REACTOR PRESSURE VESSEL LOWER HEAD PENETRATION NOZZLES
(NRC BULLETIN 2003-02)

CORNERSTONE: BARRIER INTEGRITY
INITIATING EVENTS

APPLICABILITY: This Temporary Instruction (TI) applies to all holders of operating licenses for pressurized-water reactors (PWRs). The scope of this TI is similar to TI 2515/150.

2515/152-01 OBJECTIVE

01.01 The objective of this TI is to support the review of licensees' reactor pressure vessel (RPV) lower head inspection activities that are implemented in response to Bulletin 2003-02 (NRC Accession Number ML032320153), which was issued on August 21, 2003. This TI validates that a plant is meeting its inspection commitments using procedures, equipment, and personnel that have been demonstrated to be effective in detecting signs of leakage from the RPV lower head penetration (LHP) nozzles and the detection of RPV lower head degradation.

01.02 As an ancillary benefit, this TI promotes information gathering regarding the condition of the RPV lower head to help the Nuclear Regulatory Commission (NRC) staff identify and shape possible future regulatory positions, generic communications, and rulemaking.

2515/152-02 BACKGROUND

The NRC staff summarized its review of the responses to Bulletin 2002-01 and the associated requests for additional information (RAIs) in Regulatory Issue Summary (RIS) 2003-13, "NRC Review of Responses to Bulletin 2002-01, "Reactor Pressure Vessel Head Degradation and Reactor Coolant Pressure Boundary Integrity," dated July 29, 2003 (NRC ADAMS Accession Number ML032100653). The NRC noted in RIS 2003-13 that most licensees do not perform inspections of Alloy 600/82/182 materials beyond those required by Section XI of the American Society of Mechanical Engineers (ASME) Code to identify potential cracked and leaking components. For the RPV lower head, the ASME Code specifies that a visual examination, called a VT-2, be performed during system pressure

testing. Licensees may meet the ASME Code requirement for a VT-2 inspection by performing an inspection of the RPV lower head without removing insulation from around the head and its penetrations. Many licensees perform the ASME Code-required inspections without removing insulation and, therefore, may not be able to detect the amounts of through-wall leakage that would be expected from flaws due to primary water stress corrosion cracking (PWSCC) or other potential cracking mechanisms.

The lower head and bottom mounted instrumentation (BMI) penetrations of the South Texas Project Unit 1 (STP Unit 1) RPV were visually inspected on April 12, 2003, as a routine part of the unit's refueling outage. The lower head of the reactor is surrounded by an insulating box structure with no insulation directly in contact with the lower head. The inspection was accomplished by removing three of the insulation panels forming the insulating box. Three different vantage points were used to inspect all 58 BMI penetrations in the RPV lower head. The inspection found small amounts of white residue around two of the 58 BMI penetrations (numbers 1 and 46) at the junction where the penetrations met the lower RPV head. The residue at penetrations 1 and 46 was collected for laboratory analysis to determine the source of the residue material. Approximately 150 milligrams and 3 milligrams were collected from penetrations 1 and 46, respectively. The analysis of the sample for lithium demonstrated that the lithium was approximately 99.9% lithium-7, which indicated that the reactor coolant system (RCS) was the source of the residue. The analysis of the sample for cesium indicated that the average age of the residue collected was between 3 and 5 years. The licensee for STP Unit 1 indicated that these residues were not visible during the previous inspection on November 20, 2002.

Ultrasonic inspections (using circumferential, axial, and zero degree probes) of all 58 BMI penetration tubes at STP Unit 1 were completed in May 2003, along with the visual inspections of the surfaces of the 58 J-groove welds which attach the BMI penetration tubes to the RPV lower head. In addition, eddy current testing (ECT) was used to examine the J-groove weld and inside diameter surfaces of some BMI penetration tubes. Axial cracks were found in penetrations tubes 1 and 46. The largest of these cracks was entirely through wall and extended above and below the J-groove weld. No evidence of cracking was found in any other penetrations. BMI penetrations 1 and 46 have been repaired. The licensee is continuing to investigate the cause of the cracks. The investigation has not, to date, identified any manufacturing practice or operating condition that is unique to the affected penetrations or to the RPV at STP Unit 1. The design of the area beneath the RPV at STP Unit 1 and the inspection methods used by the licensee enabled the discovery of the leaking penetrations. From the NRC staff reviews described in RIS 2003-13, the NRC staff concluded that leakage such as that observed at STP Unit 1 would likely not have been detected during inspections performed at many other PWRs.

