AREVA

March 24, 2011
NRC:11:030

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 6

In Reference 1, the NRC provided a request for additional information (RAI) regarding the U.S. EPR design certification application. AREVA NP Inc. (AREVA NP) provided a schedule for responses to the 13 questions of RAI No. 407 on June 30, 2010 (Reference 2). AREVA NP submitted Supplement 1 on October 20, 2010, to provide a revised schedule to allow additional time for AREVA NP to interact with the NRC (Reference 3). AREVA NP submitted Supplement 2 on November 22, 2010, to provide a revised schedule to allow additional time for AREVA NP to address NRC comments (Reference 4). AREVA NP submitted Supplement 3 on December 21, 2010, to provide a final response to 8 of the 13 questions (i.e., Questions 03.09.02-70, 72, 74, 75, 77, 79, 80, and 81) (Reference 5). AREVA NP submitted Supplement 4 on January 13, 2011, to provide a revised schedule to allow additional time for AREVA NP to address NRC comments on the remaining 5 questions (Reference 6). AREVA NP submitted Supplement 5 on March 14, 2011, to provide a revised schedule to allow additional time for AREVA NP to interact with the NRC (Reference 7).

The attached file, "RAI 407 Supplement 6 Response US EPR DC - Proprietary.pdf" provides a technically correct and complete response to 2 of the 5 remaining questions (i.e., Question 03.09.02-73 and Question 03.09.02-78). 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.

The following table indicates the respective pages in the response document, "RAI 407 Supplement 6 Response US EPR DC - Proprietary.pdf," that contain AREVA NP's response to the subject question.

Question #	Start Page	End Page
RAI 407 — 03.09.02-73	2	10
RAI 407 — 03.09.02-78	11	11

The schedule for the technically correct and complete response to the remaining questions is unchanged and is provided below.

Question #	Response Date
RAI 407 — 03.09.02-69	April 13, 2011
RAI 407 — 03.09.02-71	April 13, 2011
RAI 407 — 03.09.02-76	April 13, 2011

D077
NRO

AREVA INC.
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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,

for Danielle Gardner

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

Enclosures

cc: G. Tesfaye
Docket No. 52-020

References

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, Martin C. Bryan (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 407, FSAR Ch. 3," June 30, 2010.

Ref. 3: E-mail, Martin C. Bryan (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 407, FSAR Ch. 3, Supplement 1," October 20, 2010.

Ref. 4: E-mail, Martin C. Bryan (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 407, FSAR Ch. 3, Supplement 2," November 22, 2010.

Ref. 5: E-mail, Martin C. Bryan (AREVA NP Inc.) to Getachew Tesfaye (NRC), "PROPRIETARY Response to U.S. EPR Design Certification Application RAI No. 407, FSAR Ch. 3, Supplement 3," December 21, 2010.

Ref. 6: E-mail, Martin C. Bryan (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 407, FSAR Ch. 3, Supplement 4," January 13, 2011.

Ref. 7: E-mail, Martin C. Bryan (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 407, FSAR Ch. 3, Supplement 5," March 14, 2011.

bcc: NRC:11:030
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AFFIDAVIT

COMMONWEALTH OF VIRGINIA)
) ss.
COUNTY OF CAMPBELL)

1. My name is Sandra M. Sloan. I am Manager, New Plants Regulatory Affairs 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 the enclosed response to RAI 407 Questions 3.9.2-73 and 78 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 paragraph 6(b,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.

Sandra M. Sloan

SUBSCRIBED before me this 24th

day of March, 2011.

