Domestic Members
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Carolina Power & Light Co.
H.B. Robinson 2
Shearon Harris
Dominion Nuclear Connecticut
Millstone 3
Dominion Virginia Power
North Anna 1 & 2
Surry 1 & 2
Duke Power Company
Catawba 1 & 2
McGuire 1 & 2
Entergy Nuclear Operations Inc.
Indian Point 2 & 3
Exelon Generation Company LLC
Braidwood 1 & 2
Byron 1 & 2
FirstEnergy Nuclear Operating Co.
Beaver Valley 1 & 2
Florida Power & Light Co.
Turkey Point 3 & 4
Northeast Utilities
Seabrook
Nuclear Management Co.
Point Beach 1 & 2
Prairie Island 1 & 2
Kewaunee
Pacific Gas & Electric Co.
Diablo Canyon 1 & 2
PSEG - Nuclear
Salem 1 & 2
Rochester Gas & Electric Co.
R.E. Ginna
South Carolina Electric & Gas Co.
V.C. Summer
STP Nuclear Operating Co.
South Texas Project 1 & 2
Southern Nuclear Operating Co.
J.M. Farley 1 & 2
A.W. Vogtle 1 & 2
Tennessee Valley Authority
Sequoyah 1 & 2
Watts Bar 1
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Commanche Peak 1 & 2
Wolf Creek Nuclear Operating Corp.
Wolf Creek

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Tihange 1, 3
Electricite de France
Kansai Electric Power Co.
Mihama 1
Takahama 1
Ohi 1 & 2
Korea Hydro & Nuclear Power Co.
Kori 1 - 4
Yonggwang 1 & 2
British Energy plc
Sizewell B
Krsko
Krsko
Spanish Utilities
Asco 1 & 2
Vandellos 2
Almaraz 1 & 2
Ringhals AB
Ringhals 2 - 4
Taiwan Power Co.
Maanshan 1 & 2

OG-02-014
April 23, 2002

WCAP-15666, Rev. 0
Project Number 694

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

Attention: Chief, Information Management Branch,
Division of Inspection and Support Programs

Subject: Westinghouse Owners Group
Transmittal of Response to Request for Additional Information (RAI) Regarding WCAP-15666-NP, Rev. 0, "Extension of Reactor Coolant Pump Motor Flywheel Examination" (MUHP-3043)

Reference: 1) Westinghouse Owners Group Letter, R. Bryan to Document Control Desk, "Transmittal of WCAP-15666, 'Extension of Reactor Coolant Pump Motor Flywheel Examination' Non-Proprietary Class 3 (MUHP-3043)," August 24, 2001.

2) NRC Letter, D. Holland (NRC) to G. Bischoff (W), "Westinghouse Owners Group - WCAP-15666, Rev. 0, "Extension of Reactor Coolant Pump Motor Flywheel Examination," February 11, 2002.

In August 2001, the Westinghouse Owners Group (WOG) submitted Westinghouse topical report, WCAP-15666, Rev. 0, "Extension of Reactor Coolant Pump Motor Flywheel Examination," for NRC review (Reference 1). In February 2002, the NRC issued a Request for Additional Information (RAI) (Reference 2). Attachment 1 provides the WOG responses to the RAI.

If you require further information, feel free to contact Mr. Ken Vavrek, Westinghouse Owners Group Project Office at 412-374-4302.

