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SUBJECT: Forwards 120-day response to GL 97-01, "Degradation of Control Rod Drive Mechanism Nozzle & Other Vessel Closure Head Penetrations."

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Florida Power & Light Company, P.O. Box 14000, Juno Beach, FL 33408-0420

July 28, 1997
L-97-156
10 CFR 50.4
10 CFR 50.54(f)

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D. C. 20555

RE: Turkey Point Units 3 and 4
Docket Nos. 50-250 and 50-251
Generic Letter 97-01 - 120 Response

This letter provides the Florida Power and Light Company (FPL) 120 day response to Generic Letter (GL) 97-01, "Degradation of Control Rod Drive Mechanism Nozzle and Other Vessel Closure Head Penetrations," for Turkey Point Units 3 and 4. Within 120 days from the date of the GL, licensees are required to submit a written report summarizing inspection activities and a description of any resin bead intrusions that have exceeded the current Electric Power Research Institute Pressurized Water Reactor Primary Water Chemistry Guidelines recommendations for primary water sulfate levels. Attached is FPL's response relative to the requested information in accordance with the GL schedule.

This response is provided pursuant to the requirements of Section 182a of the Atomic Energy Act of 1954, as amended, and 10 CFR 50.54(f).

Very truly yours,

Rajiv S. Kundalkar

R. S. Kundalkar
Vice President
Nuclear Engineering

A075 /1

OIH

Attachments

cc: Luis A. Reyes, Regional Administrator, Region II, USNRC
T. P. Johnson, Senior Resident Inspector, USNRC, Turkey Point Plant

Turkey Point Units 3 and 4
Docket Nos. 50-250 and 50-251
L-97-156

STATE OF FLORIDA )
) ss.
COUNTY OF PALM BEACH )

R. S. Kundalkar being first duly sworn, deposes and says:

That he is Vice President, Nuclear Engineering, for the Nuclear Division of Florida Power & Light Company, the Licensee herein;

That he has executed the foregoing document; that the statements made in this document are true and correct to the best of his knowledge, information and belief, and that he is authorized to execute the document on behalf of said Licensee.

Rajiv S. Kundalkar
R. S. Kundalkar

STATE OF FLORIDA

COUNTY OF PALM BEACH

Sworn to and subscribed before me

this 28th day of July, 1997

by R. S. Kundalkar, who is personally known to me.

Bernice M. Galinis
Name of Notary Public - State of Florida

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## GENERIC LETTER 97-01 - 120 RESPONSE

Generic Letter 97-01 (GL), "Degradation of Control Rod Drive Mechanism Nozzle and Other Vessel Closure Head Penetrations," was issued on April 1, 1997, to request licensees to describe their program for insuring the timely inspection of pressurized water reactor (PWR) control rod drive mechanism (CRDM) and other reactor vessel head penetrations (RVHP's). In addition, utilities were asked to assess and provide a description of any resin bead intrusion, as described in NRC Information Notice (IN) 96-11, that would result in sulfate levels exceeding the Electric Power Research Institute (EPRI) primary water chemistry guideline recommendations. This response provides Florida Power and Light (FPL) Co.'s Turkey Point Units 3 and 4 information relative to the GL.

FPL has worked with the Westinghouse Owners Group (WOG), EPRI and the Nuclear Energy Institute (NEI) to understand the operational experience, identify technical issues, causal factors, relative importance and solutions involving cracking of alloy 600 RVHP's since the industry became aware of the issue in 1991. One of these tasks was the development of safety evaluations that characterized the initiation of damage, propagation and consequences. This safety evaluation, "WCAP 13565 Rev. 1, Alloy 600 Reactor Vessel Head Adaptor Tube Cracking Safety Evaluation," applicable to Turkey Point Units 3 and 4, was submitted to the Staff along with evaluations from the other PWR owners groups through NEI (formerly NUMARC) on June 16, 1993. The NRC reviewed the safety evaluations and issued a safety evaluation report (SER) to NEI on November 19, 1993 (Ref. 2). The SER states, "...the staff has concluded that there is no immediate safety concern for cracking of the CRDM/CEDM penetrations. This is predicated on the performance of visual inspection activities requested in GL 88-05....". In addition, the WOG addressed the NRC open issues raised in the November 19, 1993 SER with "WCAP 14219 Rev. 1, RV Closure Head Penetration Supplemental Assessment of NRC SER Issues, March 1995." This report was submitted to the NRC through NEI and is referenced in the NEI White Paper entitled "Alloy 600 RPV Head Penetration Primary Water Stress Corrosion Cracking." The White Paper, dated March 5, 1996 was submitted to Mr. Brian Sheron, NRC on March 5, 1996. These safety evaluations, WCAP 13565 Rev. 1, WCAP 14219 Rev. 1 and the SER are applicable to Turkey Point Units 3 and 4 and establish the basis for their continued operation.

