U.S. Department of Energy
Office of River Protection
P.O. Box 450
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0056699

MAR 14 2002

02-TOD-023

Mr. Michael A. Wilson, Program Manager
Nuclear Waste Program
State of Washington
Department of Ecology
1315 W. Fourth Avenue
Kennewick, Washington 99336

Dear Mr. Wilson:

SUBMITTAL OF M-48-02, "SUBMIT TO ECOLOGY THE ULTRASONIC TESTING EQUIPMENT DEVELOPMENT"

Reference: Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) Milestone Series M-48-02, dated October 30, 2001.

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, March 2002."

If you have any questions, please contact me, or your staff may contact Wen-Shou Liou, Technical Operations Division, (509) 373-9879.

Sincerely,

James E. Rasmussen, Director
Environmental Management Division

TOD:VLC

Attachment

cc: See page 2

cc w/o attach:
J. G. Field, CHG
J. W. Hunt, CHG
F. R. Miera, CHG
T. R. Pauly, CHG
M. A. Payne, CHG
M. J. Riess, CHG
D. J. Washenfelder, CHG
R. Gay, CTUIR
D. G. Singleton, Ecology
R. F. Stanley, Ecology
D. Bartus, EPA c/o Ecolgoy
D. A. Faulk, EPA
J. S. Hertzel, FHI
O. S. Kramer, FHI
T. Martin, HAB
P. Sobotta, NPT
K. Niles, Oregon Energy
E. M. Mattlin, RL
R. Jim, YN
TPA Administrative Record w/attach

STATUS REPORT FOR LOWER KNUCKLE ULTRASONIC TESTING TECHNOLOGY DEVELOPMENT
MARCH 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 (DOE) 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 (SSTs).[3]

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.

Due to curvature of the primary tank lower knuckle, UT equipment used to date is not capable of examining below approximately the upper three (3) inches of the knuckle, except within the air slots where, using the air slot UT scanner,[8] it may be possible to examine a limited region of the

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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] *Results of Double-Shell Tank 241-AN-107 Ultrasonic Inspection*, HNF-3353, Rev. 1, September 1999, C. E. Jensen.

lower part of the knuckle. Tri-Party Agreement (TPA) milestone M-48-02[9] 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 to be addressed in these status reports, per TPA 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.

The first such status report was submitted in September 2000.[10] The second status report, issued in March 2001,[11] identified two technologies selected for further development:

- Deployment of Flexible Arm on Existing Wall Crawler.
- Tandem Synthetic Aperture Focusing Technique (TSAFT) Imaging Technology.

The third status report, issued in September 2001,[12] provided updated status, schedule, and cost information on these two technologies.

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

Based on the results of an Alternative Generation and Analysis[13] conducted in December 2000, a decision was made to proceed with procurement of the flexible arm attachment, and to conduct required testing and qualification (in the second half of fiscal year 2001) so that the technology

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

[10] 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.

[11] 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.

[12] 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-T03, "Submit to Ecology the Ultrasonic Testing Equipment Development,"* 01-TOD-T021, September 24, 2001

[13] *Alternative Generation and Analysis for the Lower Knuckle Ultrasonic Testing Technology*, RPP-7532, Rev. 0, February 2001, J. C. Wolff.

will be ready for deployment in FY 2002. The flexible arm adaptation to the P-scan system (hereafter referred to as "Flexible Arm") will allow examination of a larger arc length of the lower knuckle, within the accessible regions of the DST annulus. However, the arc length that can be examined is limited by interference of the transducer assembly with the insulating concrete pad separating the primary and secondary tanks. Therefore, this approach is unable to examine the area at the intersection of the curved lower knuckle and the flat tank bottom that, based on structural analysis, is believed to be the region of maximum tensile stress, as discussed in Section 1.0.

2.2 Tandem Synthetic Aperture Focusing Technique (TSAFT) Imaging Technology

Of the three technologies evaluated in the March 2001 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 TPA milestone M-48-02. However, significant additional technology development and testing remains before the viability of TSAFT technology and its ability to detect and size flaws can be demonstrated. 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.[14] 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 DST in late FY 2002.

It is believed that TSAFT would have difficulty detecting cracks having other than circumferential orientation. Also, TSAFT may not be capable of measuring wall thickness, at least to the same level of accuracy achievable with the P-Scan system. Development work is currently in progress to enhance TSAFT to specifically attempt to provide wall thickness, pit sizing, and axial cracking capabilities. An approach that combines the capabilities of multiple technologies, i.e., Flexible Arm and TSAFT, is continuing to be pursued at this time.

