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REMARKS

Attached is a draft #3 NUREG report on "Material Selection and Processing, Inservice Inspection and Leak Detection Guidelines for BWR Piping" for your review. Because of very tight schedule for the issuance of the subject report (8/15/79) your comment by COB 7/30/79 is requested.
Thank you

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MATERIAL SELECTION AND PROCESSING, INSERVICE INSPECTION, AND LEAK DETECTION GUIDELINES FOR BWR PIPING

90016282

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Division of Systems Safety
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

I. INTRODUCTION

This report updates the NRC technical position defined in NUREG-0313, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping," July 1977. This NUREG report represents work accomplished under Generic Task No. A-42, "Pipe Cracks in Boiling Water Reactors."

Leaks and cracks in the heat-affected zones (HAZs) of welds that join austenitic stainless steel piping and associated components in BWRs have been observed since the mid-1960's. Prior to September 1974, all affected piping was Type 304 stainless steel with diameters of eight inches or less. All the cracks were attributed to intergranular stress corrosion cracking (IGSCC) due to the combination of high local stress, sensitization of material, and high oxygen content in the water. In each case, it was believed that the problem had been corrected or substantially reduced by better control of welding, contaminants, and design.

During the last quarter of 1974, a number of incidents of IGSCC in weld HAZs of [illegible] diameter recirculation bypass lines and in 10-inch diameter core spray lines were again observed. Following these occurrences, the Nuclear Regulatory Commission (NRC) formed a Pipe Cracking Study Group (PCSG) in January 1975 to (a) investigate the cause, extent, and safety implications of cracks, (b) make an interim recommendation for operating plants, and (c) recommend corrective actions to be taken by future plants. In October 1975, the Study Group published its report, NUREG-75/067, "Technical Report, Investigation and Evaluation of Cracking in Austenitic Stainless Steel Piping of Boiling Water Reactor Plants." During the same general time span, the General Electric Company (GE) conducted an independent evaluation of cracking problems and submitted their findings and recommendations to the NRC (NEDO-21000, "Investigation of Causes of Cracking in Austenitic Stainless Steel Pipes"). Following staff review of the Study Group's and GE's recommendations, the staff issued

an implementation document, NUREG-0313. This document based on the information available at that time set forth the NRC technical positions consistent with the recommendations of the Study Group.

Since 1975, IGSCC has continued to be detected in recirculation bypass and core spray lines. Incidence of IGSCC has also been observed in some stainless steel recirculation riser piping up to twelve inches in diameter in Japan and in large diameter (20 inches) recirculation piping in Germany. These incidents, together with the questions concerning the reliability of ultrasonic inspections, led to the activation of a new PCSG by NRC in September 1978.

The new Study Group was specifically chartered to reexamine the conclusions and recommendations of the 1975 PCSG report in view of cracks recently discovered in large diameter pipes. Particular attention was to be given to the significance of cracking found in large recirculation lines, to evaluate the capability of NDE methods to detect IGSCC, and in addition, to assess the significance of the safe-end cracking at Duane Arnold relative to similar material and design aspects at other facilities.

In February 1979, the Study Group issued a report, NUREG-0531, "Investigation and Evaluation of Stress-Corrosion Cracking in Piping of Light Water Reactor Plants." The new Study Group had reaffirmed that the conclusions and recommendations reported in NUREG-75/067 by the previous group and the implementing document, NUREG-0313, are valid. In addition, they presented some new ideas to reduce the potential for IGSCC and addressed IGSCC in safe-ends. During the same general time span, the General Electric Company conducted an independent evaluation of the recent cracking in large diameter pipes and submitted their findings and recommendations to the NRC. (e.g., Letter from G. Sherwood to V. Stello,

"General Electric Meeting with NRC on IGSCC", September 12, 1978. The GE conclusions are: (a) IGSCC in Type 304 stainless steel weld HAZs remains to be a non-safety problem and (b) GE approach outlined in NEDO-21000 continues to be valid.