Based on these evaluations and the Turkey Point Unit 3 and 4 NRC approved ISI program(SER from the NRC dated March 31, 1995), FPL's

Turkey Point Units 3 and 4 are in compliance with 10CFR50.55a and 10CFR50 Appendix A, General Design Criteria (GDC) 14. Turkey Point was licensed to the 1967 proposed GDC 9. Our review of this draft GDC indicates it is essentially the same as 10CFR50 Appendix A GDC 14.

The GL questions are restated below with the Turkey Point Units 3 and 4 responses:

**NRC Question 1.1**

**A description of all inspections of CRDM nozzle and other VHPs performed to the date of this generic letter, including the results of these inspections.**

**FPL Response:**

To date Florida Power and Light Company (FPL) has performed visual inspections on the top of the reactor vessel (RV) head for leakage at both Turkey Point Units 3 and 4 as part of the ASME Section XI examinations and the commitment to GL 88-05. Although leakage of reactor coolant has occurred on the RV head area of both units, (Turkey Point 4-Information Notice 86-108, Turkey Point 3 canopy seal weld D-8, in 1988) the source of leakage was identified, corrected and the resulting boric acid residue was cleaned/removed. In addition, ASME Section XI dye penetrant examinations (PT) have been performed on the outer diameter surface of the full penetration bimetallic weld of the CRDM nozzles. At Turkey Point Unit 3, PT was performed on 3 CRDM bimetallic welds in 1983. At Turkey Point Unit 4, PT was performed on 3 CRDM bimetallic welds in 1987 and again in 1996. No evidence of any leakage from the alloy 600 portion of the reactor vessel head penetrations (RVHP's) has been discovered.

**NRC Question 1.2**

**If a plan has been developed to periodically inspect the CRDM nozzle and other VHPs:**

**a. Provide the schedule for first, and subsequent, inspections of the CRDM nozzle and other VHPs, including the technical basis for this schedule.**

**b. Provide the scope for the CRDM nozzle and other VHP inspections, including the total number of penetrations (and**

**how many will be inspected), which penetrations have thermal sleeves, which are spares, and which are instrument or other penetrations.**

**NRC Question 1.3**

**If a plan has <u>not</u> been developed to periodically inspect the CRDM nozzle and other VHPs, provide the analysis that supports why no augmented inspection is necessary.**

**NRC Question 1.4**

**In light of the degradation of CRDM nozzle and other VHPs described above, provide the analysis that supports the selected course of action as listed in either 1.2 or 1.3, above. In particular, provide a description of all relevant data and/or tests used to develop crack initiation and crack growth models, the methods and data used to validate these models, the plant-specific inputs to these models, and how these models substantiate the susceptibility evaluation. Also, if an integrated industry inspection program is being relied on, provide a detailed description of this program.**

**FPL Response to NRC Questions 1.2-1.4**

FPL's Turkey Point Units 3 and 4 are participants in the WOG RPV head penetration integrated inspection program. This program is being coordinated with the NEI as part of an industry integrated program. The WOG and NEI integrated program includes volumetric inspections of head penetrations that have been performed (Point Beach Unit 1, DC Cook Unit 2, North Anna Unit 2 per Ref. 1) and additional inspections of RVHP's that will be performed. Present plans call for two CE design plants and two Babcock & Wilcox (B&W) design plants to be inspected over the next three years (Only the licensee for plants performing inspections can make commitments to the actual scope and schedule of these inspections, however results of these inspections will be shared between the owners groups through NEI). Additional Westinghouse design plants are likely to be added in the coming months. Although the representative "lead" plant list in this program is dynamic, it is intended to include volumetric inspection of plant RVHP's based on the relative susceptibility of having a 75% through wall axial crack in a RVHP. The susceptibility will be based on probabilistic modeling of Primary Water Stress Corrosion Cracking (PWSCC) in alloy 600 material with an appropriate number of plants with relatively high susceptibility performing inspections.