2.3 Comprehensive Strategy for Lower Knuckle Ultrasonic Examination

No single technology identified to date can satisfy TPA milestone M-48-02 to assess material thickness and defects of the predicted maximum stress region of the lower knuckle along a20-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, in a phased approach. The first phase will proceed with the preferred alternative selected in the Alternative Generation and Analysis process discussed in Section 2.1 (i.e., using a Flexible Arm to allow examination of a greater arc length of the lower knuckle, along at least a 20-foot circumference of the knuckle). In parallel, development of the TSAFT imaging technology will continue. If demonstrated viable for detection and sizing of circumferentially oriented cracks in regions of the knuckle that are inaccessible with the Flexible Arm, TSAFT would then be used to supplement the P-scan data. In addition, the ability of the air slot UT

[14] *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.

scanner to examine the lowermost portion of the lower knuckle within air slots will be further investigated during FY 2002. If viability of TSAFT cannot be demonstrated, the air slot UT scanner may need to be used to examine the region of predicted maximum stress within the air slots. A decision on using the air slot UT scanner to supplement the Flexible Arm will be made following completion of development and demonstration of TSAFT imaging technology.

3.0 TECHNICAL SPECIFICATIONS FOR LOWER KNUCKLE EXAMINATION

A critical foundation of DOE'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 had identified a technology need for examining the primary tank lower knuckle.[15] In response to this need, the Tanks Focus Area (TFA) 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 of a functions and requirements document for examining the lower knuckle of Hanford's DSTs.[16] In addition, based on the demonstrated progress of the technology development efforts made in FY 2001, the TFA has committed to continue to fund the development of inspection technology in FY 2002. The stated purpose of the functions and requirements document is to provide the basis for concept selection, design, fabrication, and deployment methodology. CHG 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.

Technical specifications provided in the functions and requirements 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.

<u>General Requirements</u>

- 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 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.

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

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

- Hoisting hardware shall conform to the *Hanford Site Hoisting and Rigging Manual.*[17]
- 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 in Section 4.0.

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 American Society for Nondestructive Testing (ASNT) recommended practice SNT-TC-1A.
- 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.

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

- A test report will be generated documenting the test configuration and results.

A qualification plan for the Flexible Arm[18] was prepared by PNNL to support the demonstration testing of this ultrasonic testing 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.[19] 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.[10] 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.")

Technical specifications unique to TSAFT imaging technology were provided in Section 2.3.3 of the September 2000 submittal.[10] 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[10] on lower knuckle ultrasonic testing technology development. These are also included in the functions and requirements 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

[18] *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.

[19] 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"

cited in the tank examination report for 241-AN-107.[20] 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:[21]

> "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.
>
> 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. Development of the TSAFT imaging technology prototype inspection system will continue in 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 & Demonstration	$56K	None
Tandem Synthetic Aperture Focusing Technique (TSAFT) Imaging Technology Development & Demonstration Deployment	$550K	$953K

Joint TFA and RPP funding will be used for TSAFT development in FY 2002, specifically to enable the demonstration deployment of TSAFT in 241-AW-102 in late FY 2002. Additionally,

[20] *Final Results of Double-Shell Tank 241-AN-107 Ultrasonic Inspection*, HNF-3353, Rev. 1, C. E. Jensen, September 1999.
[21] *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.

enhancements to the inspection capabilities of the TSAFT imaging technology to move beyond solely circumferential crack detection and sizing will be investigated.

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 is being 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 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 is ready for deployment in 241-AW-102, scheduled for later in FY 2002.

7.2 Tandem Synthetic Aperture Focusing Technique (TSAFT)

Building on the significant progress made in FY 2001, work has been progressing in FY 2002 to prepare the hardware, software, and documentation necessary for deploying the SAFT/TSAFT inspection technology into the annulus of Hanford underground storage tank 241-AW-102 in the Summer of 2002. The SAFT/TSAFT technology will be used to detect and size circumferential cracks through the entire height of the tank knuckle. In addition enhancements to the performance capabilities of the SAFT/TSAFT technology are on schedule to be demonstrated on a tank knuckle mockup in August 2002. Enhancements currently being investigated include:

wall pitting, wall thinning, axial cracking, and extending the detection capability to beyond the tank knuckle region.

Listed below is a summary of the planned effort for FY 2002.

- Prepare TSAFT imaging technology for demonstration deployment in DST.
- Perform demonstration deployment of TSAFT.
- Complete formal assessment of technology performance.
- Develop plan to enhance TSAFT imaging technology.
- Procure hardware for enhanced detection capability.
- Software development and enhancement.
- Integration of hardware and software.
- Test and demonstrate enhanced detection capability.

8.0 SUMMARY

During the first half of FY 2001, an Alternative Generation and Analysis[13] 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 is ready for deployment in FY 2002. However, the Flexible Arm cannot 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 2001 on development of TSAFT to provide the capability to detect and size circumferential cracks in the region of the lower knuckle, and beyond, that are inaccessible using the Flexible Arm. Should TSAFT imaging technology not be demonstrated to be viable, the air slot UT scanner, previously deployed in tank 241-AN-107 for examination of tank bottoms,[8] may be used to support examination of the predicted maximum stress region of the lower knuckle, where accessible through the air slots. Deployment of TSAFT is planned for late FY 2002, depending on successful completion of the development and demonstration activities scheduled during FY 2002.