TECHNICAL EVALUATION REPORT

FRACTURE TOUGHNESS OF STEAM GENERATOR AND REACTOR COOLANT PUMP SUPPORTS

COMMONWEALTH EDISON COMPANY
ZION NUCLEAR POWER STATION UNITS 1 AND 2

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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 Zion Nuclear Power Station Units 1 and 2 was submitted to The Chief of the Operating Reactors Branch of the Division of Operating Reactors by the Commonwealth Edison Company (CEC) by letter dated Dec 6, 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 Zion 1 and 2 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 the Zion Nuclear Power Station Units 1 and 2 for fracture toughness of S/G and RCP supports is justifiable.

2. INTRODUCTION

This report provides a technical evaluation of information supplied by CEC with its letter of Dec. 6, 1977, to Mr. Albert Schwencer, Chief Operating Reactors Branch of The Division of Operating Reactors. The information concerns the fracture-toughness design of supports for the S/Gs and RCPs for Zion Units 1 and 2. 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 consequently 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 an analysis of the 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, Zion Units 1 and 2 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 Zion Units 1 and 2 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

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

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 Zion 1 and 2 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 plates which used them, materials with an assigned Group I or Group II fracture-toughness rating were further categorized as thick or thin 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: Zion 1 & 2

UTILITY	NSSS	AE	SUPPORT SUPPLIER
Commonwealth Edison	Westinghouse	Sargent & Lundy	

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:						
A7 A-36 A-588 A-242 A-441		A-36 to fine-grain practice A-588 normalized if 3 in. thick	UT under weld areas	CVN Requirements (15 ft-lbs @ 0°F) for A-36, A-588 Weld Metal & HAZ Thru-Thickness Tensile Tests	Normal: AISC Manual Allowables Faulted: S_y (Except controlled area)	0.6 S_y
Bolting Materials:						
A-193 B7 A-194 Gr 7 AISI 4340						
Low-H Welding Material						

FABRICATION

WELDING PROCESS	WELDING PROCEDURE	POST-WELDING TREATMENT	METHODS USED TO PREVENT LAMELLAR TEARING	NDE AND INSPECTIONS PERFORMED
Low-Hydrogen	ASME Section VIII	Stress Relief	AISC Joint Designs	LP RT UT 100% under welds

DESIGN

TYPE OF SUPPORT	CODE USED	LOADING CONDITIONS	MINIMUM TEMP ...TURE OF SUPPORT
Pin-Column	1963 AISC	DL + TL DL + TL + DBE DL + TL + OBE DL + TL + PR DL + TL + PR +OBE	Measured temps. during hot shutdown: 71°F (bottom of S/G supports) 74°F (bottom of RCP supports)

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 on material specifications was examined for its 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 REVIEW FINDINGS

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

None found.

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

None found.

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

ASTM A-242 is indicated on Sargent and Lundy drawings as being used in 1/2 inch thick sections in the S/G upper lateral support ring. Although NUREG 0577 does not classify this high-strength low-alloy steel specifically, it is FRC's judgement that a Group II ranking for A-242 steel (as typically supplied when no special requirements to improve toughness are invoked) is appropriate. In view of the thin section use and the function of this support, FRC believes the fracture toughness of the steel is satisfactory in this application.

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

Steel for most of the principal members of both the S/G and RCP supports is ordered to either ASTM specification A-36 or to A-588. These material orders were supplemented by additional requirements to assure fracture-toughness of mill products.

It was required that the A-36 be produced to fine grain practice and meet Charpy V-Notch impact tests (15 ft-lbs at 0°F).

For thick-section use, A-588 steel was purchased in the normalized condition and required to meet Charpy V-Notch impact tests of 15 ft-lbs (ave. of

three tests; 10 ft-lbs min.) at 0°F, and be ultrasonically tested if furnished as plate.

The additional specification requirements invoked for both steels qualify the A-36 and the A-588 steels in these supports structures for Group III material ratings.

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

All bolting and welding materials.

5.2.6 Issues Not Completely Resolved

FRC was not able to resolve all questions that arose during the course of the review solely on the basis of the information it received for review. Two such open issues are:

1.) ASTM A-441 high-strength low-alloy steel is shown on Sargent and Lundy drawing B773 as used for 4-inch diameter rods in the RCP lateral support system. ASTM A-441 (when ordered without additional requirements specified to enhance fracture toughness of the mill product) is assigned a Group II ranking by NUREG-0577. The rods appear to have upset ends and consequently may be forged; but no other indication was found of their metallurgical condition (i.e. as-rolled, as-forged, or normalized); nor was information found concerning special testing requirements to indicate fracture toughness.

2.) ASTM A-7 is also indicated as a material of construction on the materials list given on Sargent and Lundy Drawing B771. The specific uses of A-7 steel could not be found on the drawings available at FRC for review. On the other hand, it does seem clear from FRC's review that this Group I steel is not used in any principal member of the structure.

In cases involving initial classification of plants to NUREG 0577 rankings as Group I, II, or III, FRC adopted the following policy with respect to lack of information on issues which might affect the fracture-toughness ranking of a plant. The lower of the two possible rankings was assigned (on a tentative basis) and the higher ranking was withheld pending receipt of information which could resolve the issue.

However, in cases such as that of Zion 1 and 2 where a plant has already been classified in a review by others, FRC does not believe it equitable or

proper to suggest a temporary downgrading of a previously assigned ranking based solely on lack of information available to FRC at the time of its review. This view is supported by the following considerations:

(a) There is ample evidence that attention was given to the fracture-toughness design of the supports in general and none to strongly suggest that the same care was not exercised in the particular cases noted. (b) The issue may have been previously considered and resolved in the previous review. (c) The assigned rankings are ratings relative to practice on an industry-wide basis. Zion 1 and 2, in FRC's judgment, merit a Group III ranking on such a comparative scale.

6. CONCLUSIONS

The design and construction of supports for steam generators and reactor coolant pumps at the Zion Nuclear Power Station Units 1 and 2 have 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 Commonwealth Edison Company (CEC) concerning the supports in Zion Units 1 and 2.

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 Zion Units 1 and 2 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 Zion Unit 1 and 2 in NUREG 0577-Draft is justifiable.