Kathleen A. Bennett

Kathleen A. Bennett
NOTARY PUBLIC, COMMONWEALTH OF VIRGINIA
MY COMMISSION EXPIRES: 8/31/2011

KATHLEEN ANN BENNETT
Notary Public
Commonwealth of Virginia
110864
My Commission Expires Aug 31, 2011

Response to

Request for Additional Information No. 407(4654), Revision 0, Supplement 6

6/07/2010

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 03.09.02-73:

ANP-10306P, Para 4.2.2.1 and 4.2.2.2 (page 4-10)

The applicant provided a description of the Finite Element Model in Section 4.2.2.1 and in Figures 4-6 through 4-15. The staff reviewed these figures and description and requests the applicant to:

a. Provide the ANSYS element type used to model the Core Barrel (CB) Flange.

b. Provide the ANSYS element type used to model the CB shell.

c. Explain how Core Barrel Skirt shell elements are connected to the Core Barrel Flange brick elements.

d. Provide the ANSYS element type used to model the lower support plate.

e. Provide the ANSYS element type used to model the heavy reflector.

f. Is the volume between the Core Barrel Skirt and Reactor Vessel represented by fluid elements?

g. Is the volume between the Core Barrel Skirt and the HR represented by fluid elements?

h. How many elements or free nodes are present across the thickness of the volume representing the fluid between the Core Barrel Skirt and the HR outer surface?

i. What is aspect ratio (ratio of the length to the thickness) of the elements representing the fluid volumes?

j. Which fluid element type is used to represent the fluid – for example FLUID80, FLUID30 etc.?

k. Provide the fluid volumes and an ANSYS picture of the volumes represented by fluid elements.

l. Provide a picture of the complete finite element model including all components.

m. Provide a picture of the finite element model including all boundary conditions.

n. Describe how force distributing equations representing the Fuel Assemblies are used in the finite element model

Response to Question 03.09.02-73:

a) The core barrel (CB) flange was modeled with the SOLID45 brick element type.

b) The CB skirt was modeled using the SOILIDSHELL190 element type with the nominal (design) thickness for the upper and lower shells. The structural discontinuities of the hot leg nozzles in the CB skirt were modeled with the SOLID95 element type.

c) As stated in part (a of this response, the CB flange elements were modeled with SOLID45 elements. Because the degrees of freedom (DOF) are identical for the type of elements used for the flange and skirt, there are no ANSYS type connection restrictions.

d) The lower support plate (LSP) was modeled with the SOLID45 element type with properties that account for the stiffness and mass of the detailed LSP structure. Connection between

CB skirt and LSP is verified using mesh connectivity (see the response to part c) of this response).

See the Response to Question 03.09.02-80 for additional details regarding the material and structural properties of the LSP.

e) The heavy reflector (HR) was modeled with the SOLID45 element type.

f) The volume between the CB skirt and reactor vessel (RV) was modeled with the fluid80 element type.

g) The volume between the CB skirt and the HR was modeled with the fluid80 element type.

h) One fluid element was modeled across the thickness of the volume representing the fluid between the CB skirt and the HR outer surface. The volume representing the fluid between the HR outer surface and the CB interior surface is extremely thin (its radius/thickness ratio is about 500), and therefore, a one element through thickness mesh can be used without any loss of accuracy.

As requested by the NRC staff during the teleconference on December 16, 2010, the following justification demonstrates that one fluid element between the CB skirt and the HR outer surface is sufficient for the finite element model of the RPV lower internals. In the following, some additional details are provided regarding the method used for implementing the fluid model. A benchmark allowing comparison with theoretical calculations is also provided. The implementation of the fluid model was performed as follows:

A displacement formulated fluid element was selected (ANSYS elements FLUID80). Such an element is a modification of the structural elements, simulating a continuum that is capable of resisting changes of volume through dilatation and compression of the element without allowing changes in its shape (no shear stress). When using such an element, two separate nodes are used at each interface: one for structure and one for fluid. Continuity of displacement is then enforced using kinematic constraint equations, applied only along the direction normal to the fluid-structure interface. Hence, even using a single layer of elements, the fluid can freely move inside the annulus and can "chose" to avoid change of volume, either by running along the annulus circumference or by escaping through the top of the HR.

