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July 3, 1980
809-042

Mr. Richard P. Snaider
Generic Issues Branch
Nuclear Regulatory Commission
Washington, D.C. 20555

Subject: Comments on Proposed Criteria for Major Component Support Low-Alloy Bolting

Reference: NRC (Eisenhut) letter of May 20, 1980, Additional Guidance on "Potential for Low Fracture Toughness and Lamellar Tearing on PWR Steam Generator and Reactor Coolant Pump Supports", NUREG-0577.

Dear Mr. Snaider:

1.0 Introduction

Reference 1 has been distributed for comment. This letter contains our comments on those portions of the enclosure to Reference 1 which concern low-alloy bolting. We reserve the right to comment on the applicable Standard Review Plan when it becomes available.

With respect to major component support bolting, the attachment to the reference, General Operating Reactor Review Procedure and Acceptance Criteria, provides:

a. In Part II, a criteria for evaluating the potential for stress corrosion cracking in bolting materials having a yield strength of greater than 120 ksi.

b. In Part IC, criteria for evaluating the potential for brittle fracture in bolting materials.

The Part II procedure is essentially complete, although some of the specific requirements are subject to interpretation. A stress corrosion cracking threshold toughness is defined in terms of yield strength and a specific flaw size is specified. Based on this information a fracture mechanics analysis may be performed.

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In contrast, no such method is included with respect to the potential for brittle fracture. Instead:

a. The Code materials must meet the requirements of NC-2333 of Section III, for Charpy V-notch testing, or

b. The criteria of Part IB must be satisfied, which requires that the support behavior be demonstrated to be acceptable even when the most highly-stressed member is assumed to be failed.

TES believes a fracture mechanics analysis method should be provided.

2.0 Scope of this Letter

2.1 Technical comments are made on the contents of the enclosure to Reference 1 which apply to bolting materials.

2.2 A procedure for evaluating the potential for brittle fracture is developed which is consistent with that specified by NRC for stress corrosion cracking.

3.0 Comments on Proposed NRC Rules for Stress Corrosion Cracking

3.1 Flaw Definition

The NRC procedure assumes a "1/10 T flaw". It is not clear what this means for a flaw in a bolt, so some comparison with known solutions is required.

For a "thumbnail" crack an upper limit for the stress intensity factor is

$$K_I = 1.4 \, Sa^{0.5} \qquad (1)$$

For a circumferential crack all the way around the bolt, the coefficient in the above equation is 2.0 if the crack depth is 0.05D, and the coefficient in the above equation is 2.2 for a crack depth of 0.10D. In all cases the stress in the above equation is calculated on the basis of the gross area, neglecting the presence of the crack. Therefore, a coefficient of 2 in Equation (1) is a reasonable value or a conservative value for any shape or depth of flaw in the range of interest.

However, when the flaw is defined as an absolute function of diameter, as does NRC, the effect of flaw definition becomes very important. For example, for the case of the circumferential crack:

$$K_I = 0.320\ D^{0.5} \text{ for } d/D = 0.945\ (a = 0.026D,\ (d/D)^2 = 0.90) \quad (2)$$

$$K_I = 0.448\ D^{0.5} \text{ for } d/D = 0.9\ (a = 0.05D,\ (d/D)^2 = 0.81) \quad (3)$$

$$K_I = 0.692\ D^{0.5} \text{ for } d/D = 0.8\ (a = 0.1D,\ (d/D)^2 = 0.64) \quad (4)$$

Which of these does NRC mean with the statement "assuming a 1/10 T flaw"? TES suggests that NRC consider that given by Equation (3), which has the same effect on remaining area as would two long 1/10 T flaws on opposite surfaces of a flat plate, as a reasonable definition for bolting materials _if_ the postulated flaw is to be defined as an absolute function of diameter.

However, TES recommends that the postulated flaw be defined as a function of diameter only up to some maximum value of flaw depth. Specifically, _TES recommends that the words "assuming a 1/10 T flaw" be replaced with the words "assuming a complete circumferential flaw of depth equal to 0.05D but not to exceed a flaw depth of 0.2"._

This recommendation is made for two reasons. First, detection of such a flaw by available inspection techniques should become a certainty when the flaw size reaches some absolute value, not related to bolt diameter above some bolt diameter. A 4 inch diameter bolt is, essentially, no more difficult to inspect than a larger diameter bolt. A smaller diameter bolt may be more difficult. Secondly, such an approach would eliminate a step decrease in allowable stress as the yield strength increases.

