TECHNICAL EVALUATION REPORT

FRACTURE TOUGHNESS OF STEAM GENERATOR AND REACTOR COOLANT PUMP SUPPORTS

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
SALEM NUCLEAR POWER STATION UNIT 1

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1. SUMMARY

Information concerning aspects of the fracture-toughness design of the steam generator (S/G) and reactor coolant pump (RCP) supports for the Salem Nuclear Power Station Unit 1 was submitted to The Director of Nuclear Reactor Regulation by the Public Service Electric and Gas Company (PSE&G) by letter dated Dec. 30, 1977. This information was reviewed at the Franklin Research Center (FRC) and evaluated in accordance with the criteria of the Nuclear Regulatory Commission (NRC) as set forth in NUREG 0577-Draft (henceforth referred to simply as NUREG 0577).

The information had previously been reviewed as part of the preparation of NUREG 0577, and Salem Unit 1 had been assigned a Group III (relatively best) plant ranking for fracture toughness of S/G and RCP supports. This ranking was regarded as tentative. Subsequently, the NRC requested FRC to conduct an independent review prior to finalizing the ranking.

FRC's review was confined to fracture-toughness issues in supports above the embedment. The review was conducted in accordance with NRC criteria and to a procedure standardized for the several licensees whose support designs were reviewed at FRC.

As a result of its review, FRC confirmed that the Group III plant ranking assigned to Salem Nuclear Power Station Unit 1 for fracture toughness of S/G and RCP supports is justifiable.

2. INTRODUCTION

This report provides a technical evaluation of information supplied by PSE&G with its letter of Dec. 30, 1977, to The Director of Nuclear Reactor Regulation. The information concerns the fracture-toughness design of supports for the S/Gs and RCPs for Salem Unit 1. The objective of the evaluation is to rank the design for fracture-toughness integrity on a relative scale in accordance with the grouping scheme and criteria established in NUREG 0577.

3. BACKGROUND

During the course of the NRC licensing review for two pressurized water reactors (PWR), North Anna Units 1 and 2, questions were raised regarding the fracture-toughness adequacy of certain members of the S/G and RCP supports. The potential for lamellar tearing in some support members was also questioned.

The staff's concern in the North Anna licensing process was that perhaps not enough attention had been given to the selection of materials for, and fabrication of, the S/G and RCP supports.

Fracture toughness of a material is a measure of its capability to absorb energy without failure or damage. Generally, a material is considered "tough" when, under stated conditions of stress and temperature, the material can withstand loading to its design limit in the presence of flaws. Toughness also implies that, under certain conditions, the material has the capability to arrest the growth of a flaw. A lack of adequate toughness (accompanied by the combination of low operating temperature, presence of flaws, and nonredundancy of critical support members) could result in failure of the support structure under postulated accident conditions, specifically a loss-of-coolant accident (LOCA) and safe shutdown earthquake (SSE).

To address fracture-toughness concerns at the North Anna facility, the licensee undertook tests not originally specified and not included in the relevant ASTM specifications. These tests indicated that material used in certain support members had relatively poor fracture toughness at 80°F metal temperature.

In this case, the licensee agreed to raise (by ancillary electrical heat) the temperature of the S/G support beams in question to a minimum of 225°F every time, throughout the life of the plant, that the reactor coolant system (RCS) is pressurized above 1,000 psig. The NRC staff found this to be an acceptable resolution.

Because similar materials and designs were used in other plants and because similar problems were therefore possible, this matter was incorporated into the NRC Program for Resolution of Generic Issues as "Generic Technical

Activity A--12, Potential for Low Fracture Toughness and Lamellar Tearing on PWR Steam Generator and Reactor Coolant Pump Supports."

Since the original licensing action (North Anna Units 1 and 2) involved only the S/G and RCP supports of PWRs, the staff's initial efforts were directed toward examination of the corresponding supports at other PWR facilities. However, the staff has kept in mind the possibility of expanding its review to include other support structures in PWR plants and support structures in boiling water reactor (BWR) plants.