It is the purpose of this document to set forth acceptable methods to reduce the IGSCC susceptibility of BWR piping and thus provide an increased level of reactor coolant pressure boundary and engineered safety features systems integrity. Recognizing that complete compliance with these guidelines may not be practical, or even possible, for all plants, varying degrees of conformance to our guidelines are provided in Part IV. For plants that cannot fully comply with the provisions specified in Part II of this document, varying degrees of augmented inservice inspection and leak detection requirements are established in Part III.

II. SUMMARY OF ACCEPTABLE METHODS TO MINIMIZE CRACK SUSCEPTIBILITY - MATERIAL SELECTION, TESTING, AND PROCESSING

1. Selection of Materials

Only those materials described in A and B below are acceptable to the NRC for use in BWR piping systems. Other materials shall not be used without prior evaluation and acceptance by the NRC.

A. Corrosion Resistant Materials

All pipe and fitting material including safe ends, thermal sleeves, and weld metal should be of a type and grade that has been demonstrated to be highly resistant to oxygen-assisted stress corrosion in the as-installed condition. Materials which have been so demonstrated include ferritic steels, "Nuclear Grade" austenitic stainless steels[1], Types

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[1] These materials have controlled low carbon (0.02% max) and nitrogen contents and meet all requirements, including mechanical properties requirements, of ASME specifications for regular grades of Type 304 or 316 stainless steel pipe.

304L and 316L austenitic stainless steels, Type CF-3 cast metal, and Type 308L stainless steel weld metal with at least 5% ferrite content. Ustabilized wrought austenitic stainless steel without controlled low carbon does not meet this requirement unless all such piping including welds is in the solution annealed condition. The use of such material (i.e., regular grades of Types 304 and 316 stainless steels) should be avoided except in the solution annealed condition and then only for non-welded applications. Where regular grades of Types 304 and 316 are used and welding or heat treatment is required, special measures should be taken to ensure that IGSCC will not occur. Such measures may include solution annealing subsequent to the welding or heat treatment and weld cladding which have been demonstrated to eliminate sensitization and reduce residual stresses.

B. Corrosion Resistant "Safe Ends" and Thermal Sleeves

All unstabilized wrought austenitic stainless steel materials used for safe ends and thermal sleeves without controlled low carbon contents (L-grades and Nuclear grade) should be in the solution annealed condition. If welds joining these materials are not solution annealed, they should be made between cast (or weld overlaid) austenitic stainless steel surfaces (5% minimum ferrite) or other materials having high resistance to oxygen-assisted stress corrosion. The joint design must be such that any high stress areas in the unstabilized wrought austenitic stainless steel without controlled low carbon content, which may become sensitized as a result of the welding process, is not exposed to the reactor coolant. Thermal sleeve attachment geometries that form crevices where impurities

may accumulate should not be used.

2. Testing of Materials

Tests should be made on all regular grade stainless steels to demonstrate that the material was properly annealed and is not susceptible to IGSCC. Such tests may include practices A[1/] and E[2/] of ASTM A-262, "Recommended Practice for Detecting Susceptibility to Intergranular Attack in Stainless Steel."

The Electrochemical Potentiokinetic Reactivation (EPR) test which is presently being developed and qualified has not yet been formally evaluated and accepted by the NRC.

3. Processing of Material

For initial construction and repair welds, where Types 304 or 316 stainless steel pipes are used, a corrosion resistant clad with a duplex microstructure (5% minimum ferrite) can be weld deposited on the prewelded surfaces to (a) minimize the heat affected zone (HAZ) on the pipe inner surface, (b) move the HAZ away from the highly stressed region next to the attachment weld, and (c) isolate the weldment from the environment. For initial construction, the piping including clad surfaces should be solution-annealed prior to making the attachment welds. The joint design of all welds must be such that any high stress areas in the unstabilized wrought austenitic stainless steel which may become sensitized as a result of the welding process, is not exposed to the reactor coolant.

Other processes such as Induction Heating Stress Improvement (IHSI), Heat Sink Welding (HSW) are currently being developed. Until these processes are evaluated and accepted by the NRC, they shall not be considered acceptable for use in BWR piping systems.

1/ Practice A - Oxalic Acid Etch Test for Classification of Etch Structures of Stainless Steels.

