started when the core thermal power reaches a certain level. "Flux SCRAM" assumes that the process to initiate a SCRAM is started when the core neutron flux reaches a certain level.

The same conservative delays between the time when the process to initiate a SCRAM is started and the time when the SCRAM actually begins are assumed in both cases. The same conservative SCRAM speed is also assumed in both cases.

The thermal power transient lags the flux transient due to the delay in the heat transfer to the coolant through the gas gap and cladding. Hence, the initiation of the SCRAM process based on thermal power will lead to a slightly later SCRAM; therefore, tending to cause more conservative results than the initiation of the SCRAM process based on flux.

In POLCA-T, as described in section 3.4 of WCAP-16747-P, the total power generation is [

]^{a,c}, because the CRDA has a very fast and short time scale with a significant prompt fission power peak.

Thus the total power is equal to

]^{a,c}. The POLCA-T calculated power is [
]^{a,c}.

In the case of neglected decay power, the SCRAM activation by power means an activation by fission power and thus by either neutron flux or APRM. Thus there is [
]^{a,c} described above. It has to be noted that the delay time of the SCRAM activation, after its initiation at a 120% power level, is conservatively determined as provided in the answer to RAI 7-7.

Thus the use of term "power" SCRAM has [
]^{a,c} the possible "flux" SCRAM provided in Appendix A of WCAP-16747. Moreover the inclusion of a "conservative" scram on 120 percent power in section A.4.4.1 in the 2nd from the top paragraph on page A-45 is [ ]^{a,c}. For these reasons the text of WCAP-16747-P A.4.4.1 in the 2nd from the top paragraph on page A-45 will [

]^{a,c}

<u>NRC RAI 7-17</u>

Please clarify the footnote in Table A.3-6. Does the measured peak power in the footnote refer to the time at which the peak power was measured during the experiment? Is the integrated energy based on the integral of the POLCA-T predicted power up until the time that was measured?

<u>Westinghouse Response to RAI 7-17</u>:

The correct text of the footnote should be as follow:
"Upper value shows the POLCA-T calculated integrated energy released up to the POLCA-T calculated time of peak power, while the lower value is the POLCA-T calculated integrated energy released up to the time at which the peak power was measured during the experiment". Thus the answer to both questions is "yes", as can be seen in the following table.

Measured integrated energy released up to the time at which the peak power was measured during the experiment is provided given the column labeled "SPERT".

The restructured table below contains the same results. The restructured table below contains the same results.

a,b,c

NRC RAI 7-20

In step 1 of the CRDA analysis methodology have different screening criteria been selected for the POLCA-T method, relative to the RAMONA-3B SCP2 method, for concluding that dynamic analyses are not necessary? If so, provide the POLCA-T criteria.

Westinghouse Response to NRC RAI 7-20

There is [ ]^{a,c} in the screening criteria selected in step 1 of the CRDA methodology for the POLCA-T method from the criteria used in the RAMONA-3B SCP2 method. The text provided in section A.4.6 of the topical report for step 1 of the POLCA-T method is [ ]^{a,c} in the RAMONA-3B SCP2 method.

[ ]^{a,c}. [ ]^{a,c} the text of WCAP-16747-P section A.4.6 will be corrected as follows.

The current text of step 1 will be replaced by the following text:

a,c

[ ]

NRC RAI 7-23

Section A.3 2.1 paragraph 2 states that POLCA-T simulations were performed for the TT3 test. Please provide the results of this simulation.

Westinghouse Response to RAI 7-23:

Steady-state simulations have been performed for all three Peach Bottom 2 EOC 2 turbine trip tests. The transient simulations are so far performed only for tests TT1 and TT2; only steady-state simulations have been performed for the TT3 test. Transient analysis of the TT3 test is planned and the results will be included in the Appendix C of the topical. This text corrects the text of the topical report section A.3.2.1 paragraph 2.

NRC RAI 7-25

Please describe the methods that are used to evaluate the radiological consequences resulting from fuel failure during control rod drop accidents.

Westinghouse Response to NRC RAI 7-25

If the evaluation of radiological consequences is required as a result of a POLCA-T CRDA analysis predicting fuel melting, an analysis will be performed based on the plant licensing basis; i.e., applying NRC Regulatory Guide RG 1.183 for alternate source term, or RG 1.195 using the traditional method. In both cases an approved method to evaluate the radiological consequences will be used. [

]^{a,c}.

NRC RAI 8-2

The staff requires additional information regarding the H1 and H6 heat transfer coefficient correlations. The film temperature is determined using a different method. Please comment on the different implementation of these models for POLCA-T relative to GOBLIN.

Westinghouse Response to NRC RAI 8-2

The film temperature model in POLCA-T for the correlations in the heat transfer regime of H1 and H6 are:

[ ]^{a,c}

where the subscripts c or g represent liquid and gas respectively in the bulk temperature of fluid.

The film temperature in GOBLIN is limited by [ ]^{a,c} Unlike POLCA-T which calculates temperatures above [ ]^{a,c} therefore removing the limitations on evaluating the film temperature.

NRC RAI 8-3

Please provide a more detailed heat transfer regime map. In general, the flow regime changes within each temperature range will dictate the heat transfer characteristics, please provide a more detailed figure, or series of figures, that in each temperature range shows the applicable heat transfer coefficient correlation as a function of the Reynold's number as well as void fraction. Specify the applicable range for each correlation and mark where interpolation is performed between different Reynold's numbers.

