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Our ref: LTR-NRC-08-59
December 16, 2008

Subject: Further Responses 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 further responses 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."

Also enclosed is:

1. One (1) copy of the Application for Withholding, AW-08-2506 (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-08-2506 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,

J A Gresham

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

Enclosures

cc: A. Mendiola, NRR
G. Bacuta, NRR

T007
NRR

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Our ref: AW-08-2506
December 16, 2008

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: LTR-NRC-08-59 P-Enclosure, "Further Responses 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-08-59, dated December 16, 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-08-2506 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-08-2506 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,

J A Gresham

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

Cc: A. Mendiola, NRR
G. Bacuta, NRR

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared J. A. Gresham, 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:

J A Gresham

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

Sworn to and subscribed
before me this 16th day
of December, 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 Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, 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-08-59 P-Enclosure, " Further Responses 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), for submittal to the Commission, being transmitted by Westinghouse letter (LTR-NRC-08-59) and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by Westinghouse Electric Company is that responses to RAIs.

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.

Further the deponent sayeth not.

## PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.390(b)(1).

## COPYRIGHT NOTICE

# Further Responses 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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## RAI 2-13

The staff is aware that CENPD-300-P-A is to be updated. Please describe how the POLCA-T licensing topical report (LTR) Appendices are integrated into the mixed core Reload licensing framework.

## Westinghouse Response to NRC RAI 2-13

The POLCA-T LTR and its appendices will be added as references to the revised CENPD-300-P-A topical report as an optional method for performing mixed core reload licensing. The exact application will however depend on the US NRC safety evaluation (SE) of the POLCA-T topical reports.

The core stability analysis methodology in CENPD-295-P-A is general and is also valid for POLCA-T. For a more general description of how the stability analysis methodology with POLCA-T is planned to be implemented for different approved long term stability options, see the response to RAI 6-25.

**RAI 4-8 Supplement**

In the response to RAI 4-8, WEC has provided general information regarding the time step control algorithm in POLCA-T. However, the staff requires information regarding the controls that will be in place for POLCA-T stability calculations.

**Westinghouse Response to NRC RAI 4-8 Supplement**

The WEC methodology for stability analysis with POLCA-T [

]$^{a,c}$.

RAI 6-33

Provide a stability phenomena identification and ranking table.

Westinghouse Response to NRC RAI 6-33

The Westinghouse PIRT for the stability analysis of a BWR is summarized below. Table 1 presents the ranking of the phenomena including the rationale of the ranking. Table 2 provides the definitions for the included phenomena.

Considered specific phenomena were limited to instability scenarios of interest in BWR plant stability analysis, i.e. the global, regional and channel stability modes. Dominant phenomena for individual stability modes are identified and ranked according to their relative influence on the calculated stability parameters, core power oscillation amplitude, decay ratio and frequency.

The PIRT is not developed for any specific BWR plant type in mind, but within the variation of different plant features, it is expected that most phenomena and their influence would be similar for other BWRs.

The PIRT was divided into five subcategories: [

]$^{a,c}$. Each phenomenon was assigned an importance grade with respect to their influence on the stability parameters. Importance was given according on a three-level scale: High/Medium/Low. High (H) implies a dominant impact, medium (M) implies a moderate impact and low (L) implies a minimal or zero impact on the stability parameters.

The question asked to determine the importance was:

[

]$^{a,c}$

Table 1 Westinghouse PIRT for Stability Analyses

a,c

a,c

Table 2 Definitions of Phenomenon for Stability Analyses

a,c

a,c

a,c

## RAI 7-2

Describe the xenon condition at the start of the CRDA transient analysis. Is the assumed xenon condition conservative?

## Westinghouse Response to NRC RAI 7-2

The Westinghouse approved methodology for CRDA analysis assumes [ ]$^{a,c}$. This assumption maximizes the positive reactivity inserted by the dropping control rod. As it is specified in the Westinghouse approved methodology, CENPD-284-P-A, Section 4, the impact of the dropped rod on the peak fuel enthalpy is strongly dependent on the total reactivity worth of the dropping control rod. Since the control rod worth is highest at [ ]$^{a,c}$, the maximum reactivity insertion in the core will be at these conditions. Therefore, [ ]$^{a,c}$ during the CRDA is conservative.

**RAI 7-9 Supplement 1 (followed by initial RAI 7-9)**

The staff finds that the results of the sensitivity analysis are expected. This is due to the fact that the time step size is controlled by the algorithm for every case except for the minimum time step case (DTMAX=0.001 sec). For all other cases the power pulse is tracked with the same time resolution due to the time step algorithm and therefore, these are expected to indicate very close agreement.

For the DTMAX=0.001 sec, the case indicates a subtle change in the peak power and the time of the peak power relative to the other cases. While this is a subtle shift, the staff is concerned that the sensitivity studies used to establish the appropriate time step may not yield meaningful results if the time step control algorithm is not tested by reducing the time step to a lower value to ensure convergence. This concern arises due to what appears to be a change in the physical behavior attributed to increased time step resolution.

Please demonstrate that the transient power is converged by providing additional sensitivity analyses at smaller time steps.