2/ Practice E - Copper-Copper Sulfate-Sulfuric Acid Test for Detecting Susceptibility to Intergranular Attack in Stainless Steels.

III. INSERVICE INSPECTION AND LEAK DETECTION REQUIREMENTS FOR BWRs WITH VARYING DEGREES OF CONFORMANCE TO MATERIAL SELECTION AND PROCESSING GUIDELINES

1. For plants whose ASME Code Class 1 & 2 pressure boundary piping meets the guidelines of Part II, no augmented inservice inspection or leak detection requirements beyond those specified in the present plant's technical specifications are necessary.
2. ASME Code Class 1 & 2 pressure boundary piping that does not meet guidelines of Part II is designated non-conforming and must have additional inservice inspection and leak detection requirements. The degree of augmented inspection of such piping depends on whether the specific non-conforming piping runs are classified as "Service Sensitive." "Service Sensitive" lines are defined as those that have experienced cracking in service, or that are considered to be particularly susceptible to cracking because of their unique combination of high local stress, material condition, and high oxygen content in the relatively stagnant, intermittent, or low flow coolant.

   Examples of piping runs considered to be service sensitive include but not limited to: Core spray lines, recirculation riser lines, recirculation by-pass lines (or "stub tubes" on plants that have removed the by-pass lines), CRD hydraulic return lines, isolation condenser lines, recirculation inlet lines with crevice, formed by thermal sleeve attachment, and shutdown heat exchanger lines.

   Augmented leakage detection and inservice inspection requirements for non-conforming lines and non-conforming, service sensitive lines are specified below:

A. Non-conforming lines that are not service sensitive:

(1) Augmented Leak Detection: The reactor coolant leakage detection system should be upgraded to enhance the discovery of unidentified leakage that may include through-wall cracks developed in austenitic stainless steel piping:

a. The leakage detection system provided should include sufficiently diverse leak detection methods with adequate sensitivity to measure small leaks and to identify the leakage sources within the practical limits. The acceptable leakage detection and monitoring systems are described in Section C, Regulatory Position of Regulatory Guide 1.45, "Reactor Coolant Presusre Boundary Leakage Detection Systems."

Other equivalent leakage detection and collections systems will be reviewed on a case by case basis.

b. Plant shutdown should be initiated for inspection and corrective action when any of the leakage detection systems indicates, within a periof of twenty four hours or less, an increase in the rate or its equivalent of five gallons per minute, whichever occurs first. For sump level monitoring systems with fixed measurement interval method, the level should be monitored at four-hour intervals.

c. Unidentified leakage should include all leakage other than:

(i) Leakage into closed systems, such as pump seal or valve packing leaks that are captured, flow metered, and conducted to a sump or collecting tank, or

(ii) Leakage into the containment atmosphere from sources that are both specifically located and known either not to interfere with the operations of unidentified leakage monitoring systems or not to be from a through-wall crack in the piping within the reactor coolant pressure boundary.

(2) Augmented Inservice Inspection: Inservice inspection of the non-conforming lines should be conducted in accordance with the following program:

a. For ASME Code Class 1 components and piping, each pressure retaining dissimilar metal weld subject to inservice inspection requirements of Section XI should be examined at least once in no more than 80 months (two-thirds of the time prescribed in the ASME Boiler and Pressure Vessel Code Section XI). Such examination should include any internal attachment welds that are not through wall welds but are welded to or form part of the pressure boundary.

b. The following ASME Code Class 1 pipe welds subject to inservice inspection requirements of Section XI should be examined at least once in no more than 80 months:

(i) all welds at terminal ends[1/] of pipe at vessel nozzles;

(ii) all welds having a designed combined primary plus secondary stress range of $2.4S_m$ or more;

(iii) all welds having a design cumulative fatigue usage factor of 0.4 or more; and

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[1/] Terminal ends are the extremities of piping runs that connect to structures, components, (such as vessels, pumps, valves) or pipe anchors, each of which acts as rigid restraints or provides at least two degrees of restraint to piping thermal expansion.

