TARGET – Development of Submersible ROV System for BMN Inspection

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ABSTRACT

Most PWRs have penetrations in the RPV lower heads for in-core nuclear instrumentation. These penetrations generally are made of nickel-based Inconel Alloy 600. Weld materials are typically Alloy 82/182. Operating conditions of PWR plants are causing nickel-based alloys cracking through a process called primary water stress corrosion cracking (PWSCC). In 2003, the licensee for the South Texas Project Unit 1 (STP-1) identified apparent boron deposits on the lower RPV head near two bottom mounted nozzles (BMNs). The NRC issued Bulletin 2003-02 to obtain information on licensee inspection activities and inspection plans for the RPV lower head. EPRI issued MRP-206 report that provides inspection and evaluation guidelines for BMNs for PWR plants, including guidelines for periodic bare metal visual examination for evidence of primary coolant leakage, or periodic non-visual nondestructive examinations for indications of service-induced cracking. The non-visual inspections (ultrasonic testing examination) may detect service-induced degradation before through-wall cracking, leakage, circumferential cracking below the bottom of the J-groove weld, release of loose parts, or incipient boric acid wastage of the low-alloy steel reactor vessel lower head material occurs. Therefore, periodic examinations will adequately manage potential for cracking by PWSCC and preserve structural integrity. INETEC developed TARGET system for BMNs inspection, consisted of submersible ROV and specially designed probe, composed of several UT probes. UT system and technique to detect, length and depth size the service-induced degradation in the BMN volume material is developed. The EPRI NDE Center performed a technical review and validated INETEC's ultrasonic examination technique for BMNs. Aforementioned validation was done according to requirements defined by: 1) MRP-206, 2) MRP-411.

Keywords: *Submersible ROV, BMN Inspection, nondestrucitve examination, ultrasonic testing examination, ultrasonic examination technique*

1 INTRODUCTION

Most pressurized water reactor (PWR) type of nuclear power plants have penetrations in the reactor pressure vessel (RPV) lower heads for in-core nuclear instrumentation. The RPV bottom mounted nozzles (BMN) in PWR are fabricated from nickel-chromium-iron Alloy 600 [1]. J-groove welds connect BMNs to the lower head of the RPV and is usually made from Alloy 82 and/or Alloy 182 [1]. These components are susceptible to age-related degradation due to primary water stress corrosion cracking (PWSCC) [1].

In the spring of 2003, the licensee for the South Texas Project Unit 1 (STP-1) identified apparent boron deposits on the lower RPV head near two BMNs [2]. The NRC issued Bulletin 2003-02 to obtain information on licensee inspection activities and inspection plans for the RPV lower head [3]. In October, 2013, during a scheduled visual examination of the BMNs at Palo

Verde Nuclear Generating Station Unit 3, white residue around the BMNs were identified [1]. Nondestructive examinations confirmed that axial cracking at the nozzle weld was responsible for the leakage [1]. Periodic visual examinations of the BMNs are specified in ASME Code Case N-722-1 [4]. The examination is performed from the exterior of the reactor coolant system for evidence of leakage, such as boron or corrosion product deposits [4]. In alternative to Code Case N-722-1, Electric Power Research Institute (EPRI) issued "Materials Reliability Program: Inspection and Evaluation Guidelines for Reactor Vessel Bottom-Mounted Nozzles in U.S. PWR Plants (MRP-206). This report provides guidelines not only for visual examination, but also for periodic non-visual nondestructive examinations for indications of service-induced cracking. The non-visual inspections such as ultrasonic testing examination, may detect service-induced degradation before through-wall cracking, leakage, circumferential cracking below the bottom of the J-groove weld, release of loose parts, or incipient boric acid wastage of the low-alloy steel reactor vessel lower head material occurs [2]. Periodic examinations will adequately manage potential for cracking by PWSCC and preserve structural integrity. Therefore, INETEC developed new system for inspection of Westinghouse PWR 2-loop. 3-loop and 4-loop type of BMNs.