In summary, the current RPV lower head inspection requirements as implemented from the ASME Code by 10 CFR 50.55a require visual examination of the insulated surface or surrounding area for signs of leakage. Such inspections are not sufficient to reliably detect signs of leakage from LHP nozzles or corrosion of the RPV lower head. Degradation of RPV LHP nozzles and corrosion of the RPV lower head pose a safety concern because of the possibility of a nozzle ejection or loss-of-coolant accident if the conditions are not detected and repaired. The experience at STP Unit 1 in the spring of 2003 in which cracks were identified in two BMI penetrations further exemplifies the need for more effective inspections of the RPV lower head.

Additional background information pertaining to RPV upper heads is contained within TI2515/150 Revision 2.

2515/152-03 INSPECTION REQUIREMENTS

03.01 Responses Affirming Compliance with Applicable Regulatory Requirements. The inspector will review the licensee's response and supporting basis demonstrating that their inspection program will ensure compliance with existing regulations.

03.02 Bare Metal Visual Examination

The BMV examination is implemented to verify the absence of boric acid crystals, which may be evidence of a leak in the LHP nozzles, and to verify the integrity of the RPV lower head. If a BMV examination is performed, the inspection will consist of the following activities:

a. Review the qualifications and certification of the inspection personnel and the inspection techniques to assess the licensee's ability to detect or identify small boric acid deposits on the head.

b. Review the examination procedure to determine whether it provides adequate guidance and examination criteria to implement the licensee's examination plan.

c. Conduct a performance-based inspection to verify that the licensee properly performed the procedure. Pay particular attention to ensure that the visual clarity of the examination process was adequate; the method used to track identification of the penetrations being inspected is effective; and that prior (pre-existing) boric acid deposits, debris, and insulation were effectively identified and evaluated. Also, review the inspection procedure to verify that it provides specific actions to be implemented should boric acid deposits (or other interfering deposits) be identified on the RPV head or related insulation.

d. Independently review a sample of the visual examination of the RPV lower head including the LHP nozzles. The sample should consist of LHP nozzles at different points distributed around the RPV lower head curvature. The sample should also allow for assessment of the physical difficulties in conducting the examination. Inspectors will follow IP 57050, "Visual Testing Examination." Inspection requirements and guidance associated with inspection objective 01.01 in IP 57050 will be excluded from the inspection scope. The inspection of the licensee's LHP nozzle examinations may be considered part of the sample required by IP 71111.08, "Inservice Inspection Activities," Sections 02.01 and 02.03.

e. If an inspection opportunity is available, inspectors will independently review a sample of LHP nozzle examinations (i.e., 360° around penetration) and assess the condition of the RPV lower head. In particular, inspectors should look for evidence of possible leakage at the vessel to penetration interface and for conditions of the RPV lower head, such as debris, insulation, dirt, boric acid deposits from preexisting leaks such as from the reactor cavity seal, coatings or peeling coatings,

or other obstructions, physical layout, and viewing obstructions. If an opportunity to independently review the RPV lower head does not become available, inspectors will briefly describe the circumstances (i.e., is this a routine outage condition that does not permit viewing the RPV head) and what they could independently review.

f. If boric acid deposits are identified on the surface of the RPV lower head or related insulation, the inspector will review the licensee's action for verifying the integrity of the affected area and nozzles. These activities should be performed before returning the plant to operation. The inspection of these licensee activities will consist of the following:

   1. A review of the process the licensee follows for resolving the source of any boric acid deposits identified.

   2. A review of the scope of the licensee's plan to examine the pressure-retaining components above the RPV lower head to ensure that all possible sources of boric acid leakage have been identified.