Westinghouse Response to NRC RAI 8-3

The figure below shows how the heat transfer coefficients are calculated on the "void – surface temperature plane " as described in the WCAP-16747 topical report.

a,c

Figure 1: Heat transfer map, void versus surface temperature.

In addition, the figure below shows how the heat transfer coefficient, htc, is calculated in the "Reynolds number – void plane" for different surface temperatures, below and above the critical temperature T_{crit}.

a,c

Figure 2: Heat transfer map, Reynolds number vs. void, non-dryout condition. $T_{surface} < T_{crit}$

a,c

Figure 3: Heat transfer map, Reynolds number vs. void, stable post-dryout condition $T_{surface} > T_{leid}$

The heat transfer coefficients are interpolated in the region between α_1 and α_2 and between δ_1 and δ_2. The heat transfer coefficient htc in the transition becomes equal for the two flow regimes due to Reynolds number.

The applicable range of the correlations is listed below.

Pre-dryout Heat Transfer ($T_{surf} > T_{sat}$, Boiling or Steam cooling)

a,c

[ ]

Pre-dryout Heat Transfer ($T_{surf} \leq T_{sat}$, Single-phase Water or Steam)

a,c

[ ]

a,c

Post-Dryout Heat Transfer

a,c

Steam Condensation

a,c

[ ]

NRC RAI 8-4

The staff does not find that the current countercurrent flow limitation correlation adequately bounds the available data to justify use of the correlation for SVEA-96 Optima 2 fuel designs. Please refer to WCAP-16078-P-A. The hydraulic diameter definition in POLCA-T is consistent with earlier versions of GOBLIN, but is not consistent with the conservative approach proposed in the most recent application. Please revise this model to be consistent with the staff's most recently approved model.

Westinghouse Response to RAI 8-4

The countercurrent flow limiting (CCFL) condition is [ ]^{a,c}. The POLCA-T calculation will be updated to the effective diameter in a flow channel as required for use in the CCFL correlation together with modern fuels as SVEA-96 Optima2 for Transient and ATWS applications which will be detailed in Appendices C & D.

NRC RAI 8-6a

Please provide additional details regarding the formulation of the momentum conservation equation.

(a) *Describe the momentum conservation equation, as formulated, when calculating pressure losses along a flow direction that is not vertical.*

Westinghouse Response to NRC RAI 8-6a

Chapter 7.2 of WCAP-16747-P describes how the momentum equation and its terms are adjusted for a vertical flow. The formulation is similar to the horizontal flow formula, but the gravity, Δp_{grav} , term is set to zero. If the direction is an incline, the cosine of the angle is multiplied to the gravity term with its sign dependant on the defined positive direction of the flow.

The momentum equation reads:

$$I_j \frac{\partial W}{\partial t} = p_i - p_{i+1} - \Delta p_{fric} - \Delta p_{loc} - \Delta p_{grav} - \Delta p_{flux} + \Delta p_{pump}$$

NRC RAI 8-6b

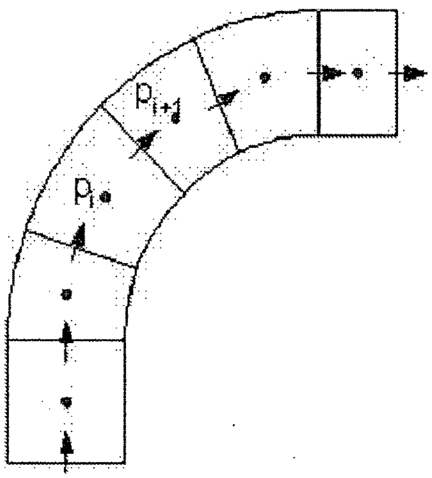
(b) *Describe the models in POLCA-T that calculate the pressure drop across a volume cell representing an elbow in a pipe*

Westinghouse Response to NRC RAI 8-6b

To take into account the pressure losses through a bend, the user has to provide the appropriate loss coefficient for the bend and the roughness value for friction in order to calculate the terms, Δp_{loc} and Δp_{fric}, in the equation above.

If the entire bend is divided into several volume cells the loss coefficient is distributed equally over the flow junctions that connect the volume cells.

The figure below shows a horizontal bend, divided into a number of volume cells. At the flow junction the state vector is the liquid and gas velocities indicated by an arrow and calculated at the surface of the volume cell. In each volume cell the state vector at the dot is the pressure, void, liquid and gas temperatures and average liquid and gas velocities. The liquid and gas velocities are solved by iteration of the momentum equation and the drift flux correlation.

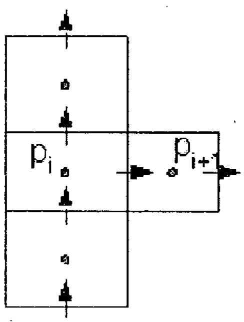


<u>**NRC RAI 8-6c**</u>

(c) *Describe the models in POLCA-T that calculate pressure drops and flow fractions for volume cells that are attached to more than two neighboring cells, specifically explain these models in terms of linked volume cells where flow exiting the volume cell may be either vertical through one exit path or horizontal through another exit path (i.e. a tee).*

<u>**Westinghouse Response to NRC RAI 8-6c**</u>

Below a sketch of a tee-junction is shown:

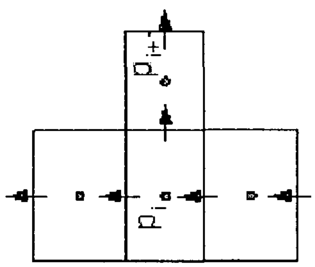


Assuming no gravitation the momentum equation for the flow mixture from the junction to the branch would be:

$$I_j \frac{\partial W}{\partial t} = p_i - p_{i+1} - \Delta p_{fric} - \Delta p_{loc} - \Delta p_{flux}$$

The term Δp_{flux} is multiplied by a factor from [ ]^{a,c} in order to simulate the amount of downstream momentum that would be transferred to the branch. The friction and form loss for the branch is also set by the user.