**Modeling:** FPL has been aggressively addressing the issue of CRDM nozzle degradation since knowledge of the 1991 Bugey-3 leakage became available. FPL has worked with each of the three PWR vendors and owners groups, NEI, EPRI and others to best evaluate the issues associated with PWSCC in RVHP's as well as the susceptibility and consequences of PWSCC in the RVHP's at Turkey Point Units 3 and 4. FPL has performed an assessment of the PWSCC susceptibility of each CRDM/RVHP at Turkey Point Units 3 and 4 using the Dominion Engineering Inc., CRDM Nozzle PWSCC Inspection and Repair Strategic Evaluation (CIRSE) software tool. CIRSE is a long range planning model and is also being used by the B&W Owners Group (7 plants), 14 other Westinghouse designed plants (including Turkey Point), and is currently being funded by the members of the Combustion Engineering Owners Group for future modeling efforts. The CIRSE model is also being incorporated into an EPRI CHECWORKS® application.

CIRSE was developed to assist utilities in evaluating the appropriateness of various inspection, repair, and replacement strategies to determine the lowest lifetime cost for keeping the risk of leakage acceptably low (10CFR50 Appendix A, GDC 14). This tool uses a probabilistic approach to the development of a crack or through-wall leak within a CRDM nozzle during a plant's lifetime. This information is then used to evaluate a utility's need for reactor vessel head inspection. In addition, this long-range planning model determines the economic consequences of following various inspection strategies.

The CIRSE model is described in Attachment 2 of this response.

**Plant Specific Model Input:** Each Turkey Point Reactor has vessel head nozzle penetrations as noted in the table below. All 65 RVHP's are 4" diameter nozzles. All 45 of the full length CRDM nozzles contain thermal sleeves. In addition to the RVHP's in the table, each unit has one 3/4" head vent line in the top of the head.

| Turkey Point Unit # | Total # RVHP's | Full Length CRDM Nozzles | Part Length CRDM Nozzles | Instrument Columns Nozzles | Spare RVHP's |
|---|---|---|---|---|---|
| 3 & 4 | 65 | 45 | 4 | 8 | 8 |

The yield strength and hillside angle of each nozzle are significant input parameters in determining the residual stress at each nozzle location. The location of each specific heat (yield strength) is known and is input for each location in the residual stress analysis. Turkey Point Unit 3 utilized 6 different heats of Huntington Alloys material for RVHP's with yield strength values

between 30.0 ksi to 32.5 ksi for 64 penetrations and 1 penetration with 46.5 ksi. Turkey Point Unit 4 utilized 8 different heats of Huntington Alloys material for RVHP's with yield strength values between 30.0 ksi to 32.5 ksi for 59 penetrations and 6 penetration with values from 40.5 ksi to 63.0 ksi (Two nozzles have unknown yield strength values and were conservatively assigned at 63.0 ksi based on the highest yield strength known to have been supplied by Huntington Alloys for CRDM material).

Time of operation and nozzle temperature are also inputs into the CIRSE model. As of January 1, 1997, Turkey Point Unit 3 and 4 had approximately 136K and 132K effective full power hours (EFPH) respectively. The nozzle temperatures for both units are listed in Table 1 of Attachment 2 in the description of the CIRSE model.

**Model Predictions:** The crack prediction results for the Turkey Point Units 3 and 4 RVHP's using the CIRSE model will be incorporated into the WOG/NEI integrated inspection program. The scope of examination, how many and which plants, will be determined after the probability calculations have been performed for all WOG plants using the plant specific input. The time remaining prior to having a conservatively predicted 75% through wall flaw will be compared between all WOG plants and ultimately between each of the three PWR Owners Groups to determine the appropriate number of plants to inspect.

Although the probability predictions are not available for all WOG plants, the specific Turkey Point Units 3 and 4 results indicate there is greater than 2 full cycles(~ 3 years) of operation (EOC 18) before a 75% through wall flaw (84th percentile or one sigma probability in a Weibull distribution) is conservatively predicted to have occurred at Turkey Point Units 3 and 4 and therefore, sufficient time exists for the WOG and NEI integrated inspection plans to be finalized. The results will then be used to determine the appropriate number of inspections that are needed to demonstrate the adequacy of the WOG integrated inspection program. FPL anticipates that the WOG integrated inspection plan will be complete by December 31, 1997.

