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BWR Vessel and Internals Project Technical Basis for Revisions to Generic Letter 88-01 Inspection Schedules (BWRVIP-75NP)

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BWR Vessel and Internals Project Technical Basis for Revisions to Generic Letter 88-01 Inspection Schedules (BWRVIP-75NP)

TR-113932NP

Final Report, October 1999

EPRI Project Manager
R. Carter

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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CITATIONS

This report was prepared by

Inservice Engineering
1013 Fairlawn Drive
Hueytown, AL 35023

Author
R. L. Dyle

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REPORT SUMMARY

The Boiling Water Reactor Vessel and Internals Project (BWRVIP), formed in June 1994, is an association of utilities focused on BWR vessel and internals issues. This report provides the technical basis for revising the inspection schedules required by Generic Letter 88-01.

Background

Intergranular stress corrosion cracking (IGSCC) in boiling water reactor (BWR) piping was observed in small-bore piping in the early 1970s and in large-bore piping in 1982. The BWR Owners Group for IGSCC research formed in 1979 to address IGSCC in a safe and cost-effective manner. Options developed to control or eliminate IGSCC included pipe replacement with improved materials, stress improvement, and water chemistry controls.

The U.S. Nuclear Regulatory Commission (NRC) initially responded to this problem by issuing generic communications addressing pipe replacement and weld inspections in 1984; the NRC developed a long-range plan that was documented in SECY 84-301. In 1988, NRC published an updated position on IGSCC in Generic Letter 88-01, "NRC Position on IGSCC in BWR Austenitic Piping." The generic letter included NRC staff positions on material categorization and associated inspections, mitigation options, repair methods, and flaw evaluation. The BWR industry developed special examination procedures, standardized repair methods, and improved mitigation schemes including industry-wide water chemistry improvements. All these enhancements have resulted in reliable inspections and a significant reduction in IGSCC initiation and growth.

Objectives

- To provide evidence that IGSCC is adequately managed and that existing programs exceed what is needed to manage future problems.
- To justify revising the examination frequencies of Generic Letter 88-01 for welds classified as Categories A through E.

Approach

Inspection experience, risk insights, and knowledge regarding benefits of improved water chemistry formed the basis for revising inspection frequencies in GL 88-01. An industry survey was used to compile the inspection history. Results from the development and application of American Society of Mechanical Engineers (ASME) risk-informed code cases were used to evaluate the safety aspects of reduced inspections. These performance data, in combination with current understanding of mitigation tools, were used to develop new examination schedules.

Results

A revision to the schedule of piping inspection frequencies in GL88-01 was developed. The final report provides technical bases to support a reduction in the number of welds to be examined in some categories or an increase in the time between inspections in other categories.

EPRI Perspective

This report demonstrates that IGSCC has been well managed by U.S. BWR utilities through the effectiveness of various IGSCC controls and improvements in inspection capability. Since GL 88-01 was issued, the BWR industry has performed several thousand weld examinations on piping subject to the generic letter requirements. During this time, the industry has improved the water chemistry of reactor coolant thereby reducing IGSCC initiation and growth. The report's revised examination criteria will continue to adequately assure piping integrity and safety while resulting in significant cost reductions to the industry.

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Keywords

BWR
Intergranular stress corrosion cracking
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Piping
Welds

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G. Park - Chairman	Alliant Energy
M. Baig	Illinois Power
R. Carter	EPRI
C. Garrow	Entergy Nuclear Generation Co.
J. Gilman	EPRI Consultant
S. Lewis	Entergy Operations, Inc.
T. Oliveri	Public Service Electric and Gas
P. O'Regan	EPRI
B. Penny	New York Power Authority
D. Ramey	Energy Northwest
J. Spanner	EPRI
J. Sparks	Tennessee Valley Authority
D. Swann	Southern Nuclear Operating Co.
B. Swoyer	Pennsylvania Power & Light
G. Warren	Southern Nuclear Operating Co.
C. Wirtz	FirstEnergy Corp.
L. Yemma	Carolina Power & Light

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1
INTRODUCTION

1.1 Purpose

NRC Generic Letter 88-01 [1] defines inspection schedules for stainless steel piping welds in boiling water reactors. This document presents the technical basis for revisions to the Generic Letter 88-01 inspection schedules.