Regarding the accuracy level of displacement formulated elements, a test-case was set up to demonstrate the level of accuracy obtained with a seemingly crude discretization. A finite element model of a moderately thin annulus (radius/thickness ratio of 10) was built and a coarse mesh employed using one element through the thickness and a 5° pitch along the circumference as shown in Figure 03.09.02-73-4.

The hydrodynamic mass matrix corresponding with the inner cylinder can be estimated by enforcing a unitary acceleration and measuring the reaction force, which must be real valued, negative and correspond with the prediction from theoretical formulations. Measuring and comparing the transmitted force on the outer cylinder allows checking that the coupling effect is also well estimated.

Notations and formulas as provided by ASME III Division 1, Appendix N-1450 "free vibration of coupled fluid-shell" have been used in the following nomenclature:

a = radius of inner cylinder or (when used as a subscript or superscript) pertaining to the inner cylinder.

b = radius of outer cylinder or (when used as a subscript or superscript) pertaining to the outer cylinder.

c = velocity of sound.

f = frequency in Hz.

ρ = mass density of fluid.

Based on the incompressibility assumption, the generalized hydrodynamic masses per unit length for the beam mode (n=1) are:

$$\overline{H}^{a} = \rho\pi a^2(b^2 + a^2)/(b^2 - a^2)$$

$$\overline{H}^{ab} = -2\pi\rho a^2 b^2 /(b^2 - a^2)$$

By definition, these expressions correspond with the reaction force on the inner cylinder and the transmitted force exerted by the fluid on the outer cylinder when subjecting the inner cylinder to a unitary acceleration.

The corresponding simulation was executed using ANSYS Version 12.1. The following values, representative of an incompressible fluid, have been used to make the comparison.

a=1. 0 (unit: length)

b=1.1 (unit: length)

c=1000 (unit: length/time)

f=1 (unit: cycle/time)

rho=1000 (unit: mass/length^3)

The acceleration field (for a unitary acceleration on the inner cylinder) is plotted in Figure 03.09.02-73-5 . As expected by virtue of the conservation of mass, a peak acceleration value of about 10 is obtained, which corresponds with the ratio between inner cylinder radius and the annulus thickness.

The comparison between theoretical and numerical values is:

Quantity	Theoretical	Numerical	Error [%]
Inner cylinder	33601.5	33055.5	-0.02

Outer cylinder	-36203.1	-36179.9	-0.06

Excellent agreement is obtained. Therefore, using a single layer of acoustic finite elements is appropriate to capture fluid dynamic effects for shells coupled by a moderately thin annulus (R/t=10). In the case of the Heavy Reflector/Core Barrel annulus (R/t=500), this assumption is equally valid.

i) The aspect ratio (height/width) of the elements representing the fluid volumes is equal to 16 for the elements. The aspect ratio was assessed through sensitivity studies, which showed a deviation in the analytical results with an aspect ratio of 20.

j) The FLUID80 element type was used.

k) The fluid volume modeled with the RV and CB annulus is equal to [ ]. The volume of fluid located above the upper core plate (UCP) elevation was not included in the numerical model. The influence of this modeling simplification is small because the response of the CB beam mode is insensitive to the hydrodynamic mass of the surrounding fluid located between the UCP and the CB flange elevations due to its close proximity to the anchoring location of the CB flange.

   The fluid volume modeled for the CB and HR annulus is equal to [ ]. See Figure 03.09.02-73-1 for an ANSYS representation of the fluid elements represented by these volumes.

l) See Figure 03.09.02-73-2.

m) See Figure 03.09.02-73-3.

n) The fuel assemblies (FAs) were not modeled with force distributing equations. Only modal analysis of the loaded core was performed. See Technical Report ANP-10306P, Section 4.2.5.1.2 for additional details. The rationale for the flow-induced vibration (FIV) analysis of this configuration is provided in Technical Report ANP-10306P, Section 4.2.5.1.3.