This time frame is sufficiently conservative since the FPL and industry approach is based on the conclusion that the issue is not a safety concern, because (1) the PWSCC process is slow; (2) the allowable or critical flaw size is large; (3) leak before break (LBB) will occur to allow safe shutdown of a plant; (4) at least six additional years of operation with an undetected penetration leak is required before ASME Code structural margins of the pressure vessel steel are challenged. These conclusions have been identified in the previous submittals and more recently summarized in WCAP 14902, "Background Material for Response to NRC Generic

Letter 97-01: Reactor Vessel Closure Head Penetration Integrity for Westinghouse Owners Group" (Ref. 1) which has been provided to the NRC under separate cover from the WOG.

FPL believes that the number of plants that have or will be inspected is sufficient to demonstrate the adequacy of the WOG/NEI integrated inspection program.

The need and schedule for re-inspection will be based on an evaluation of the inspection results from the WOG and NEI integrated inspection programs. The individual plant performing re-inspections will keep the NRC staff informed of its future re-inspection plans.

**NRC Question 2**

**Provide a description of any resin bead intrusions, as described in IN 96-11, that have exceeded the current EPRI PWR Primary Water Chemistry Guidelines recommendations for primary water sulfate levels, including the following information:**

**2.1 Were the intrusions cation, anion, or mixed bed?**

**2.2 What were the durations of these intrusions?**

**2.3 Does the plant's RCS water chemistry Technical Specifications follow the EPRI guidelines?**

**2.4 Identify any RCS chemistry excursions that exceed the plant administrative limits for the following species: sulfates, chlorides or fluorides, oxygen, boron, and lithium.**

**2.5 Identify any conductivity excursions which may be indicative of resin intrusions. Provide a technical assessment of each excursion and any followup actions.**

**2.6 Provide an assessment of the potential for any of these intrusions to result in a significant increase in the probability for IGA of VHPs and any associated plan for inspections.**

**FPL Response to NRC Questions 2.1 through 2.5**

FPL has reviewed the plant historical records to determine if any incident of resin ingress similar to those of 1980 and 1981 at the Jose Cabrera (Zorita) plant has occurred at Turkey Point Units 3 and 4. This data search was planned to identify all events of resin intrusion into the primary coolant system which were of a

magnitude greater than 1 cubic foot (30 liters). This threshold of 1 cubic foot was chosen as a conservative lower bound since it represents less than a very conservative 15% of the estimate for the volume of resin released into the reactor coolant system during the two events at Jose Cabrera.

For the period of plant operation prior to the routine analysis for sulfate in reactor coolant, the data search was based on a review of the plant's reactor coolant chemistry records relative to specific conductance of the reactor coolant. An elevation of a 28 micro siemens/cm (S/cm) increment in specific conductance was a value used as an indicator of cation resin ingress equivalent to 1 cubic foot.

Sulfate levels determined from analysis of reactor coolant were evaluated for plant operation from December 1990 to present. In this case a sulfate concentration of up to the range of 15 to 17 ppm concentration was used as the indicator of cation resin ingress, again equivalent to a volume of 1 cubic foot.

Had either specific conductance or sulfate increases indicated resin ingress to the magnitude of the threshold quantity identified above, additional data evaluation would have been conducted to ascertain a corresponding depression in pH or elevation in lithium as corroborating information of the incident. Had a significant in-leakage event been identified by the use of sulfate data as the indicator, specific conductance would also have been included as the confirmatory data. No evidence of resin ingress was identified.

FPL considered that it was unnecessary to review plant records for boron, chlorides, fluorides and oxygen since these species are not viewed as valid indicators of cation resin ingress and degradation within the primary coolant system of a PWR. Borate, chloride, and fluoride anions could be associated with the anion portion of mixed bed resin (cation plus anion); however, if mixed bed resin leakage to the Reactor Coolant System (RCS) occurred, the cation portion of the resin would contain the sulfate indicator described above. Detectable dissolved oxygen in reactor coolant, during power operation with appropriate hydrogen overpressure (on the volume control tank) and specified residual dissolved hydrogen in the reactor coolant, could not occur and therefore, could not be associated with resin in-leakage.