(iv) sufficient additional welds with high potential for cracking to make the total equal to 25% of the welds in each piping system.

c. The following ASME Code Class 2 pipe welds which are subject to inservice inspection requirements of Section XI, excluding those in Residual Heat Removal Systems, Emergency Core Cooling Systems and Containment Heat Removal Systems, should be inspected at least once in no more than 80 months:

(i) all welds at locations where the stresses under the loadings resulting from Normal and Upset plant conditions as calculated by the sum of Eqs. 9 and 10 in NC-3652 exceed $0.8\ (1.2S_h + S_A)$;

(ii) all welds at terminal ends of piping, including branch runs;

(iii) all dissimilar metal wedls;

(iv) additional welds with high potential for IGSCC at structural discontinuities[1/] such that the total number of welds selected for examination includes the following percentages of circumferential piping welds:

For Boiling Water Reactors

(a) 50% of the main steam system welds, and

(b) 25% of the welds in all other systems.

For Pressurized Water Reactors

(a) 10% of all main steam systems piping welds of 8-inch nominal pipe size and smaller, and

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[1/] Structural discontinuities include pipe weld joints to vessel nozzles, valve bodies, pump casings, pipe fittings (such as elbows, tees, reducers, flanges, etc. conforming to ANSI Standard B 16.9) and pipe branch connections and fittings.

(b) 25% of the welds in all systems.

d. The following ASME Code Class 2 pipe welds, subject to inservice inspection requirements of Section XI, in each Residual Heat Removal Systems, Emergency Core Cooling Systems, and Containment Heat Removal Systems should be examined at least once in no more than 80 months:

(i) all welds of the technical ends of pipe at vessel nozzles, and

(ii) at least 10% of the welds selected proportiontely from the following categories:

(a) circumferential welds at locations where the stresses under loadings resulting from <u>any</u> plant conditions as calculated by the sum of equations (9) and (10) in NC-3652 exceed 0.8 $(1.2S_h + S_A)$;

(b) welds at terminal ends of piping, including branch runs,

(c) dissimilar metal welds,

(d) welds at structural discontinuity, and

(e) welds that cannot be pressure tested in accordance with IWC-5000.

The welds to be examined shall be distributed approximately equally among runs (or portions of runs) that are essentially similar in design, size, system function, and service conditions.

e. If examinations of a, b, c, and d above conducted during the first 80-month reveal no incidence of stress corrosion cracking, the examination frequency thereafter can revert to 120-month

as prescribed in Section XI of the ASME Boiler and Pressure Vessel Code.

Sampling schemes other than those described in b, c, and d above for the same total number of welds will be reviewed on a case by case basis.

B. Non-conforming lines that are service sensitive:

(1) Augmented Leak Detection: The leakage detection requirements, described in III2A(1) above, should be implemented.

(2) Augmented Inservice Inspection:

a. The welds and adjoining areas of bypass piping of the discharge valves in the main recirculation loops, and of the austenitic stainless steel reactor core spray piping up to and including the second isolation valve should be examined at each reactor refueling outage or at other scheduled or unscheduled plant outages. Successive examinations need not be closer than six months, if outages occur more frequently than six months. This requirement applies to all welds in all bypass lines whether the 4-inch valve is kept open or closed during operation.

In the event these examinations find the piping free of unacceptable indications for three successive inspections, the examination may be extended to each 36-month period (plus or minus by as much as 12 months) coincident with a refueling outage. In these cases, the successive examination may be limited to all welds in one bypass pipe run and one reactor core spray piping run. If unacceptable flaw indications are detected, the remaining piping runs in each group should be examined.

In the event these 36-month period examinations reveal no unacceptable indications after three successive inspections, the welds and adjoining areas of these piping runs should be examined at least once on a sampling basis as described in III 2A(2)a for disimilar metal weld and b for other welds at a frequency of 80-month period.

b. The welds and adjoining areas of other ASME Code Class 1 service sensitive piping should be examined on a sampling basis as described in III 2A(2) a for dissimilar welds and b for other welds above except that the frequency of such examinations should be at each reactor refueling outage or at other scheduled or unscheduled plant outages. Successive examinations need not be closer than six months, if outages occur more frequently thax six months.

In the event these examinations find the piping free of unacceptable indications for three successive inspections, the examination may be extended to each 36-month period (plus or minus by as much as 12 months) coinciding with a refueling outage.