**Westinghouse Response to NRC RAI 7-9 Supplement**

Three additional runs to determine POLCA-T CRDA sensitivity to time step size have been performed as required with [ ]$^{a,c}$. The selected time step upper limits were [ ]$^{a,c}$. The summary of the obtained results is presented in Table 1a.

a,c

[ ]

As show in Table 1a the variation of the time step upper limit between [ ]$^{a,c}$ only slightly affects the timing of [ ]$^{a,c}$. Their variation is limited to [ ]$^{a,c}$. While the peak power value is affected by roughly [ ]$^{a,c}$ the value of the maximum variation in fuel enthalpy is limited to [ ]$^{a,c}$.

The deviations in peak power, maximum fuel enthalpy, maximum hot rod node average and centerline fuel temperatures from those observed in the reference case with a constant time step of [ ]$^{a,c}$ are provided in Table 2a. It is observed that while the predicted [ ]$^{a,c}$ is affected by the time step variation, the [ ]$^{a,c}$ show insignificant variations.

[ ]a,c

Figures 2a through 4a show POLCA-T predicted fission power, hot rod peak fuel enthalpy and maximum hot rod fuel centerline temperature time histories at different time step upper limits. [

]a,c.

a,c

Figure 2a. POLCA-T predicted Fission Power Time Histories at different time step upper limits

a,c

Figure 3a. POLCA-T predicted Peak Fuel Enthalpy Time Histories at different time step upper limits

[ ]$^{a,c}$

Figure 4a. POLCA-T predicted Maximum Hot Fuel Rod Centerline Temperature Time Histories at different time step upper limits

Figure 5a illustrates the actual time step produced by POLCA-T time step algorithm at different time step upper limits. [ ]$^{a,c}$.

As it was mentioned in the answer to RAI 4-9 the POLCA-T CRDA methodology states that the code user should specify the time step upper limit that leads to an almost [ ]$^{a,c}$ to make it sure that the neutron kinetics converge. Due to the very high neutron flux changes that take place in the RIA the upper limit of the time step is normally set to [ ]$^{a,c}$. For a given set of analysis the user is also required to investigate the time step effect on the peak power value, [ ]$^{a,c}$. However, as can be seen in Figure 6.a, the peak power vs. time step converge first when the time step decreases from 0.05 to 0.002 s. The second convergence occurs when the time step goes from 0.001 to 0.0001 s. The change of time step in the given time intervals affects the enthalpy and the pellet centerline temperature in a minor way. Therefore, the time step should be reduced until the first convergence of the power peak occurs. A requirement is, however, that the enthalpy and the centerline pellet temperature will show stable values. The time step limit obtained in such a sensitivity study is then used in the later analyses.

a,c

Figure 5a. POLCA-T actual time step produced at differing time step upper limits

Figure 6a presents POLCA-T predicted peak power and fuel enthalpy values versus the time step upper limit. The peak power changes significantly only in the time step upper limit interval between 1 and 2 milliseconds (log(DTMAX) = -3 and -2,7), while in the intervals below 1 and higher than 2 milliseconds it reaches saturation.

a,c

Figure 6a. POLCA-T predicted maximum power and fuel enthalpy versus time step upper limit.

## RAI 7-9

Describe any controls on the time step or other controls in the iterative solution technique that ensure sufficient nuclear power distribution iterations between thermal hydraulic iterations to ensure that the transient pin power distribution is adequately characterized to determine the integrated hot pin energy deposition during CRDAs.

## Westinghouse Response to NRC RAI 7-9:

Details about POLCA-T time size control algorithm are provided in the answer to RAI 4-8. The time step size control approach that is specific for reactivity transients is discussed in the answer to RAI 4-9. It was mentioned that a sensitivity study is performed in order to determine the suitable upper limitation of the time step which is normally set to a few milliseconds. Example analyses indicating that the time step control does not adversely impact the numerical results of the transient reactor behavior predicted by POLCA-T were provided in the answer to RAI 6-3 (see also Reference 2).

The above mentioned information provides a background to the RAI response provided hereafter.

- Kinetics - thermal-hydraulics iteration scheme

The 3-D-kinetics model is solved using an [ ]$^{a,c}$. If the solution does not converge, [ ]$^{a,c}$ is made until convergence is reached. If no convergence is achieved and [ ]$^{a,c}$ is at its lowest allowed size the code stops, with an alarm message. This procedure leads to a consistent solution of power generation and thermal-hydraulics, i.e. consistent solution between power and reactivity feedback. Thereafter the enthalpy can be evaluated by [ ]$^{a,c}$ for each fuel rod at different axial elevations. Figure 1 shows the outline of the computational procedure in POLCA-T.

- POLCA-T CRDA sensitivity to time step size

In order to investigate the sensitivity to time step size of POLCA-T results on nodal and pin level during CRDA simulation a set of calculations had been performed with increasing time step upper limit. The simulation with [ ]$^{a,c}$ provides a reference case with constant time step, i.e. no effect of the time step size algorithm on the results is assumed in this case. The other time step upper limits selected were [ ]$^{a,c}$. The summary of the obtained results is presented in Table 1.

a,c

[ ]

**Figure 1. Time integration of the power - thermal hydraulic interaction**

a,c

[ ]

As shown in Table 1, the variation of the time step upper limit between [ ]$^{a,c}$ only slightly affects the timing of [ ]$^{a,c}$. Their variation is limited to [ ]$^{a,c}$. While the peak power value is affected by roughly [ ]$^{a,c}$ the value of the maximum fuel enthalpy variation is limited to [ ]$^{a,c}$.