The integrity of support embedments was not questioned during the North Anna licensing action; consequently, emphasis was placed on resolving the most immediate generic issue--whether or not problems similar to those uncovered at North Anna exist at other facilities. It was the staff's judgment that inclusion of an evaluation of support embedments in the initial review would require detailed, plant-specific investigations that were beyond the scope of the preliminary, overall generic review. Such considerations were deemed more suited to a subsequent phase when more detailed investigations of individual plants might be undertaken.

Requests for information were sent to licensees in late 1977; responses to these requests were received during 1978.

Sandia Laboratories in Albuquerque, New Mexico, was retained to assist the staff in the review and analysis of the information received from licensees and applicants. Based on analysis of this information, the technical studies performed by Sandia Laboratories, and review of the issues by the NRC staff, the NRC developed an NRC staff technical position on these issues, which is presented in NUREG 0577, "Potential for Low Fracture Toughness and Lamellar Tearing on PWR Steam Generator and Reactor Coolant Pump Supports."

In addition, NUREG 0577 establishes criteria for evaluation of the fracture-toughness adequacy of S/G and RCP supports. NUREG 0577 also applies certain of these criteria to the support structures of a number of PWR plants to achieve plant groupings according to the relative fracture-toughness integrity of these supports.

The plant ratings are:

- Group I (lowest)
- Group II (intermediate)
- Group III (highest)

During the generic study, a number of PWR plants were reviewed for the fracture-toughness adequacy of their RCP and S/G designs. As a result of these reviews, each plant was assigned a tentative plant ranking of either Group I, II, or III.

Several Plants, Salem Unit 1 among them, were tentatively ranked Group III. In the appendix to NUREG 0577 prepared by Sandia Laboratories, who initially established the rankings which subsequently received NRC staff endorsement, the significance of the Group III ranking is described as: "considered to be as good as careful, reasonable engineering practice can produce."

However, before finalizing the tentative Group III rankings, the NRC requested FRC to conduct an independent review of the Group III plants (in conjunction with similar FRC task assignments to review the fracture-toughness adequacy of corresponding supports in certain other plants) and to prepare a Technical Evaluation Report for each plant, presenting the review findings.

The technical evaluation reported herein applies the criteria of NUREG 0577 to the S/G and RCP supports for Salem Unit 1 to provide an assessment of the fracture-toughness adequacy of these supports leading to a plant ranking.

4. CRITERIA APPLIED IN THE EVALUATION

4.1 FRACTURE-TOUGHNESS GROUPING OF MATERIALS USED IN SUPPORT CONSTRUCTION

4.1.1 Criterion

Table 4.6, Material Groups, of Appendix C to NUREG 0577 groups materials according to their relative fracture toughness as:

- Group I (poorest)
- Group II (intermediate)
- Group III (best)

4.1.2 Interpretation

If no supplementary requirements were called out in the material specification aimed at procuring a product with fracture-toughness properties superior to those routinely supplied under the material specification, then the material was grouped in accordance with Table 4.6.

If additional requirements aimed at procuring a product with superior fracture-toughness properties were specified, consideration was given to crediting this specific material order with an improved material-group rating.

4.2 PLANT GROUPING FOR FRACTURE-TOUGHNESS RANKING OF S/G AND RCP SUPPORT STRUCTURES

4.2.1 Criterion

Plants are classified on the basis of the construction materials used in the supports after giving consideration to the importance of their location and function within the structure, and their consequent importance to support-structure integrity. (Refer to pages 5 and 6 of NUREG 0577, Part I.)

4.2.2 Interpretation

Plants were assigned a plant-group ranking identical to the material-group ranking of the least fracture-tough material used in the construction, provided this usage is important to support integrity.