1.2 History

Intergranular stress corrosion cracking (IGSCC) in boiling water reactor (BWR) piping was identified as a problem in the United States in the early 1970s. The cracking initially was observed in small-bore piping. Cracking caused by IGSCC in large-bore piping was identified in 1982. The US Nuclear Regulatory Commission (NRC) responded by, among other actions, issuing two generic letters (GL) in response to the large-bore pipe crack findings. One was GL 84-07, "Procedural Guidance for Pipe Replacements at BWRs", which offered the NRC staff's preferred means of addressing the IGSCC issue. The other generic letter was GL 84-11, "Inspection of BWR Stainless Steel Piping", which gave early guidance on acceptable approaches to pipe inspection. The NRC also developed a long-range plan to deal with BWR pipe cracking and provided it to the commission in SECY 84-301.

The BWR Owners Group for IGSCC Research was formed in 1979 by the BWR utilities to address IGSCC in a safe and cost-effective manner. Some utilities chose to replace piping using a material that was more resistant to IGSCC. Others chose to implement one or both of the mitigation methods that involved stress improvement (SI) processes: Induction Heating Stress Improvement (IHSI) or the Mechanical Stress Improvement Process (MSIP). Several BWR owners chose to mitigate IGSCC through the implementation of hydrogen water chemistry (HWC). In 1988, the NRC published an updated position on IGSCC in a new generic letter, GL 88-01 "NRC Position on IGSCC in BWR Austenitic Stainless Steel Piping," [1]. In the generic letter, NRC noted that the BWR Owners Group for IGSCC Research program and the work of other organizations, along with confirmatory research by NRC, led to the revision of the NRC staff positions on IGSCC.

In GL 88-01, the NRC included staff positions on materials, inspections, mitigation options, repairs, and crack evaluation. The generic letter applied to "all BWR piping made of austenitic stainless steel that is four inches or larger in nominal diameter and contains reactor coolant at a temperature above 200°F during power operation regardless of code classification." NUREG-0313, Rev.2, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping," [2] contained the technical bases for the staff

positions. The generic letter required that all licensees, under oath and affirmation, provide their plans to NRC within 180 days regarding the staff positions. In 1992, NRC issued a supplement to GL 88-01 [3] that modified some staff positions in the original generic letter including inspection guidance for reactor water cleanup system (RWCU) welds outside containment isolation valves.

Licensees have continued to perform activities in accordance with their initial commitments to GL 88-01, or as revised by agreement with the NRC. Special examination procedures have been developed and repair methods improved. Research by the BWR industry concerning the methods to mitigate IGSCC continues today.

Special examination methods were developed in response to the need for improved detection and sizing of IGSCC. The BWR Owners Group for IGSCC Research and EPRI developed a program, the 3-party NDE Coordination Plan, which the NRC endorsed as part of GL 88-01. This program remained in place until March 1996. At that time, a transition from the NDE Coordination Plan to a new qualification program was initiated. This new program was agreed to by the NRC, by the GE BWR Owners Group (BWROG), and by the Performance Demonstration Initiative Steering Committee [4]. This new qualification program brought the IGSCC examination qualification process into alignment with the Performance Demonstration Initiative (PDI) program for satisfying the rules of Appendix VIII of ASME Section XI as amended by Reference 5.

Industry efforts regarding weld overlays resulted in the development of Code Case N-504 which was approved for use by ASME on April 30, 1992 [6]. NRC initially endorsed use of N-504 by inclusion in RG 1.147, Rev. 11 [7]. More recently in RG 1.147, Rev. 12 [8], the NRC has endorsed revision 1 of N-504 (N-504-1) with no limitations. (Note: Revision 1 to the code case made it editorially correct with other changes that were made to ASME Section XI.)

The BWROG assumed responsibility for the regulatory interface on issues related to IGSCC when the BWR Owners Group for IGSCC Research was discontinued in 1988. The Improved Water Chemistry Committee within the BWROG developed criteria for determining acceptable performance of HWC systems for the purpose of extending inspections schedules for BWR piping weldments. This was submitted to the NRC for review [9] and NRC issued a safety evaluation (SE) in January 1995 [10]. After the SE was issued, additional work was performed by the BWROG to resolve limitations that the NRC imposed in the SE. In April 1998, the BWROG submitted a response to the NRC SE [11] and is awaiting completion of the NRC's review. In parallel, the BWR Vessel and Internals Project (BWRVIP), which was formed in 1994, has worked extensively on the mitigation of IGSCC for BWR internals components. The BWRVIP has developed a demonstration program for Noble Metal Chemical Application (NMCA) which enhances the effectiveness of HWC. It has also developed a basis for applying credit to reactor internals inspection programs for effective HWC that is comparable to the BWROG basis for piping. The BWRVIP has submitted the report to NRC for review [12]. Two licensees submitted requests to NRC seeking credit for their HWC programs and approval to alter their piping inspection schedules. The NRC has issued safety evaluations to Duane Arnold and Pilgrim [13, 14].