Very truly yours,

Robert H Bryan

Robert H. Bryan, Chairman
Westinghouse Owners Group

attachment

02og014.doc

D048

cc: WOG Steering Committee (1L, 1A)
WOG Primary Representatives (1L, 1A)
WOG Licensing Subcommittee Representatives (1L, 1A)
WOG Materials Subcommittee Representatives (1L, 1A)
B. Barron, Duke Energy (1L)
G. Shukla, USNRC OWFN 07 E1 (1L,1A)
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	W.H. Bamford	(1L, 1A)	ECE 3-04
	J.M. Brennan	(1L, 1A)	ECE 4-16
	B.A. Bishop	(1L, 1A)	ECE 4-22
	R.J. Lutz	(1L, 1A)	ECE 4-16
	T.A. Meyer	(1L, 1A)	ECE 4-22
	P.L. Strauch	(1L, 1A)	ECE 3-4
	S.A. Swamy	(1L, 1A)	ECE 3-4
	S.R. Bemis	(1L)	ECE 5-16
	S.A. Binger	(1L, 1A)	ECE 5-16
	P.V. Pyle	(1L)	ECE 5-16
	S.T. Byrne	(1L, 1A)	Windsor
	J. Ghergurovich	(1L, 1A)	Windsor
	J. Molkenthin	(1L)	Windsor
	P.J. Hijeck	(1L)	Windsor
	S.W. Lurie	(1L, 1A)	Windsor
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Responses to NRC Request for Additional Information on WCAP-15666, Rev. 0, "Extension of Reactor Coolant Pump Motor Flywheel Examination"

RAI Number 1:

The parameter on the pipe size shown in Table 3-4 of the Structural Reliability and Risk Assessment (SRRA) Benchmarking Study considers a range of pipe sizes (pipe outside diameter (OD) and wall thickness) that are much smaller than the characteristic dimensions of flywheels discussed in WCAP-15666. How will the fracture mechanics model used in the SRRA code be applicable to validate the results obtained in Table 3-8 using the flywheel-specific fracture mechanics model discussed in Section 2 of the submittal? Please explain what parts of the flywheel failure probability code calculations (e.g., the PROF object library) are validated by the SRRA results by comparing the results of the SRRA code with that of the pc-PRAISE code as shown in Tables 3-3 and 3-4.

Response to RAI Number 1:

The probability of failure (PROF) program flow chart in Figure 3-5 of WCAP-15666 for the reactor coolant pump flywheel (RCPFW) failure is the same as that for the PROF program for piping failure in Supplement 1 of WCAP-14572, Rev. 1-NP-A (Figure 3-1 of Reference 4). However, five of the boxes in these flow charts represent PROF program subroutines that are written for a specific analysis problem. For example, the Inservice Inspection (ISI) subroutine would typically provide the probability of detection and its variation with flaw size, which would obviously depend upon the specific component geometry and inspection method being analyzed.

The SRRA model (PROF subroutines) for nonductile failure of the RCPFW, as described in WCAP-14535A (Reference 5), directly uses Equations 7 through 11 in Section 2.3 of WCAP-15666 to calculate the failure probabilities given in Table 3-8 of WCAP-15666.

The pipe sizes (OD and wall thickness) in Table 3-4 of WCAP-15666 were used in the SRRA model for calculating the probability of small and large leaks or a full break of the piping in accordance with Supplement 1 of WCAP-14572, Rev. 1-NP-A (Reference 4). These parameters do not directly correlate to the flywheel characteristic dimensions (OD and bore) in Table 2-5 of WCAP-15666, which were used in the SRRA model for flywheel failure, based on brittle fracture at design-limiting overspeed conditions. The purpose of Table 3-4 and corresponding Figure 3-4 in WCAP-15666, was to show that the SRRA methodology (PROF Program) can be used to accurately calculate probabilities over a very large range (e.g., 10 orders of magnitude) for a variety of conditions and input parameters.

The comparison of the piping SRRA methods with those of pc-PRAISE was meant to validate the following aspects of the probabilistic calculations in the PROF object library. These same aspects were also used for the RCPFW probability calculations:

1) The overall Monte-Carlo simulation techniques, including
   a) generation of random numbers,
   b) sampling of uniform and log-uniform distributions,
   c) sampling of normal and log-normal distributions, and
   d) use of variance reduction techniques, such as
      - importance sampling for SRRA
      - stratified sampling for pc-PRAISE
2) The effect of design-limiting events on failure probability with time, and
3) The effect of ISI on failure probability with time.

