AREVA

January 25, 2012
NRC:12:004

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Response to U.S. EPR Design Certification Application RAI No. 407, Supplement 16

Ref. 1: E-mail, Getachew Tesfaye (NRC) to Martin C. Bryan (AREVA NP Inc.), "U.S. EPR Design Certification Application RAI No. 407(4654), FSAR Ch. 3," June 7, 2010.

Ref. 2: E-mail, Dennis Williford (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 407, FSAR Ch. 3, Supplement 15," December 15 2011.

In Reference 1, the NRC provided a request for additional information (RAI) regarding the U.S. EPR design certification application. Reference 2 provided a schedule for the 2 remaining questions and a history of the prior supplemental responses.

Enclosed is a technically correct and complete final response to the 2 remaining questions of RAI 422, as shown in the below table.

AREVA NP considers some of the material contained in the attached response to be proprietary. As required by 10 CFR 2.390(b), an affidavit is attached to support the withholding of the information from public disclosure. Proprietary and non-proprietary versions of the enclosure to this letter are provided.

The following table indicates the respective pages in the enclosed response that contain AREVA NP's final response to the subject questions.

Question #	Start Page	End Page
RAI 407 — 03.09.02-69	2	7
RAI 407 — 03.09.02-71	8	9

This concludes the formal AREVA NP response to RAI 422, and there are no questions from this RAI for which AREVA NP has not provided responses.

D077
NRD

AREVA INC.
3315 Old Forest Road, P.O. Box 10935, Lynchburg, VA 24506-0935
Tel.: 434 832 3000 www.areva.com

If you have any questions related to this submittal, please contact me by telephone at 434-832-2369 or by e-mail to sandra.sloan@areva.com.

Sincerely,

Sandra M. Sloan

Sandra M. Sloan, Manager
New Plants Regulatory Affairs
AREVA NP Inc.

Enclosures

cc: G. Tesfaye
Docket No. 52-020

AFFIDAVIT

COMMONWEALTH OF VIRGINIA)
) ss.
COUNTY OF CAMPBELL)

1. My name is Russell D. Wells. I am U.S. EPR COLA Licensing Manager for AREVA NP Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by AREVA NP to determine whether certain AREVA NP information is proprietary. I am familiar with the policies established by AREVA NP to ensure the proper application of these criteria.

3. I am familiar with the AREVA NP information contained in "Response to Request for Additional Information No. 407, Supplement 16," and referred to herein as "Document." Information contained in this Document has been classified by AREVA NP as proprietary in accordance with the policies established by AREVA NP for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by AREVA NP and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information".

6. The following criteria are customarily applied by AREVA NP to determine whether information should be classified as proprietary:

(a) The information reveals details of AREVA NP's research and development plans and programs or their results.

(b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.

(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for AREVA NP.

(d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for AREVA NP in product optimization or marketability.

(e) The information is vital to a competitive advantage held by AREVA NP, would be helpful to competitors to AREVA NP, and would likely cause substantial harm to the competitive position of AREVA NP.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(d) above.

7. In accordance with AREVA NP's policies governing the protection and control of information, proprietary information contained in this Document has been made available, on a limited basis, to others outside AREVA NP only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. AREVA NP policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

[signature]

SUBSCRIBED before me this 25th day of January, 2011.

Kathleen A. Bennett
NOTARY PUBLIC, COMMONWEALTH OF VIRGINIA
MY COMMISSION EXPIRES: 8/31/2015
Registration No. 110864

KATHLEEN ANN BENNETT
Notary Public
Commonwealth of Virginia
110864
My Commission Expires Aug 31, 2015

Response to

Request for Additional Information No. 407 (4654) & 422(4792)
Supplement 16

6/07/2010 & 8/3/2010

U.S. EPR Standard Design Certification
AREVA NP Inc.
Docket No. 52-020
SRP Section: 03.09.02 - Dynamic Testing and Analysis of Systems Structures and Components
Application Section: 3.9.2

QUESTIONS for Engineering Mechanics Branch 2 (ESBWR/ABWR Projects) (EMB2)

Question 03.09.02-69:

ANP-10306P, Para 2.1.1 (page 2-1) and Para 4.2.1 (page 4-2)

Section 2.1 (1) of the Reg. Guide 1.20 states that the vibration and stress analysis submittal describe the theoretical structural and hydraulic models, analytical formulations and scaling laws, including errors and uncertainties.