The deviation in the values of peak power, maximum fuel enthalpy, maximum hot rod node average and centerline fuel temperature from those observed in the reference case with a constant time step of [ ]$^{a,c}$ are provided in Table 2. It is observed that while the predicted [ ]$^{a,c}$ is affected by the time step variation, the [ ]$^{a,c}$ only show insignificant variations.

a,c

Figures 2 through 4, show POLCA-T predicted fission power, hot rod peak fuel enthalpy and maximum hot rod fuel centerline temperature time histories at different time step upper limits. [

]$^{a,c}$.

a,c

Figure 2. POLCA-T predicted Fission Power Time Histories at different time step upper limits

a,c

Figure 3. POLCA-T predicted Peak Fuel Enthalpy Time Histories at different time step upper limits

a,c

Figure 4. POLCA-T predicted Maximum Hot Fuel Rod Centerline Temperature Time Histories at different time step upper limits

Figure 5 illustrates the actual time step produced by the POLCA-T time step algorithm at different time step upper limits. [

]$^{a,c}$.

As it was mentioned in the answer to RAI 4-9 the POLCA-T CRDA methodology states that the code user should specify the time step upper limit that leads to an almost [ ]$^{a,c}$ to make it sure that the neutron kinetics converge. Due to the very high neutron flux changes that take place in the RIA, the upper limitation of the time step is normally set to [ ]$^{a,c}$. For a given set of analysis the user is also required to investigate the time step effect on the peak power value, [ ]$^{a,c}$. The time step limit obtained in such a sensitivity study is used in further analyses. Thus, it is assured that the transient pin power distribution is adequately characterized to determine the integrated hot pin energy deposition during CRDA.

a,c

Figure 5. POLCA-T actual time step produced at different time step upper limits

**References:**

[1] Ulf Bredolt, "On the Time Integration Method and its Impact on Prediction of Hydraulic Stability by the POLCA-T Code" 15th International Conference on Nuclear Engineering ICONE15, Nagoya, Japan, April 22-26, 2007, paper CONE15-10033.

RAI 7-10

Provide descriptive details of the qualification of the POLCA-T pin power reconstruction model. For CRDA high radial peaking across a bundle is expected given the strong local reactivity perturbation as a result of the dropped rod and the highly decoupled nature of the reactor. Provide a confirmatory calculation using predicted CRDA transient results for the peak pin power and compare to the equivalent power predicted by PHOENIX4 using local nodal thermal hydraulic and control conditions.

Westinghouse Response to NRC RAI 7-10

POLCA-T shares [ ]$^{a,c}$ concerning both the equations and the numerical implementation. Consequently, the conditions for qualification of POLCA7 are, in this regard, equally applicable to POLCA-T. The essentials of the qualification analysis for POLCA7 (that is based on the results of the gamma scanning measurements) are given in Reference 1.

For POLCA-T, the qualification is additionally enhanced by the 2-dimensional benchmark calculations and the comparison of the pin power distributions with reference results from the neutron transport code PHOENIX4. To simplify the procedures, POLCA7 was used in the benchmark, but the considered core configurations were selected [ ]$^{a,c}$.

Six core configurations were analyzed with a varying number of control rods inserted and different layouts of bundle exposure. The examined configurations are variants of [ ]$^{a,c}$. Reflective boundary conditions are applied on the core sides, turning the system infinite. [ ]$^{a,c}$ and have identical nuclear designs. To further stress the benchmark conditions, the chosen nuclear design is characterized by a relatively high average U-235 enrichment and high gadolinium content that is typical for long reactor cycles [ ]$^{a,c}$.

Since POLCA7 does not allow positioning of control rods at the external corners of the core, the equivalent POLCA7 core configuration consists of [ ]$^{a,c}$. For this configuration, periodic boundary conditions are used to simulate the [ ]$^{a,c}$ with reflective boundary conditions modeled in the PHOENIX4 calculations. The figure below shows the basic configuration as used in PHOENIX4 and the fully equivalent POLCA7 core.

[ ]a,c

The most serious consequences in terms of a local enthalpy increase during a CRDA transient are expected to occur under cold conditions. Therefore, all examined core configurations have a [

]a,c.

In the evaluation of the benchmark results, the assembly pin power distributions obtained from both codes were normalized to the same power level before comparing. To comply with the analysis of the gamma scanning results used in the qualification of POLCA7 (see Reference 1) the normalization was performed individually for each assembly in order to give the average pin power of an assembly equal to 1:

$$\frac{1}{N}\sum_{i=1}^{N} p_i = 1$$

with $N$ being the number of fuel pins in an assembly.

This type of normalization eliminates possible errors in the total assembly power (nodal power in 3-D calculations) that is treated separately in the POLCA7/POLCA-T uncertainty analysis and is less relevant in the intra-nodal reconstruction of pin power distribution.

Based on this normalization, the difference $\varepsilon_i$ in pin power between the two codes is calculated for each pin as:

$$\varepsilon_i = p_i^{P7} - p_i^{PHX}$$

where $p_i^{P7}$ and $p_i^{PHX}$ are normalized powers of pin $i$ computed respectively by POLCA7 and PHOENIX4.

