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MEMORANDUM FOR: G. A. Arlotto, Director
Division of Engineering Standards
Office of Standards Development

FROM: R. J. Mattson, Director
Division of Systems Safety

SUBJECT: PROPOSED REVISION OF REGULATORY GUIDE 1.44, "CONTROL OF THE USE OF SENSITIZED STAINLESS STEEL"

The current Regulatory Guide 1.44 was issued in May 1973, and from the start it has been considered one of our most controversial guides. The Materials Engineering Branch has had numerous meetings with members of industry, code bodies, and of our own staff to discuss revisions to this document.

We have followed the direction of the R³C at their 61st meeting and have proposed that Branch Technical Position MTEB 5-7, "Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping" (i.e., NUREG-0313 of July 1977) be included in the subject guide. In addition, an effort has been made to resolve controversial areas, to clarify various portions of the guide, and to effect needed changes.

Enclosure 1 discusses in more detail some of the controversial areas and the proposed action. In this respect, we recommend that the Office of Standards Development further conduct an in-depth investigation of several of the areas to ensure that any necessary changes to improve safety can be effected with due consideration for impact/value factors.

We recommend that the Office of Standards Development prepare a revision to the current guide, incorporating therein the changes and recommendations shown in Enclosure 2 and that subsequently the proposed revision to Regulatory Guide 1.44 be submitted to the R³C for consideration and approval.

R. J. Mattson, Director
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For enclosure & cc's, see attached sheet

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Enclosure:
As stated

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ENCLOSURE 1

Proposed Revision of Regulatory Guide 1.44,
"Control of the Use of Sensitized Stainless Steel,"
Comments Concerning

I. Introduction

The current guide describes methods of implementing requirements with regard to control of the application and processing of stainless steel to avoid severe sensitization that could lead to stress corrosion cracking. The proposed revision and the current regulatory guide are both applicable to light water reactors. However, the proposed revision recognizes that inherent differences exist between the design of boiling water reactors (BWRs) and pressurized water reactors (PWRs) which result in the need for different parameters and methods for the control of the quality of primary reactor coolant water, and water used in auxiliary systems such as the containment spray system.

The proposed revision also recognizes that in BWRs, sensitized field welds which are not subsequently solution annealed are susceptible to oxygen-assisted stress corrosion cracking and recommendations for use of safe-ends or weld overlays with specific delta ferrite numbers have been included. These requirements which are currently shown in Branch Technical Position MTEB 5-7 have R^3C approval, and its inclusion in the proposed document has been recommended by that group.

We propose that the subject document clarify the portions of the guide pertaining to intergranular corrosion tests and weld procedure qualification tests.

We recommend that new requirements for hardfacing and wear surfacing be investigated for incorporation into the proposed revision of the guide. Also, revisions to the current exemption requirement for castings and weld metal should be examined.

II. Comments

A. Water Chemistry

Strong opposition to the current guide has been made by the General Electric Company and by utilities with boiling water reactors. The current guide does not recognize basic differences in water chemistry between PWRs and BWRs. Also, since sensitized stainless steel welds in a BWR exposed to oxygenated water are

susceptible to oxygen-assisted stress corrosion cracking, the need for special treatment of BWR field welds has been recognized.

The proposed revision to the guide specifies different water chemistry parameters for controlling the maintenance of purity in the primary reactor coolant water, and different parameters for controlling water used in the engineered safety systems such as the core cooling system and the containment spray systems. The current Regulatory Guide 1.44 requirements for control of water are inconsistent with Regulatory Guide 1.56, which specifies the requirements for maintenance of water purity in BWR reactors, and with the staff approved General Electric Company standard SARs, GESSAR-238 and GESSAR-251.

The proposed revision, by recognizing different parameters for controlling water quality in BWRs and PWRs, strengthens the guide, and makes it consistent with other guides and positions shown in the Standard Review Plan.

B. Processing of Sensitized BWR Field Welds

The current Regulatory Guide 1.44 does not discuss requirements for processing field welds. In BWRs the exposure of sensitized field welds to oxygenated reactor coolant water could lead to oxygen-assisted stress corrosion cracking. To avoid this, the Branch Technical Position, MTEB 5-7, requires special processing of these welds. The proposed recommendation for processing field welds in BWRs makes these welds less susceptible to oxygen-assisted stress corrosion cracking, and thus improves safety.