RAI Number 2:

Were the failure probabilities of ductile and excessive deformation failure modes stated in Regulatory Guide (RG) -1.174, "An Approach for Using Risk Assessment in Risk-Informed Decisions on Plant Specific Changes to the Licensing Basis" calculated? If not, please provide your rationale.

Response to RAI Number 2:

The failure probabilities of ductile and excessive deformation failure modes stated in RG-1.14, "Reactor Coolant Pump Flywheel Integrity," are not calculated, because they would not be as high as those for the nonductile failure mode that was calculated. Considering a double-ended guillotine break in the main reactor coolant loop piping, coincident with an instantaneous loss of electrical power results in a peak RCP speed of 3321 rpm, which is the highest LOCA speed calculated (WCAP-15666, Table 3-1). This speed is less than the limiting speed calculated for ductile failure considering that no crack is present (3430 rpm, WCAP-15666, Table 2-6). This speed is also less than the limiting speed calculated for ductile failure considering that a 2-inch crack is present (3333 rpm, WCAP-15666, Table 2-6). A 2-inch crack is much larger than those expected in the probabilistic fracture mechanics analyses and risk evaluation contained in WCAP-15666.

A 3321 rpm overspeed condition results in a change in the flywheel bore radius and outer radius of 0.015 inches and 0.030 inches, respectively, based on Table 2-9 of WCAP-15666, considering proportionality to the square of the rotational speed (ω^2). This change is small, and would not be expected to result in failure of the flywheel.

RAI Number 3.a:

Section 3.3 states that the nominal rotation per minute (rpm) for a flywheel is 1200 rpm and discusses "peak speed[s]" of 1500 rpm or 3321 rpm that are "used in the evaluation" of failure frequency. The entries in Table 3-8 identify the failure frequencies by these peak speeds. Table 3-5 includes input parameters as "Number of Transients per Operating Cycle" and "Speed Change per Transient (rpm)".

a. What is the relationship between the "peak speed" and the probability of failure at 40 and 60 years? For example, does the calculation in Table 3-8 for 1500 rpm assume that the flywheel runs continuously at 1500 rpm during the life of the plant? Does the calculation for 3321 rpm assume that the flywheel runs continuously at 3321 rpm during the life of the plant?

Response to RAI Number 3.a:

The RCP has a synchronous speed of 1200 rpm, and a design speed of 1500 rpm. The peak speed for a LOCA considering no loss of electrical power to the RCP, or for a LOCA considering an instantaneous loss of electrical power and up to a 3 ft^2 break area, is 1200 rpm. A peak speed of 1500 rpm was conservatively used in WCAP-15666 for these cases. For the double-ended guillotine break of the main coolant loop piping, a speed of 3321 rpm was used. The calculations assume that the flywheel normally operates at a median value of 1200 rpm, and at the peak speeds (1500 rpm or 3321 rpm) only for the LOCA design-limiting events.

RAI Number 3.b:

Section 3.3 states that the nominal rotation per minute (rpm) for a flywheel is 1200 rpm and discusses "peak speed[s]" of 1500 rpm or 3321 rpm that are "used in the evaluation" of failure frequency. The entries in Table 3-8 identify the failure frequencies by these peak speeds. Table 3-5 includes input parameters as "Number of Transients per Operating Cycle" and "Speed Change per Transient (rpm)".

b. If the flywheel is assumed to run at 1200 rpm and only increases speed to 1500 rpm or at 3321 rpm after an event, please describe the input frequency of each event and the development of the frequency. If an event frequency is included in the failure frequency calculation in Table 3-8 for either of the cases, 1500 rpm or 3321 rpm, how does this comport with the multiplication of the failure frequencies with initiating event frequencies in Tables 3-12 and 3-13?