BWR Water Chemistry Guidelines were first published by EPRI in 1989. Periodic revisions have been prepared by an industry ad hoc committee, reflecting advances in technology and improvements in industry practice for IGSCC mitigation, including hydrogen water chemistry. Reference 15 is the current version of the BWR Water Chemistry Guidelines.

Beginning in 1997 several separate licensee actions involved requests to the NRC to change various parts of the inspection schedule contained in GL 88-01. Vermont Yankee submitted a request to use Code Case N-560 [16] on Class 1 welds, including those subject to GL 88-01. (Note: At VY, the GL 88-01 welds were Category A.) NRC approval was granted in 1998 [17]. TVA developed an ISI program revision for the entire inservice inspection (ISI) program using risk-based Code Case N-577 [18]. This update included all piping covered by GL 88-01. NRC evaluation is not complete. EPRI, in coordination with some members of the BWROG, developed a technical basis report supporting the alteration of the inspection frequency for weld overlays [19]. In response to the multiple submittals, the NRC suggested to the BWRVIP that the industry would be better served if a generic effort were undertaken. After a meeting on March 16, 1999, between NRC and BWRVIP representatives, the BWRVIP agreed to develop a technical basis document and revised inspection schedule that could be used as an alternative to the GL 88-01 schedule.

2
GL 88-01 SUMMARY

GL 88-01, in combination with Supplement 1, [1,3] specified inspection frequencies based on material conditions of the piping and provided guidance for sample expansion. The following section provides the current GL 88-01 requirements by weld category. The material definitions are taken from NUREG-0313, Rev. 2 [2]. Sample expansion is discussed at the end of the section.

2.1 Category A

2.1.1 Definition

IGSCC Category A weldments are those with no known cracks and that have low probability of experiencing IGSCC because they are made entirely of IGSCC resistant materials or have been solution heat treated after welding. Corrosion resistant clad (CRC) is considered to be IGSCC resistant, and welds joining cast pump and valve bodies to resistant piping are considered to be resistant weldments.

Materials that satisfy this definition are austenitic stainless steels that have a carbon content below 0.035% (e.g., 304L, 316L, and 316NG). Cast austenitic stainless steels, like that used for pump casings and valve bodies, with low carbon (<0.035%) and high ferrite (minimum of 7.5 FN) are Category A materials. Austenitic stainless steel that was solution heat treated after welding or that has been protected by CRC is also considered resistant. Additionally, Inconel 82 and low carbon weld metals with controlled ferrite (such as 308L) are resistant.

Castings with a carbon content higher than 0.035% are generally not considered resistant to sensitization. However, experience has shown that welds joining these castings to resistant piping have performed well and can therefore be included in Category A. If extensive weld repairs were performed, the welds should be included in the Category D population.

2.1.2 Inspection Requirement

IGSCC Category A weldments should be examined according to a schedule similar to that called for in Section XI of the ASME Boiler and Pressure Vessel Code (the Code). A representative sample of 25% of the welds should be examined every 10-year interval. The sample selection should reflect the best technical judgement of the owner. At least 12% of the population were to be examined during the first six years of the interval.

2.2 Category B

2.2.1 Definition

IGSCC Category B weldments are those not made of resistant materials, but that have been treated by an SI process either before service or within two years of operation. If the stress improvement is performed after plant operation, a post-SI ultrasonic (UT) examination is required to ensure that the welds are not cracked.

The staff position in GL 88-01 is that either IHSI or MSIP would upgrade non-resistant material and reduce IGSCC susceptibility.

2.2.2 Inspection Requirement

The NRC staff position was that Category B welds were more likely to crack than Category A welds, so a larger sample size was required. A sample of 50% of the Category B welds was required to be examined every 10-year interval with 25% to be completed within the first six years of the interval.

2.3 Category C

2.3.1 Definition

IGSCC Category C weldments are those not made of resistant materials and that have been treated by an SI process after more than two years of operation. As part of the process, a UT examination is required after the SI treatment to ensure the weldment is not cracked.