The latter point is illustrated by Figure 1 which applies the NRC material property curve to the defined flaw. At yield strengths below 120 ksi, the allowable stress is independent of diameter and increases as the tensile properties increase. With the flaw defined as a function of diameter, the allowable stress at yield strength in excess of 120 ksi is dependent upon diameter and decreases as the yield strength increases. A step decrease in allowable stress is indicated by Figure 1 for bolt diameters greater than 3.7" as the yield strength increases from just below 120 ksi to just above 120 ksi. With the parameters used on this Figure, use of a maximum annular crack depth of 0.2" would essentially eliminate this discontinuity, in that the curve labeled "4" would apply to bolt diameters 4" and greater.

There is also a physical reason for establishing a maximum flaw size. The concern in stress corrosion cracking is an undetected flaw which results from the manufacturing or installation procedures. Such flaws usually have depths of thousandths of an inch, seldom have depths of hundreths of an inch and would not be expected to have depths of tenths of an inch. In fact, if 4340 bolts in general application did have initial flaw depths measured in tenths of inches most of them would fail by stress corrosion cracking. This doesn't happen very often!

Experience indicates that stress corrosion cracking becomes of concern in AISI 4340 material for properties in excess of 180 ksi yield strength, 200 ksi tensile strength or hardnesses above 43 HRC. The NRC proposed procedure forces concern at yield strengths lower than 180 ksi for bolts of diameter larger than 0.5 inches. This result comes about not necessarily because of the K_{Iscc} curve adopted by NRC, although it is a lower bound, but because of the very large defect size which NRC requires to be postulated. The previous TES recommendation with respect to maximum flaw depth, 0.2", was based on considerations other than the physical source of the initial defect. Therefore, <u>TES further recommends that NRC consider a reduction in the maximum postulated flaw depth on the basis of the physical source of such initial flaws.</u> It is expected that a depth of 0.02" may be appropriate.

3.2 Material Property Definition

Figure 2 of the enclosure to Reference 1 defines a stress corrosion cracking threshold as a function of yield strength for low alloy steels. TES has recently reviewed the available data on this subject and has no major objection to this curve as an approximation to the lower bound data, with one exception. That exception relates to the property at high yield strengths. Available data indicate that the minimum range for K_{Iscc} is generally between 10 and 15 ksi $in^{0.5}$, with all available data above 8 ksi $in^{0.5}$ with the exception of one point at 5 ksi $in^{0.5}$ at a yield strength of 225 ksi. On this basis, TES recommends that the curve be defined with some minimum value independent of yield strength. As a suggestion, this maximum value could be taken as 8 ksi $in^{0.5}$. Provision of such a finite value would permit some acceptable stress level for material of unknown yield strength.

NRC Figure 2 identifies the property of interest as yield strength, but fails to define whether the intent is to use the minimum specified yield strength or the actual yield strength. In other sections of the procedure NRC has identified the intended value. From a technical viewpoint, TES recommends that NRC Figure 2 be identified as using the actual yield strength. In addition, since the actual yield strength may not be known and can not be measured in situ, TES recommends that NRC include an acceptable connversion table between actual yield strength and material hardness (Rockwell C), since that property can be measured in situ.

TES recognizes that the first of the above recommendations will cause extreme difficulties to the designer. He will essentially have to shift the yield strength coordinate on Figure 1 by the permissible variation between the specified minimum yield strength and the actual yield strength, or a specified maximum yield strength which he will have to define. This procedure will add conservatism to the design process which NRC should recognize exists when they consider other comments on the proposed rules. In spite of these difficulties, TES recommends the use of the actual yield strength because excessive yield strength is the source of the real problem.

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4.0 Comment on Proposed NRC Rules Relative to Brittle Fracture

The contents of NRC Section IC are described in the introduction to this letter.

With respect to Charpy test requirements, the requirements of NF-2333 should be used rather than those of NC-2333. The requirements differ only in the addition in NC of an absorbed energy requirement for diameters in excess of 4". This latter requirement is excessive for low-alloy bolting materials of the type used for supports. In addition Code materials ordered for component supports may not have an energy absorption value reported, since they would have been ordered to NF.

For other than Code materials meeting NC-2333, the NRC procedure would require satisfaction of the criteria of Section I.B. In the analysis associated with that criteria, "the most highly-stresses member is assumed to be failed". What does this mean for a bolted joint? Must one assume that a single bolt fails, or that all bolts fail, or that no bolts fail if the stress is higher in some other location in the assembly? TES recommends that the procedures of Section I.B be further defined in order that the intent is clear for bolting.