Response to RAI Number 3.b:

As discussed in the response to RAI Number 3.a. above, the design-limiting LOCA event is inherently postulated to occur after each cycle (one year) of operation (frequency = 1.0) in the flywheel failure probability calculation, as the stresses at its speed are used in the critical size check for nonductile fracture. It should be noted that the flywheel failure probabilities in Section 3.3 of WCAP-15666 are conservatively calculated values used to estimate the <u>increase</u> in the cumulative failure probability for eliminating inspections. Therefore, the LOCA event frequencies used in the risk calculations in Tables 3-12 and 3-13 of WCAP-15666 are not included in either the input (Table 3-6 of WCAP-15666) or output (Table 3-8 of WCAP-15666) for the SRRA calculation of failure probability shown in Table 3-7 of WCAP-15666.

RAI Number 4:

The submittal's estimate of an initiating event frequency of 2E-6/yr for large break loss-of-coolant accidents (LOCAs) is two orders of magnitude lower than the estimates used in the individual plant examinations (IPEs). The submittal uses 2E-2 from NUREG/CR-6538 (Reference 1) for the conditional probability of getting a loss of offsite power (LOOP) following a LOCA. The same NUREG suggests that the frequency of a large LOCA in a pressurized water reactor (PWR) is in the range of 5E-4/year to 2E-4/year. These estimates of LOCA frequency are also much higher than the submittal's estimate of 2E-6/year. Additionally, although the 3321 rpm speed is discussed as the bounding speed, Table 3-11 and the following paragraph indicate that the 2E-6/yr LOCA frequency only includes large cold leg breaks which would, on loss of the reactor coolant pump (RCP) power, result in the 3321 rpm. Therefore, although the speed may be a bounding value, the frequency is not a bounding value because the lesser equivalent break area equal to 60 percent of the double-ended break area (resulting in 2609 rpm) is not included in the risk calculation. The analysis should include consideration of the uncertainty in the LOCA frequency as part of an overall uncertainty or bounding evaluation.

Response to RAI Number 4:

The LOCA frequency used in the risk analysis of the RCP flywheel in WCAP-15666 was based upon the failure probability calculations for piping risk-informed ISI using the WOG methodology contained in WCAP-14572, Rev. 1-NP-A (Reference 6). This Risk-Informed-ISI methodology, including the SRRA model for failure probability calculation contained in Supplement 1 of WCAP-14572, Rev. 1-NP-A (Reference 4), satisfies all the requirements of NUREG-1661 (Reference 7), and was reviewed and approved by the NRC in December 1998. Recent NRC questions regarding the use of SRRA in particular, and probabilistic fracture mechanics (PFM) in general, to generate similar frequency information to support a Risk-Informed Part 50, Option 3 initiative to redefine the large break LOCA break size have also been addressed in the responses contained in References 8 and 9. The following conclusions can be made from those responses:

1) The mean value for the frequency of a large LOCA of $2x10^{-6}$/year in WCAP-15666 is comparable to that of $5x10^{-6}$/year given for a "Large Pipe Break LOCA" in Table 3-5 of NUREG/CR-5750 (Reference 10).

2) The large LOCA probability is very conservatively calculated for a large leak rate of only 5000 GPM, which would be significantly less than 60% of the flow from a full double-ended pipe break.

3) The expected uncertainties on large leak probabilities calculated using the PFM approach in the piping SRRA models for RI-ISI (see Figure 4-5 of Reference 4 and Section 3.6.1 of Reference 6) have been used in a Monte-Carlo simulation to determine the mean LBLOCA probability that is typically an order of magnitude higher than the SRRA calculated probability. The mean value calculated in this manner, which does include the effects of uncertainty, was used for the risk calculation in WCAP-15666.

