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Office of River Protection
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02-TOD-064

Mr. Michael A. Wilson, Program Manager
Nuclear Waste Program
State of Washington
Department of Ecology
1315 W. Fourth Avenue
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Dear Mr. Wilson:

SUBMITTAL OF M-48-02, "SUBMIT TO ECOLOGY A REPORT ASSESSING TECHNOLOGY DEVELOPMENT"

Reference: Federal Facility Agreement and Consent Order (Tri-Party Agreement) Milestone Series M-48-02, dated January 2, 2002.

The above referenced Tri-Party Agreement Milestone series, M-48-02, requires that a semi-annual updated report be submitted to the State of Washington Department of Ecology. Attached is the "Status Report for Lower Knuckle Ultrasonic Testing Technology Development, September 2002.

If you have any questions, please contact me, or your staff may contact Victor L. Callahan, Technical Operations Division (509) 373-9880.

Sincerely,

James E. Rasmussen

James E. Rasmussen, Director
Environmental Management Division

TOD:VLC

Attachment

cc: See page 2

STATUS REPORT FOR LOWER KNUCKLE ULTRASONIC TESTING TECHNOLOGY DEVELOPMENT SEPTEMBER 2002

1.0 BACKGROUND

Environmental regulations applicable to the River Protection Project (RPP) require integrity assessment of the double-shell tank (DST) system.[1,2] By agreement between the U.S. Department of Energy, Office of River Protection (ORP) and the State of Washington Department of Ecology (Ecology) ultrasonic testing (UT) using remotely operated equipment is performed to support integrity assessment of DSTs. UT is used to measure wall thickness and to detect and size pits and cracks. Detection of cracks on the inside surface of the tank (i.e., the surface in contact with waste) could indicate the onset of stress-corrosion cracking (SCC). SCC has been determined to be the cause of failure for many of the single-shell tanks (SST),[3] as they were not stress relieved like the DSTs.

Various structural analyses have generally indicated the maximum tensile stress on the inside surface of the tank is located at the intersection of the curved lower knuckle and the flat bottom of the tank.[4,5,6] This stress is primarily due to bending from gravity loads, which create tensile stress on the inside and compressive stress on the outside surface of the tank. SCC from such bending stress would tend to be circumferentially oriented. In addition to bending stress from gravity loads, tensile stress in the horizontal direction (i.e., across a vertical plane through the tank wall) results from hydrostatic loads due to tank waste. This type of stress is commonly referred to as hoop stress. SCC from such hoop stress would tend to be longitudinally oriented (i.e., along a tank meridian). For design loading conditions, previous stress analyses indicate the location of maximum hoop stress is in the upper portion of the lower knuckle region, or the lower part of the vertical tank wall.[7] The loading conditions considered in these structural analyses include various combinations of dead weight of the tank structure, soil overburden, uniform live load, concentrated live load, hydrostatic loads, and thermal loads due to waste temperature. Due to limitations inherent in structural models, there is some uncertainty involved in estimating the magnitude and distribution of stress in this region.

Federal Facility Agreement and Consent Order milestone M-48-02[8] requires (until equipment has been deployed) biannual submittals of status reports on development of "ultrasonic testing equipment, or an equivalent technology, for assessing material thickness and defects of the predicted maximum stress region of the lower knuckle base metal of double-shell tanks." Areas

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[1] Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities, 40 CFR 265.191.

[2] Washington State Department of Ecology Dangerous Waste Regulations, Chapter 173-303, Washington Administrative Code, Section 173-303-640(2).

[3] *Characterization of the Corrosion Behavior of the Carbon Steel Liner in Hanford Site Single-Shell Tanks*, WHC-EP-0772, Rev. 0, R. P. Anantatmula, E. B. Schwenk, and M. J. Danielson, June 1994.

[4] *A Comprehensive Summary of the Analysis of the 241-AW Underground Waste Storage Tanks, Hanford, Washington*, prepared by URS/John A. Blume & Associates, San Francisco, CA for Vitro Engineering, Richland, Washington, July 1981.

[5] *Parametric Studies to Support Inspection Criteria for the Hanford Site Double-Shell Waste Storage Tanks*, M. S. Shurrab, M. D. Thomson, J. R. Friley, M. R. Garnich, M. W. Rinker and F. A. Simonen, WHC-EP-0508, 1991.