   3. A review of the licensee's corrective actions in response to the identification of boric acid deposits on the RPV lower head or related insulation.

g. If boric acid deposits are attributed to a source other than leakage through the pressure boundary and if supplemental non-visual nondestructive examination (NDE) is not performed of the area, inspectors will review the process used by the licensee to determine the source of the boric acid deposits (this is to ensure that the boric acid deposits are not the result of reactor coolant leakage from a through-wall or through-weld crack in the LHP assembly). Inspectors should review reports of any chemical analyses to ensure that the conclusions are logical and supported by the analysis. Questions regarding detailed aspects of chemical analyses of boric acid deposits may be referred to the Materials and Chemical Engineering Branch contacts for this Temporary Instruction.

h. Inspectors will report areas of the RPV lower head or LHP nozzles obscured by debris, insulation, dirt, boric acid deposits from preexisting leaks such as from the reactor cavity seal, coatings or peeling coatings, or other obstructions, physical layout, and viewing obstructions.

i. Inspectors will report anomalies, deficiencies, and discrepancies associated with the RCS structures or the examination process including those identified by the licensee. Verify they are placed in the licensee's corrective action process. The inspectors will report lower-level issues concerning data collection and analysis, as well as any issues that are deemed to be significant to the phenomenon described in the bulletin or when such problems are judged to be significant enough to potentially impede the examination process. These items should be reported in accordance with the reporting instructions of this TI.

03.03 Volumetric Examination

Volumetric examinations are not expected to be performed unless boric acid deposits are identified at or near the interface between the RPV head and a LHP nozzle (similar to what was found at STP 1); however, if volumetric examinations are performed, the NRC inspection will consist of the following activities:

a. Inservice Inspection (ISI) specialist inspectors will perform Inspection Procedure (IP) 57080, "Ultrasonic Testing Examination." Inspection requirements and guidance associated with inspection objective 01.01 in IP 57080 will be excluded from the inspection scope. The inspection of the licensee's LHP examinations may be considered part of the sample required by IP 71111.08, "Inservice Inspection Activities," Sections 02.01 and 02.03. The inspection sample will consist of:

   1. Independently review a sample of the LHP nozzle volumetric examinations. If all LHP nozzles are examined during the outage, a minimum 10% sample will be reviewed.

   2. If applicable, review one or two of examinations from the previous outage with recordable indications that have been accepted by the licensee for continued service. This step is not expected to be applicable during the first outage following issuance of this bulletin. Any flaws that will be left in service should be brought to the attention of NRR/DE/EMCB given the potential uncertainty in the cause of the degradation.

   3. If applicable, review one examination of a repaired nozzle. This review may be included in the 10% sample described in 03.04.a.1.

   4. If applicable, review one or two repairs.

b. The inspector will independently review the licensee's implementation of the chosen method to inspect the LHP nozzles.

c. Identify any anomalies, deficiencies, and discrepancies associated with the RCS structures or the examination process including those identified by the licensee and then verify they are placed in the licensee's corrective action process. The inspectors will report lower-level issues concerning data collection and analysis, as well as any issues that are judged to be significant enough to potentially impede the examination process. The inspector will report whether the demonstrated examination procedures were implemented properly. These items should be reported in accordance with the reporting instructions of this TI.

03.04 Surface Examination

Surface examinations are not expected to be performed unless boric acid deposits are identified at or near the interface between the RPV head and a LHP nozzle (similar to what was found at STP 1); however, if a surface examination (i.e., liquid penetrant or eddy current) is performed, the NRC inspection will consist of the following activities:

a. ISI specialist inspectors will follow Inspection Procedure (IP) 57060, "Liquid Penetrant Testing Examination," using a sample of LHP nozzles to assess the licensee's qualified surface examination. The inspection of the licensee's LHP nozzle and/or J-groove weld surface examinations may be considered part of the sample required by IP 71111.08, Sections 02.01 and 02.03. The inspection sample will consist of:

   1. Independently review a sample of LHP nozzle and/or J-groove weld surface examinations. If all LHP nozzles are examined during the outage, a minimum 5% to 10% sample will be reviewed.