RAI Number 5:

The sensitivity study in Table 3-9 indicates that the results are quite sensitive to some input parameters when the values of the parameters are individually varied. There is no discussion on how the results could vary when the input parameters are simultaneously varied. Furthermore, Table 3-5 includes other parameters that appear to represent highly uncertain parameters, particularly "Fatigue Crack Growth Rate," that are not included in the sensitivity study. Another parameter with large uncertainties that is not included in the sensitivity analysis is the LOCA frequency. RG 1.174 requires that uncertainty be considered in any risk-informed analysis. If the calculated metric is sufficiently small, "a simple bounding analysis may suffice." Please provide an analysis that bounds the final result (change in risk) based on the potential variation in all the input parameters. Alternatively, a systematic uncertainty analysis as described in Reference 2 and illustrated in Reference 3 may be performed.

Response to RAI Number 5:

It should be noted that the flywheel failure probabilities in Section 3.3 of WCAP-15666 are conservatively calculated values used to estimate the increase in the cumulative failure probability for eliminating inspections after 10 years. Comparing the differences in the failure probabilities with and without inspections after 10 years in Table 3-9 of WCAP-15666 indicates that the probability difference for the base case either equals or exceeds the probability difference for the other 6 variations shown in Table 3-9 of WCAP-15666. The conclusion is that the input values for the base-case analyses (i.e., those shown in Table 3-8 of WCAP-15666) bound the differences in the failure probability with and without inspections after 10 years. Note that the result of the base-case analyses in Table 3-8 of WCAP-15666 does in fact calculate the effects of eight input parameters being varied simultaneously. The eight input values simultaneously varied are numbers 4, 9, 10, 11 (fatigue crack growth rate coefficient), 13, 14, 15, and 16 in Table 3-6 of WCAP-15666.

As indicated in the response to RAI Number 4, the effects of uncertainties in the SRRA calculated LOCA probability (1-sigma factors from 5 to 20 per Section 3.6.1 of Reference 6) have already been considered in the mean value of the LOCA frequency. Therefore, it was concluded that a sensitivity study was not necessary for this parameter. Additionally, the calculations in Tables 3-12 and 3-13 of WCAP-15666 show that the change in risk with and without ISI after 10 years for the large LOCA event (7.67E-13/year – 7.67E-13/year) would be zero, regardless of what event frequency is used.

Since the calculated risk metric of change in core damage frequency in Tables 3-12 and 3-13 of WCAP-15666 is sufficiently small, relative to the risk goal in Regulatory Guide 1.174, a simple bounding analysis was determined to be sufficient. The risk analyses in these tables are considered to be bounding in the following ways:

1) The total risk and its change with ISI are controlled by the first two items in Tables 3-12 and 3-13 of WCAP-15666. The frequency of these events is bounded by the assumed value of 100%/year.

2) The fatigue crack growth of the initial flaw is calculated, assuming that a complete change in the flywheel speed of 1200 rpm occurs (i.e., the RCP is started) 100 times each year.

3) The critical flaw size is calculated for the first two items in Tables 3-12 and 3-13 of WCAP-15666 assuming a pump speed of 1500 rpm, which is 25% higher than the speed during normal operation.

4) The failure probabilities with and without ISI after 10 years are calculated for items 1) and 2) above, assuming an additional 1-sigma uncertainty of 10% for the key (underlined) parameters identified in items 2) and 3) above.

5) The conditional core damage probability is bounded by an assumed value of 1.0.

RAI Number 6:

How is the safe shutdown earthquake load factored into the evaluation of nonductile, ductile and excessive deformation?

Response to RAI Number 6:

The safe shutdown earthquake (SSE) was not considered for the deterministic evaluations of non-ductile, ductile, and excessive deformation failures in the original submittal that was accepted by the NRC (Reference 5). The SSE was not considered for the probabilistic evaluation of non-ductile failure in WCAP-15666 because it is not expected to be a significant contributor to risk. This is due to: 1) the frequency of the SSE event is very low (<1.0E-3/year), and 2) the SSE induced stress is much lower than the limiting stresses already considered, as demonstrated in the discussion below.

The following discussion provides a conservative estimation of the hoop stresses at the flywheel bore for the safe shutdown earthquake (SSE), for comparison with the hoop stresses produced at the flywheel bore due to a loss of coolant accident (LOCA) overspeed condition and the normal operating condition.