In the event these 36-month period examinations reveal no unacceptable indications after three successive inspections, the frequency of examination may revert to 80-month period (two-thirds the time prescribed in the ASME Code Section XI).

c. All pressure retaining welds and adjoining areas of one half of the creviced safe-ends including the internal attachment welds in recirculation inlet lines should be examined during next refueling outage. The welds and adjoining areas of the other half of the creviced safe-ends and internal attachment welds should be examined during the subsequent refueling outage. This sequence of inspections shall be maintained through the subsequent refueling outages.

In the event the examinations of each safe-end and internal attachment weld reveal no unacceptable indications after three successive inspections, the frequency of examination of each safe-end and internal attachment weld may revert to 80-month period.

d. The area, extent, and frequency of examination of the augmented inservice inspection for ASME Code Class 2 service sensitive lines will be determined on a case by case basis.

C. Nondestructive Examination (NDE) Requirements: The method of examination and volume of material to be examined, the allowable indication standards, and examination procedures should comply with the requirements set forth in the applicable Edition and Addenda of the ASME Code, Section XI specified in the paragraph (g), "Inservice Inspection Requirements," of 10 CFR 50.55a, "Codes and Standards."

In some cases, the code examination procedures may not be effective for detecting or evaluating IGSCC and other ultrasonic (UT) procedures or advanced non-destructive examination techniques may be required to detect and evaluate stress corrosion cracking in austenitic stainless

steel piping. However, improved UT procedures have been developed by certain organizations and other improved NDE techniques are still being developed. Specific guidance for implementation of these improved techniques cannot be provided at this time. Recommendations for the development and eventual implementation of these improved techniques are included in Part V.

IV. IMPLEMENTATION OF MATERIAL SELECTION AND PROCESSING GUIDELINES

A. For plants under review, but for which a construction permit has not been issued, all lines should conform to the guidelines stated in Part II.

B. For plants that have been issued a construction permit, all lines should conform to the guidelines stated in Part II unless it can be demonstrated to the staff that implementing the guidelines of Part II would result in undue hardship.

C. For plants that have been issued an operating license, NRC designated service sensitive lines should be modified to conform to the guidelines stated in Part II, to the extent practicable. Lines that have experienced cracking plant service should be replaced with piping that conforms to the guidelines stated in Part II.

V. GENERAL RECOMMENDATIONS

The measures outlined in Part II of this document provide for positive actions that are consistent with current technology. The implementation of these actions should markedly reduce the susceptibility of stainless steel piping to stress corrosion cracking in BWRs. It is recognized that additional means could be used to limit the extent of corrosion of BWR pressure boundary piping materials and to improve the overall system integrity. These include plant design and operational procedure considerations to reduce system

exposure to potentially aggressive environment, improved material selection, special fabrication and welding techniques, and provisions for volumetric inspection capability in the design of weld joints. The use of such means to limit IGSCC will be reviewed on a case basis. The items identified below may be expected to lead to means of limiting the extent of IGSCC improving the chances of detecting such IGSCC. These items have not yet been fully developed and accepted by the NRC.

Specifically, areas that need further NRC and/or industry consideration are:

1. Improved ultrasonic inspection methods. Such methods should be codified or included in a Regulatory Guide.
2. Development and implementation of an improved focussed inservice inspection program based on stress rule index, material of construction, history of cracking, etc.
3. Improved weld jont design for better inspectability.
4. Reduction of oxygen content in reactor coolant during all phases of reactor operation by water chemistry control, de-aeration of systems, etc.
5. Minimization of stagnant or low flow coolant pressure boundary piping.
6. Evaluation of newly developed alternate corrosion resistance materials in BWR water.
7. Improvement of material corrosion resistance by cladding, heat sink welding, induction heating stress improvement, mechanical working of the inside surface of pipe welds, etc.
8. Development of Electrochemical potentiokinetic reactivation technique for detecting and quantifying the degree of sensitization in stainless steel piping.

9. Reevaluation of leak before break postulation.
10. Evaluation of leakage detection capability to improve early detection of small leaks.

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