4.3 CRITERIA FOR FRACTURE-TOUGHNESS ADEQUACY OF S/G AND RCP SUPPORTS

It is the clear intent of NUREG 0577 that licensees demonstrate the fracture-toughness adequacy of the S/G and RCP supports or that they take appropriate corrective measures to assure their fracture-toughness integrity. NUREG 0577 provides guidance for such demonstrations.

4.3.1 NDT Criteria for Screening

$$\overline{NDT} + 1.3\hat{\sigma} + \begin{cases} 30°F \\ \text{or} \\ 60°F \end{cases} \leq T_{supports}(°F)$$

where:

- $\overline{NDT}$ is the mean nil ductility transition temperature appropriate to the material as given by Table 4.4 of Appendix C to NUREG 0577.
- $\hat{\sigma}$ is the standard deviation for the data used to determine NDT as listed in Table 4.4.
- $T_{supports}$ is the lowest metal temperature that the support member will ever experience throughout the plant life when the plant is in an operational state. In the absence of measured, plant-specific data, $T_{supports}$ is taken as 75°F.
- The temperature term, 30°F or 60°F, is an allowance for section size (30°F for thin sections and 60°F for thick sections).

4.3.2 Interpretation

If evidence is furnished by the licensee proving that other values of $\overline{NDT}$, $\hat{\sigma}$, or $T_{supports}$ are actually valid for the S/G or RCP supports and materials in the licensee's plant, such data may be used. If acceptable alternative evidence is not available, the above-stipulated values should be used.

4.3.3 Alternative Criteria

NUREG 0577 also recognized that fracture-toughness integrity is a complex matter involving a number of interrelated factors, most of which are plant specific. Consequently, demonstration of compliance with the screening criteria is but one means of providing satisfactory assurance of fracture-toughness adequacy.

NUREG 0577 not only recognizes that other means of showing compliance with the intent of NUREG 0577 are possible, but also offers extensive guidance relating to several approaches by which such a demonstration may be achieved. Because of the plant-specific character that such demonstrations must take, NUREG 0577 does not restrict the licensees to any single approach but, instead, encourages each licensee to review the fracture-toughness adequacy of his S/G and RCP supports and submit evidence of his findings.

5. TECHNICAL EVALUATION

The information furnished to the NRC regarding the fracture toughness of, and the potential for lamellar tearing in, S/G and RCP supports at Salem Unit 1 was reviewed at FRC. This information was supplied in response to the NRC staff's generic letter to PWR licensees concerning these issues. A copy of the staff's request-for-information letter (in generic form) may be found in NUREG 0577, Appendix B.

Only fracture toughness issues were addressed in the FRC review; the review procedure is described below.

5.1 REVIEW PROCEDURE AND IMPLEMENTATION OF NRC CRITERIA

The drawings and information submitted were first examined to become familiar with the structural design, material selection, and construction practices. Key items from this information were condensed to tabular form and are presented in Table 5.1.

In accordance with a review procedure standardized for the licensees whose plants were evaluated at FRC, the first step was to compile a list of materials used in all members significant to the structural integrity of the S/G and RCP supports. The listed materials were taken from those reported in the response to Item 1 of the NRC's request for information, supplemented by a survey of the support drawings for additional materials which might be indicated there.

To each of the materials so identified, two criteria tests were applied:

1. The NDT criteria for screening (paragraph 4.3.1 of this report).

2. The material group ranking in accordance with the procedures of Section 4.1.

For plants which used them, materials with an assigned Group I or Group II fracture-toughness rating were further categorized as thick or thin by using the formula shown on the following page to determine the section thickness above which brittle (plain strain) behavior may be anticipated under dynamic load.

TABLE 5.1

COMPONENT SUPPORT SUMMARY

PLANT: SALEM 1

UTILITY	NSSS	AE	SUPPORT SUPPLIER
Public Service Electric & Gas	Westinghouse	P.S.E.&G.	