In the case of a vertical branch, the sketch is shown below:



The momentum equation in the flow junction to the branch now reads:

$$I_j \frac{\partial W}{\partial t} = p_i - p_{i+1} - \Delta p_{fric} - \Delta p_{loc} - \Delta p_{grav} - \Delta p_{flux}$$

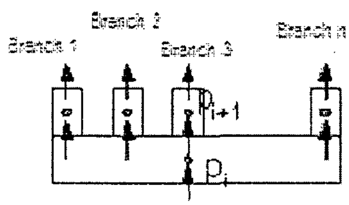
The difference being the inclusion of a term for gravitational pressure drop.

NRC RAI 8-6d

(d) Describe the application of the momentum equation for mixing volumes, such as a lower plenum with potentially many connecting parallel volume cells.

Westinghouse Response to NRC RAI 8-6d

The sketch below shows a volume cell, connected to a number of branches.



For each of the flow junctions, the arrows, the momentum equation reads;

$$I_j \frac{\partial W}{\partial t} = p_i - p_{i+1} - \Delta p_{fric} - \Delta p_{loc} - \Delta p_{grav} - \Delta p_{flux}$$

where each equation set up takes into account the downstream conditions in the common volume cell, manifold.

NRC RAI 8-6e

(e) Please describe how the single fluid formulation of the momentum equation captures the virtual mass effect

Westinghouse Response to NRC RAI 8-6e

The virtual mass effect is [ ]^{a,c} In two-phase flows this phenomenon is [ ]^{a,c} which is a correlation derived from measurements.

NRC RAI 8-6f

(f) Please rewrite the momentum equation in terms of the two phases, explain how the equation is solved based on volume cell state parameters (such as void fraction, pressure, and phase velocities). It is not clear to the staff how the single fluid properties are determined.

Westinghouse Response to NRC RAI 8-6f

The unknown quantities in the flow junctions are the state vector velocities u_{liq} and u_{gas}. From the momentum equation and the drift flux correlation the velocities can be determined by iteration for each time step.

$$I_j \frac{\partial W}{\partial t} = p_i - p_{i+1} - \Delta p_{fric} - \Delta p_{loc} - \Delta p_{grav} - \Delta p_{flux}$$

The mass flow rate, mixture, is calculated from:

[ ]^{a,c}

and from the very simple drift flux equation below:

[ ]^{a,c}

where S is equal to the slip ratio.

The single fluid properties are taken from the neighbor volume cells where p, void, t_{liq}, t_{gas}, u_{liqm}, u_{gasm}, are calculated and from those the steam-water properties can be found out (such as, densities, derivatives and transport properties for water and steam and gas in the case of non-condensable gases.

The entire systems of equations are solved simultaneously by iteration and for each iteration a linear equation system is solved.

When convergence is achieved all secondary variables are calculated and the state vectors are updated, ready for the next time step.

NRC RAI 8-6g

(g) Please describe how interfacial shear is treated

Westinghouse Response to NRC RAI 8-6g

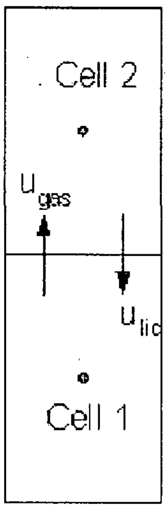
POLCA-T uses [ ]^{a,c} instead of a [ ]^{a,c} system with extra constitutive correlations for momentum transfer between the phases. The interfacial shear between the phases, water and gas is implicitly taken into account in the drift flux correlation which is based on measurements.

NRC RAI 8-6h

(h) Please describe how the momentum equation is solved when counter current flow is predicted

Westinghouse Response to NRC RAI 8-6h

The sketch below shows two vertical cells, if the void content in cell 2 is lower than the void content in cell 1 a counter current flow situation has occurred.



When counter current flow conditions are detected, as above, the momentum equation is solved for the mixture of liquid and gas

Instead of the [ ]^{a,c} is solved for the gas velocity

The unknown quantities in the flow junction are the u_{liq} and u_{gas} state vector velocities. From the momentum equation and the drift flux correlation the velocities can be determined by iteration for each time step.

$$I_j \frac{\partial W}{\partial t} = p_i - p_{i+1} - \Delta p_{fric} - \Delta p_{loc} - \Delta p_{grav} - \Delta p_{flux}$$

The mass flow rate, mixture, is calculated from

$$W = \dot{m}_{liq} + \dot{m}_{gas} = u_{liq} A_{liq} \rho_{liq} + u_{gas} A_{gas} \rho_{gas} = A((1-\alpha) u_{liq} \rho_{liq} + \alpha u_{gas} \rho_{gas})$$

and the gas velocity from the CCFL equation.

NRC RAI 8-6i

(i) Under countercurrent flow conditions the staff does not understand how the one fluid momentum equation allows for accurate convection of momentum and energy between fluid volumes, please provide additional details regarding the momentum and energy associated with each phase and how it is convected.