Table 2-2 of WCAP-15666 provides reactor coolant pump (RCP) flywheel dimensional information for the Westinghouse domestic plants included in WCAP-15666. As shown, the outer diameters range from 72 to 76.5 inches, the bores range from 8.375 to 9.375 inches, and the keyway radial lengths range from 0.863 to 0.937 inches. Therefore, these flywheels are dimensionally very similar, since the dimensions are all within approximately 12%. The material for all of the flywheels is SA533B carbon steel.

Figure 2-1 of WCAP-15666 provides an example of a typical flywheel, showing the thickness of each of the two flywheel plates that makes up the overall flywheel. The dimensions of the typical flywheel will be used in the representative evaluation discussed below.

The overall weight of the typical flywheel assembly is (using a density of 0.283 lb/inch^3):

$$[\pi\,(37.5^2 - 4.7^2)(7.5) + \pi\,(32.5^2 - 4.7^2)(6.5)]\,[0.283] = 15{,}206 \text{ pounds.}$$

Conservatively assuming an SSE seismic maximum acceleration of 10 g's, the force imparted to the flywheel by the RCP shaft is 152,060 pounds. For conservatism, it was assumed that the inertial forces generated by the SSE from the overall flywheel assembly are absorbed solely by the smaller flywheel plate. This plate has a smaller outer diameter and a smaller thickness.

For calculational purposes, a section of the flywheel, as shown in Figure 1, was "removed" in order to determine the stresses at the flywheel bore (Point "B"). Due to symmetry, one-half of the load, or 76,030, pounds acts on this section of the flywheel bore.

Reference 11 (pages 5-42 and 5-43) provides formulas for short blocks loaded eccentrically in compression or tension, i.e., not through the center of gravity. In this situation, a combination of axial and bending stress occurs.

The axial stress is (P/A)

where:

P = loading = 76,030 pounds

A = area over which the load acts = (27.8)(6.5) = 180.7 inch^2

Thus, the axial stress = 76,030 / 180.7 = 0.4 ksi.

The bending stress is Pey/I

where:

P = loading = 76,030 pounds

e = eccentricity of the loading from the center of gravity (cg) = 18.6 inches

y = distance from the cg for stress determination (Point "B") = 13.9 inches

I = moment of inertia = $(6.5)(27.8^3)/12$ = 11,638 inch^4

Thus, the bending stress = (76,030)(18.6)(13.9)/11,638 = 1.7 ksi.

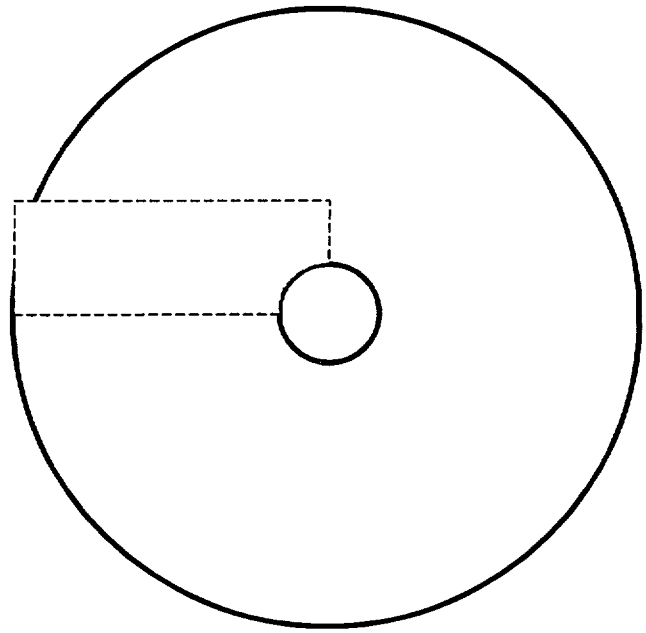
The total hoop stress is therefore 0.4 + 1.7 = 2.1 ksi.