MATERIALS

TYPE	MILL CERTS. AVAILABLE	HEAT TREATMENT	NDE ON MATERIAL	FRACTURE TOUGHNESS TEST	MAXIMUM ALLOWABLE DESIGN STRESS: MEMBRANE & BENDING (NORMAL)	MAXIMUM ALLOWABLE DESIGN STRESS: THROUGH THICKNESS
Construction Materials: A-36 A-441 AISI 4140 AISI 4640 Bolting Materials: A-194 GR 2 A-325 A-490 Vascomax 300 Camvac 200 Welding Materials: E7016, 17, 18, E70-T1,T2 F71-EL12	Yes	Silicon Killed +Normilized A-441 AISI 4140 H.T. to 77 ksi. Yield AISI 4640 Annealed +cold drawn to 97 ksi. min. Y.P.		A-36 not in tension CVN on A-441 (20 ft-lb @ 20°F)	Normal: AISC Allowables Upset: 1.33xAISC Allowables Emergency: $0.9\ S_y$ Faulted: $1.0\ S_y$	Max. Thru. Thickness Stress 19.23 ksi

FABRICATION

WELDING PROCESS	WELDING PROCEDURE	POST-WELDING TREATMENT	METHODS USED TO PREVENT LAMELLAR TEARING	NDE AND INSPECTIONS PERFORMED
Manual Metal Arc Flux Cored Submerged Arc	AWS D2.0 with preheat dependent on thickness			M.P. at 4 weld depth UT where possible

DESIGN

TYPE OF SUPPORT	CODE USED	LOADING CONDITIONS	MINIMUM TEMPERATURE OF SUPPORT
Space Frame	-	DL + TL - normal DL + TL + OBE - upset DL + TL + PR - emergency DL + TL + DBE - faulted DL + TL + PR + DBE - faulted	70°F (Minimum operating temperature in containment building).

The critical thickness is given by:

$$t_c = 2.5 \left[\frac{K_{ID}}{\sigma_{yD}}\right]^2$$

where:

σ_{yD} is the dynamic yield strength of the steel.

K_{ID} is the nominal, minimum assured fracture toughness of the steel in accordance with values supplied by NUREG 0577.

t_c is the critical thickness. In members thicker than t_c, brittle (i.e., plane strain) behavior may be expected.

A similar categorization for Group III materials was not deemed necessary for purposes of the review, because such materials are sanctioned for thick-section use by virtue of their group rating.

Structural drawings were then examined for:

1. All structurally significant uses of Group I materials.

2. All structurally significant uses of Group II materials in thick sections.

3. Structurally significant applications of materials known to be sensitive to stress corrosion cracking or other special failure mechanisms which might make them prone to brittle behavior.

The circumstances associated with such usage were then examined. Consideration was given to factors such as: direction of loadings (always compressive or sometimes tensile), stress levels in the member as indicated in the licensee's response, the presence of stress raisers in member geometries, redundancy of load paths, and the like. Applications judged to be of problematic fracture toughness were identified for more detailed evaluation at a future date.

In addition, information furnished on welding and material specifications was examined for fracture-toughness implications by a welding engineer and a metallurgist, respectively.

As a result of the review findings and in accordance with the criteria procedure described in Section 4.2 of this report, a tentative plant ranking for fracture-toughness adequacy of S/G and RCP supports was assigned.

5.2 EXTENT OF FRC REVIEW

FRC's evaluations were restricted to assessments of the fracture toughness of supports for steam generators and reactor coolant pumps. Assessment of the fracture-toughness adequacy of supports for the other components and of the embedment was not included in the scope of FRC's work assignment and was not investigated.

The upper region of the steam generators is also constrained against lateral displacement by additional structure. Drawings showing this structure and its materials of construction were not provided in the material furnished for review. FRC's evaluations are therefore based upon the review of all support structures other than these.

5.3 REVIEW FINDINGS

5.3.1 Use of Group I Materials in Applications Important to Structural Integrity of Supports

None found.