2.3.2 Inspection Requirement

IGSCC Category C welds were in service longer prior to SI than Category B welds so they are more likely to have contained undetected cracking. All Category C welds were to be examined within two refueling cycles after the post-SI examination and once every 10 years thereafter. Fifty percent (50%) of the examinations were to be completed within six years.

2.4 Category D

2.4.1 Definition

IGSCC Category D weldments are those not made with resistant materials and not given an SI treatment, but that have been examined by personnel using procedures in conformance with Section 5.2.1 of NUREG-0313, Rev. 2 (i.e., NDE Coordination Plan or the PDI program [4, 5]),

and found to be free of cracks. As noted in 2.1.1 above, welds with extensive repairs that join resistant materials and castings should be included in Category D.

2.4.2 Inspection Requirement

Category D weldments are to be examined at least once every two refueling cycles. NUREG-0313, Rev. 2, suggested that approximately 50% be examined each outage. However, GL 88-01 did not impose that as a requirement.

2.5 Category E

2.5.1 Definition

IGSCC Category E weldments are those with known cracks that have been reinforced by an acceptable weld overlay or have been mitigated by an SI treatment with subsequent examination by qualified examiners and procedures to verify the extent of cracking. Guidelines for acceptable weld overlay reinforcement and the extent of cracking considered amenable to SI treatment are covered in sections 3.2 and 4.5 of NUREG-0313, Rev. 2.

The staff initially considered the overlay a short-term repair option, but noted in Reference 1 that it could be considered for longer term operation provided the overlays were in accordance with the criteria of IWB-3600 of the 1986 Edition of Section XI and are examined in accordance with staff recommendations. As was noted earlier and is detailed in Reference 19, the overlay came to be accepted as a long-term repair option, was approved by ASME in Code Case N-504 [6] and endorsed by NRC [7,8].

Use of stress improvement to mitigate cracked welds is limited to welds with minor cracking. GL 88-01 specified that SI could be used for welds with cracks no longer than 10% of the circumference and no deeper than 30% of the wall thickness.

2.5.2 Inspection Requirement

IGSCC Category E welds are to be inspected once every two refueling cycles. Approximately 50% of them should be examined during the first refueling outage after repair.

The NRC stated that it was desired that the examination method used for weld overlays be able to detect cracking in the outer 25% of the original pipe wall.

2.6 Category F

2.6.1 Definition

IGSCC Category F weldments are those with known cracks that have been approved by analysis for limited additional service without repair. Weldments found to have significant cracking or an uncertain extent of cracking that have been minimally overlay reinforced (not in conformance with 4.1 of the NUREG-0313, Rev. 2) are considered acceptable only for interim operation. Weldments with significant cracking that have been SI treated may also be considered to be in this category. Sections 3.0 and 4.0 of NUREG-0313, Rev. 2, provided guidelines to evaluate specific cases.

Welds that are categorized as F because the weld overlay repair or the stress improvement did not meet the staff criteria may be upgraded to Category E after four successive examinations if no adverse change in the crack is detected.

2.6.2 Inspection Requirement

IGSCC Category F weldments are approved for limited service and should be examined every refueling outage, unless a shorter service period has been specified.

2.7 Category G

2.7.1 Definition

IGSCC Category G weldments are those that are not made of resistant materials, have not been given an SI treatment and have not been examined in accordance with section 5.2.1 of NUREG-0313, Rev. 2. Stress improved welds that were not examined after the SI treatment are considered to be Category G weldments until the post-SI examination has been performed. Once examined, the welds will be categorized based on the examination results.

2.7.2 Inspection Requirement

IGSCC Category G weldments should be examined at the next refueling outage.

2.8 Inspection Schedule with HWC

The NRC staff position documented in GL 88-01 was that use of hydrogen water chemistry combined with stringent control of conductivity would inhibit the initiation and growth of IGSCC. It was also recognized that each BWR responds differently to hydrogen injection; therefore, a plant-specific evaluation was required before credit for HWC could be obtained. However, if fully effective HWC is maintained, the period between inspections could be

lengthened by a factor of two for Category B, C, D, and E weldments. Two plants, Duane Arnold and Pilgrim, have received approval to alter weld examination frequencies based on their HWC programs [13, 14].