The applicant describes that the prototype HYDRAVIB mock-up represents the lower internal structures consisting of the CB, LSP, FDD, HR, hold-down spring, irradiation capsule baskets and the RV inside, including the RC inlet nozzle, and the shape of the radial keys.

The staff noted that Figure 4-1 indicates that individual slabs representing the Heavy Reflector (HR) are positioned by a pair of male and female spigots, which prevents radial sliding between any two HR slabs. However, the details of the HR in Figure 2-3 does not show the spigots (smooth), which can result in radial sliding. In addition, the staff did not find an adequate description of the flow distribution device (FDD) that could be used to verify the FEM input.

The staff was unable to determine if the theoretical structural model of the HYDRAVIB mock-up is an accurate representation of the reactor internals. The applicant is requested to provide details of the following and describe how they have been included in the finite element models:

a. How is the Core Barrel Flange secured in the Reactor Vessel? – It is recommended that the applicant provide a figure that details the retaining assembly.
b. Explain if the scaling is purely geometric for all components
c. Explain the scaling used for the hold-down spring
d. Describe the spigot construction of the HR and how they are scaled.
e. Provide details of the FDD that can be used to confirm the FEM input.

Response to Question 03.09.02-69:

a. The hold-down spring is a “Belleville-type washer” mounted between the flanges of the upper and lower internals. It is designed to provide adequate preload to both the upper and lower internals to prevent the mating surfaces from separating. The stiffness of the different components, specifically the core barrel (CB) flange, hold-down spring, and the upper support plate (USP) flange, were considered in the design of the hold-down spring. The effects of differential thermal expansion, and the resulting mechanical/hydraulic forces exerted by the RPV internals, were also considered in the design of the hold-down spring.

   The thickness of the hold-down spring is customized to the depth of the groove in the reactor pressure vessel (RPV) flange and the thickness of the internal flanges in order to obtain the required compression. The hold-down spring maintains the contact between the CB flange and the RPV ledge, and between the USP flange and the vessel head flange.

   For the full-scale design, the hold-down spring is compressed enough so that the minimum clamping force applied to the CB flange on the lower internals is large enough that the clamping force always exists during steady-state normal operating conditions and RCS

transients, including the momentary 10 percent RCP over-speed transient conditions where primary flow may be approximately 10 percent larger.

The minimum clamping load criterion for the CB flange includes the load sources created by the:

- Weight of the lower internals.
- Hydraulic force acting on the lower internals.
- Force exerted by the fuel assemblies on the lower support plate.
- Force of the hold-down spring.

This same criterion is applied to the upper internals where the applicable load sources are the:

- Weight of the upper internals.
- Force exerted by the fuel assemblies on the UCP.
- Hydraulic force on the upper internals.
- Force of the hold-down spring.

The hydraulic loads are based upon the best-estimate values of RCS flow rates and the nominal dimensions of the components.

The design of the hold-down spring does not take into consideration the hydraulic loading that would be created by the RCP acoustic pressure fluctuations generated at its shaft and blade passing frequencies. Experience with existing PWR units shows that this type of excitation has a very low contribution to response of the global beam mode of the lower internal assembly. Thus, there is no influence to the clamping force of the hold-down spring by this hydraulic loading. The compression of the hold-down spring and the clamping force that will resist the above loadings is sufficient to keep these mating surfaces from separating as a result of the response of the lower internal assembly to flow excitation created by the RCP acoustic pressure fluctuations and random turbulence such that the modal characterization of the lower internal assembly is not altered and the FIV performance of the design is maintained.

The compression of the hold-down spring and the clamping force applied to the mating flanges is not large enough to prevent their separation during faulted events. Separation of these mating surfaces in the vertical direction will momentary occur during the safe shutdown earthquake (SSE) and loss-of-coolant accident (LOCA) events. The holddown spring is designed such that it remains in the elastic domain even in the case of full compression. Therefore, the design function of the hold-down spring is maintained even after an SSE or a LOCA.

The functionality of the hold-down spring during the operating life of the RPV is verified by in-service visual inspections, in accordance with ASME Section XI, of the upper and lower internals to confirm that there is no abnormal wear or damage caused by unexpected vibration. The hold-down spring is fabricated from martensitic steel which is not susceptible to thermal relaxation.