From the $\varepsilon_i$ differences, statistical parameters are derived that characterize uncertainties of POLCA7 pin power calculations as compared to the reference results from PHOENIX4. These are: the maximum and minimum (i.e. most negative) pin power difference for each assembly in the considered core configuration, standard deviations per assembly and the global standard deviation for the whole system. The applied formula for the standard deviation is given by:

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\varepsilon_i^2}$$

where $N$ is the number of fuel pins either in an assembly or in the whole core.

In the following summary of the benchmark results, each considered core configuration is schematically presented showing assembly exposures and the positions of inserted control rods.

Core configuration 1

[ ]a,c

Core configuration 2

a,c

Core configuration 3

a,c

Core configuration 4

[ ]a,c

Core configuration 5

[ ]a,c

Core configuration 6

[ ]$^{a,c}$

The results of the analysis demonstrate [ ]$^{a,c}$. Among the investigated core configurations, the highest assembly standard deviation is [ ]$^{a,c}$. It corresponds to Core Configuration 4, which has [ ]$^{a,c}$. The results obtained are entirely in parity with [ ]$^{a,c}$.

The largest observed pin power difference of [ ]$^{a,c}$ is also found in the configuration with [ ]$^{a,c}$. A similar difference although negative in value, [ ]$^{a,c}$ can be seen in Core Configuration 3 where [ ]$^{a,c}$. However, the averaged error distribution in the [ ]$^{a,c}$ of this configuration is lower than that of configuration 4 and the resulting standard deviation is [ ]$^{a,c}$.

[ ]$^{a,c}$ as in configurations 5 and 6 does not seem to contribute in any remarkable way to the magnitude of observed errors or to the standard deviation. They are both at the similar level as the values of the corresponding configuration 3 with [ ]$^{a,c}$. What can be noticed is a change in the assembly location where the maximum error occurs.

For the configuration [ ]$^{a,c}$, the consistency of pin power distributions between the two codes [ ]$^{a,c}$.

In conclusion, the benchmark results show generally [ ]$^{a,c}$.

## References

1. W. R. Harris, E. Fuentes, The Advanced PHOENIX and POLCA Codes for Nuclear Design of Boiling Water Reactors, CENPD-390-P-A Rev 00

## RAI 7-12

Recognizing that a larger transient increase in fuel temperature results in an increased Doppler feedback, how is a conservative gap conductance determined for the CRDA? Are the hot and average fuel pins in any particular node modeled using separate STAV calculations? Specifically, does POLCA-T track the fuel burnup dependent gap closure and fission gas release for each pin within a node separately? Comment on the conservatism of the gas gap conductance based on the modeling of the hot pin and the expected trends in Doppler feedback and heat transfer characteristics.

## Westinghouse Response to NRC RAI 7-12

The modeling of fuel rod gas gap in POLCA-T is described in Section 14.1 of WCAP-16747-P. When utilizing the models of the Westinghouse licensed fuel performance code, POLCA-T, transient simulations do not require the results of any separate STAV calculations. STAV models are incorporated into POLCA-T and the values of required parameters are calculated during the transient simulation. The gas gap heat conductance model considers the heat transfer due to three contributors: thermal radiation, gas thermal conductance and fuel cladding surface contact.

POLCA-T code as a minimum models [ two fuel rods ][a,c] for each fuel assembly – [ ][a,c]. This allows the user to specify, if required by the application options, different models and/or data to be used [ ][a,c]. Normally the [ ][a,c] uses options, models and/or data that are considered to be [ ][a,c] while [ ][a,c] can utilize more [ ][a,c] For example, this can include the gas gap heat conductance. [ ][a,c] are axially nodalized in a way similar to coolant channel nodalization. The steady state and transient heat conduction equation is solved the same in [ ][a,c] determining the radial temperature distribution for each axial location. Thus for [ ][a,c] the properties and parameters are calculated separately using the same licensed fuel performance code models. In this way, the actual parameters accounted for in the fuel rod modeling include the fuel rod design, burnup, gas gap closure/size, fission gas release, fuel, cladding and the actual gap gases properties at actual temperature and/or pressure. The solution for [ ][a,c] is used as [ ][a,c] in the coupled neutronics–thermal-hydraulics, while the [ ][a,c] is only used to [ ][a,c].

It is true that the gas gap heat transfer model plays a contradictory role (e.g., for maximum fuel and maximum cladding temperature). There are other contradiction/ compensation effects such as the higher gas gap heat transfer leading to a lower fuel temperature, and Doppler feedback that in turn results in higher power release increasing the Doppler feedback. Assuming lower gas gap heat transfer leads to higher fuel temperature and Doppler feedback, in turn resulting in lower power release and decreased Doppler feedback. Our sensitivity studies performed earlier indicate that, in practice, [ ][a,c] tend to increase the severity of the [ ][a,c] shown to be limiting in the Section A.4.4 of WCAP-16747-P.

As stated on page A-76 of WCAP-16747-P, "[ ][a,c]" Thus POLCA-T utilizes the conservatism built into the Westinghouse licensed fuel performance code and used in the fuel rod design. Moreover, additional conservatism in the modeling of gas gap heat conductance is introduced by the maximum fuel enthalpy evaluation being based on the [ ][a,c].