   In the case where the FAs were not included in the model (un-loaded core), as described in Technical Report ANP-10306P, Section 4.2.2.2, force distributing equations were used to model the hydrodynamic mass of the fluid contained by the HR (or the CB shell, depending on the elevation). The force distributing equations for the fluid mass in this model transmit only the inertia effects of this mass in the horizontal direction to either the HR or CB.

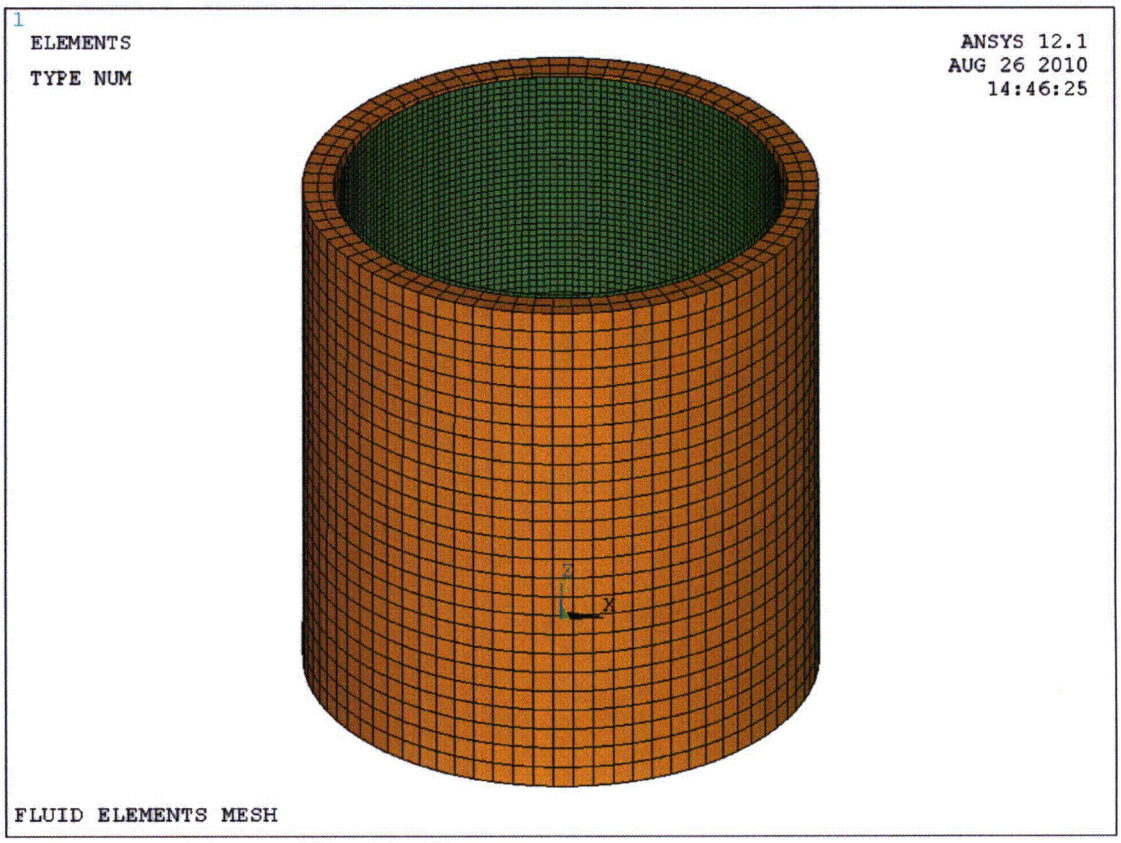
FSAR Impact:

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.

Figure 03.09.02-73-1—ANSYS Model of Fluid Volumes



Note(s):

1. Although not depicted by this figure, the boundary conditions for the acoustic volume that represents the RPV downcomer are open at the top surface and closed at the bottom surface. The boundary conditions for the acoustic volume that represents the CB/HR annulus are closed at the top and bottom surfaces.