   2. If applicable, review one or two of examinations from the previous outage with recordable indications that have been accepted by the licensee for continued service. This step is not expected to be applicable during the first outage following issuance of this bulletin. Any flaws that will be left in service should be brought to the attention of NRR/DE/EMCB given the potential uncertainty in the cause of the degradation.

   3. If applicable, review one examination of a J-groove weld that was repaired during a previous inspection. This review may be included in the 5% - 10% sample described in 03.03.a.1.

   4. If applicable, review one or two repairs.

b. The inspector will independently review the licensee's implementation of the chosen method to inspect relevant surface conditions.

c. Identify any anomalies, deficiencies, and discrepancies associated with the RCS structures or the examination process including those identified by the licensee and then verify they are placed in the licensee's corrective action process. The inspectors will report lower-level issues concerning data collection and analysis, as well as any issues that are judged to be significant enough to potentially impede the examination process. The inspector will report whether the demonstrated examination procedures were implemented properly. These items should be reported in accordance with the reporting instructions of this TI.

2515/152-04 GUIDANCE

General

In response to Bulletin 2003-02, each licensee will submit their own plans for inspecting the RPV LHPs; however, the staff expects that licensees will perform a BMV inspection of 100% of the circumference of each penetration as it enters the RPV lower head during their next refueling outage (except as discussed below). If licensees are unable to perform these BMV inspections at all penetrations during their next outage because of the inability to perform the necessary planning, engineering, procurement of materials, and implementation, the licensee should provide a description of the actions that will be taken

to permit a bare-metal visual inspection of each penetration during subsequent refueling outages.

Based on the results of the BMV inspection, licensees may perform additional diagnostic testing including ultrasonic testing, eddy current testing, and/or surface examinations of the LHP nozzles and the associated J-groove weld.

The inspectors should be cognizant of extenuating circumstances at their respective plant(s), such as the operational history, physical layout and material condition of the RPV lower head, and any identified LHP nozzle leakage or other Alloy 600 PWSCC indications that would suggest a need for more aggressive licensee inspection practices. Factors that may affect crack initiation and growth include operating time, temperature, material heat, microstructure, and residual stresses. The residual stresses for LHPs may vary significantly from one nozzle to the next based on fabrication procedures (e.g., straightening of nozzles). In conducting inspections or other activities on the RPV lower head, licensees should recognize that entry into and work in cavities under PWR reactor vessels present very high radiation hazards. Access controls to these areas should require, among other things, close communication between plant operations and radiation protection staff on the status of the highly activated components (e.g., thimble retraction from the core into the reactor cavity) so that required reactor cavity access controls and oversight can be fully implemented before very high radiation levels are created. More information on these under-vessel hazards is provided in Appendix B of Regulatory Guide 8.38, "Control Of Access To High And Very High Radiation Areas In Nuclear Power Plants."

04.01 Responses Affirming Compliance with Applicable Regulatory Requirements. Bulletin 2003-02 contains a discussion of applicable regulatory requirements. Questions regarding detailed aspects of compliance determinations may be referred to the Materials and Chemical Engineering Branch contacts for this Temporary Instruction.

04.02 Bare Metal Visual Examination

a. Qualifications should be based on demonstrating, through mockups, the ability to detect boric acid deposits around nozzle penetrations on the order of those found at South Texas, Unit 1; i.e., as small as a few milligrams.

b. The licensee's examination procedures should meet the following minimum criteria:

    1. A complete RPV head examination is planned and successfully implemented. A complete examination means that all LHP nozzles are examined 360^{o} around the circumference of the nozzle. A LHP nozzle location indexing plan may be established to ensure that the examination accounts for all nozzles.

    2. Work is documented such that the examination scope, process, criteria, and results are complete and clearly described.