## RAI 7-13

Since the Doppler reactivity feedback coefficient decreases in magnitude with increasing fuel temperature, are there potential conditions of operation where a nominal power level above cold zero power may potentially result in larger fuel enthalpies assuming a maximum inlet subcooling. If so, how are these more limiting power levels or conditions established in determining the limiting CRDA scenario?

## Westinghouse Response to NRC RAI 7-13

As it is specified in the Westinghouse-approved methodology, CENPD-284-P-A, Section 4, the control rod drop accident (CRDA) event is analyzed at cold clean conditions. The initial conditions sensitivity study documented in CENPD-284-P-A, Figure 4.5.14 shows the highest peak fuel enthalpy occurs when the CRDA is initiated from cold conditions.

The CRDA analysis is performed for cold conditions to allow an unambiguous determination of the most limiting control rod configuration. This approach also anticipates the conclusion that the CRDA is most limiting when initiated from a sufficient subcooled condition to avoid coolant saturation during the transient. While it is true the Doppler reactivity feedback coefficient decreases in magnitude with increasing fuel temperature, the Doppler reactivity feedback has lower impact on the fuel peak enthalpy than the total reactivity worth of the dropped control rod and reactivity feedback from voiding. Therefore cold conditions, when the control rod drop inserts maximum reactivity in the core, are a conservative assumption.

RAI 7-18

The staff requires some more details regarding the POLCA-T qualification against SPERT III E experiments.

Section A.3.2.2 states that the POLCA-T predicted power shapes agree with the SPERT III E measured power shapes. Please provide the results of the comparison performed as part of this qualification in regards to the comparison of SPERT III E power shapes.

Additionally, provide a figure that is substantially similar to the graphs in Figure A.3-10 that show the transient results for the case 18 test.

Provide a figure similar to Figure 5.3.16 of CENPD-284-P-A with data points predicted using POLCA-T.

Westinghouse Response to NRC RAI 7-18

The statement in Section A.3.2.2 that POLCA-T predicted power shapes agree with SPERT III E measured power shapes is addressing the comparison with power time shapes, (i.e. power time histories). No measured data concerning any other power shapes, axial or radial, are provided in the SPERT report (see Reference 1 below equal to Appendix A Reference 9). The power time histories for SPERT cases 43 and 49 are provided on Appendix A Figure A.3-10. Figure A.3-10a below presents the power time history: the transient results for the SPERT case 18 test.

a,c

**Figure A.3-10a. Comparison of POLCA-T Predicted and Measured Fission Power for Cold Case 18.**

Figure A.3-10b below is similar to Figures 5.3.16 and 5.3.17 of CENPD-284-P-A except for the fact that the data points are predicted using POLCA-T. Two performed POLCA-T calculations are presented in the figure – [ ][a,c]. The Doppler coefficient increase [ ][a,c] reduces the peak power by [ ][a,c].

[a,c]

**Figure A.3-10b. Comparison of POLCA-T Predicted and Measured Fission Power for Cold Case 43 including predictions with [ ][a,c] of the Doppler coefficient.**

## References

1. R. K. McCardell, D. Herborn and J. E. Houghtaling, "Reactivity Accident Test Results and Analyses for the SPERT-III E-Core – A Small, Oxide-Fueled, Pressurized-Water Reactor," IDO-17281, U.S. Atomic Energy Commission, March 1969.

RAI 7-19

The staff requires additional clarification in regards to the sensitivity analysis performed on the core mass flow rate. Specifically, is the base case evaluated for a critical control rod pattern? If so, is the control rod pattern adjusted to accommodate criticality at the same power level for the increased mass flow rate? The peak fuel enthalpy is sensitive to the initial power. Provide a sensitivity analysis to mass flow rate that considers a base case critical rod pattern and nominal flow rate. Without adjusting the rod pattern determine the sensitivity of the peak fuel enthalpy to a small increase in the core mass flow rate.

Westinghouse Response to NRC RAI 7-19

The base case for the sensitivity analysis performed on the core mass flow rate in WCAP-16747-P was not evaluated for a critical control rod pattern. This was considered to be unnecessary as the steady-state core multiplication factor and power at CZP were unaffected by changes in the flow. Thus, the very same reactivity was inserted in both provided cases, i.e., base case at 3112 kg/sec and flow variation at 8900 kg/sec.

In the following table, the results of a sensitivity study to mass flow rate are given, considering a base case critical rod pattern and nominal flow rate of [ ]$^{a,c}$. The study was performed at the same initial conditions reported in WCAP-16747-P of [ ]$^{a,c}$ bar reactor pressure and [ ]$^{a,c}$ core inlet temperature. All the cases provided below have been run at the critical rod pattern and the same static CR worth of [ ]$^{a,c}$. Table A.5-8a presents the main results for the peak values of power and the time of that peak, the fuel enthalpy and the temperature observed in the analyses. The reference case has been run at a core mass flow of [ ]$^{a,c}$ kg/sec. Without adjusting the rod pattern, the sensitivity of the peak fuel enthalpy to mass flow has been investigated by different perturbations in the flow of [ ]$^{a,c}$ kg/sec.

a,b,c

[ ]

The results demonstrate that [ ]$^{a,c}$ is sensitive to core flow at CZP. This also confirms the observations made from sensitivity studies reported earlier in WCAP-16747-P for GE reactors and of the sensitivities performed with POLCA-T for a Westinghouse (ASEA Atom) BWR reactor.