2 BOTTOM MOUNTED NOZZLE

The attachment of the BMN (Figure 1) to the bottom head consisted of either Alloy 182 or Alloy 82 weld metal in a prepared J-groove, which was machined into the inside surface of the vessel adjacent to each previously drilled penetration hole. The design of the J-groove was essentially the same for all plants. The BMNs examination volume (Figure 2) is 25.4 mm below the lowest point of the root of the J-groove weld to the highest point at the toe of the J-groove weld. A-B-C-D volume is extent of volumetric examination for the tube (base metal) [5].

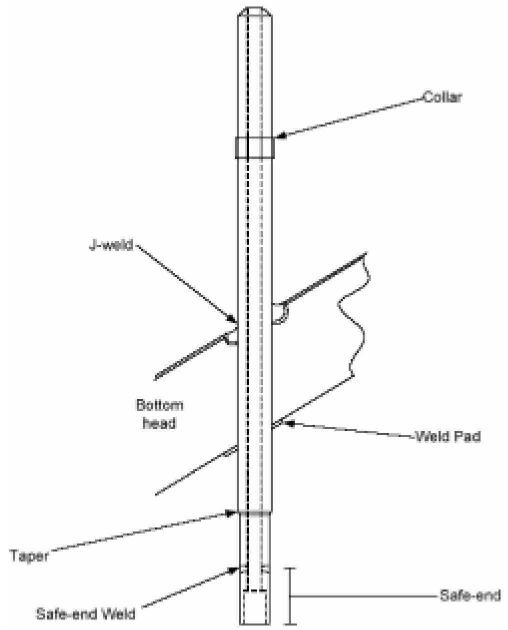

Figure 1: Westinghouse-designed BMN [5]

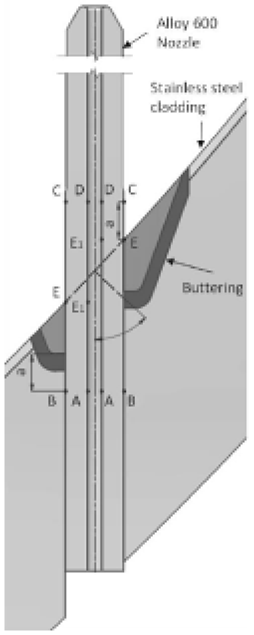

Figure 2: BMN examination volume [5]

3 TARGET INSPECTION SYSTEM

The TARGET inspection system is designed to perform the complete ultrasonic examination of BMNs in reactor pressure vessel, which provides probe movement, and with control system that controls tool and generates position pulses. Schematic description of the inspection system is shown below (Figure 3).