Regarding the testing performed with the HYDRAVIB mockup, the Technical Report ANP-10306P, "Comprehensive Vibration Assessment Program for U.S. EPR Reactor Internals," Revision 0, Figure 4-1 and Figure 03.09.02-69-1, show the attachment of the CB flange to the RPV. Before securing these flanges, shims are added between the vessel head flange and the upper internals flange. This addition reduces the [ ] gap between the vessel flange and the head flange to [ ] to allow for [ ] of compression of the hold-down spring (see Figure-03.09.02-69-1).

The boundary conditions on the finite element model (FEM) at the CB flange juncture are modeled through a series of one-dimensional translational spring elements with a stiffness derived through characterization tests on the hold-down ring. The stiffness of the hold-down spring used with the HYDRAVIB mockup was determined for the [ ] of compression that will be experienced during bolt-up of the mating surfaces. The value of the stiffness for the translational spring elements was confirmed for use with the numerical model by the static tests on the HYDRAVIB mockup.

As described in the Response to Question 03.09.02-74, [ ] of lateral displacement was applied to the mockup at the LSP elevation to experimentally derive the stiffness of the hold-down spring. The static displacement of [ ] with the HYDRAVIB mockup scale corresponds to [ ] with the full-scale design. With the scale of the HYDRAVIB mockup, [ ] of static displacement corresponds to approximately the 4σ statistical amplitude of vibration at the LSP elevation. From the Technical Report ANP-10306P, Table 4-9, the predicted amplitude of vibration at the LSP elevation for the full-scale design is approximately [ ], rms. The maximum amplitude of vibration considering a statistical probability of 4σ would be [ ] which is less than [ ]. Furthermore, the radial keys at the LSP elevation limit the displacement to [ ]. Consequently, the range of displacement evaluated with the static testing of the HYDRAVIB mockup to derive the stiffness of the hold-down spring bound the predicted amplitudes of vibration for the full-scale design.

b. The scaling is geometric for the HYDRAVIB structural components and the annuluses of the RPV internals (RPVI) where flow occurs. Although there are differences between the heavy reflector (HR) slabs of the HYDRAVIB mockup and the full-scale design, the critical aspects of the HR necessary to create dynamic similitude were maintained. The geometric properties of the HR that were maintained through scaling of the mockup are as follows:

- The scaling of the overall height and the radial dimensions of the HR stack were maintained, even though the HYDRAVIB mockup has five HR slabs and the full-scale design has 12 slabs.

- The number of tie rods is identical between the two scale designs. The diameter of the tie rods for the mockup was proportioned to create an axial stiffness that is 1/8 of the full-scale design. The dynamic similitude between the scale of the HYDRAVIB mockup and the full-scale design was assured by the relations provided in Table 03.09.02-69-1.

From this table, the axial stiffness of the tie rods (K as defined in Table 03.09.02-69-1) is adjusted by the factor ($1/\alpha$) where α is the scale factor (8.168).

The geometric properties of the HR that were not maintained with the mockup are:

- The HR slabs for the full-scale design have bores through the thickness that allow internal cooling. The slabs of the HR for the HYDRAVIB mockup were fabricated as solid plates. The differences in the natural frequencies of the HR due to the influence of the cooling holes on the mass and stiffness of the HR are insignificant and will not impact the test results.

- The alignment of the full-scale HR slabs is maintained by [ ] located around the circumference of the slabs and by centering rings and pins. The HYDRAVIB mockup HR slabs has spigots that align the HR slabs and represent the actual alignment devices. The dynamic behavior of the HR is maintained and this difference does not impact the test results.

With the full-scale design of the HR and the tie rods, the frictional forces between the mating surfaces of the twelve HR slabs created by the tensile preload in the tie rods is sufficient to prevent sliding between each individual slab. Each of the [ ] tie rods are preloaded to approximately [ ] (minimum) for a total preload of [ ] in cold conditions. As stated in the Response to Question 03.09.02-69 (Part a), the 4σ amplitude of vibration at the LSP elevation is [ ]. The fundamental frequency of the beam mode for the CB is approximately [ ], as reported in the Technical Report ANP-10306P, Table 4-5. Therefore, the resulting horizontal acceleration at the LSP elevation is equal to;

LSP_{acc} = [ ]

The weight of the HR is equal to [ ] (See the Response to Question 03.09.02-103). The inertial force in the horizontal direction for the HR is equal to:

$F_{inertia}$ = [ ]

$F_{preload}$ = [ ]

The ratio between the inertial force and the preload is equal to [ ], so the friction between the HR slabs will prevent sliding.