[6] *Accelerated Safety Analyses, Structural Analyses Phase III, Double-Shell Waste Storage Tank Evaluations of the Dome, Haunch, Wall and Footing*, WHC-SD-WM-SARR-40 (draft), 1996.

[7] Ibid.

[8] Federal Facility Agreement and Consent Order Change Control Form, Change Number M-48-01-01, October 30, 2001

to be addressed in these status reports, per Federal Facility Agreement and Consent Order milestone M-48-02, are as follows:

- Cost of development
- Identification of vendors
- Technical specifications
- Data quality requirements
- Estimated schedule for delivery and deployment into DSTs

Previous status report identified two technologies selected for deployment:

- Deployment of a flexible arm on an existing wall crawler
- Tandem synthetic aperture focusing technique (TSAFT) imaging technology

2.0 TECHNOLOGY EVALUATION

This section provides results of evaluation of capabilities and limitations of the two technologies listed in Section 1.0, and describes a strategy for examining the high-stress region of the lower knuckle that incorporates multiple technologies.

2.1 Flexible Arm Development

The flexible arm adaptation to the P-scan system (hereafter referred to as "flexible arm") was successfully deployed in DST AW-102 in July 2002. The flexible arm extended downward and examined a larger arc length of the lower knuckle, within the accessible regions of the DST annulus. However, the arc length that was examined is limited by interference of the transducer assembly with the insulating concrete pad separating the primary and secondary tanks. The flexible arm is unable to reach and examine the area at the intersection of the curved lower knuckle and the flat tank bottom that, based on structural analyses, is believed to be the region of maximum tensile stress, as discussed in Section 1.0.

2.2 Tandem Synthetic Aperture Focusing Technique Imaging Technology

Of the three technologies evaluated and reported in the March 2001[9] status report, only the TSAFT imaging technology has the potential to examine the area of the lower knuckle at its intersection with the flat tank bottom along a 20-foot circumference of the tank, as required by Federal Facility Agreement and Consent Order milestone M-48-02. During FY 2000, laboratory testing on a mockup test plate demonstrated TSAFT could be effective in detecting and sizing circumferentially-oriented flaws in the knuckle region and beyond.[10] In FY 2001, development work was authorized to develop a prototype remotely operated inspection system utilizing the TSAFT imaging technology with the plan of demonstrating the capability of the technology on a

[9] Letter from James E. Rasmussen, U.S. Department of Energy, Office of River Protection, to Michael A. Wilson, State of Washington Department of Ecology, *Submittal of X-032-20B-T02, "Submit to Ecology the Ultrasonic Testing Equipment Development,"* 01-OPD-031, March 30, 2001.

[10] *Evaluation of SAFT/TSAFT Technology for the Inspection of Hanford's Double-Shell Waste Tank Knuckle Regions*, PNNL-13321, A. F. Pardini, A. A. Diaz, September 2000.

DST in late FY 2002. In FY 2002 the prototype TSAFT and its robotic crawler was developed and acceptance testing completed in May 2002. Operator training and qualification started at the end of August 2002, with the performance test and deployment in DST AW-102 scheduled for completion during September 2002.

The TSAFT has difficulty detecting cracks having other than circumferential orientation. Also, testing to date has indicated that the TSAFT system as currently configured will not be capable of measuring wall thickness or provide pit detection or sizing capability. A strategy that combines the capabilities of both the flexible arm and TSAFT, will be pursued to complete DST lower knuckle inspections.

2.3 Comprehensive Strategy for Lower Knuckle Ultrasonic Examination

No single technology identified to date can satisfy Federal Facility Agreement and Consent Order milestone M-48-02 to assess material thickness and defects of the predicted maximum stress region of the lower knuckle along a 20-foot circumference. Also, there is some uncertainty relative to the location of the predicted maximum stress region. Accordingly, a robust approach is needed for conducting ultrasonic examination of the lower knuckle. The selected approach will use a combination of technologies. The flexible arm will be used to detect wall thinning, pitting, and cracking in the lower knuckle region, and the TSAFT will be used in supplement the flexible arm to detect and size circumferentially-oriented cracks in regions of the knuckle that are inaccessible with the flexible arm.