Figure 03.09.02-73-2—ANSYS Model of the Complete RPVI Lower Assembly

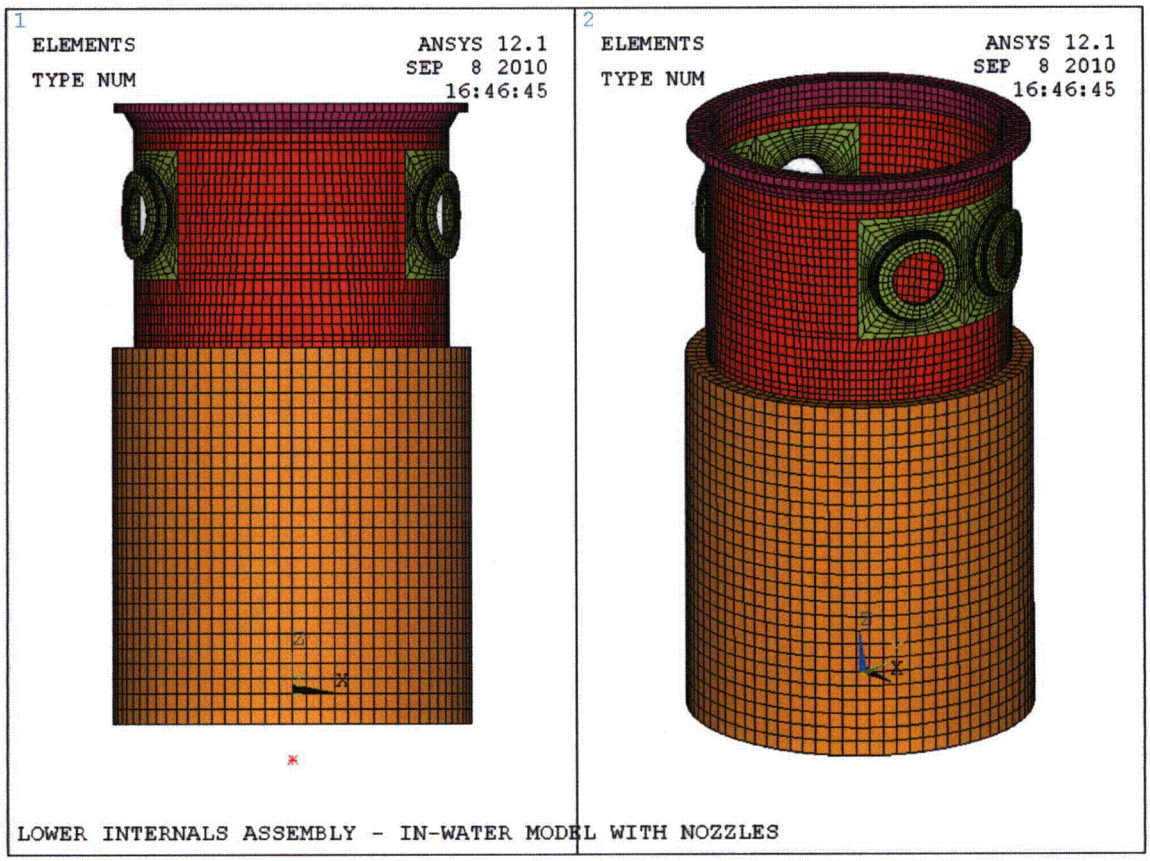
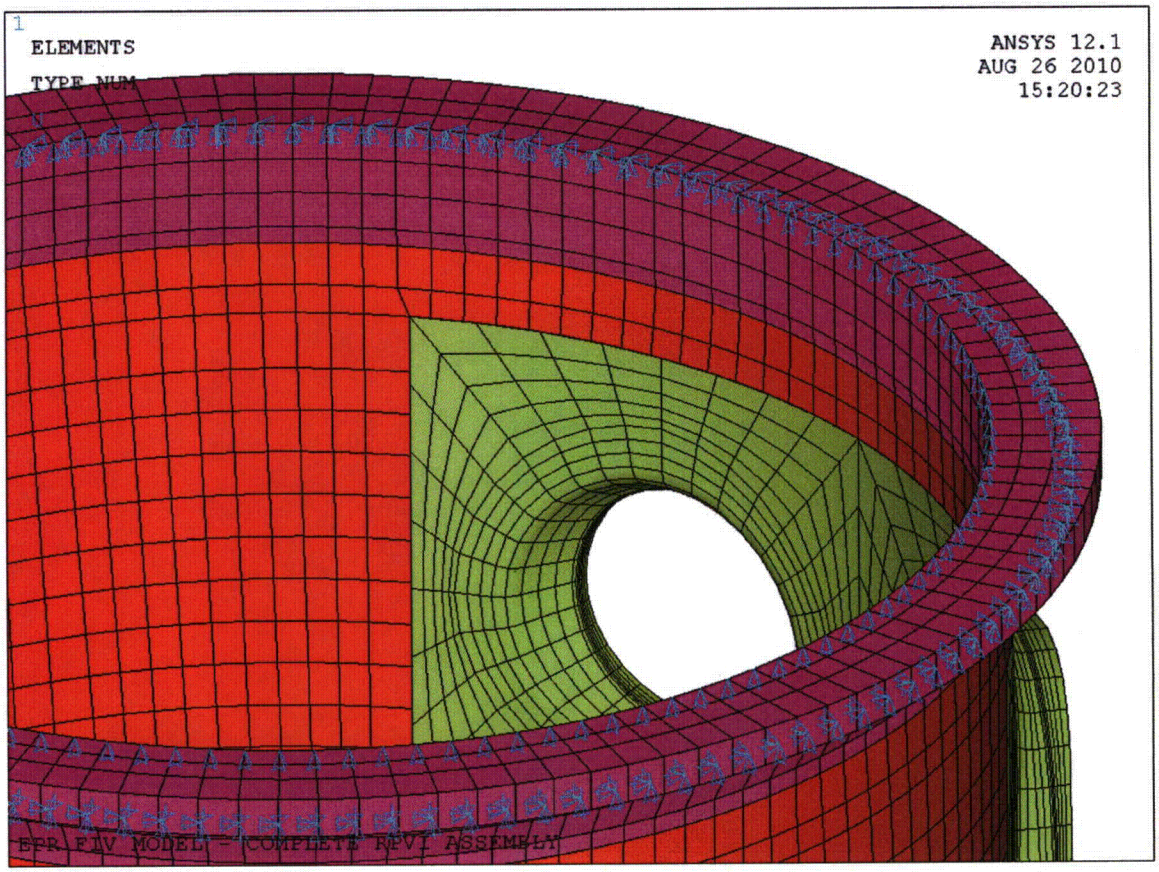


