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Alternatives Generation and Analysis for Lower Knuckle UT Technology

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Alternatives Generation and Analysis for Lower Knuckle Ultrasonic Testing Technology

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1.0 Introduction

Environmental regulations applicable to the River Protection Project require integrity assessment of the double-shell tank (DST) system.[1,2] In the early 1990s a strategy and plans were developed to conduct the required tank system examinations and integrity assessments. This included plans to conduct ultrasonic testing of six DSTs.[3] In 1997, an ad hoc committee (Tank Structural Integrity Panel, TSIP) working under the direction of the Office of Environmental Restoration and Waste Management, U. S. Department of Energy, published guidelines for managing risks associated with aging degradation of high level waste storage tanks.[4] This included recommendations on non-destructive examination of specific regions of tanks. For the lower knuckle region, defined as the curved transition from the vertical portion of the tank wall to the flat portion of the tank bottom, the TSIP guidelines contained the following recommendation:

> "Examine the lower knuckle region including 5% of the length of the upper weld, at least 2.5% of the area of the predicted maximum stress region of the knuckle base metal and 2.5% of the lower weld if accessible. Emphasis should be on weld/HAZ cracking such as SCC. If the lower weld is not accessible, one-square-foot sections whose length adds up to 5 % of the circumference of the knuckle base metal shall be examined."

Also in 1997, the U.S. Department of Energy and Washington Department of Ecology formalized an agreement on the DST system integrity assessment work scope required to satisfy the applicable regulatory requirements. This cited the TSIP guidelines, and included an agreement to conduct ultrasonic examination on six representative DSTs for determination and extent of cracks, corrosion, and pitting.[5]

In June 2000, the State of Washington Department of Ecology issued Administrative Orders[6] requiring the US Department of Energy, Office of River Protection, US

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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] Tank Waste Remediation System Tank System Integrity Assessments Program Plan, Westinghouse Hanford Company, WHC-SD-WM-AP-017, Rev. 1, June 1994, Section 3.3.2

[4] Guidelines for Development of Structural Integrity Programs for DOE High-Level Waste Storage Tanks, K. Bandyopadhyay, S. Bush, M. Kassir, B. Mather, P. Shewmon, M. Streicher, B. Thompson, D. van Rooyen, and J. Weeks, BNL-52527, January 1997.

[5] Double-Shell Tank System Integrity Program Plan, Rev. 0, November 1997, transmitted by letter from J. K. McClusky, Director, Waste Storage Division, U. S. Department of Energy, Richland Operations Office, to H. J. Hatch, President, Fouor Daniel Hanford, Inc., 97-WSD-258, December 23, 1997

[6] Letter from Dan Silver, Deputy Director, State of Washington, Department of Ecology to Richard French, U. S. Department of Energy, Office of River Protection, Keith Klein, U. S. Department of Energy, Richland Operations, and Mary P. Delozier, CH2M Hill Hanford Group, *Failure to Comply with Major Milestone M-32 of the Tri-Party Agreement; Administrative Order Nos. 00NWPKW-1250 and 00NWPKW-1251*, June 13, 2000

Department of Energy, Richland Operations, and CH2M Hill Hanford Group (CHG) to carry out specific actions through September 2007 related to double-shell tank (DST) system integrity assessment. These actions include the 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.

Examination of the knuckle region poses a significant technical challenge. Using existing ultrasonic testing equipment, only the upper ~3 inches of the lower knuckle can be measured, due to the curvature of the knuckle, which is above the region believed to be most highly stressed.

Recently, three approaches were evaluated that could be used to examine the most highly-stressed region of the lower knuckle. These three alternatives include:

1) Annulus floor crawler with manipulating arm
2) Magnetic wall crawler with a pre-bent metal, flexible arm
3) Tandem Synthetic Focusing Aperture Technique (TSAFT) Imaging Technology

Evaluation Team

The evaluation was held on December 1st, 2001 at the Cogema offices located at 2525 Stevens Drive. The evaluation team consisted of:
John Wolff - Facilitator
David Smet – Facilitator
Will Willingham – Cogema I&C Engineer
Wes Nelson – Cogema NDE
Mike Sumsion – CHG Field Work Supervisor
Ed Fredenburg – CHG Cognizant Engineering Manager
Dave Shuford – CHG Maintenance & Reliability Manager
Ron Reed – Double Shell Tank Design Authority
Chris Jensen – CHG Project Engineer

2.0 Evaluation Methodology

After defining the three alternatives, an evaluation team, knowledgeable in DST systems, was assembled. The purpose of this group was to evaluate and finalize the proposed evaluation decision criteria for each alternative, to establish a basis for ranking the merits of each alternative, and to rank the alternatives.

The proposed decision criteria were:
Initial Cost
Life-Cycle Cost
Versatility
Reliability
ALARA

Meets Requirements
Meets Schedule

These were suggested as starting points only. The team decided that some were acceptable and should be kept while others were suggested and agreed upon by consensus. The final decision criteria were determined to be:
Life-Cycle Cost
Diagnostic Capabilities
Schedule Risks
Operability
Reliability
Versatility.