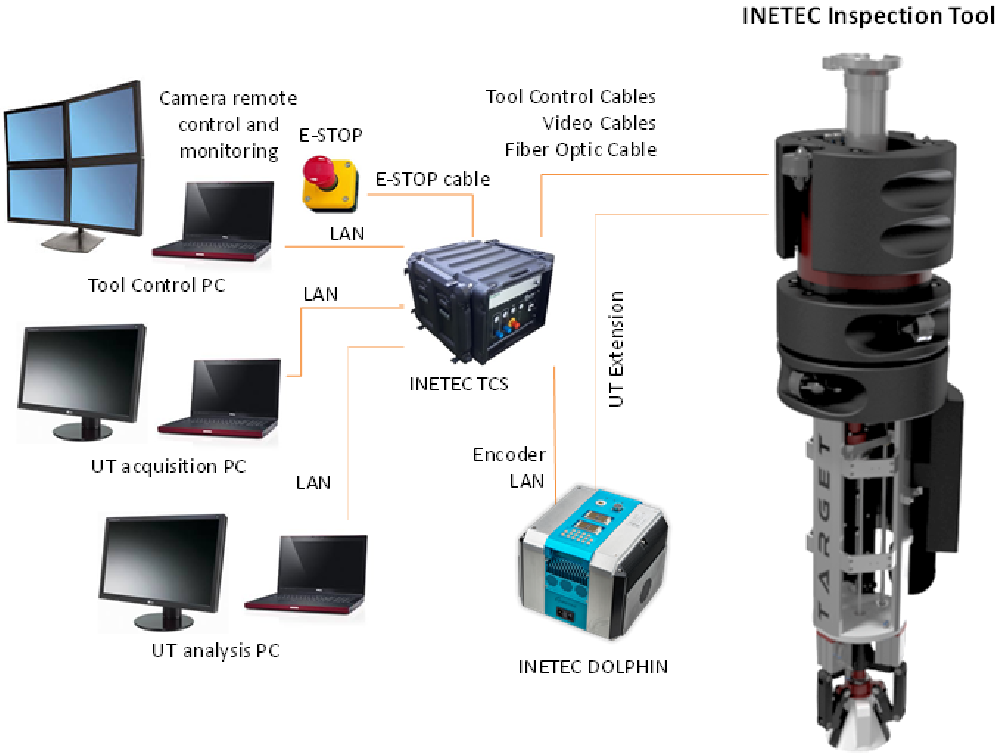

Figure 3 Schematic description of the TARGET inspection system [5]

3.1 TARGET

TARGET is remotely operated vehicle (ROV) that is able to work underwater. Once underwater, there is no need for any type of crane to support the ROV. It has propulsion system using thrusters to navigate itself. Bell like design of bottom of the ROV facilitates navigation to the top of BMN. Centering and fixating of the ROV is done with gripper that is pneumatically actuated (Item 3, Figure 4). There are two motor driven axes for the probe translation (Item 1, Figure 4) and rotation (Item 2, Figure 4). Both axes are have predetermined positions where each axis can be calibrated. To avoid any type of accident during scanning, multiple safety precautions are introduced. Both mechanical and software limits are set to prevent probe from breaking.

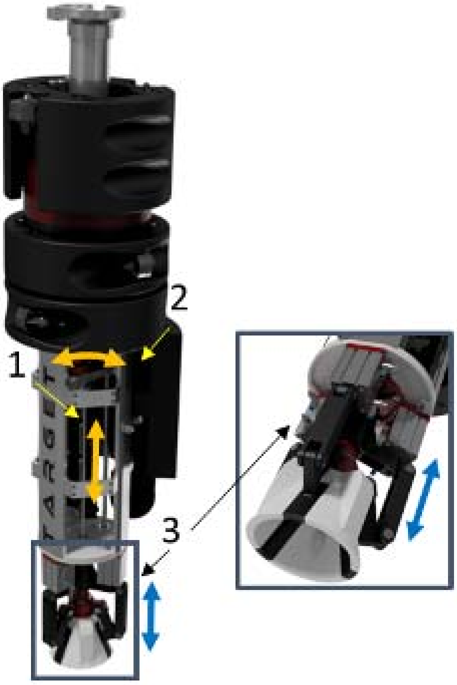

Figure 4. TARGET – Degrees of freedom driven by motors and pneumatic cylinders
1) Probe translation; 2) Probe rotation; 3) Gripper extension/retraction.

Neutral buoyancy of the ROV enables easy navigation through the water. On the ROV itself, two cameras are placed to help operator navigate the ROV on chosen BMN. Additional camera on side of the ROV is placed for the surveillance.

TARGET is operated through manipulator control software (Figure 5). Manipulator Control software supports two modes of operation – the standard mode and the admin mode. The standard mode is designed so the ROV can always be driven safely, without the possibility of accidentally causing it to behave incorrectly. The admin mode allows the user full control over the ROV and can only be accessed with an administrator password. Additionally, for the ease of navigation and driving through the water one can initialize joystick controller.

Figure 5. Manipulator control software layout
1) Ribbon menus; 2) Axes controls; 3) Event log window; 4) Thruster controls;
5) Pneumatics panel; 6) Visualization window; 7) Scan plan control.

3.2 UT data collection

UT data is obtained via INETEC’s Dolphin 128/128 PR (Figure 6). It is a phased-array ultrasonic instrument with support for all common ultrasonic inspection techniques. It comes in an industrial grade housing and easily fit into a multitude of inspection system scenarios.