2.9 Sample Expansion

The staff position on sample expansion for Category A, B, C, and E welds is identified in GL 88-01. The position for Category D welds is contained in GL 88-01, Supplement 1. There are no sample expansion criteria for Category F welds since they are examined each outage. Similarly, there are no expansion criteria for Category G welds. Category G welds are those that have not yet been examined. They were required to be examined at the next outage and re-categorized based on the examination results. The staff positions are summarized below.

If cracking is detected in any Category A, B, or C weld as part of a sample examination, an additional sample of approximately the same number of welds from the same category will be examined. The sample should be similar in distribution (size, system, etc.) to the original sample unless there is a technical basis for selecting a different sample. If cracking is detected in any welds in the expanded sample, all remaining welds in that Category are to be examined.

If Category D welds are examined on a sample basis and cracking is detected, the remaining Category D welds are to be examined. However, if technically justified, the sample expansion may be limited to the piping system in which cracking was initially detected.

All remaining Category E welds are to be examined if significant crack growth or additional cracking is detected in the initial sample. For weld overlays, significant cracking is defined as cracking that was less than 75% through-wall growing to a depth greater than 75% of the wall. For cracking initially greater than 75% through the wall, crack growth into the effective overlay is considered significant. For SI mitigated welds, significant growth is such that a crack exceeds 10% of the circumference in length or 30% of the wall in depth.

3
REVISED INSPECTION CRITERIA

The following section describes the revised inspection criteria for piping subject to GL 88-01 [1]. The criteria will be presented by category. There are no new inspection criteria for Categories F or G. The changes in inspection criteria are summarized in Table 3-1.

It should be noted that in some cases, the sample size required to be examined by this report is smaller than that required by ASME Section XI. For those cases, it is recognized that when this report is approved for use by NRC, each licensee will have to submit a request for relief from, or alternative to, the Code to use the sample sizes specified in this report. In that request, they will describe how the conditions contained in this report are applicable to their plant.

In addition to new inspection frequencies, the report also provides new sample expansion criteria for some categories. Also provided is a modified inspection frequency for each category that provides credit for effective HWC. The definition of effective HWC is provided in Section 3.6.

Examination personnel and the procedures used for the examinations will continue to be in accordance with the program identified in Reference 4 and 5.

There are two favorable developments that are applicable to all the piping under consideration and to the inspection frequency revisions that follow. One is that the entire industry has implemented EPRI guidelines for water chemistry control that reduces the propensity for initiation and growth of IGSCC. Second, since the mid-1980s, industry efforts have resulted in improved examination procedures and techniques for the detection and sizing of IGSCC. Personnel have developed years of experience in IGSCC crack detection and evaluation resulting in higher confidence in the results of the examinations and thus, higher confidence in the integrity of the piping.

At the beginning of this effort, a survey was sent to each BWR owner to obtain information concerning the number of welds in each IGSCC Category, the stress improvement technique used, the number of inspections performed and the number of welds protected by HWC. Data from 33 of the 34 operating BWRs was provided. In some cases inspection results for the applicable piping were provided from the plant startup to date. In other cases, plants provided inspection results since the implementation of their GL 88-01 programs. Plants that have replaced pipe reported results since that point in time. The result is an excellent cross section of industry inspection results from which to draw conclusions. This service experience, combined with information gained from additional research by the BWRVIP, BWROG and EPRI since GL 88-01 [1] was issued, provides the bases for the new inspection schedules.

3.1 Category A

The materials in Category A are resistant to IGSCC due their metallurgical properties. As such, the current required inspection scope and frequency per GL 88-01 is 25% of the population every 10 years. This is essentially the same as ASME Section XI.

3.1.1 New Criteria

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3.1.2 Basis

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3.2 Category B

Category B welds are those made of material not considered resistant to IGSCC, but treated with a stress improvement process prior to two years of service. The inspection scope and frequency specified by GL 88-01 is that 50% of the population be examined every 10 years.

3.2.1 New Criteria

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3.2.2 Basis

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3.3 Category C

Category C welds are made from material that is considered susceptible to IGSCC, but mitigated by stress improvement after more than two cycles of operation. GL 88-01 specifies that the entire population is to be examined once every ten years.

3.3.1 New Criteria

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3.3.2 Basis

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3.4 Category D

Category D welds are those made of susceptible material that have not been treated with an IGSCC remedy and in which cracks have not been reported.