Of even more importance is the absence from the NRC procedure of a method for the fracture mechanics analysis of bolting when the Code impact test requirements are not met. This is no more difficult to define than is the NRC defined fracture mechanics analysis for stress corrosion cracking. TES recommends that a fracture mechanics evaluation method be included in Section I.C of the NRC procedure. To assist in preparation of that procedure, TES has developed the procedure discussed in Section 5.0 of this letter.

It is essential that such an option be provided for plants presently under construction, since many support materials were not ordered to the Code; and, even for those ordered to the Code, compliance with NC-2333 may not be demonstratable.

5.0 TES Proposed Fracture Mechanics Analysis Procedure

5.1 Fracture Toughness

The fracture toughness, K_{IR} is defined as a function of actual yield strength, for yield strengths in excess of 120 ksi, by the following:

a. K_{IR} = 110 ksi $in^{0.5}$ at Sy = 120 ksi.

b. The fracture toughness decreases linearly from that value to a value of 40 ksi $in^{0.5}$ at Sy = 215 ksi.

c. The value remains constant as the yield strength increases above 215 ksi.

5.2 Postulated Defect

The postulated defect is an annular crack of depth equal to 10% of the nominal bolt diamter, but not to exceed a depth of 0.2 inches. The stress intensity factor may be calculated from the equation

$$K_I = 2.2 \ S \ a^{0.5} \qquad (5)$$

where: S is the applied stress on the gross cross-section (neglecting postulated crack)
a is the crack depth.

5.3 Acceptance Criteria

With the above definitions, the configuration is acceptable if $K_I < K_{IR}$

5.4 Discussion

The recommended fracture toughness curve is essentially a lower bound curve to available data.

The postulated defect is taken as a larger portion of the diameter than that recommended for the evaluation of stress corrosion cracking, but the same maximum postulated depth is used.

The results of applying this evaluation method without a limit on the maximum postulated flaw depth are shown by Figure 2 of this letter. Comparison of the results at 120 ksi yield with those on Figure 1 at the same yield strength level indicates that the Figure 2 values are just slightly above the Figure 1 values. This should be true if 120 ksi is considered to be the yield strength level of concern. At higher values of yield strength, the Figure 2 allowable stresses do not decrease as rapidly as those shown on Figure 1. This is consistent with the lesser effect of increasing yield strength on fracture toughness. Finally, Figure 2 indicates no effect of the postulated flaw on the allowable stress value for bolts less than about 5/8 inch to diameter. This is certainly a conservative consequence of service experience.

With the maximum postulated flaw depth of 0.2", the curve labeled "2" is applicable to all bolting materials with diameter equal to or greater than 2". This also has the effect of increasing the yield strength level of concern with respect to brittle fracture to slightly above 140 ksi, rather than 120 ksi, a result more consistent with experience but still conservative.

6.0 Summary

The TES recommendations made in this letter may be summarized as follows:

1. In Part II of the enclosure to Reference 1:

   a. That the words "assuming a 1/10 T flaw" be replaced with the words "assuming a complete circumferential flaw of depth equal to 0.05D but not to exceed a flaw depth of 0.2 inches."

b. That NRC consider a reduction in the maximum postulated flaw depth, below the 0.2 inches, on the basis of the physical source of such initial flaws.

c. That NRC Figure 2 curve be defined with some minimum value independent of yield strength (such as 8 ksi $in^{0.5}$)

d. That NRC Figure 2 be identified as using the actual yield strength, not the specified minimum yield strength.

e. That NRC include an acceptable conversion table between actual yield strength and material hardness (Rockwell C), since that property can be measured in situ.

2. In Part IB of the enclosure to Reference 1:

a. That the procedure be further defined in order that the intent is clear for bolting.

3. In Part IC of the enclosure to Reference 1:

a. That the requirements of NF-2333 be used rather than those from NC-2333.

b. That a fracture mechanics evaluation method be included (and a detailed proposal is included in Section 5.0 of this letter).

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We appreciate your consideration of these comments and would be pleased to discuss them further. We do, however, object to the incomplete NRC submittal and the brief time available for review.