Figure 03.09.02-73-3—ANSYS Model Depicting the Boundary Conditions used with the Numerical Model of the RPVI Lower Assembly



Note(s):

1. The nodes corresponding to contact line between CB shell and RPV flange are fixed along the radial, vertical and tangential axes around the periphery of the flange. The nodes corresponding to the contact line with the Hold Down Spring have been linked to a series of one dimensional spring elements acting in the vertical direction with the ground node fixed in the vertical translational DOF.

Figure 03.09.02-73-4—Finite Element Model of a Moderately Thin Annulus

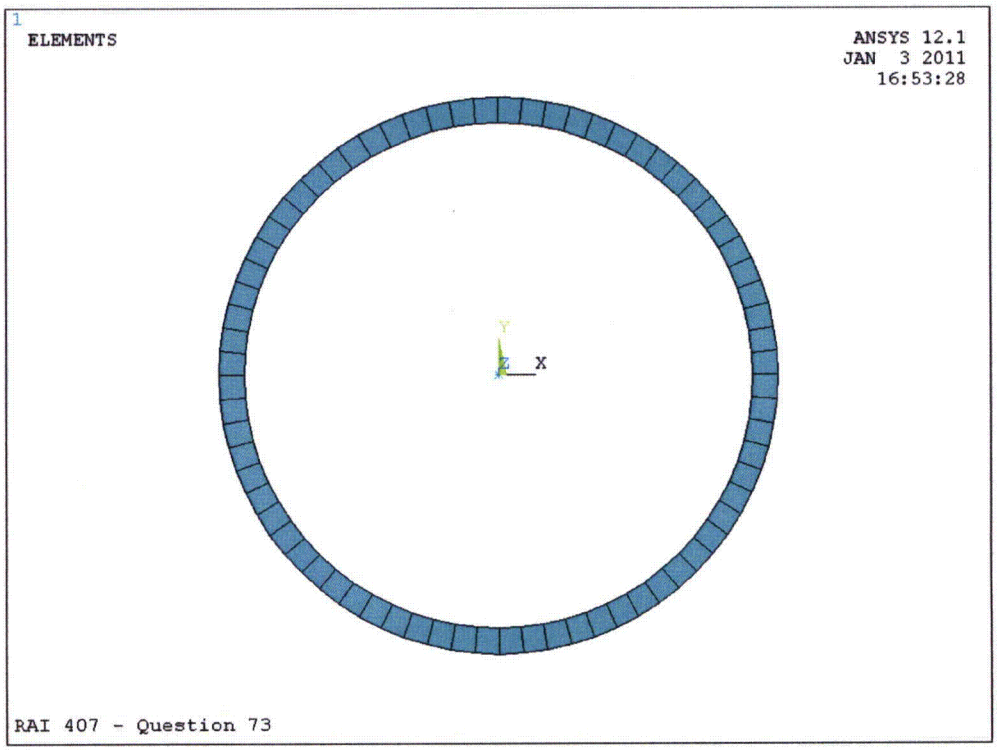
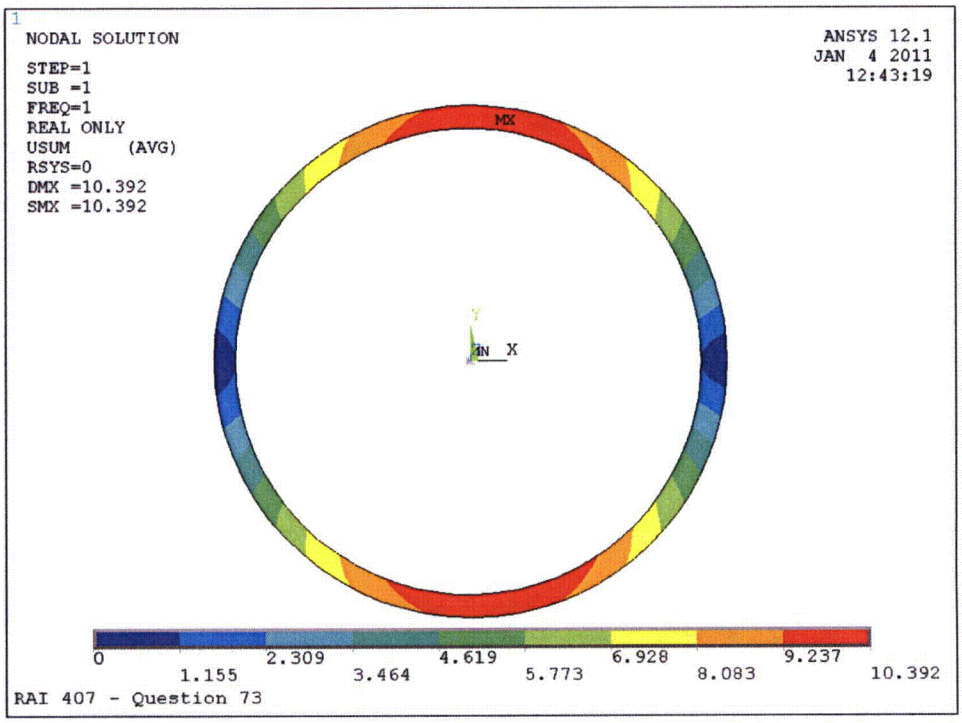