3.0 TECHNICAL SPECIFICATIONS FOR LOWER KNUCKLE EXAMINATION

A critical foundation of ORP's technology development program is to solicit input from throughout the DOE complex in identifying science and technology needs. As part of this process, RPP has identified a technology need for examining the primary tank lower knuckle.[11] In response to this need, the Tanks Focus Area (TFA) has funded related technology development and testing during FY 2000 and FY 2001 (see Section 2.2 of this status report), and also supported development (during FY 2001) for a functions and requirements (F&R) document to examine the lower knuckle of Hanford's DSTs.[12] In addition, TFA co-funded with ORP the development of a TSAFT prototype in FY2002. The stated purpose of the F&R document is to provide the basis for concept selection, design, fabrication, and deployment methodology. CH2M HILL Hanford Group Inc. reviewed and provided input to Pacific Northwest National Laboratory (PNNL) in development of this document. The document addresses supporting services, environmental conditions, characterization objectives, sizing and accuracy requirements, training, testing, and demonstration, without regard to specific technology approaches. The document will be used as a basis for evaluating further the merits of candidate technologies and for completing development of an overall examination approach including testing and qualifying equipment, procedures, and personnel.

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[11] *Technology Needs Statement Endorsement, "Tank Knuckle NDE,"* RL-WT022, http://www.pnl.gov/stcg/fy01needs/wt022.pdf.

[12] *Functions and Requirements for the DST Knuckle Region Ultrasonic Scanning System*, PNNL-13436, Rev. 0, A. F. Pardini and T. J. Samuel, January 2001.

Technical specifications provided in the F&R document cited above address general requirements, environmental constraints, diagnostic capability, personnel training, and equipment and personnel testing. A summary of technical specifications for ultrasonic examination of the primary tank lower knuckle is provided below.

General Requirements

- Ultrasonic examination system components shall incorporate modular design.
- Equipment interchangeability shall be maximized to the extent practical.
- Standard commercially available parts shall be used to the extent practical.
- Components having a higher probability of failure shall be mounted on fixtures that are easily removed for servicing.
- Design and operation shall limit worker exposure, minimize secondary waste, minimize external contamination, and ease maintenance of potentially contaminated components.
- Hoisting hardware shall conform to the *Hanford Site Hoisting and Rigging Manual.*[13]
- Equipment shall be designed to minimize risk of damage to the waste tank.
- Equipment shall be retrievable from DST annulus.

Operating Environment Constraints

- Annulus temperatures up to 130 degrees Fahrenheit.
- Tank wall temperatures up to 200 degrees Fahrenheit.
- Outside temperatures ranging from –20 degrees Fahrenheit to 120 degrees Fahrenheit.
- Outside weather conditions involving rain, snow, wind gusts up to 80 mph, and blowing sand.
- Equipment storage in non-temperature controlled containers with temperature range from 32 degrees Fahrenheit to 110 degrees Fahrenheit.
- Annulus radiation field of up to 640 R/hr.

Diagnostic Capability

- Equipment shall be capable of measuring wall thickness.
- Equipment shall be capable of detecting and sizing pits.
- Equipment shall be capable of detecting and sizing planar flaws on the inside surface of the lower knuckle.
- Data quality and accuracy shall be as specified (i.e., in Section 4.0 of the F&R document).

Training

- Ultrasonic examination system operators and analysts shall be qualified and certified to at least level II in accordance with the American Society for Nondestructive Testing (ASNT) recommended practice SNT-TC-1A.
- Ultrasonic examination reports shall be reviewed and accepted by a level III in accordance with the ASNT recommended practice SNT-TC-1A.

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[13] *Hanford Site Hoisting and Rigging Manual*, DOE-RL-92-36, March 16, 2001, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

- Ultrasonic examination system operators and analysts using lower knuckle ultrasonic examination equipment shall have 40 hours of advanced detection and sizing training applicable to that equipment.