    3. The procedures provide inspection standards and acceptance criteria that are clear and on which personnel have been trained.

c. Specific actions to be taken by licensees if boric acid deposits (or other interfering deposits) are identified on the RPV head or related insulation may include following a prescribed process for evaluating the source of the deposits (discussed further under 3/4.02 g.), evaluating the significance of any corrosion, removing the boric acid deposits or other interfering deposits to establish a baseline for future inspections, and documenting the baseline conditions. If the source of deposits is determined to be reactor coolant, additional actions taken by the licensee would include extensive volumetric and surface examinations and repairs.

d. The effectiveness of a visual examination may be seriously compromised by the presence of insulation, pre-existing deposits on the RPV lower head, coatings, or other factors that could interfere with the detection of leakage.

e. If an inspection opportunity is available, inspectors may assess the condition of the RPV lower head through either direct observations, video inspections, or some other means of independent review, such as an examination of photographs of the lower head penetrations.

f. Licensees should report any identified leakage to the NRC consistent with the requirements of 10 CFR 50.72/73. Licensees should evaluate the possible corrosion effects associated with all deposits.

g. Determinations made to identify the source of boric acid deposits should be part of a process described in a procedure and should be based on sound engineering arguments or data without reliance on unverified assumptions. Engineering arguments may appropriately take into account the location of deposits. Deposits adjacent to a penetration or at the interface between the vessel and the penetration are of significant concern because they may have resulted from cracking in the penetrations and, therefore, require a high level of rigor and, likely data, to disposition. Data may include chemical analysis of boric acid deposits and data from performing supplementary non-visual non-destructive examinations (NDE). Chemical analysis of boric acid deposits resulting in very low amounts of lithium is consistent with refueling water rather than reactor coolant. Natural lithium contains approximately 92% lithium-7. Chemical analysis of boric acid deposits resulting in a very high percentage of lithium-7 (e.g., 99%) is consistent with reactor coolant being the source of the deposit.

04.03 Volumetric Examination

a. The following criteria are applicable to volumetric examinations performed by the licensee:

1. An acceptable equipment qualification/ demonstration will address the following attributes:

(a) the flaws used in the qualification or demonstration program should include artificial or real cracks. Demonstrations that rely exclusively on electro-discharge machine notches are not acceptable.

(b) a vendor mockup with or without a third party (industry or NRC) review is acceptable provided:

(1) the mockup is representative of the LVH equipment configuration, is of the same material types, and contains actual or closely simulated flaws, and

(2) the equipment/procedure used on the mockup identify and control the essential equipment variables, such as type and frequency of transducer used in the examination, within appropriate ranges.

2. The examination procedures and equipment used in the examinations should be consistent with those used during the qualification or demonstration.

3. Essential equipment variables should be consistent with those used during qualification or demonstration.

4. Inspection personnel should have successfully participated in a qualification or demonstration program with the equipment and procedures being used.

5. Examination procedures should provide inspection standards and acceptance criteria that are clear and on which personnel have been trained.

6. The examination procedure should require documentation of work, such that the examination scope, process, criteria, and results are complete and clearly described.

b. The implementation of the method chosen for examinations should be consistent with the qualification or demonstration of that method.

04.04 Surface Examination

a. The following criteria are applicable to volumetric examinations performed by the licensee:

1. The examination procedures and equipment used in the examinations should be consistent with those used during the qualification or demonstration.

2. Inspection personnel should have successfully participated in a qualification or demonstration program with the equipment and procedures being used.

3. Examination procedures should provide inspection standards and acceptance criteria that are clear and on which personnel have been trained.

4. The examination procedure should require documentation of work, such that the examination scope, process, criteria, and results are complete and clearly described.

b. The implementation of the method chosen for examinations should be consistent with the qualification or demonstration of that method.