C. Welding, Hardfacing and Wear-Surfacing Procedure Qualifications

The current Regulatory Guide 1.44 specifies in Regulatory Position (C-6): "An intergranular corrosion test such as ASTM A-262-70, 'Recommended Practices for Detecting Susceptibility to Intergranular Attack in Stainless Steel,' Practices A or E,[2] or another method that can be demonstrated to show non-sensitization in austenitic stainless steel should be performed during welding procedure qualification to verify that intergranular corrosion has not occurred when austenitic stainless steel materials having a carbon content greater than 0.03 percent are welded together." The current guide does not include any requirements on controlling sensitization during hardfacing or wear-surfacing of wrought or cast austenitic stainless steel materials.

It is recommended that the proposed revision correct this situation by requiring that the same intergranular corrosion test used for welding procedure qualification be used during each hardfacing or wear-surfacing procedure qualification, to verify that wrought or cast austenitic stainless steels having a carbon content greater than 0.035 have not been severely sensitized by the procedure employed.

D. Material Exemptions

The current guide currently exempts austenitic stainless steel castings and weld metal containing 5 percent or greater delta ferrite from requirements (1) for solution heat treatment following processing within a temperature range of 800-1500°F, and (2) for testing to determine the susceptibility of this material to attack by intergranular corrosion.

We recommend that OSD consider deleting these exemptions and adding a new requirement which would require that when hardfacing is performed on cast austenitic stainless steel components, that suitable tests be subsequently performed on the material to verify that intergranular corrosion will not occur. Our investigation showed that exemptions for some grades of castings with duplex structures and weld metal with a minimum ferrite content of 5 percent may be justified.

A survey[3, 11] revealed that in the pump and valve industry, hardfacing of castings is a common practice, and there have been no significant failures from intergranular stress corrosion. This was confirmed by a computer run out[6] of Licensing Event Reports on pump and valve failure involving corrosion, from 1967 to the present made by the Office of Management Information and Program Control. The output was sorted by component and facility. This study revealed a number of pump and valve failures, but in no instance was component failure attributed to defective hardfaced parts in which hardfaced surfaces had broken off and separated from the basis metal, or from intergranular stress corrosion attack due to sensitization caused by hardfacing.

We did find one case history[21] of cracking due to flame carbonization during oxyacetylene gas torch "stelliting" of a 304 stainless steel casting prior to placing the component in service. We recommend that the oxyacetylene gas torch process of hardfacing be prohibited.

F. Consequences of Failure of Valves to Close

We considered the consequences of the failure of a valve to completely close due to the loss of part of a hardfaced valve seat due to undermining by corrosion. We reviewed numerous reports[6-8, 11] and found that a small amount of bypass leakage was the most probable mode of valve failure.

The failure of a valve to perform its safety related function because of a separation of hardfacing material from its basis material seems very remote, since a review of nuclear valve failures from 1969 to the present has failed to disclose any such type of failure.

It would seem that such a failure of a valve to fully close, due to this postulated mechanism, would be another random valve failure mechanism which has been discussed in some detail in references 17 and 18. The single failure criterion applied to safety related valves in nuclear power plants takes into account failures of valve components due to a variety of causes (i.e., material, mechanical and electrical).[19, 20]

There are a number of ongoing technical activities by NRR and OSD which are underway and which are looking into a number of aspects of valve failures, such as Technical Activity C-11, "Assessment of Failure and Reliability of Pumps and Valves," and B-58, "Possible Mechanical Failures."

G. Valve Inspection

We considered the need for an augmented inservice inspection program that would include examination of the valve internals. We determined that since leak testing of a valve is sufficient to detect any incipient failure, liquid penetrant examination of valve internals would subject personnel to excessive radiation, and would also considerably increase the time needed for inspection without comensurate increase in safety assurances.

ASME Code Section XI contains extensive requirements for inservice testing of valves. For example, Section XI of the ASME Code requires that valves for which seat leakage is of safety consequence be tested every three months (IWV-3411).

References

1. Regulatory Guide 1.56, Revision, "Maintenance of Water Purity in Boiling Water Reactors."

2. ASTM Specification, A-262-70, Practice E, "Copper-Copper Sulfate-Sulfuric Acid Test for Detecting Susceptibility to Intergranular Attack in Stainless Steels," Annual Book of ASTM Standards, Part 3, American Society of Testing and Materials.

3. Industry Survey of Five Valve Manufacturing Companies and Two Pump Manufacturing Companies by R. M. Gustafson, Approximately April, 1978.

4. Licensee Event Report (LER) Output on Valve and Pump Failures Involving Corrosion, From 1969 to the Present, dated April 17, 1978, NRC Office of Management Information and Program Control.