Equipment and Personnel Testing

- Testing of ultrasonic examination equipment shall be done in accordance with an approved test plan that identifies all necessary equipment and procedures for the test.
- Testing of ultrasonic examination equipment shall be performed on a primary tank lower knuckle mockup, containing real or simulated defects.
- Cold testing shall be performed to demonstrate operation of the scanning equipment, collection of a data set, and transfer of the data set to the analysis computer.
- Following completion of cold testing and demonstration, a performance demonstration test will be performed on a mockup of the knuckle with crack-like indications of known geometry to qualify equipment, procedures, and personnel.
- A test report will be generated documenting the test configuration and results.

A qualification plan[14] for the Flexible Arm was prepared by PNNL to support the demonstration testing of this UT equipment. The objective of the demonstration testing was to qualify the flexible arm for examination of the lower knuckle regions of the DSTs. The qualification test was successfully conducted in September 2001.[15] This qualification test demonstrated the ability of the flexible arm system to detect, locate, and measure length and depth of simulated cracks (sawcuts) within a 12.5 inch arc length along the lower knuckle measured from the point of tangency with the vertical wall. The RMS error for crack depth measurement for this test was determined to be 0.044 inches, which meets the specified accuracy requirement of +/- 0.10 inch as discussed in Section 4.0, Data Quality Requirements.

Technical specifications unique to the Flexible Arm were provided in Section 2.2.3 of the September 2000 submittal[16] The only change to those specifications is as indicated below:

- Flexible Arm scan length -- Sufficient to allow knuckle examination up to the point of transducer assembly interference with the insulating concrete slab (changed from "7.5 inches minimum.")

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[14] *Qualification Plan for the CHG P-Scan Y-Arm*, prepared by A. F. Pardini, Pacific Northwest National Laboratory, Richland, Washington, for CH2MHILL Hanford Group, Richland, Washington, August 13, 2001.

[15] Letter from Allan F. Pardini, PNNL, to Chris E. Jensen, CHG, September 21, 2001, with attached PNNL Letter Report, "Qualification of the Y-Arm Attachment"

[16] Letter from Clifford E. Clark, U.S. Department of Energy, Office of River Protection, to Michael A. Wilson, State of Washington Department of Ecology, *Transmittal of Reports Requested under Administrative Orders No. 00NWPKW-1250 and No. 00NWPKW-1251, Dated June 13, 2000*, 00-OSD-108, September 18, 2000, Attachment 2.

Technical specifications unique to TSAFT imaging technology were provided in Section 2.3.3 of the September 2000 submittal.[16] The only change to those specifications is as indicated below:

- Transducer scan bridge – Will mount to a magnetic-wheel remotely operated wall crawler that can traverse horizontally along the lower knuckle weld to take readings (changed from "Will mount to current wall crawler and follow the knuckle weld while taking readings vertically at a rate of 6 inches per second.")

4.0 DATA QUALITY REQUIREMENTS

Data quality requirements were addressed in the September 2000 status report[16] on lower knuckle ultrasonic testing technology development. These are also included in the F&R document discussed in Section 3.0. Data quality requirements are expressed in terms of accuracy as follows:

Wall thinning	+/- 0.02 inches
Pit dimensions	+/- 0.05 inches
Crack depth	+/- 0.10 inches

The accuracy values above are the same that have been used for qualifying equipment, procedures, and personnel in the ultrasonic examinations of DSTs performed to-date as originally cited in the tank examination report for tank 241-AN-107.[17] Demonstration of data accuracy will be by means of a performance demonstration test, as indicated in Section 3.0. Following are requirements for performance demonstration testing that were used for the existing P-scan system for ultrasonic examination of DSTs[18]:

- "CHG will provide test specimens containing crack, pit, and thinning flaws to allow demonstration of the Contractor's ability to detect and size the flaws as follows (all accuracy requirements are root mean square values):

- *Pits* – Contractor to size the depth dimension within 0.050-inch accuracy.

- *Thinning* – variable thickness. Contractor to size the thickness within 0.020-inch accuracy.

- *Cracks* – Contractor to detect the existence of a crack at the inner wall surface on the primary tank and size the crack depth within 0.1-inch accuracy. The crack orientation will be provided by CHG. For the secondary knuckle, the Contractor is to detect cracks at both the inner and outer surface and size the crack depth within 0.1 inch.