FPL reviewed reactor coolant chemistry logs for Turkey Point Unit 3 from December 1972, and for Turkey Point Unit 4 from March 1972 to present. Where specific conductance increased above 25 micro S/cm, these values were compared with theoretical specific conductance based on boron, lithium and ammonia with no indication of resin

ingress.

Turkey Point Units 3 and 4 Technical Specifications for RCS chemistry only address chloride, fluoride, and oxygen. The limits for operational modes 1 and 2 are as follows; chloride and fluoride, less than or equal to 150 ppb. The limit for oxygen is less than or equal to 100 ppb. The Technical Specifications do not address sulfate. Administratively sulfate is a diagnostic parameter with the same limits listed by EPRI. Sulfate, as well as other parameters identified by EPRI are routinely monitored. In some cases, our monitoring schedule is more conservative than the EPRI Guidelines.

EPRI Guidelines, by definition, must be more conservative than Technical Specifications as the Technical Specifications are more directed to safe operation of the plants and not chemistry controls.

**FPL Response to NRC Question 2.6**

The results of the FPL's review of Turkey Point Units 3 and 4 historical RCS chemistry records indicate no resin intrusion was identified as described above. Based on these results there would be no increase in the probability for intergranular attack of RVHP's and therefore, FPL has no plans to inspect for degradation as found at Zorita as described in NRC IN 96-11 and GL 97-01.

**REFERENCES**

1 "Background Material for Response to NRC Generic Letter 97-01: Reactor Vessel Closure Head Penetration Integrity for Westinghouse Owners Group," Westinghouse Owners Group, July 1997, WCAP 14902.

2 NRC Letter, "Safety Evaluation for Potential Reactor Vessel Head Adaptor Cracking," Letter from William T. Russell, NRC to William Rasin, NUMARC, November 19, 1993.

## DESCRIPTION OF THE CIRSE MODEL

The following items describe the overall methodology of the CRDM Nozzle PWSCC Inspection and Repair Strategic Evaluation (CIRSE) model:

- Use of a Weibull distribution of industry control rod drive mechanism (CRDM) cracking data corrected for temperature, stress, material, and fabrication to predict crack initiation.

- Use of a power-law stress intensity equation corrected for temperature with distributed growth rates to predict crack growth.

- Use of Monte Carlo analysis to handle variable-cracking-susceptibility population and distributed input parameters and to calculate probability of a crack or leak.

- Calculation of lifecycle cost for alternative strategic scenarios for inspection, repair, and remediation.

Because prediction of Primary Water Stress Corrosion Cracking (PWSCC) can best be treated as a statistical process, the Monte Carlo Method is used by the CIRSE model. The Monte Carlo Method allows input parameters to have distributed values rather than just single numerical values. As discussed below, the time to crack initiation and crack growth rate do not have single values, but rather can hold a continuous range of values. In addition, many other input parameters are best described using statistical distributions. Furthermore, the wide variation in PWSCC susceptibility between nozzles in a single unit precludes the use of a semi-deterministic prediction scheme based on a median ranking of a single Weibull curve.

The CIRSE model predicts on a statistical basis, the time when a nozzle cracks and the maximum crack depth within a nozzle as a function of time combining crack initiation and crack growth models. CIRSE uses a two-parameter Weibull distribution to calculate the probability that a nozzle will have initiated a crack by a certain time:

$F(t) = 1 - \exp(-(t/\theta)^b)$ where

$F$ = probability of a nozzle cracking by time t
$t$ = degradation time
$\theta$ = "characteristic time" to 63.2% probability of cracking
$b$ = Weibull "slope" which represents scatter

Rather than using θ, the CIRSE model requires the input of a corresponding quantity, the time to 10% probability of cracking ($t_{10\%}$):

$$t_{10\%} = \theta \, [ -\ln ( 0.9) ]^{1/b}$$

Because the time to PWSCC initiation is believed to be a function of surface stress, operating temperature, material susceptibility (microstructure properties and surface condition), and water chemistry environment, any reference time to 10% must be scaled to account for differences in these variables. This is done using a Relative Susceptibility Factor (RSF):

$$t_{10\%} = t_{10\%,\,ref} \, / \, RSF$$

$$RSF = [f_{chem} / f_{chem,ref}][f_{fab} / f_{fab,ref}][f_{mat} / f_{mat,ref}][s_{sur} / s_{sur,ref}]^x \exp[- Q_i(1/T - 1/T_{ref})/R]$$

where

$t_{10\%}$= time to 10% probability of crack initiation (used to calculate probability F in above equation)