Westinghouse Response to NRC RAI 8-6i

The momentum equation is set up and solved for as described in the above response to paragraph h. The energy and mass conservation equations are set up for each phase and each volume cell with its flow directions of the phases.

NRC RAI 8-6j

(j) Please explain how the wetted perimeter fractions are determined

Westinghouse Response to NRC RAI 8-6j

The wetted perimeter is determined in each volume cell as:

[ ]a,c

[ ]^{a,c}

Parameter α_1 is set to a constant equal to [ ]^{a,c} The basis for this number is as follows. The ramp in void fraction is chosen to give a reasonably smooth transition from two-phase to steam. The data base for the friction pressure drop covers void fractions as high as [ ]^{a,c} At 100% void fraction i.e. for pure steam the ramp ensures that a correct single phase expression is used.

NRC RAI 8-6k

(k) Please explain the basis, qualification, and coefficient values for the velocity distribution correction factor based on void fraction.

Westinghouse Response to NRC RAI 8-6k

The void correction factor is used to take into account the velocity distribution in the channel when void occurs. It is a correction factor, [ ]^{a,c} drift flux correlation.

The form of the correction factor is:

[ ]^{a,c}

The basis for this correlation is the pressure drop rod bundle data. The factor represents the difference between [ ]^{a,c} or in other words the effect of the two-phase flow on the velocity distribution in water near the wall.

NRC RAI 8-6l

(l) Please provide validation of the single fluid momentum formulation for cases where a large sudden pressure drop results in void formation downstream of the local loss.

Westinghouse Response to NRC RAI 8-6l

An application of POLCA-T for a fast flashing event demonstrates that the current formulation of the momentum equation is sufficient to predict this type of events. POLCA-T has been compared to the Edwards Experiment (Edwards, A. R., and T. P. O'Brien, " Studies of Phenomena Connected with the Depressurization of Water Reactors!", J. Brit. Nuclear Energy Soc. 9 (1970)).

The figure below shows the comparison:

a,b,c

NRC RAI 8-7

The staff has several questions regarding the momentum equation (see NRC RAI 8-6). To assist the staff in understanding the momentum equation and solution technique please provide a sensitivity analysis that will help the staff to determine whether the model potentially results in momentum errors. This analysis should take a complex model, as included in the qualification studies in the Appendices. Please initialize this model such that there are no energy sources (set core power to zero, set all boundary conditions to no flow boundary conditions, and remove all pump work), additionally please set the initial fluid conditions to purely liquid at uniform pressure with a relatively high degree of subcooling with zero initial velocity. Under these conditions there should not be a driving force for fluid flow. Please run a transient calculation. Verify that there are no residual momentum sources by checking the mass flow rate. If there is a feature in POLCA-T that would allow a similar calculation to address the staff's concern, it is acceptable to provide the results of this alternative analysis.

Westinghouse Response to NRC RAI 8-7

As a demonstration of the behavior of the momentum equation, a closed circulation loop with a pump was set up with POLCA-T. [

]a,c

The momentum equation for each flow path reads:

$$I_j \frac{\partial W}{\partial t} = p_i - p_{i+1} - \Delta p_{fric} - \Delta p_{loc} - \Delta p_{grav} - \Delta p_{flux} + \Delta p_{pump}$$

Figure 1: POLCA-T results for mass flow rate (kg/s) versus time (s) for a pump with homologous pump curves.

a,b,c

[ ]

Figure 2: POLCA-T results for mass flow rates (kg/s) versus time (s) for pump with non-homologous pump curves.

a,b,c

From the Figures above it can be concluded that the [ ]a,c as it should when there are no artificial momentum sources.

NRC RAI 8-8

The staff has several questions regarding the use of the component models that were previously reviewed and approved as part of the BISON methodology.

With use of the PARA steam line model, the user has the flexibility of modeling valves and control system functions through the use of user supplied tables and control systems. Modeling of these systems greatly affects the amount of conservatism in the transient outcome for certain event analysis. Provide justification for these user controlled items to assure conservatism in licensing applications.

Westinghouse Response to RAI 8-8(1)

The PARA model from BISON is used to provide flexibility so that exisiting steam line models can be used. When new models are created, the plan is to use POLCA-T thermal-hydraulics for the entire model.

NRC RAI 8-8(2)

In regards to the recirculation pump model, provide verification that all previously imposed conditions, limitations, and restrictions are maintained for its use in POLCA-T.

Westinghouse Response to RAI 8-8(2)

POLCA-T does not use any part of the BISON pump model.

NRC RAI 8-8(3)

In regards to the steam separator, please compare the POLCA-T model to the BISON model with increased L/A or previously referenced qualification data, such as the 1985 TVO1 rapid pressurization event.

Westinghouse Response to RAI 8-8(3)

A comparison of the steam separator model with test data for the carry under is shown below for the old ASEA Atom separator AS16 and for the new steam separator AS01 developed and tested in the late 90's.

Carry under fraction AS16 steam separator: Calculated versus measured

a,b,c

Carry under fraction AS01 steam separator Calculated versus measured

a,b,c

NRC RAI 9-1

Please provide additional descriptive details of the power generation model. Following a reactor SCRAM the power generation includes sources from transient fission power (during the rod insertion and from delayed neutrons), fission product decay, actinide decay, decay of structural activation products, heat transfer from vessel internals, and exothermic energy release from metal-water reactions. Please discuss the models and capabilities of POLCA-T in regards to each of these heat sources.