2515/152-05 REPORTING REQUIREMENTS

Document inspection results in a resident inspectors' routine inspection report (i.e., quarterly inspection report), and send a copy of the applicable sections to NRR/DE/EMCB, Attention: Ted Sullivan or e-mail to ejs@nrc.gov. Mr. Sullivan can also be reached by telephone at (301) 415-2796. In addition, as soon as it is finalized, a copy of the feeder to the quarterly inspection report will be sent to NRR/DE/EMCB, to the attention of Mr. Sullivan, as indicated above. One purpose of this TI is to support NRR/DE/EMCB by inspecting and reporting on the licensees' performance of RPV lower head examinations. Specifically, the inspectors will provide a qualitative description of the effectiveness of the licensees' examinations. At a minimum, the inspectors will briefly answer the following questions (with a description of inspection scope and results) in Section 4OA5, "Other," of the next integrated inspection report.

a. For each of the examination methods used during the outage, was the examination:

   1. Performed by qualified and knowledgeable personnel? (Briefly describe the personnel training/qualification process used by the licensee for this activity.)

   2. Performed in accordance with demonstrated procedures?

   3. Able to identify, disposition, and resolve deficiencies?

   4. Capable of identifying pressure boundary leakage as described in the bulletin and/or RPV lower head corrosion?

b. What was the physical condition of the RPV lower head (e.g., debris, insulation, dirt, boric acid deposits from other sources, physical layout, viewing obstructions)?

c. Could small boric acid deposits, as described in the Bulletin 2003-02, be identified and characterized?

d. What material deficiencies (i.e., cracks, corrosion, etc.) were identified that required repair?

e. What, if any, impediments to effective examinations, for each of the applied non-destructive examination methods, were identified (e.g., insulation, instrumentation, nozzle distortion)?

f. Did the licensee perform appropriate follow-on examinations for indications of boric acid leaks from pressure-retaining components above the RPV lower head?

Any findings identified during this inspection will be processed and documented in accordance with NRC Inspection Manual Chapter (IMC) 0612, "Power Reactor Inspection Reports." Significance of inspection findings should be evaluated in accordance with applicable appendices of IMC 0609, "Significance Determination Process." Any noncompliance resulting from this inspection will be evaluated and documented in accordance with NRC Enforcement Policy (NUREG -1600) and Section 3.12 of the NRC Enforcement Manual. Also, licensees are required to address the findings resulting from these inspections (i.e. perform analyses and repairs) in accordance with existing requirements in the ASME code and 10 CFR 50.55a. Failure to meet these requirements must be identified as violations of these requirements.

2515/152-06 COMPLETION SCHEDULE

This TI will be completed at least once prior to its expiration date. If there are insufficient inspection weeks to inspect all units during an outage season, the following priority ranking should be used to determine which units will be inspected at a subsequent outage:

a. Units that plan to perform non-visual NDE of RPV LHPs should be given the highest priority.

b. Units that have never performed bare metal visual examinations of the RPV lower heads should be given the next highest priority. [Additional prioritizing information may be available from NRR/DE/EMCB following receipt of the Bulletin responses].

2515/152-07 EXPIRATION

This TI will expire in December 31, 2005.

2515/152-08 CONTACT

For questions regarding the performance of this TI and emergent issues, contact Mr. Ted Sullivan at 301-415-2796. Alternatively, Mr. Sullivan may be reached by E-mail at ejs@nrc.gov.

2515/152-09 STATISTICAL DATA REPORTING

All direct inspection effort expended on this TI is to be charged to 2515/152 for reporting by the Regulatory Information Tracking System (RITS) reporting with an IPE code of SI.

2515/152-10 ORIGINATING ORGANIZATION INFORMATION

10.01 Organizational Responsibility

This TI was initiated by the Materials and Chemical Engineering Branch (NRR/DE/EMCB).

10.02 Resource Estimate

The estimated direct inspection effort to perform this TI is estimated to be 15 to 30 hours per PWR unit.

10.03 Training

No formal training is proposed for the performance of this TI. If the licensee concludes that visual examination is sufficient because the licensee does not identify evidence of deposits from reactor coolant leakage, this temporary instruction can be performed by the resident inspectors. However, if the licensee finds evidence of deposits from reactor coolant leakage and expands its inspection to include volumetric and surface NDE methods, the inspector should be trained and experienced in these NDE techniques. If technical support is needed during the inspection of licensee's programs, contact EMCB through IIPB at least 30-days before the anticipated need for technical support.

END