Since the heavy reflector responds as a rigid body, the beam stiffness of the HR is higher than that of the CB. As such, the equivalent stiffness of the beam mode for the HR has no significant influence to the overall response of the lower internal assembly or specifically the response of the beam mode for the CB. If sliding were to occur between the HR slabs, the re-distribution of mass along the length of the CB would have an insignificant affect on the response of the global beam mode of the lower internal assembly.

c. The dimensions of the hold-down spring for the HYDRAVIB mockup is scaled to the same proportions as the other HYDRAVIB components (scale = 1 / 8.168). The compression on

the hold-down spring during bolt-up is proportionally scaled. The hold-down spring constant is different for each scale. To account for the differences in temperature with the full-scale design, the spring constant is multiplied by the ratio of the modulus of elasticity at the appropriate temperatures.

For the full-scale design, the compression of the spring is [ ] and is [ ] for the HYDRAVIB mockup. As discussed in part a) of this response, the properties of the hold-down spring used with the HYDRAVIB mockup were verified through a comparison of numerical and experimental simulations.

d. The full-scale HR slabs are not fabricated with spigots. The interference created by the [ ] and the [ ] verifies that the relative motion between any two slabs is limited. Additionally, [ ] tie rods extend through the twelve HR slabs. The tensile preload of the tie rods creates additional bearing and friction between the slabs that limit differential motion in the radial direction. See part b) of this response for additional details on the HYDRAVIB mockup.

e. Technical Report ANP-10306P, Section 4.2.2.1 states that the FDD was modeled as a non-structural lumped mass of [ ] located on the CB axis with an elevation corresponding to the center of gravity for the FDD.

Because of the simplified method used to represent the FDD in the numerical model of the RPV lower internals, the RPV lower internal assembly response will not be impacted due to the separation in the frequency of the fundamental beam mode of the CB assembly and the higher frequency beam modes of the FDD.

From testing performed with the HYDRAVIB mockup, the cantilever beam modal frequencies of the FDD in water were [ ] and [ ]. The fundamental beam modal frequency of the CB lower internal assembly was approximately [ ]. Therefore, the base excitation of the FDD beam modes is insignificant and the inclusion of the hydrodynamic mass for the FDD is unnecessary. This simplification has a negligible impact to the results as shown by the comparison of CB beam mode frequency determined from testing and the numerical model shown in Technical Report ANP-10306P, Table 4-2.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Technical Report Impact:

ANP-10306P, "Comprehensive Vibration Assessment Program for U.S. EPR Reactor Internals Technical Report," Revision 0 will not be changed as a result of this question.

Table 03.09.02-69-1—Relations of Similitude between the Scale of the HYDRAVIB Mockup and the Full-Scale Design

	Full Scale	Mock-up
Stiffness	K	K/α
Hydraulic forces (See note 2)	F	F/α^2
Natural frequencies	f_N	αf_N
Flow induced vibration frequencies (See note 2)	f_F	αf_F
Static and dynamic displacements	D	d/α

Notes for Table 03.09.02-69-1;

1. The factor "α" is the scale factor (α = 8.168 for the HYDRAVIB mockup).
2. With the actual velocity of the fluid in the HYDRAVIB mockup equal to the full-scale design (i.e., $U_{mock\text{-}up} = U_{full\text{-}scale}$)
3. For the hold-down spring, the compression imposed to the full-scale design is divided by the scale factor. The ratio for the preload of the hold-down spring between the mock-up and the full-scale design is: $1/\alpha^2$ which is also equal to the ratio applied to the hydraulic forces between the mock-up and the full-scale design.

Question 03.09.02-71:

ANP-10306P, Para 2.1.1 (page 2-2)

Reg. Guide 1.20, Section 2.1 (2) states that uncertainties are often associated with difference between ideal models and "as manufactured" structures, such as differences in material properties, connections and geometries. These uncertainties and their influence on vibrational responses are to be addressed. The applicant has not described various manufacturing tolerances that can result in geometric uncertainties and also did not describe how they are addressed in the model or in the calculation of flow induced vibrations. The applicant is requested to explain how tolerances in the following members are accounted for:

a. Upper skirt plate

b. Lower skirt plate

c. Reactor Vessel (note that ID tolerance = +/- 1.0 in will also have an effect on the calculation of hydraulic diameters and flow distributions)

Response to Question 03.09.02-71:

Response to Subparts (a & b)

The manufacturing and design analyses of the RPV internals conform to the requirements delineated in the 2004 ASME Section III, subsection NG. The rules and guidelines outlined in subsection NG for the materials, fabrication, examination and the design analysis will address how considerations to the classification and computation of stresses are integrated so that uncertainties associated with the geometry and material properties of these components do not create an unconservative stress result. The following addresses how these uncertainties are manifested in the forcing functions and the response of the lower internal assembly to sources of flow excitation.