5. Paper on "The Mechanism of Intergranular Corrosion and Intergranular Stress Corrosion in Duplex 308 Stainless Steel," by T. M. Devine, General Electric Company, San Jose, California presented at Corrosion Meeting in Houston, Texas March 6-10, 1978.

6. Brookhaven National Laboratory Memorandum to H. F. Conrad from Dr. J. R. Weeks and B. Vyas, dated March 7, 1978, "Resistance of Furnace Sensitized Duplex Stainless Steels to Stress Corrosion Cracking in a BWR Environment."

7. Brookhaven National Laboratory Memorandum to B. Turovlin from Dr. J. R. Weeks dated June 2, 1978, "Stress Corrosion Resistance of Austeno-Ferritic Stainless Steel in BWR Environments: Discussions at GE with W. L. Clarke May 5, 1978."

8. Pacific Northwest Laboratories, Battelle Memorial Institute Report, dated March 8, 1973, "Stress Corrosion in Nuclear Systems," by S. H. Bush and R. L. Dillon.

9. "New Cast High Strength Alloy Grades by Structure Control" by F. H. Beck, E. A. Schoefer, J. W. Flowers, and M. G. Fontana, Reprint of original paper by the Alloy Casting Institute, New York, New York.

10. "Corrosion and Age Hardening Studies of Some Cast Stainless Alloys Containing Ferrite," by J. W. Flowers, F. H. Beck, and M. G. Fontana, Reprint of Paper in Corrosion Magazine, Volume 19, No. 5, pp. 186t-198t (1963) May.

11. Oak Ridge National Laboratory letter report, "Hardfacing of Austenitic Stainless Steels for Nuclear Reactor Applications - A Literature and Industrial Survey," by D. P. Edmonds, Metals and Ceramics Division, NRC Technical Assistance Program FIN B-0234, dated May 8, 1978.

12. "Welding Metallurgy of Stainless and Heat Resisting Steels" by R. Castro and J. J. DeCadenet - Cambridge University Press (1968) (English Translation by R. C. Jain, 1975).

13. "Use of Duplex Stainless Steels to Retard Stress Corrosion Cracking," by A. Desestret, Societe Creusot-Loire, Centre de Recherches d'Unieux, BP 34, F 42701 - Firminy, France, First U.S.-Japan Symposium on LWRs, May 1978.

14. "Stainless Steels in Boiling Water Reactors, Corrosion Problems and Possible Solutions," by P. Combrade, A. Desestret, F. Leroy of Centre de Recherche, Creusot-Loire, Firminy, France and H. Coriou, Services d'Etudes de La Corrosion Nucleaire, Centre d'Etudes Nucleaires, First U.S.-Japan Symposium on LWRs, May 1978.

15. "IGC and IGSSC Susceptibility of Duplex Cast Stainless Steels," by I. Hamada, T. Maruyama, G. Nakao, and K. Yamauchi; Babcock-Hitachi K. K. Kure Research Laboratory, Japan, First U.S.-Japan Symposium on LWRs, May 1978.

16. Westinghouse Corporation, Bettes Laboratory Proprietary Reports as discussed by J. Halapatz, NRC and Memorandum J. Halapatz to H. Conrad et al, "Report of Meeting Re Potential Defects in Regulatory Guide 1.44," July 25, 1978.

17. "Staff Discussion of Fifteen Technical Issues Listed in Attachment to November 3, 1976 Memorandum from Director NRR to NRR Staff," NUREG-0138, Issue 7, "Passive Failures Following A Loss-of-Coolant Accident."

18. "Staff Discussion of Twelve Additional Technical Issues Raised by Responses to November 3, 1976 Memorandum from Director NRR to NRR Staff," NUREG-0153, Passive Mechanical Valve Failures.

19. Memorandum, R. Ireland to R. Bosnak et al, "Single Failure Information Paper," June 16, 1977.

20. Information Report for the Commissioners, from E. G. Case, NRR, "Single Failure Criterion," SECY-77-439, August 17, 1977.

21. Memorandum for H. F. Conrad from J. Halapatz, "Proposed Changes to Regulatory Guide 1.44, 'Control of the Use of Sensitized Stainless Steel,'" dated August 4, 1978.

ENCLOSURE 2

RECOMMENDATIONS FOR REVISION OF REGULATORY GUIDE 1.44, "CONTROL OF THE USE OF SENSITIZED STAINLESS STEEL"

Shown below are recommended changes to Regulatory Guide 1.44 dated May 1973, and reasons for the proposed changes.