3.4.1 New Criteria

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3.4.2 Basis

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3.5 Category E

Category E welds are defined by GL 88-01 as cracked weldments that have been mitigated by either a weld overlay repair or a stress improvement process.

3.5.1 New Criteria

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3.5.1.1 Weld Overlay Repair

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3.5.1.2 Stress Improved Welds

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3.5.2 Basis

3.5.2.1 Weld Overlay Repair

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3.5.2.2 Stress Improved Welds

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3.6 Effective HWC

The introduction to this report included a short discussion on the history of efforts by the BWR industry and vendors to develop hydrogen water chemistry as a viable means to mitigate IGSCC. The NRC has adopted HWC as described in their safety evaluation on the early BWROG submittals for piping welds [10, 13, 14]. More recently, the BWRVIP has submitted BWRVIP-62 that provides a systematic methodology for evaluating the effectiveness of HWC, with or without NMCA, for the mitigation of IGSCC.

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Figure 3-1
Plot of Stainless Steel Crack Growth Rate Factors of Improvement (FOI) based on HWC Availability as a Function of ECP

Table 3-1
Summary of Changes

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Table 3-2
GL 88-01 (NUREG-0313): Weld Count Survey

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Table 3-3
GL 88-01 (NUREG-0313): Weld Count Survey (concluded)

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4
RISK CONSIDERATION

This section addresses the impact associated with reducing the inspection frequencies of weldments originally under the scope of the Generic Letter 88-01 program.

4.1 Background

ASME Section XI Table IWB-2500-1 contains the inspection requirements for Category B-F and B-J welds. These requirements consist of surface and/or volumetric examination of 25% of the B-J welds and 100% of the B-F weld population over a ten-year inspection interval. The Class 1 welds, for which GL 88-01 is applicable, are included in these code categories. Historically, Section XI has been the inservice inspection mechanism for assuring a robust reactor coolant pressure boundary. Thus, the sampling percentages and inspection frequencies defined in Section XI have provided the baseline for defining an adequate level of plant safety with respect to inservice inspection programs.

The current ASME Section XI selection criteria requires examination of dissimilar metal welds, structural discontinuities and relatively highly stressed welds. However, the real measure of protection against catastrophic failure of a piping system component is the combination of good design and leak-before-break behavior. All of the service-induced failure mechanisms which affect piping subject to Generic Letter 88-01, except one (Flow-Assisted Corrosion), have been shown to be of a local and gradually progressing nature, which generally produce detectable leakage before significantly reducing the inherent safety margins of the piping relative to gross rupture. The combination of periodic leak tests required by Section XI, in conjunction with continuous leakage monitoring requirements for all primary coolant systems during operation has proven to be more than adequate protection against a large pipe break. The potential for flow-assisted corrosion, which has caused large pipe breaks without prior leakage, is minimal in stainless steel Class 1 systems and as discussed previously in Section 3, the occurrence of new cracks or crack growth due to IGSCC in the subject piping has also been shown to be minimal.

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4.2 Impact of the Proposed Change

Table 3-1 of this report provides a summary of the revisions to the Generic Letter 88-01 inspection requirements. The following is organized consistent with the Section 3 format.

4.2.1 Category A without HWC

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4.2.2 Category A with HWC

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4.2.3 Category B, C and E (Weld Overlays Only) without HWC

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4.2.4 Category B, C and E (Weld Overlays Only) with HWC

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4.2.5 Category D and E (Stress Improvement) without HWC

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4.2.6 Category D and E (Stress Improvement) with HWC

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CONCLUSION

Since GL 88-01 was issued, the BWR industry has performed several thousand weld examinations on piping subject to the generic letter requirements. During this time, the industry has improved the water chemistry of reactor coolant thereby reducing initiation and growth of IGSCC. Stress improvement has also been employed as an IGSCC remedy. Examination procedures have been, and continue to be, improved. Examination personnel have received training on the latest techniques and have gained years of experience in the detection and sizing of IGSCC. Sufficient examinations have now been performed so that those welds that might have had shallow undetected cracking in 1988 have now been re-examined with qualified methods ensuring pipe integrity and a low likelihood of IGSCC. Therefore, the revisions specified in Section 3 are appropriate. These revised examination criteria described in this report will continue to provide adequate assurance of piping integrity and safety while resulting in a significant reduction in undue burden to the industry by reducing both personnel radiation exposure and the unnecessary expenditure of resources.

6
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EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.1212 • askepri@epri.com • www.epri.com