Table 1 provides the hoop stresses for a LOCA (with and without a loss of electrical power to the RCP) and for normal operation, as well as the SSE hoop stress expressed as a percentage of the LOCA and normal operation stress. As shown Table 1, the SSE stress is small in comparison to the LOCA and normal operation stresses, which were calculated using Equation 2 of WCAP-15666. More importantly, the SSE stress is small in absolute magnitude (2.1 ksi).

Table 1: Comparison of Seismic SSE Stresses to LOCA and Normal Operation Stresses

Condition	Flywheel Speed (rpm)	Hoop Stress (ksi)	SSE Hoop Stress/Hoop Stress (%)
LOCA (double-ended guillotine break of the cold leg, coincident with an instantaneous loss of electrical power to the RCP)	3321	103.1	2
LOCA (double-ended guillotine break of the cold leg, no loss of electrical power to the RCP)	1500	21.0	10
Normal Operation	1200	13.5	16

Note: SSE Hoop Stress is 2.1 ksi, as calculated above.



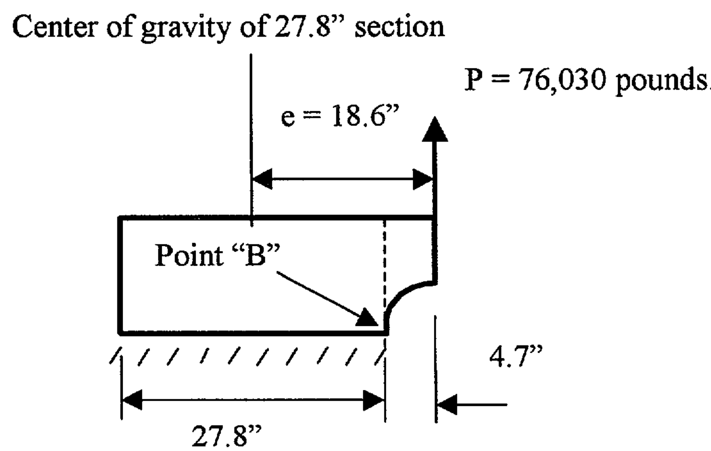


Figure 1: Determination of Seismic Stress at the RCP Flywheel Bore

References

1. “Evaluation of LOCA with Delayed LOOP and LOOP with Delayed LOCA Accident Scenarios,” BNL, NUREG/CR-6538, July 1997.

2. “Best Estimate Calculations of Emergency Core Cooling System Performance,” U.S. Nuclear Regulatory Commission, Regulatory Guide 1.157, May 1989.

3. “Quantifying Reactor Safety Margins,” U.S. Nuclear Regulatory Commission, NUREG/CR-5249, December 1989.

4. Westinghouse Report WCAP-14572, Supplement 1, Rev. 1-NP-A, “Westinghouse Structural Reliability and Risk Assessment (SRRA) Model for Piping Risk-Informed Inservice Inspection,” February 1999, Westinghouse Non-Proprietary Class 3.

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8. “Questions on LBLOCA Redefinition Program,” Enclosure 1 of Letter from A. R. Pietrangelo (NEI) to T. L. King (NRC), February 8, 2001.

9. “WOG Resolution of Issues Contained in SECY-01-133, Attachment 2, Appendix A,” Attachment 1 of Letter OG-01-059 to R. A. Meserve, USNRC Chairman, “Transmittal of Westinghouse Owners Group Comments on SECY-01-133 (MUHP3062),” October 2, 2001.

10. “Rates of Initiating Events at U.S. Nuclear Power Plants: 1987 – 1995,” NUREG/CR-5750 (INEEL-EXT-98-00401), Idaho National Engineering and Environmental Laboratory, February 1999.

11. Marks’ Standard Handbook for Mechanical Engineers, Eighth Edition, McGraw-Hill Book Company, 1978.