Westinghouse Response to RAI 9-1:

The prompt fission power is calculated by POLCA7 from the thermal-hydraulic conditions calculated in POLCA-T.
The POLCA7 part of POLCA-T solves the two-group diffusion equations with a number of delayed neutron families determined by the code user.
The figure below shows the interaction between POLCA7, neutron kinetics, and RIGEL, (the thermal-hydraulic portion.) The quantities that are transferred between the modules are listed on the figure.

a,c

Data communication between POLCA7 and RIGEL takes place through a few arrays stored in a data structure for communication between the two codes:

a,c

The fission power generation is divided in two parts: power generation in the fuel plus direct power generation in the coolant. The fission power contains the prompt and delayed powers generated in the core.

The decay power is calculated from [ ]^{a,c}, the number of decay groups is user defined. Standardized included files simulating ANS decay power curves are available with [ ]^{a,c}, or other decay power data depending on the purpose of the simulation.

The stored energy in the user defined heat structures is released/stored according to the solution of the transient heat conduction equation for each heat structure, with its thermal properties temperature integrated, if it has such dependency, and appropriate boundary condition. The number of heat structures and their material properties have virtually no limit in the code.

In case of simulating metal-water reactions an internal heat generation source in the heat structures containing Zircaloy is added based on a power generation model, Baker-Just for conservative estimation and Cathcart-Pawel for best estimate simulation.

NRC RAI 11-1

Section 14. (First paragraph)

The introductory paragraph states: "This simulation only uses the thermal hydraulic environment for the average rod to calculate maximum temperatures when an internal peaking factor is set for this hot rod."

Please clarify use of average environment for maximum temperature. Is it not possible for the local "hottest rod" environment to be hotter than the average environment?

Westinghouse Response to RAI 11-1:

POLCA-T code models as minimum two fuel rods for each fuel assembly – one average rod and one hot rod. Both rods are axially nodalized consistent with the coolant channel nodalization. The steady state and transient heat conduction equation is solved in both rods to determine the radial temperature distribution for each axial location. The solution for the average rod is used as [ ]^{a,c} in the coupled neutronics– thermal-hydraulics, while the hot rod solution is only used for [ ]^{a,c}. The coolant boundary conditions for both the average and the hot rods are assumed to [ ]^{a,c}. This is true when the coolant is at [ ]^{a,c}. In the cases when the coolant is at [ ]^{a,c} the hot rod "environment" could be [ ]^{a,c} however, [ ]^{a,c} conditions do not challenge the cladding and fuel integrity. Thus the model is adequate at the conditions when the extreme fuel and cladding temperatures might occur.

NRC RAI 11-2(1)

Section 14.1.1

(1) Please verify if surface temperature of the cladding (T_c) refers only to the surface in contact with the fuel (i.e. the inner surface of the cladding), or if the temperature is modeled as a constant across the cladding thickness.

Westinghouse Response to RAI 11-2(1)

T_c refers to the inner surface of the cladding. POLCA-T code calculates at least three temperatures of the cladding: Temperature on the inner surface, temperature on the outer surface and an average cladding temperature, when there are two rings of cladding.

NRC RAI 11-2(2a)

(2) Equation 14.2 is incorrect.

(a) Please demonstrate that this is, or is not, a typographical error.

Westinghouse Response to RAI 11-2(2a)

Equation 14.2 has a typographical error. It should be + (plus sign) instead of – (minus sign). The correct Equation 14-2 shall be:

$$h_{rad} = C_{f,c} \cdot \left(T_f + T_c\right)\left(T_f^2 + T_c^2\right)$$

Because:

[ ] a,c

NRC RAI 11-2(2b)

(b) Provide documentation that the error does not exist anywhere in the source code.

Westinghouse Response to RAI 11-2(2b):

The typo "-" in Eq. (14-2) has only appeared in the topical report (WCAP-16747-P), not in POLCA-T source code as can be seen in the extracted part of the source code for that equation:

[ ] a,c

NRC RAI 11-2

Please present calculations and corresponding test data for comparison.

Westinghouse Response to RAI 11-2

Since it was a typographical error only in topical report, not in source code, no calculation is needed for verification of the correction.

NRC RAI 11-3(1)

Section 14.1.3 and 14.2 states POLCA-T can be applied to either UO_2 or (U,Gd) O_2.

(1) For $(U,Gd)O_2$, please present relevant fuel cracking data inputs to the code to demonstrate that POLCA-T predicts correct results for this fuel.

Westinghouse Response to RAI 11-3(1)

Two parameters, Γ and $\Re$, as shown in Eq. (14-24), are used to calibrate model results against the measured fuel pellet temperatures, as described in section 3.2 of Topical Report WCAP-15836-P-A. $\Re$ is the [ ]^{a,c} and Γ is the [ ]^{a,c} which controls the mean gap heat transfer, as shown in Figure 1 below.

The maximum radial displacement of the [ ]^{a,c} and the fractional contact of the [ ]^{a,c} with cladding for UO_2 and $(U,Gd)O_2$ are treated in the [ ]^{a,c} However the pellet [ ]^{a,c} are different for UO_2 and $(U,Gd)O_2$, as seen in Eq. (14-32) & (14-37).

The implementation of the mean heat transfer coefficient of the gap containing the [ ]^{a,c} was described as follows in Topical Report WCAP-15836-P-A:

Generalized Mean Values of Cracked Pellet Gap Conductance

Mathematical statistics formalism is used to calculate the gap conductance for a cracked fuel pellet.