1. Page 1.44-1

   A. Introduction

   Before the last sentence, insert the following:

   "However, because of inherent differences in the design of boiling water reactors (BWRs) and pressurized water reactors (PWRs), different methods and techniques are specified for control of water chemistry and other special processes."

   Reason - To emphasize that different controls are needed for BWRs and PWRs.

2. Page 1.44-1

   B. Discussion

   Paragraph 1, Second Sentence - revise as follows:

   Test data demonstrate that under certain environmental conditions specific to light water reactors, sensitized stainless steel is significantly more susceptible to stress corrosion cracking than nonsensitized (solution heat treated) stainless steel.

   Reason - The blanket statement in the current guide that sensitized stainless steels are more susceptible to stress corrosion cracking than nonsensitized steels is considered an overly broad generalization that has significant exception, (e.g., the case of caustic cracking). It would be preferable to qualify the statement with an addition such as "under certain conditions of environment."

3. Page 1.44-1

   B. Discussion

   First Paragraph, Third Sentence - revise to read as follows:

   "Of specific concern to this guide are the unstabilized austenitic stainless steels which include American Iron and Steel Institute

(AISI) Types 304, 304L, 316 and 316L normally used for components of the reactor coolant system and other safety related systems."

Reason - Regulatory Guide, Position C.4 discusses use of L grades or "types."

4. Page 1.44-2

   B. Discussion

   Third Paragraph, Lines 2 and 4 change "0.03" to "0.035."

   Reason - To reflect the carbon level which is more truly indicative of the maximum used for the austenitic stainless steels, "L" Grades or types.

5. Page 1.44-2

   B. Discussion

   Fourth Paragraph, delete this paragraph in its entirety and replace with the following:

   "Controls should be maintained on the chemistry of the reactor coolant water and engineered safety system fluids to which the material is exposed. Since different mechanisms are used in boiling water reactors and pressurized water reactors to provide suitable water, the following controls are specified:

   (a) Pressurized Water Reactor (PWRs):

   (1) Reactor Primary Coolant Water

   Chloride and fluoride ion concentrations should be specified to be less than 0.15 parts per million (ppm) at all times. Dissolved oxygen concentrations should be maintained below 0.10 ppm during periods when the material is at temperatures above 250°F.

   (2) Engineered Safety System Fluids

   Borated water used in the auxiliary systems of PWRs, such as the containment spray system, should be controlled to ensure a neutral pH.

(b) Boiling Water Reactors (BWRs):

(1) Reactor Primary Coolant Water

High quality water in a BWR is obtained by deaeration equipment, by the use of demineralizers, and the use of a water cleanup system. In a BWR, the most important criteria for the establishment of high purity reactor coolant water are conductivity, pH and control of chlorides. Control of these items should be performed in accordance with the requirements of Regulatory Guide 1.56, 'Maintenance of Water Purity in Boiling Water Reactors.'

(2) Engineered Safety System Fluids

Water used in the engineered safety systems should be controlled to provide assurance against stress corrosion cracking of unstabilized austenitic stainless steel components.

Water used for containment spray systems should be controlled to ensure the following limits:

Conductivity = 3 to 10 μmhos/cm at 25°C
Chloride (as Cl^-) $\leq$ 0.50 ppm
pH = 5.3 to 8.6 at 25°C

Boiling water reactor components which are fabricated by welding wrought unstabilized austenitic stainless steel products having carbon contents $\geq$ 0.035 percent should be subsequently heat treated to place the metal in a solution annealed condition. If the welds joining these components are not scheduled for solution annealing, they should (1) be made between cast austenitic stainless steel safe-ends having a duplex metallurgical structure with a minimum ferrite number of 8, or (2) the austenitic stainless steel components to be joined should have stainless steel weld overlays which have a minimum delta ferrite number of 5, or (3) the safe-ends used shall be of other materials which have a high resistance to oxygen-assisted stress corrosion cracking. Also, the joint design employed must be such, that any unstabilized wrought austenitic stainless steel containing $\geq$ 0.035 percent carbon and having a delta ferrite number < 5 and which may become significantly sensitized as a result of the welding process is not exposed to the reactor coolant water. Carbon level

control may not be required for piping if its diameters are sufficiently small (e.g., instrument lines and control rod drive hydraulic systems) so that it could withstand a single failure without an accompanying loss-of-coolant accident as defined in 10 CFR Part 50, Appendix A."