Figure 6. Dolphin 128/128 PR UT instrument [5]

INETEC designed new type of probe for the BMN inspection, called “PRO ULTRA TARGET”. It has multiple variants depending on the ID/OD diameters for different BMN penetrations. Each probe is composed of three pairs of time of flight diffraction (TOFD) transducers (one axial and two circumferential) and one 0° longitudinal wave probe.

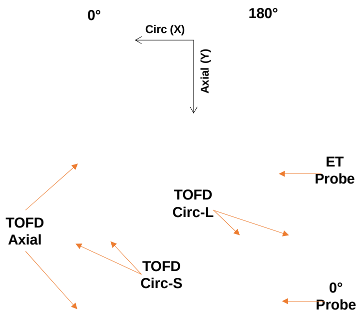

Figure 7. “PRO ULTRA TARGET” probe [5]

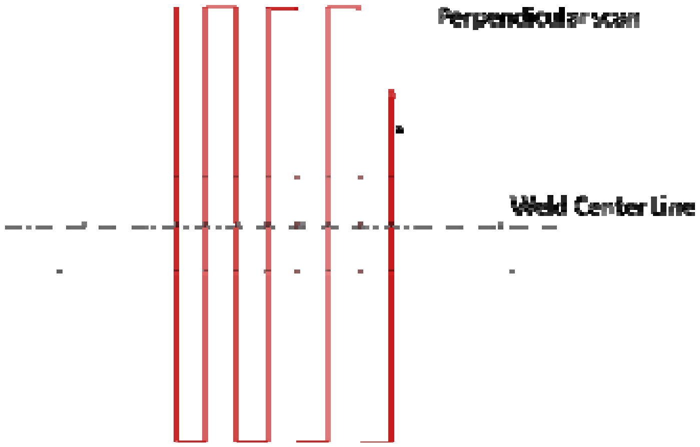

Figure 8. Scan pattern [5]

Probe is translated and rotated using two motor axes. Scan pattern is shown in the Figure 8. Inside the ROV, secondary calibration of the probe could be performed. With this approach it reduces unnecessary movement and loss of precious time during inspection. Evaluation of the data is performed using INETEC’s SignyOne software. Standard C-scan, B-scan and A-scan combination is used for data evaluation.

4 INSPECTION METHODOLOGY

INETEC’s approach to ISI of BMNs is result of experience on similar inspections and improvements as a result of gathered experience and lesson learned.

For the BMN inspection remotely controlled TARGET is used. Operator’s workstation is situated outside of the reactor building and radiologically controlled area, thus minimizing radiological exposure and reducing necessary space reservation inside the containment.

Figure 9. Positioning TARGET on top of BMN

Communication from inside to the outside of the containment is done using fiber optics cables through available penetration. TARGET is deployed in water with remote docking tool. It is pneumatically actuated assembly of rods that are used to transfer different INETEC manipulators from their respective stand to the water. After the TARGET is submerged into the reactor vessel water, remote docking tool is disconnected and the ROV is driven down to BMNs by using thruster propulsion system. TARGET functionality, installation, inspection and probe movements are monitored with several cameras installed on TARGET (Figure 9) for precise adjustments above BMN and fine positioning. Once the TARGET is positioned on top of BMN, it can be gripped using pneumatic cylinders. All axes can be calibrated by using reference locations defined by limit switches. Furthermore, for probe calibration secondary calibration block is available. Defining scan plan according to applicable standards operator can start the examination. Probe movement is shown in Figure 8. Once the scan is over, probe returns to home position in which it is enabled to detach the ROV from BMN.

5 QUALIFICATION

INETEC developed a UT technique and probe to perform demonstration for examination of bottom mounted nozzles. EPRI BMN Westinghouse 2, 3 and 4 loop flawed mockups were provided to INETEC. Six BMN mockups were examined: two Westinghouse two loop mockups; two Westinghouse three loop mockups, and two Westinghouse four loop mockups. All acquired data was evaluated by INETEC and provided to EPRI for independent review.

Each mockup has multiple flaws that are manufactory processed. Flaw manufacturing processes may include cold isostatic processing (CIP), hot isostatic processing (HIP), laboratory-grown stress corrosion cracks (SCC), weld contamination flaws, and/or a combination of these processes. The mockups contain the axial/radial and circumferential/radial flaws in the tube located above, below, and/or over the attachment weld area.