- Definition

For any monotonic continuous function f an expectation value of any stochastic variable X can be defined as:

$$E_f(X) = f^{-1}(E[f(X)])$$

$$E_f(X) = f^{-1}\left(\int f(u)W(u)\,du\right) \qquad \text{(A-1)}$$

where f^{-1} is the inverse function of f and $W(u)$ is the weighting function.

If f is a linear function, the *arithmetic mean* value is obtained, and if $f(x)=1/x$, the so called *harmonic mean* value is obtained by the above definition.

- Application

A combination of arithmetic and harmonic mean values is used to treat the gap heat conductance, thus the following function is selected:

$$f(x) = \frac{1}{x+k} \qquad \text{(A-2)}$$

where k is a constant. Note that for small k, $f(x)$ gives a harmonic mean value, while for large k, $f(x)$ reduces to a function for arithmetic mean value. For the weighting function, a simple exponential distribution function is chosen, namely:

[ ]^{a,c} (A-3)

where R_{eq} and G_T are defined in (14-24).

The stochastic variable is the local heat transfer coefficient, $x=h_g^{loc}$.
Consequently (A-2) will be,

[ ]^{a,c} (A-4)

where κ is the fuel pellet conductivity, a is the pellet radius and C (=15.0) is an empirical constant. The mean heat transfer coefficient of the gap with the fragmented pellet is obtained by employing Eqs. (A-3) and (A-4) in (A-1) and carrying out the integration. The integration is performed numerically with the aid of the Gauss-Laguerre integration method.

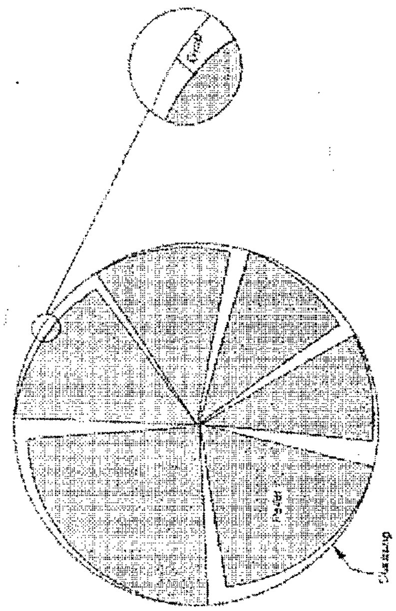


Figure 1: Model representation of pellet relocation.

NRC RAI 11-3(2)

(2) If the code is intended for MOX or any other fuel, please present similar information.

Westinghouse Response to RAI 11-3(2)

The code will [ ]^{a,c}

NRC RAI 11-3(3)

(3) Please justify why pellet cracking is important to section 14.1.3, yet in section 14.2, "Pellet cracking is not considered explicitly."

Westinghouse Response to RAI 11-3(3)

The text in the second paragraph shall read as follows:
[

]^{a,c}

NRC RAI 11-3(4)

(4) Please explain how the effect of pellet cracking is taken into account. Be specific for each fuel, UO_2 and $(U,Gd)O_2$.

Westinghouse Response to RAI 11-3(4)

Please see the answer to RAI 11-3 part (1).

NRC RAI 11-3(5)

(5) Please enumerate code limitations due to the non-consideration of fuel restructuring.

Westinghouse Response to RAI 11-3(5)

The sentence "Fuel restructuring is not presently treated in the code" on page 14-9 of the Topical Report shall be removed.

In the athermal model of the Westinghouse fuel performance code the fuel restructuring in the pellet rim at high burnup has to some extent been taken into account in order to model high burnup enhanced fission gas release, see WCAP 15836-P-A, section 2.1.5-3.

<u>NRC RAI 11-4(1)</u>

Section 14.2.3

(1) Will the POLCA-T code be applied to UGd >12% O_2?

<u>Westinghouse Response to RAI 11-4(1)</u>

The pellet thermal expansion formulation shown in 14.2.3 can be applied to [ ]^{a,c}

<u>NRC RAI 11-4(2)</u>

(2) If so, please present the justification including the correct use of the coefficient of thermal expansion at transient temperatures.

<u>Westinghouse Response to RAI 11-4(2)</u>

POLCA-T code is currently applied to the same level of burnable poison of Gd2O3 as in Topical Report WCAP-15836-P-A, [ ]^{a,c} However, regarding thermal expansion behavior, it was shown in Ref. 1 that the thermal expansion coefficient of the UO2-Gd2O3 solid solution could be regarded as [ ]^{a,c} of pure UO2 in the relatively wide composition range of GD2O3, [ ]^{a,c} see Figure 11-4-1.

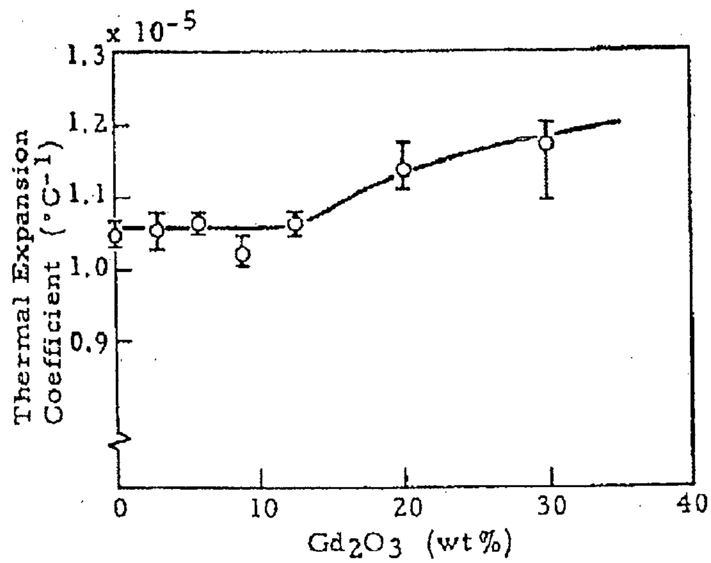


Figure 11-4-1, Gd fuel thermal expansion data up to temperature 1233°C (Ref. 1 below)