RAI 7-21

The staff requires clarification of the PB2 EOC2 TT test qualification analysis.

(1) How were the axial power profiles in Figures A.3-4 and A.3-5 generated? Is the P1 edit the adapted core power shape as determined by the core monitor? Is the PHOENIX XS plot based on a purely predictive cycle follow calculation using POLCA7?
(2) What is meant by APRM Probes 1 and 2? Does this refer to particular APRM channels?
(3) The staff does not understand table A.3-5 based on the units for each value. Does "m/sec" mean milliseconds?
(4) What is meant by "measured" in Figure A.3-6?

Westinghouse Response to NRC RAI 7-21

*(1) How were the axial power profiles in Figures A.3-4 and A.3-5 generated?*

The axial power profile using "PSU XS data" in Figure A.3-4 was generated by a simple POLCA-T run as the exposure was embedded in the XS data and core nodalization provided by the benchmark team (see Reference 1). Axial power profiles using "PHOENIX4 XS data" in Figures A.3-4 and A.3-5 are generated after depleting the core through Cycles 1 and 2 by running POLCA7 and then performing POLCA7 and POLCA-T steady-state simulations for each corresponding state prior to the turbine trip tests TT1, TT2 and TT3. Thus the comparison provided in Figure A.3-4 is of results obtained by using the same code with different XS data sets. This highlighted the importance of properly accounting for historical effects and the detailed nodalization of the core. The results obtained by PSU XS data are [

]$^{a,c}$. More details about the Westinghouse core power distribution results obtained by POLCA7 and POLCA-T and their comparison with both "P1 edit" and TIP measurements have been reported in References 2 and 3. Some results and discussion are also provided in the answer to RAI 7-24.

*Is the P1 edit the adapted core power shape as determined by the core monitor?*

As explained during the NRC audit in March 2008, the P1 edit is not a measurement (not a TIP trace). It is the adapted core power shape as determined by the core monitoring system. Thus, the answer to this question is yes.

*Is the PHOENIX XS plot based on a purely predictive cycle follow calculation using POLCA7?*

As stated during the audit and recorded in the Audit summary report, the [

]$^{a,c}$. Thus the answer to this question is also yes.

*(2) What is meant by APRM Probes 1 and 2? Does this refer to particular APRM channels?*

APRM Probes 1 and 2 refer to traversing in-core probes 1 and 2 which were available during the turbine trip tests TT1, TT2 and TT3. Thus, two separate APRM channels were available as described in the Reference 4.

*(3) The staff does not understand table A.3-5 based on the units for each value. Does "m/sec" mean milliseconds?*

Yes, originally the shorter term "msec" has been used. Please find the correct table below.

a,b,c

*(4) What is meant by "measured" in Figure A.3-6?*

"Measured" in Figure A.3-6 means the average of the fission power signals from all 80 LPRM. The explanation has been provided in Note 4 to Table A.3-5, but missed in the footnotes to the mentioned figure.

## References


1. J. Solis, et al., "Boiling Water Reactor Turbine Trip (TT) Benchmark Volume I: Final Specifications". NEA/NSC/DOC(2001) 1, June (2001).

2. Panayotov, D., 2004. OECD/NRC BWR Turbine Trip Benchmark: Simulation by POLCA-T Code. *Nuclear Science and Engineering, 148, 247-255*

3. D. Panayotov, U. Bredolt, H. Lindgren, "POLCA-T – A Coupled Multi-Physics Tool for Design and Safety Analyses", *Invited paper Mathematics and Computation (M&C 2005) Topical Meeting: Supercomputing, Reactor Physics and Nuclear and Biological Applications,* Technical Session: "Multi-physics coupled code systems for nuclear reactor design and safety", Avignon, France, September 12-15, 2005.

4. L. A. Carmichael and R. O. Niemi, "Transient and Stability Tests at Peach Bottom Atomic Power Station Unit 2 at End of Cycle 2", EPRI NP-564, Project 1020-1, Topical Report, June (1978).

RAI 7-22

In order to assist the staff in understanding the dynamic reactivity feedback modeling, please provide figures that are substantially similar to Figures A.3-6 through A.3-9 except please shift the curves so that each transient response is plotted according to a time "zero" that is defined as the time of the initial core exit pressure response.

Westinghouse Response to NRC RAI 7-22

Figures A.3-6a through A.3-9a below are substantially similar to Figures A.3-6 through A.3-9 except that the curves are shifted so that each transient response is plotted according to a time "zero" (defined as the time of the initial core exit pressure response). Values used to shift the time coordinate are provided in Table A.3-5a below and taken from the answer to RAI 7-21 Table A.3-5. The curve of POLCA-T results obtained with PSU XS provided in Figure A.3-6a, for information only, is shifted by 438 milliseconds. Note that this value is not available from Tables A.3-5 and A.3-5a.

a,b,c

Note also that the time of the initial core exit pressure response differs for measurements and for each set of simulations. The corresponding time of the initial core exit pressure response has been used to obtain the "shifted" curves in the figures.