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[17] *Final Results of Double-Shell Tank 241-AN-107 Ultrasonic Inspection*, HNF-3353, Rev. 1, C. E. Jensen, September 1999.
[18] *Engineering Task Plan for the Ultrasonic Inspection of Hanford Double-Shell Tanks – FY 2001*, RPP-6839, Rev. 0, C. E. Jensen, October 9, 2000, Appendix C.

- As part of the performance demonstration, the Contractor shall examine eighteen test specimens; six for a wall examination demonstration, six for a weld examination demonstration, and six for a primary tank bottom examination demonstration. If the knuckle examination transducers are not the same as the wall knuckle examination transducers, another six plates shall be examined."

5.0 DEVELOPMENT COSTS

Procurement and testing for the flexible arm was completed in FY 2001 and deployment in AW-102. Deployment of the TSAFT imaging technology prototype inspection system is scheduled for September FY 2002. The following is a summary of activities and funding levels for this effort in FY 2001 and FY 2002:

Technology	FY 2001 Cost	FY 2002 Cost
Flexible arm development and demonstration	$56K	None
TSAFT imaging technology development and demonstration deployment	$550K	$953K

6.0 TECHNOLOGY VENDORS AND DEVELOPERS

The flexible arm is provided by FORCE Institute of Denmark, through Swain Distribution Inc., located in Searcy, Arkansas, its U.S. supplier. Testing and qualification of the system are conducted by Cogema Engineering Corp., Richland, Washington, with support and oversight by (PNNL) Non Destructive Examination (NDE) Measurement Systems Group, Richland, Washington.

TSAFT was developed, tested, and demonstrated by PNNL, Richland, Washington. PNNL has been working to develop and enhance this technology for the past 10 years for the Nuclear Regulatory Commission and the Department of Energy. PNNL is executing a development strategy that focuses on utilizing off-the shelf crawler technology and computer hardware and integrating it with their specialized software and transducer motion control hardware.

7.0 DEVELOPMENT AND DEPLOYMENT SCHEDULE

Since the September 2001 status report,[12] work has proceeded supporting TSAFT. Technology development and demonstration relating to the Flexible Arm was essentially completed as of the end of FY 2001. Work accomplished to date, and the anticipated schedule for remaining development and demonstration, for each of these technologies, is summarized in Sections 7.1 and 7.2. Based on current planning, the Flexible Arm and TSAFT will be deployed during FY 2002 for examination of 241-AW-102. Since the Flexible Arm is a relatively straightforward adaptation to existing technology, its schedule risk is considered minimal. Schedule risk for the TSAFT imaging technology is greater, due to higher uncertainties related to diagnostic capability

and as-yet undemonstrated actual deployment and operation in a DST. Development status and schedule for each technology is further addressed in the following sections.

7.1 Flexible Arm

As of the date of preparation of this report, procurement, testing and qualification of the Flexible Arm had been completed, and the system successful deployment in 241-AW-102 was completed in July 2002.

7.2 Tandem Synthetic Aperture Focusing Technique (TSAFT)

The SAFT/TSAFT prototype has been developed and the acceptance testing was completed in May FY2002. The performance demonstration test and deployment in a DST AW-102 is scheduled to complete in September 2002.

8.0 SUMMARY

During the first half of FY 2001, an Alternative Generation and Analysis was conducted to evaluate candidate technologies for examining the primary tank lower knuckle. Results of this analysis led to a decision to proceed with procurement, procedure development, testing, and qualification of the Flexible Arm. This process was completed in FY 2001, and the Flexible Arm was deployed in July FY 2002. However, the Flexible Arm cannot reach far enough to examine the intersection of the tank knuckle and tank bottom, where maximum tensile stresses on the inside tank surface are predicted. Accordingly, work progressed during FY 2002 on development of TSAFT to provide the capability to detect and size circumferential cracks in the region of the lower knuckle, and beyond, which are inaccessible using the flexible arm. The first deployment of TSAFT is scheduled to complete in September FY 2002.

Federal Facility Agreement and Consent Order M-48-02 "Submit To Ecology A Report Assessing Technology Development", requires bi-annual updates to Ecology, until such equipment is developed and deployed.

SEP 0 6 2002

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