Reference:

1) T. Wada, K. Noro, and K. Tsukui, Behavior of UO_2-Gd_2O_3 Fuel Proceedings of the International Conference on Fuel Performance, British Nuclear Energy Society, 15-19 October 1973, London, England

<u>**NRC RAI 11-5(1)**</u>

Section 14.2.4

(1) *Please identify where the degree of pellet cracking is applied in the calculation of fission gas release from the pellet.*

<u>**Westinghouse Response to RAI 11-5(1)**</u>

The effects of pellet cracking on the fission gas release are [ ]^{a,c} Instead the effects of pellet cracking on the [ ]^{a,c} that impacts the fuel temperature and in turn the fission gas release, were taken into account by Eq. (14-24) and (14-26) when the fission gas release formulation Eq. (14-49) was developed based on the calculations from the NRC licensed Westinghouse fuel performance code, (WCAP-15836-P-A).

<u>**NRC RAI 11-5(2)**</u>

(2) *If it is not considered, please justify the reasoning.*

<u>**Westinghouse Response to RAI 11-5(2)**</u>

See the answer to RAI 11-5 part (1).

NRC RAI 11-6(1)

Section 14.3

(1) The material is stated to be zircalloy. Please identify all specific alloys to which POLCA-T will be applied.

Westinghouse Response to RAI 11-6(1)

POLCA-T code models at least one average fuel rod per fuel assembly. Thus any fuel design including any cladding material is modeled explicitly with its properties. Whatever the material is the code has the flexibility to model it as far as appropriate models are available and implemented into the code. [ ]^{a,c} We utilize the fuel behavior models developed for fuel thermal mechanical design. In case that those models are too detailed and could became a CPU burden for transient POLCA-T code [ ]^{a,c}

NRC RAI 11-6(2a)

(2) If Zirlo, Optimized Zirlo, or any alloys other than Zircaloy-2 and Zircaloy-4:
(a) Please explain hydrogen pick-up in cladding as modeled in POLCA-T.

Westinghouse Response to RAI 11-6(2a)

The answer to RAI 11-6 part (1) is also valid here.
(a) At the present we [ ]^{a,c} the hydrogen pick-up in cladding in POLCA-T. If such a model is [ ]^{a,c} from our thermal mechanical design tools and validate it against test data.

NRC RAI 11-6(2b)

(b) Present test data to verify code predictions.

Westinghouse Response to RAI 11-6(2b)

Please see the answer to RAI 11-6 part (2) (a)

NRC RAI 11-6(2c)

(c) Please show test data to explain any hydrogen pick-up data differences between Westinghouse results and similar tests performed at Argonne National Laboratory.

Westinghouse Response to RAI 11-6(2c)

Please see the answer to RAI 11-6 part (2) (a)

NRC RAI 11-6(3)

(3) *Please explain why thermal expansion is anisotropic, while elasticity, plasticity, creep and growth are all isotropic.*

Westinghouse Response to RAI 11-6(3)

LWR Zircaloy cladding, in principle, is anisotropic, however the macro-behavior of thermal expansion data from MATPRO (Ref. 1 below) shows that the texture effects are negligible compared to temperature impact.

Nevertheless, we have decided to eliminate the following sentence, "The material is considered to be isotropic except for the thermal expansion, which is taken to be different in the radial and axial direction." Since isotropic means a micro property here, differential thermal expansion strains in axial and diametric direction are the macro properties. Eliminating the above statement does not affect the rest of the text in WCAP-16747-P.

Reference:

1) D.L. Hagrman and G.A. Reymann, MATPRO-version 11- A handbook of materials properties for use in the analysis of light water reactor fuel behavior , NUREG/CR-0497, 1979.

NRC RAI 11-7(1)

Section 14.3.1

(1) An equation (14.60) is given for the "alpha phase." Please identify if the alpha phase is for zirconium, zircalloy-4 or something else.

Westinghouse Response to RAI 11-7(1)

The Eq. (14.60) is the MATPRO correlation that was developed mainly based on Bunnell et al. data for Zircaloy-4 at alpha phase in which the temperature [ ]^{a,c} It was justified (Ref. 1 below) that it also shows good agreement for [ ]^{a,c}

NRC RAI 11-7(2)

(2) Are there no other phases or metastable phases present in any materials to which POLCA-T will be applied?

Westinghouse Response to RAI 11-7(2)

For temperatures higher than [ ]^{a,c} the cladding is so soft that typical in-reactor stress caused [ ]^{a,c} The thermal expansion involved in the transition phase (1073K-1244K) and the beta phase (>1244 K) is considerably [ ]^{a,c} for cases in which cladding temperature is higher than [ ]^{a,c}

NRC RAI 11-7(3)

(3) If other phases are present, then please explain why this single equation is sufficient to properly calculate thermal expansion.

Westinghouse Response to RAI 11-7(3)

See the answer to RAI 11-7 part (2)

NRC RAI 11-7(4)

(4) Equation 14.60 is stated to be valid from room temperature to 1073K. Please verify that POLCA-T will not be used to predict phenomenon above 1073K. If it is used higher temperatures, please justify its use.