RSF = relative susceptibility factor for scaling $t_{10\%}$

$f_{chem}$= water chemistry factor (constant for all nozzles in a unit)

$f_{fab}$= nozzle fabrication factor (to account for undesirable surface conditions caused during fabrication)

$f_{mat}$= material factor (constant for all nozzles of a given heat)

$s_{sur}$= maximum operating inside surface tensile stress

x = stress exponent (approximately 4.0)

$Q_i$ = activation energy for initiation (kcal/mole)

R = gas constant ($1.103 \times 10^{-3}$ kcal/mol°R)

T = absolute nozzle operating temperature

and the "ref" subscripts denote the reference curve values.

The maximum operating surface stresses have been calculated for all 130 (65 each unit) Turkey Point Units 3 and 4 nozzles using the results of Dominion Engineering's Finite Element Analysis (FEA) weld process-induced residual stress model. To date, material, fabrication, and water chemistry factors have not been developed for CRDM or thermocouple nozzles, so these factors are all set to 1.0. In addition, CIRSE does not input values for $f_{chem,ref}$, $f_{fab,ref}$, and $f_{mat,\,ref}$; these parameters are assumed to be one (1.0) for the reference time to 10% ($t_{10\%,\,ref}$).

Additional details concerning the development of the time to 10% crack initiation parameter and its use in the CIRSE model have been described in References (1) and (2).

Crack growth, for the safety evaluation work, was originally based on the model developed by Peter Scott (Ref. 3). Recent industry testing has substantiated this model (Ref. 4). In general, the materials used in the testing were typical of those used throughout the industry, and in particular, several heats of material manufactured by Huntington Alloys (manufacturer of the material used for the Turkey Points Unit 3 & 4 RVHP's) were included in the tests.

The crack growth model used by CIRSE uses the same linear-elastic fracture mechanics model developed by Peter Scott that has become the accepted industry standard for CRDM nozzle PWSCC. (The use of linear-elastic fracture mechanics is conservative for this situation given that the welding residual stresses exceed the material yield strength.) The rate of crack growth into the nozzle wall is calculated as follows:

$\mathring{a} = A\,(K - K_{th})^n$ where

$\mathring{a}$ = rate of crack depth increase (usually in m/s or mm/yr)

$A = A_{ref}\exp[-Q_g(1/T - 1/T_{g,ref})/R]$

= reference growth rate constant scaled for the effect of nozzle temperature

$K = 1.1 s_{mid}\sqrt{\pi a}$

= nozzle maximum stress intensity (usually in units of $MPa\sqrt{m}$)

$K_{th}$ = stress intensity threshold (default value of 4.0 $MPa\sqrt{m}$)

$n$ = power-law exponent (default value is the Scott value of 1.16)

$Q_g$ = activation energy for growth (kcal/mole)

$R$ = gas constant ($1.103 \times 10^{-3}$ kcal/mol x $^oR$)

$T$ = absolute nozzle operating temperature

$a$ = crack depth

$s_{mid}$ = maximum operating stress (the CIRSE model used the maximum midwall stress)

and the "ref" subscripts denote the reference values.

The CIRSE model uses the exact analytic solution to the crack growth rate differential equation to calculate the time required for a crack to grow from one depth to another. A finite value is required for the initial crack depth, and the default value is assumed to be 0.1 mm (0.004 inch). The stresses required for the stress intensity calculation have also been calculated using Dominion Engineering's stress analyses, which include both operating and residual stresses. Because field and laboratory data show considerable scatter in the relationship between crack growth rate and stress intensity, CIRSE uses a statistical distribution of crack growth rate constants $F(A_{ref})$.

Reference Plant Selection: Both Turkey Point Units 3 and 4 are Westinghouse designed plants that were fabricated by Babcock &

Wilcox with SB 167-600 extruded material supplied by Huntington Alloys.