It is observed that in both the TT2 (see Figure A.3-6a) and the TT1 (see Figure A.3-7a) tests the differences between the predicted and calculated time of peak fission power is about [ ]a,c. It has to be noted that while the change of time coordinate for the TT2 test resulted in [ ]a,c in Figure A.3-6a when compared to Figure A.3-6, for the TT1 test the curve [ ]a,c. This can be explained by noting that the differences in predicted to measured time of core exit pressure initial responses are [ ]a,c in the TT2 test and [ ]a,c in the TT1 test (see Table A.3-5a above).

a,b,c

[ ]

**Figure A.3-6a.** [

]a,c

a,b,c

**Figure A.3-7a.** [ ]a,c

a,b,c

**Figure A.3-8a.** [ ]a,c

a,b,c

**Figure A.3-9a.** [ ][a,c]

RAI 7-24

Compute the nodal RMS difference in core power between the POLCA-T generated axial power shape using PHOENX4 cross section with spectral interaction to the P1 edit. Compare this RMS difference to previously established values for nodal power differences quoted in CENPD-390-P-A.

Westinghouse Response to NRC RAI 7-24

The computed nodal RMS differences in core power, observed between the POLCA-T generated axial power shape using PHOENX4 cross sections with spectral interaction and the P1 edit, for the state prior to the transient of Peach Bottom 2 turbine trip test TT2 are provided in Table A.3-3a below. The nodal RMS differences are calculated for POLCA-T obtained core average axial power profiles provided in Figure A.3-4 of Appendix A of WCAP-16747-P and published in Reference 1.

a,c

[ ]

For comparison, the previously established RMS difference value for relative axial power is [ ]$^{a,c}$ as quoted in CENPD-390-P-A Section 6.2.2.2.

The difference between the POLCA-T demonstrated RMS error for Peach Bottom Unit 2 turbine trip test TT2 simulation and the error quoted in CENPD-390-P-A is [ ]$^{a,c}$. The [ ]$^{a,c}$ could be explained by the fact that while comparisons provided in CENPD-390-P-A were performed [ ]$^{a,c}$ in this case POLCA-T results are compared with [ a ]$^{a,c}$ axial power shape -- [ ]$^{a,c}$ also contributed to the observed [ ]$^{a,c}$ in the POLCA-T predicted axial power shape.

A direct comparison of the POLCA7 predicted axial power shape, using a spectral index correction option, against 43 TIP string measurements collected at Peach Bottom 2 EOC 2 has also been performed and reported in Reference 1. Figure A.3-4a and Table A.3-3b below present the comparison of POLCA7 calculated versus measured TIP core relative responses and the core average deviation and RMS of TIP comparison respectively. The comparison is performed for Data set 37 (see Reference 2). Observed RMS differences for both [ ]$^{a,c}$ are [ ]$^{a,c}$ the respective values of [ ]$^{a,c}$ quoted in CENPD-390-P-A section 6.2.2.2 (Reference 3).

Therefore it can be concluded that [ ]$^{a,c}$.

a,c

**Figure A.3-4a.** [ ][a,c]

a,c

It should be noted in connection to the audit discussion that the significant improvement seen in [ ][a,c] is due to the better representation of the [ ][a,c] and more accurate [ ][a,c] utilized in our simulation as compared to the [ ][a,c]. The use of [ ][a,c] has a smaller contribution to the [ ][a,c] as it is seen on Figure A.3-6. The use of different [ ][a,c] has at least twice the effect on the [ ][a,c] value as the utilization of the [ ][a,c] model. This conclusion is also supported by the results of a similar study using CASMO prepared multi-table XS in a TRAC/BF1-ENTRÉE-NASCA (see Reference 4) coupled code that also pointed out the importance of proper accounting for historical effects in BWR modeling.

**References**

1. D. Panayotov, U. Bredolt, H. Lindgren, "POLCA-T – A Coupled Multi-Physics Tool for Design and Safety Analyses", Invited paper Log #212 Mathematics and Computation (M&C 2005) Topical Meeting: Supercomputing, Reactor Physics and Nuclear and Biological Applications, Technical Session: "Multi-physics coupled code systems for nuclear reactor design and safety", Avignon, France, September 12-15, 2005.

2. N. H. Larsen, "Core Design and Operating Data for Cycles 1 and 2 of Peach Bottom 2", EPRI NP-563, Project 1020-1, Topical Report, June 1976.

3. The Advanced PHOENIX and POLCA Codes for Nuclear Design of for Boiling Water Reactors, ABB CENPD-390-P-A (Proprietary), April 1999.

4. A. Hotta, M. Zhang, H. Shirai, "Application of TRAC/BF1-ENTRÉE-NASCA to OECD NEA/NSC BWR Turbine Trip Benchmark", *Nuclear Science and Engineering*, **Vol. 148**, pp. 208-225, October (2004).

RAI 8-5 S1

The pressure units listed in Table 3 are in error. The units are $10^5$ Pa (or bars). Please correct this typographical error in the RAI response to be included in the final LTR revision with the staff's safety evaluation attached.

Westinghouse Response to NRC RAI 8-5 S1

A decimal point in the column for the pressure in table 3 is missing. An update will be included in the approved version of the topical report.

## RAI 8-7 Supplement

The response to RAI 8-7 in the letter to the NRC dated June 25, 2008, is insufficient for the staff to complete its review. The original response requested an analysis using a complex model with features common in reactor modeling. It is acceptable to provide an analysis with a simple model so long as it includes the features the staff has previously requested additional information regarding in RAI 8-6. The staff notes that the current model includes elbows, but lacks other features.