Figure 03.09.02-73-5—Acceleration Field on the Inner Cylinder



Question 03.09.02-78:

ANP-10306P, Para 4.2.6.2 (Page 4-86)

The applicant stated that the mean stress in core barrel is less than PL+PB+Q stress range of 27.2 psi, therefore, fatigue curve "A" was selected for evaluating the RV Core Barrel.

The staff noted that per ASME NG-3222.4 (c), the fatigue curves of Figure I-9.0, are selected based on meeting specific criteria, including mean stress. The applicant is requested to explain the basis for the selection of fatigue curve "A" and how it was determined that the mean stress in core barrel is less than PL+PB+Q stress range of 27.2 psi.

Response to Question 03.09.02-78:

The PL + PB + Q stress range for the Level A & B service limits are described by U.S. EPR FSAR Tier 1, Table 2.2.1-5, Item 3.16. When these stresses are determined, the primary plus secondary stress range in the core barrel (CB) flange, for which the alternating flow-induced vibration (FIV) stress is cyclic, will be less than 27.2 ksi. From this comparison, fatigue curve "A" is justified for use.

Referring to the flow chart in ASME Section III, Appendices, Figure I-9.2.3, for an elastic analysis of a stress location that is within three wall thickness of a weld with a (P_L + P_b +Q) stress range > 27.2 ksi, the more conservative fatigue curve "C" is prescribed. Following the methodology in Technical Report ANP-10306P, Section 4.2.7.2, an endurance limit of [ ] is estimated for fatigue curve "C" (see Technical Report ANP-10306P, Figure 4-21). This allowable stress is approximately [ ] times the peak stress of [ ]. Fatigue failure of the reactor pressure vessel (RPV) CB resulting from random turbulence in the RV downcomer is not predicted to occur. Technical Report ANP-10306P, Section 4.2.7.2, will be revised to refer to fatigue curve "C".

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 be revised as described in the response and indicated on the enclosed markup.

ANP-10306P, Revision 1
Markups

4.2.7.2 Stress Levels

The distribution of stress is displayed in Figure 4-26. As expected, peak stresses are located at the junction between the CB shell and the flange (local bending occurs in this region) with secondary stress concentrations in the vicinity of the nozzles.

03.09.02-78

A maximum stress of [ ] MPa, rms (or [ ] psi, rms) is shown in Figure 4-26 at the CB flange elevation. ~~Considering~~Applying a fatigue strength reduction factor (FSRF) of [ ] for the cylinder to flange juncture, a weld quality factor (f=1) for dynamic loading dynamic as prescribed by ASME Section III, Table NG-3352-1 for the category C, Type I weld joint, and the scaling factor of [ ], a peak stress of approximately [ ] psi, rms is obtained for the full power normal operating condition.

To evaluate the RV lower internals for fatigue, the number of cycles per unit time is taken from the displacement results (See Table 4-10). Considering a crossing frequency of [ ] Hz and based upon 60 years of continuous operation (i.e., assuming a 100 percent capacity factor), this yields a number of cycles of about [ ] . Using ~~Table 4-21~~Figure 4-21 and fatigue "C", the allowable number of cycles for the [ ] psi, rms peak stress is > 10^{13} cycles. Therefore the fatigue usage factor is less than [ ] The endurance limit of approximately [ ] psi, rms at [ ] cycles is greater than four times the stress in the CB ([ ] psi, rms). ~~an endurance limit of approximately 6000 psi, rms is estimated, which is well above the stress in the CB, which is 850 psi, rms.~~ Therefore, high cycle fatigue failure resulting from the random turbulence in the RV downcomer is not predicted to occur.

03.09.02-78