Very truly yours,

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W. E. Cooper

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Consulting Engineer

WEC:dem

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BY 2M. DATE 800611

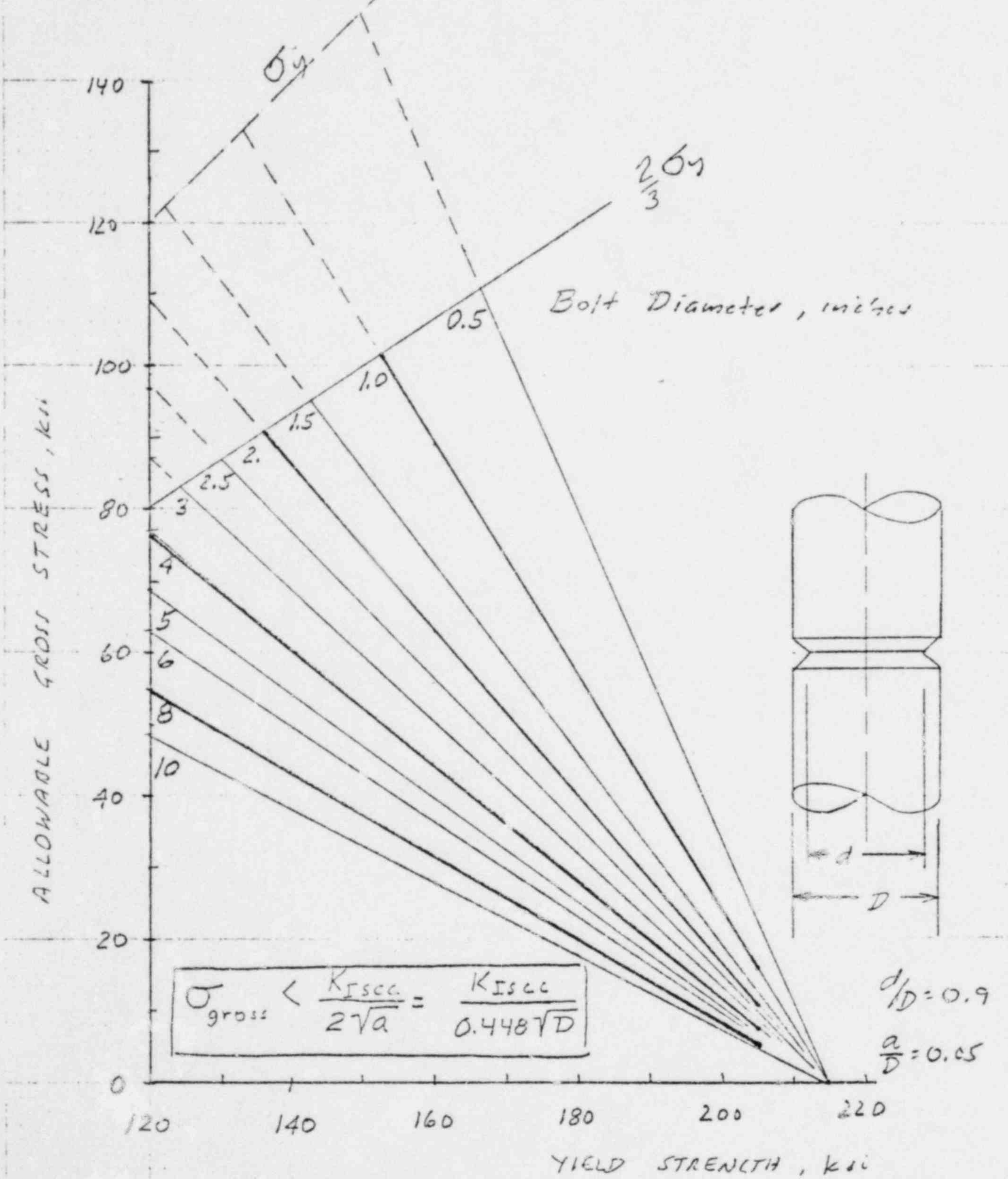
CHKD. BY J.T. DATE 6/11/80

FIGURE 1

STRESS CORROSION LIMIT
LOW ALLOY BOLTING

SHEET NO. ____ OF ____

PROJ. NO. A100



$$\sigma_{gross} < \frac{K_{Iscc}}{2\sqrt{a}} = \frac{K_{Iscc}}{0.448\sqrt{D}}$$

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FIGURE 2

BRITTLE FRACTURE LIMIT
LOW-ALLOY BOLTING

SHEET NO. ______ OF ______

PROJ. NO. A100