Reason - To recognize that water control is different in BWRs and PWRs. Also, to provide controls for processing BWR sensitized welds to prevent oxygen-assisted stress corrosion cracking.

6. Page 1.44-2

B. Discussion

Paragraph Five, Fifth Line change "undue" to "severe."

Reason - The word "severe" is used in ASTM Specifications, ASTM A-262-70 and ASTM A-708-74 when describing unacceptable stress corrosion conditions.

7. Page 1.44-2

B. Discussion

Paragraph Seven, First Sentence, Lines 4 and 5. In line 4, substitute the words "low heat input" for the word "typical," and in line 5 insert after the word "chemistry" the word "controls."

Reason - The changes better describe the welding process and the materials employed.

Paragraph Seven, Line 7 delete the word "atypical."

Reason - The word is not needed and its inclusion makes the sentence less clear.

8. Page 1.44-2

B. Discussion

Paragraph Seven, Second Sentence - revise the second sentence as follows:

"However, there is evidence that welding methods using high heat input could result in stress corrosion cracking in the heat-affected zones of the weldments."

Reason - To clarify the source of high heat input.

9. Page 1.44-2

B. Discussion

Paragraph Seven, Third Sentence, substitute the word "severe" for the word "undue."

Reason - Better describes the sensitization condition obtained with high heat input processes.

10. Page 1.44-3

B. Discussion

First Paragraph (top-of-page) Line 4, change the figures "0.03" to "0.035."

Reason - Same as previously indicated.

11. Page 1.44-3

C. Regulatory Position

Numbered Paragraph 3, First Line, insert the word "base" between "the" and "material."

Reason - To better identify the material.

12. Page 144-3

Footnote No. 4 - revise to read as follows:

"Material of product forms with simple shapes not subject to distortion during heat treatment such as plate, sheet, bars, pipe, tubes, forgings, fittings and other shaped products which do not have inaccessible cavities or chambers that would preclude rapid cooling when water quenched, need not be tested provided the solution heat treatment is followed by water quenching."

Reason - To include other products capable of being rapidly cooled following solution heat treatment without distortion.

13. Page 144-3

    C. Regulatory Position 4(a)

    Third Line, delete the figures "200°F" and replace with "250°F."

    Reason - Industry has indicated that the 200°F is not realistic, and that it is extremely difficult to control dissolved oxygen level down to 0.10 ppm at that temperature.

14. Page 144-3

    C. Regulatory Position 4

    Line 6, change "0.03" to "0.035."

    Reason - To reflect the carbon level which is more truly indicative of the maximum used for austenitic stainless steels, "L" Grades or types.

15. Page 144-3

    C. Regulatory Position 4(b)

    Investigate the need for deletion of this item.

    Reason - Cast austenitic stainless steels may not have the resistance to intergranular stress corrosion attack previously believed to be the case.

16. Page 144-3

    C. Regulatory Position 5(a)

    Investigate the need for deletion of this item.

    Reason - Same as 15 above.

17. Page 144-3

    C. Regulatory Position

    Paragraph six, line 6, after the work "welding" insert the words, "hardfacing and wear-surfacing."

Reason - Provide assurance that hardfacing and wear-surfacing procedure qualifications are adequate to prevent severe sensitization, since the same intergranular corrosion test used to check weld procedures is specified.

Line 8, change the figures "0.03" to "0.035."

Reason - Same as previously given.

18. Page 1.44-3

C. Regulatory Position

Add a new paragraph No. 7 as shown below:

"7. Welded, unstabilized austenitic stainless steel products used in BWR construction having a carbon content $\geq$ 0.035 percent should be subsequently heat treated to place the base metal and weldments in a solution annealed condition. If the welds joining these components are not scheduled for solution annealing they should (1) be made between cast austenitic stainless steel safe-ends having a duplex metallurgical structure with a minimum delta ferrite number of 8, or (2) the austenitic stainless steel components to be joined should have stainless steel weld overlays which have a minimum delta ferrite number of 5, or (3) safe-ends should be specified which are made of other materials which have a high resistance to oxygen-assisted stress corrosion cracking. Also, the joint design used for the field welds must be such that any unstabilized wrought stainless steel having a carbon content $\geq$ 0.035 percent, which may become significantly sensitized as a result of the welding process, is not exposed to the reactor coolant.

Reason - To provide assurance that BWR field welds will be adequately protected. Such welds are likely to be in the sensitized condition, and when exposed to BWR oxygenated water, they can be expected to be susceptible to oxygen-assisted stress corrosion cracking.