The fluid-structure coupling mechanism for random turbulence is weak because the flow field induced by the structural motion is linearly superimposed on the incident flow field. A strongly coupled fluid-structural system, which is characterized by large structural motion, will induce fluid velocities and distort the incident flow field. Vortex-shedding induced vibration and fluid-elastic instability of heat exchanger tubes are examples of strongly coupled fluid-structure systems. In strongly fluid-structural coupled systems, the natural frequencies of the components are fundamental to the sensitivity of the flow-induced vibration (FIV) mechanism and the strength of the response. For the weak fluid-structure coupling associated with random turbulence, the relationship between the natural frequencies and the response of the structure is not as strongly associated. The variation in the natural frequencies that is attributed to the manufacturing tolerances and variation of the material property values does not significantly alter the response of the structure.

An assessment of the impact to the natural frequencies of these structures and their response to flow excitation due to random turbulence is provided in the Response to Question 03.09.02-108. Differences associated with the material properties, connections and geometries manufacturing tolerances, the forcing function and the influence of these considerations to the vibrational response of the RPV lower internals are addressed.

Response for Subpart (c)

U.S. EPR FSAR Tier 1, Table 2.2.1-6 identifies a tolerance of ± 1.0 inch on the ID of the RPV for the design certification. However, a stricter degree of tolerance is defined on the detailed engineering drawings that will be adhered to during the fabrication of the RPV. The design tolerances for the inner diameter (ID) of the RPV and the outer diameter (OD) of the CB result in an uncertainty in the width of the downcomer of about [ ]. This value is based on a design tolerance of [ ] inches on the RPV ID and [ ] inches on the CB OD, and the nominal width of the downcomer equal to [ ] inches. The uncertainty in the response of the RPVI, as determined from the numerical model, would be approximately [ ] in the overall amplitude of vibration. This does not consider the eccentricity of the CB assembly within the RPV. Based on the conservative method by which the above approximation is performed, (i.e., the application of this tolerance along the entire length of the downcomer), the uncertainty in the response of [ ] will bound the tolerance on the eccentricity. However, assuming a +/- 0.1 concentricity tolerance, the width of the larger channel is [ ] larger than the narrow channel. The uncertainty in the response would then be [ ].

The FIV response of the RPV lower internal assembly was computed using the design dimensions and the mean fluid velocity in the RPV downcomer. As described in Technical Report ANP-10306P, the relationships for the power spectral densities (PSDs) developed from the HYDRAVIB mockup testing are based on the mean flow velocity and the nominal hydraulic diameter of the downcomer to obtain a "best estimate" PSD. Consistency is maintained in the analytical methods applied to the scale and full-scale numerical analyses, as required by RG 1.20. The application of this PSD to the full-scale numerical model provides the most appropriate and accurate method to determine the best estimate response of the full-scale prototype, which allows a credible comparison to the results that will be obtained during hot functional testing (HFT).

The [ ] value of uncertainty defined above for the RPVI response is based on a simple but conservative method. In the Response to Question 03.09.02-108, a more elaborate assessment of the inherent uncertainties and bias errors in the numerical solution is provided for the RPVI response. In the Response to Question 03.09.02-108, an assessment is provided of the uncertainties and bias errors associated with:

- The structural compliance of the finite element model.
- The fluid forcing function(s).
- The global uncertainty on the response levels that could be expected from the combination of the above sources of uncertainties.

The following are incorporated into this assessment to provide a composite solution for uncertainties and bias errors:

- The uncertainties in the calculation of the natural frequencies.
- The magnitude of the mean and peak response.

- The magnitude of stress created by the sources of uncertainties and bias errors, including the uncertainties associated with the manufacturing tolerance of the downcomer width, and with the eccentricity of the CB within the RPV, considering the magnitude of tolerance provided.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Technical Report Impact:

ANP-10306P, "Comprehensive Vibration Assessment Program for U.S. EPR Reactor Internals Technical Report," Revision 0, will not be changed as a result of this question.