Westinghouse Response to RAI 11-7(4)

See the answer to RAI 11-7 part (2)

Reference:
1) D.L. Hagrman and G.A. Reymann
MATPRO-version 11- A handbook of materials properties for use in the analysis of light water reactor fuel behavior , NUREG/CR-0497, 1979.

NRC RAI 11-8(1)

Section 14.3.2

(1) Please explain the cold work parameter, C_3.

Westinghouse Response to RAI 11-8(1)

C_3 is a constant accounting for the effects of cold work on Young and Shear moduli, which is taken from Eq. (4-74) in MATPRO (Ref.1). LWR cladding elastic moduli are affected primarily by temperature and oxygen content. Cold work effects are much less important. The effects of cold work on Young and Shear moduli are shown to be small in the Table 4-15 –"Young's Modulus measurements by Busby" in MATPRO.

In applications, if the degree of cold work is not available, the use of the default, zero, will not result in an error which is larger than the standard model uncertainty.

NRC RAI 11-8(2)

(2) C_3 appears to be a constant value, not a variable. Please explain if it is constant or variable, and justify its use as such especially in reference to time-temperature annealing of cold work.

Westinghouse Response to RAI 11-8(2)

See the answer to RAI 11-8 part (1).

NRC RAI 11-8(3)

(3) Please state why cold work has a default value of zero.

Westinghouse Response to RAI 11-8(3)

See the answer to RAI 11-8 part (1).

NRC RAI 11-8(4)

(4) After equation (14.68), to what does the term "(3.23)" refer? Please explain.

Westinghouse Response to RAI 11-8(4)

The term "(3.23)" is a typo and should be removed from the text.

NRC RAI 11-8(5)

(5) Again, please explicitly identify "zircaloy" in these equations.

Westinghouse Response to RAI 11-8(5)

The model was developed based on a large variety of Zircaloy data published by Bunnel et al (4.6-1 in Ref.1), Fisher and Renken (4.6-2 in Ref.1 below), Armstrong and Brwn (4.6-3 in Ref.1 below) and Padel and Groff (4.6-4 in Ref.1 below). Data from other sources (4.6-5 to 4.6-11 in Ref.1 below) were used to evaluate the expected standard error of the model. The data used for model development and evaluation includes Zirconium, Zircaloy-2 and Zircaloy-4.

NRC RAI 11-8(6)

(6) Please provide test data to compare with calculations.

Westinghouse Response to RAI 11-8(6)

A part of the datasets used to develop and evaluate the Young's Modulus model are shown in the following Figure:

a,b,c

Reference:

1) D.L. Hagrman and G.A. Reymann
MATPRO-version 11- A handbook of materials properties for use in the analysis of light water reactor fuel behavior , NUREG/CR-0497, 1979.

NRC RAI 11-9(1)

Section 14.3.3: Poisson's ratio for isotropic materials is employed for cladding.

(1) If this equation is employed in the code, demonstrate (provide metallographic and/or directional mechanical properties test data) that POLCA-T modeled claddings are isotropic (i.e. any forming processes such as rolling, extrusion, pilgering, or others do not introduce any anisotropic properties, such as, in particular, texture).

Westinghouse Response to RAI 11-9(1)

Poisson's ratio used in POLCA-T has the same formulation as in the NRC licensed Westinghouse fuel performance code (WCAP-15836-P-A), which was based on the MATPRO model (Ref. 1 below). More specifically, the Poisson's ratio is a function of [ ]^{a,c}

As stated (Ref. 1 below) the cladding elastic moduli are affected primarily by temperature and oxygen content. Other conditions, such as [ ]^{a,c} are not as important as [ ]^{a,c} Therefore, to reduce the complexity of the calculation, the [ ]^{a,c} is applied in both the Westinghouse fuel performance code and in POLCA-T.

NRC RAI 11-9(2)

(2) Please compare code calculations to experimental data..

Westinghouse Response to RAI 11-9(2)

A comparison between the model calculations to experiment data is provided in the answer to RAI 11-8 part (6).

Reference:

1) D.L. Hagrman and G.A. Reymann
MATPRO-version 11- A handbook of materials properties for use in the analysis of light water reactor fuel behavior, NUREG/CR-0497, 1979.

NRC RAI 11-10

Section 14.3.4:

Please justify why equation (14.70), even if previously approved, is valid.

Westinghouse Response to RAI 11-10

Cladding creep is important in modeling the size of the fuel cladding gap, gap heat transfer and initial stored energy at the start of transients. Eq. (14.70) describes the contribution of tangential clad deformation due to creep and elastic strains to gap size change. It is a correlation verified against the Westinghouse fuel performance code results which are validated against the test data (WCAP-15836-P-A).

NRC RAI 11-11(1)

Section 14.3.5:

(1) The subscript, φ, is not clearly defined. Please explain what it represents.

Westinghouse Response to RAI 11-11(1)

The subscript, φ, means tangential direction.

NRC RAI 11-11(2)

(2) Since POLCA-T is a 3-D code, please explain why cladding elastic deformation is modeled in only two dimensions.

Westinghouse Response to RAI 11-11(2)

Within each axial node, the cladding tube is an asymmetric object, thus the model is applied to each node in two dimensions. The axial dimension is covered by the fuel rod axial nodalization, in which the loadings are different between nodes, especially during pellet-clad interaction. Therefore, POLCA-T models cladding thermal mechanical behavior in 3 dimensions.