5.3.2 Thick Section Use of Group II Materials in Applications Important to Structural Integrity

None found.

5.3.3 Thin Section Use of Group II Materials in Applications Important to Structural Integrity

Occasional use of ASTM A-36 steel was found in the Salem support structures, but only in applications which clearly pose no fracture-toughness problems. Use in principal elements of the structure was not found and, in the only applications indentified, the A-36 steel was not subject to tensile loads.

5.3.4 Use of Materials Classified Group III by NUREG 0577, Upon Condition

Major structural members of both the S/G and RCP supports are constructed of ASTM A-441, a high-strength low-alloy steel. This steel, as routinely furnished from the mill, is ranked Group II by NUREG 0577. Here however, the steel was ordered silicon-killed, normalized, and subject to supplementary requirements for Charpy V-Notch testing. These requirements were added to assure a mill product of enhanced fracture toughness. When A-441 is ordered to such requirements, the steel is deemed to merit a Group III ranking.

Camavac 200, an 18% nickel maraging steel, is specified for hinge pin use in the RCP support structure. Camavac 200 is a material known to be susceptible to stress corrosion cracking. Because of this, it is classified as a Group I material by NUREG 0577 when no restriction is placed upon its use. In the hinge pin application, however, the pins are not subjected to tensile loads and must only sustain shear (and possibly bending) loads upon occasion. Under these circumstances the pins are not considered to present a fracture-toughness problem and thus, in this application, the steel may be considered equivalent to a Group III steel.

Corresponding hinge pins in the S/G generator support structure are 8 1/2 inch diameter. Here AISI 4640, annealed and cold drawn to 97 ksi minimum yield strength, is specified as a replacement steel for a Vascomax steel originally specified. In this application the AISI 4640 steel is not in tension but may become occasionally loaded in shear (with some superimposed bending). Although not classified by NUREG 0577, AISI 4640 steel, can in this application be considered equivalent to a Group III steel, in FRC's judgement.

Although Vascomax 200 is not specifically classified in NUREG 0577, Vascomax 300 is. Because this grade is also sensitive to stress corrosion cracking when used in humid atmospheres and subjected to significant stress, NUREG 0577 classifies it as a Group I material for unrestricted use in S/G and RCP supports.

Vascomax 300 is used in Salem only for a 4 inch diameter bolt which provides hold-down capability to the RCP under jet reactions from certain postulated pipe ruptures. In all other circumstances, this bolt remains unstressed. Thus, in this specific application, stress corrosion cracking does not appear likely to present a problem, and the use of Vascomax 300 for this bolt can be sanctioned.

5.3.5 Use of Materials Classified Group III by NUREG 0577, Outright

All bolting and welding materials

6. CONCLUSION

The design and construction of supports for steam generators and reactor coolant pumps at Salem Unit 1 has been reviewed for fracture-toughness adequacy at the FRC.

Criteria for the suitability of materials and construction practices for S/G and RCP supports were provided by the NRC staff, as published in NUREG 0577- Draft. In the review, general criteria of NUREG 0577 were specifically applied to information furnished by Public Service Electric and Gas Company (PSE&G) concerning the supports in Salem Unit 1.

The review was restricted to supports (above the embedment) for steam generators and reactor coolant pumps. Conclusions relating to them do not necessarily extend to the support design of other components.

In the case of Salem Unit 1, FRC concludes that:

1. Engineering measures taken in support design, material selection, material specification, material acceptance testing, fabrication methods, and inspections provide reasonable evidence that the steam generator support structures possess adequate fracture toughness to meet NRC criteria for a Group III rating.

2. Engineering measures taken in the design and construction of the reactor coolant pump supports provide similar evidence to qualify them for a Group III rating also.

3. The Group III (relatively highest) plant rating for fracture-toughness adequacy of supports assigned to Salem Unit 1 in NUREG 0577-Draft is justifiable.

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