EdF and Westinghouse concluded that the following factors contributed to the Bugey Unit 3 PWSCC failure:

- Susceptible material microstructure - $f$(n) of alloy 600 supplier processing
- Surface finish on the inside of the penetration - $f$(n) of vessel penetration fabricator
- Stress induced during welding - $f$(n) of design/weld size

Considering these 3 factors, the best predictions of CRDM nozzle cracking at Turkey Point Units 3 and 4 are made based on inspection results at Oconee Unit 2 (the reference plant). Oconee Unit 2 is a B&W designed and fabricated vessel with SB 167-600 extruded material RVHP's supplied by B&W tubular products and the specific material/penetration locations are known for correlation to the inspection results. The selection of Oconee 2 as the reference plant for both Turkey Point units is appropriate for the following reasons.

Both Turkey Point Units 3 and 4 and Oconee Unit 2 plants were fabricated by B&W with SB 167-600 extruded material. Since the weld stresses produced during fabrication are primarily a function of design (weld size) and operation and have been specifically modeled with the Dominion Engineering's FEA model, comparison can be made to any (reference) plant provided design aspects and material hole locations of the reference plant can be quantified. Surface finish and penetration fabrication are not variables that are specifically modeled but can influence PWSCC susceptibility. Therefore, a reference plant made by the same vessel fabricator would account for many of the subtle fabrication method differences that are not modeled such as surface finishing and other specific fabrication practices. A reference plant that also contained Huntington Alloys SB 167-600 material would have been ideal but at present no Huntington Alloys supplied RVHP material plants have detected cracking indications.

Other reference plants considered include Point Beach Unit 1 which would have been an ideal reference plant for Turkey Point Units 3 and 4 since it was fabricated by B&W with Huntington Alloys SB 167-600 material and shares three of the high strength heats of CRDM nozzle material in use at Turkey Point Units 3 and 4: NX-4906, NX-4909 and NX-5212. This plant had approximately 5 EFPY's more time of operation at the time of inspection than either Turkey Point Units 3 and 4 without indication of cracking, the specific material heat/vessel hole locations were unknown and therefore modeling could not be performed. The only other vessels that have been inspected with Huntington Alloys supplied SB 167-600 are the Spanish plants Almarez 1 & 2, and Asco 2. These Spanish plants were not considered as reference plants since they did not detect PWSCC and the specific nozzle yield strength values were unknown.

Many of the inputs to the CIRSE model are best treated as statistically distributed parameters. For example, the time until crack initiation is assumed to follow a two-parameter Weibull distribution. For each Monte Carlo trial, CIRSE randomly samples two initiation times for each nozzle, one for the above weld region and one for the below weld region, by inverting the Weibull distribution. Table 1 below contains a list of the CIRSE model inputs with the range of input values used. All distributions are triangular except for the Reference Crack Growth Curve Constant which is Log triangular distribution.

Table 1: Inputs Used in the CIRSE Model For Turkey Point PWSCC Evaluation

| CIRSE Input | Units | Lower Bound | Nominal Values | Upper bound |
|---|---|---|---|---|
| **Nozzle Inputs** | | | | |
| Nozzle Temp Turkey Point 3&4[1] | °F | 599.8 | 604.8 | 609.8 |
| Nozzle Stress - *f* (yield strength, FEA results) | % from Nom. | -10% | Nominal | +10% |
| Material/Fab Factor[2] | ----- | 1.0 | 1.0 (not used) | 1.0 |
| Water Chemistry Factor[2] | ----- | 1.0 | 1.0 (not used) | 1.0 |
| **Crack Initiation Inputs** | | | | |
| Ref time to 10%[3] | EFPY | 20 | 32 | 50 |
| Weibull Slope | ----- | 2 | 3 | 4 |
| Activation Energy | kcal/mole | 45.0 | 50.0 | 55.0 |
| Stress Exponent | ----- | 3 | 4 | 5 |
| **Crack Growth Inputs** | | | | |
| Ref. Growth Curve Constant[4] | m, s, MPa | .366E-12 | .164E-11 | .310E-11 |
| Activation Energy | kcal/mole | 30.0 | 33.0 | 35.0 |

Table Notes:
1) Future predictions based on these temperatures. In October 1996 both units initiated a thermal power uprate. Prior to that time 600.3°F was used as the nozzle temperature.
2) Since these factors have not been defined, these parameters are assigned a value of 1.0, which has no effect on predictions.

3) Reference Parameters are $T_{ref} = 602°F$ and $S_{sur,ref} = 56.7$ ksi.
4) Reference Parameters are $T_{ref} = 617°F$.

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