It is acceptable to provide an analysis that is similar to the analysis performed and documented in the response with the following features: (1) please include a tee junction, this tee junction should not be at a right angle with the main fluid path and should reconnect to the closed loop, (2) please include plena for parallel flow paths, (3) please include at least two parallel flow paths in the model with different pressure drop characteristics, and (4) please include a flow path that is axially slanted.

This revised model should address questions that staff has regarding several features of the momentum equation described in RAI 8-6, including: flow splitting at tee junctions, flow distribution for parallel flow paths, and the gravitational term. To assist the staff in understanding the results please provide a nodalization diagram and provide plots of the flow rate coast down for several nodes in the loop, particularly near fluid cell junctions for the features described in aforementioned items (1) through (4).

## Westinghouse Response to NRC RAI 8-7 Supplement

As a complement to the previous test case, a new test case was set up. The test case consists of lower and upper plenum, three parallel channels, a main channel connected as T-junction, a bypass channel connected at the end of the plena and a slanted channel whose size is equal to the main channel connecting the plena. The pressure drop characteristic differs by about a factor of sixteen between the main and the bypass channels for the quantity

$$\sum \frac{\varsigma}{A^2},$$

where $\varsigma$ is equal to the equivalent loss coefficients and A is the area.

Figure 1 below shows an outline of the model with its main blocks. Each block contains a different number of volume cells. The channels are divided into 25 axial volume cells as is normally done when modeling BWR reactors. The sub-cooling is about 180°C, the pressure is 25 bar and the liquid phase temperature was set to 40°C.

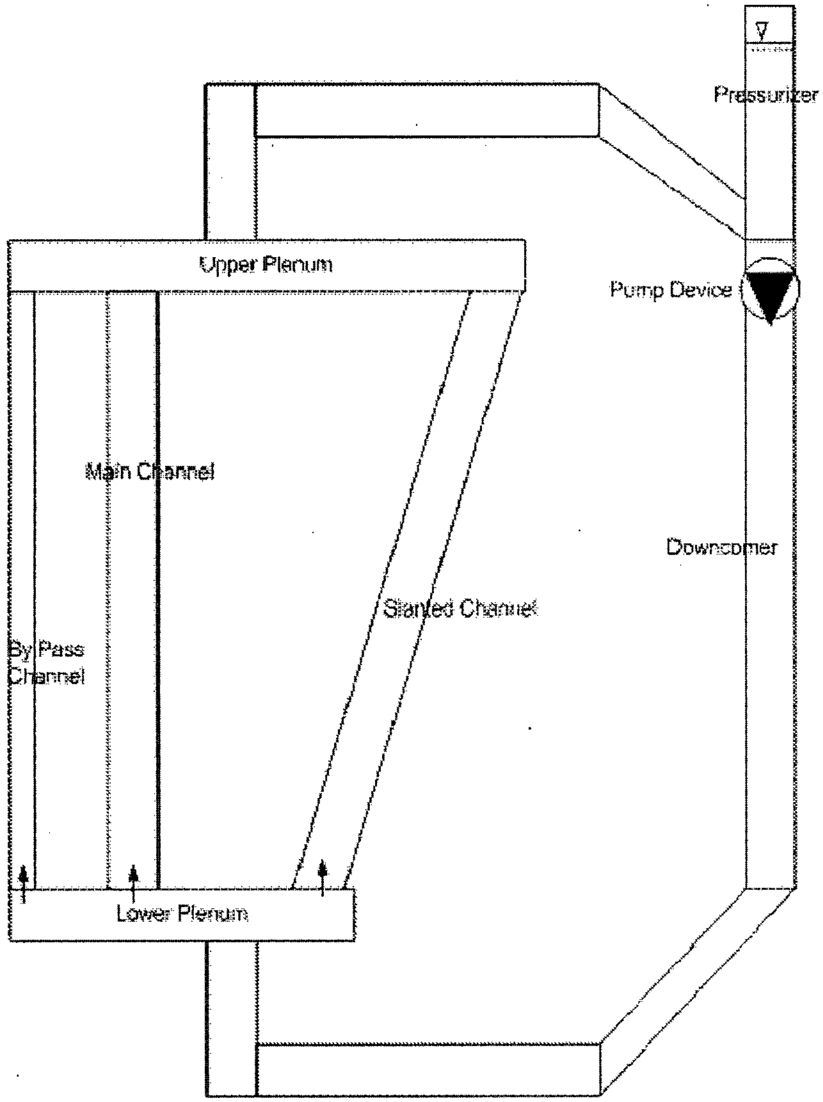


**Figure 1.** **Test model for artificial momentum sources**

[

]$^{a,c}$

a,c

[ ]

**Figure 2.** **POLCA-T result, mass flow rate (kg/s) versus time (s) at the inlet and outlet of the main channel**

a,c

**Figure 3.** **POLCA-T result, mass flow rate (kg/s) versus time (s) at the inlet and outlet of the by pass channel**

a,c

**Figure 4.** POLCA-T result, mass flow rate (kg/s) versus time (s) at the inlet and outlet of the slanted channel

a,c

[ ]

**Figure 5. Mass flow balance for the lower plenum**

From the figures above, it can be concluded that [ ]a,c