In order to prove theoretical presumptions and newly designed probe, INETEC evaluated mockups to document basic flaw detection, location capabilities, characterization and length and depth sizing on representative mockups. It was performed in a non-blind fashion. INETEC personnel collected and analysed data (Figure 10) in accordance to INETEC procedure. The UT results including raw data were provided to EPRI to perform a technical review and for validation of technical justification versus raw data.

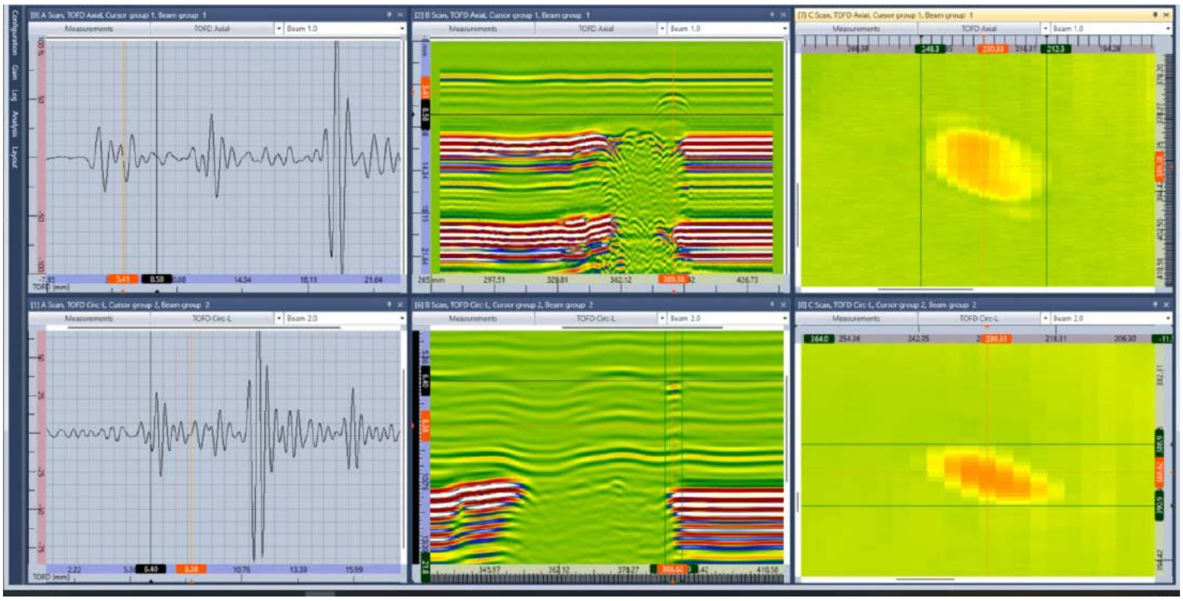

Figure 10. OD flaw on a mockup [5]

6 CONCLUSION

INETEC developed new remotely controlled TARGET system for BMN inspection. Once submerged, it becomes independent from polar crane or refuelling bridge, thus reducing unnecessary time loss for maintenance operations. Its ease of navigating and operating helps it to move quickly on designated BMN. For UT data collection, INETEC uses its own Dolphin, phased-array ultrasonic instrument with support for all common ultrasonic inspection techniques. Furthermore, INETEC developed probe “PRO ULTRA TARGET” with multiple variants for different Westinghouse type of BMNs. Probe is composed of three pairs of time of flight diffraction (TOFD) transducers (one axial and two circumferential) and one 0° longitudinal wave probe. Demonstration of examination of bottom mounted nozzles was performed and UT technique was developed on previously delivered flawed mockups given by EPRI. In order to prove theoretical presumptions and newly designed probe, INETEC evaluated mockups to document basic flaw detection, location capabilities, characterization and length and depth sizing on representative mockups. All acquired data was evaluated by INETEC and provided to EPRI for independent review. Review showed that INETEC demonstrated capabilities of the system that satisfied demands for proper flaw detection and characterization.

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