Once all of the categories were agreed upon the discussion moved into weighting each category. It was determined that Diagnostic Capabilities should be weighted the highest with a score of 35% while Life-Cycle Cost received the lowest score of 5%.

The categories were designed to represent a broad range of requirements. To get more exact definitions the categories were broken down further into sub criteria. Every criterion was placed within its respective category. Each grouping of criteria was then weighted on a scale of 1 to 100. For example, Schedule Risks had two criteria. Initial deployment by Fiscal Year 2002 garnered 80% while Completion by Fiscal Year 2005 without 'heroic efforts' received 20%.

The weighting factors for each category were then multiplied by the weighting factors for their corresponding criteria. This resulted in percentage relative values.

3.0 Alternatives Description

In this section, each of the three alternatives is described.

3.1 Alternative 1 – Annulus Floor Crawler with Manipulating Arm

This alternative involves deployment, through a 24-inch diameter riser, of a remotely operated tracked vehicle that operates from the floor of the secondary tank. A full range of motion manipulating arm (Python™, manufactured by TEK Engineering), mounted on the deployment vehicle, is used to position an ultrasonic transducer array to obtain data from the tank knuckle region. The existing P-Scan system could be used , with software modifications, for data processing, or standalone data processing may be employed. Data is gathered at multiple locations by repositioning the arm and/or the deployment vehicle. A major advantage of this alternative is the flexibility for multiple applications of this system. Data can also be obtained from the secondary wall, the floor, or the system could be used as a retrieval unit should problems with the current wall scanner or air slot system develop.

3.2 Alternative 2 – Magnetic Wall Crawler with Pre-Bent Metal, Flexible Arm

This approach involves the use of the existing Force Institute magnetic wall crawler and P-Scan data acquisition system. A flexible arm attached to the wall crawler, specifically for this application, allowing deployment of the transducer in the knuckle region of the primary tank.

The design is based on a preformed, flexible steel band. One end of the band holds a single probe while the other is attached to the wall crawler. Since the steel strip would be pre-bent to a slightly smaller curvature than the tanks lower knuckle, it allows the band to act as a spring-loaded arm. Depending on the size of the probe used, the device could measure 55-60° of the 90° curvature of the lower knuckle. It is limited because of the potential of probe impact to concrete pad beneath the tank. If not for the concrete pad the extension could reach to its maximum stroke length of 15.5" or 74° of the lower knuckle. The advantage of this approach is its simplicity of design. The disadvantage is that the manipulating arm can only hold one sensor, which requires retrieval of the tracked vehicle, change out of the transducer, and re-deployment through the 24-inch riser for each of the three unique scans.

3.3 Alternative 3 – Tandem Synthetic Focusing Aperture Technique (TSAFT) Imaging Technology

This approach involves propagating ultrasound through the curved lower knuckle for detection of flaws. The PNNL SAFT/TSAFT (TSAFT) system provides circumferential stress corrosion crack evaluation, which is the anticipated degradation mechanism for the knuckle region. The TSAFT system can use existing crawlers such as the Force Institute AWS-5 with a modified scanning bridge to acquire TSAFT data from two transducers at the same time. This system is the only alternative of the three that could potentially scan the entire lower knuckle of the primary tank (within the region accessible through a 24 inch riser), including a portion of the knuckle and tank bottom in contact with the insulating concrete pad, for detection and sizing of circumferentially-oriented cracks (e.g., due to bending stress from gravity loads). The TSAFT system does not provide pitting or wall thinning evaluation, and cannot detect longitudinally oriented cracks (e.g., due to hoop stress from hydrostatic loads from contained waste). This system would therefore need to be used in conjunction with one of the other technologies discussed above to collectively satisfy the Administration Order requirements. Although the approach for this application is still in the R&D phase it is believed that with proper funding the system could be ready by the end of Fiscal Year 2001.

4.0 Alternative Evaluation

Once the weighting criteria were established, the percentage relative value found, and each alternative described, the alternatives were evaluated against the criteria to obtain a relative numerical score, using a scale of 1 to 10 (larger is better),which reflected how well that alternative met the criteria. To facilitate the analysis, a comparison matrix was

compiled (Table 1). In addition, a cost comparison summary was provided (Table 2). The following discussions summarize the key results of the alternative evaluation sorted by criteria.

4.1 Life-Cycle Costs

The TSAFT system would require the greatest initial cost due to the requirement for significant software modifications at this time. Budget estimates are $100K for the software modifications. By comparison the FORCE wall crawler will require the purchase of the flexible Y-arm, software modifications, and miscellaneous fabrication and assembly costs preliminarily estimated at $35K.

The FORCE wall crawler requires the least cost spare parts as existing major system components are available and interchangeable.

4.2 Diagnostic Capabilities

By using the A-Scan system on the floor crawler and the P-Scan system on the wall crawler, both alternatives could reliably detect and size pits and cracks of circumferential or longitudinal orientation, as well as measure wall thickness. TSAFT cannot, currently, detect pits, longitudinally oriented cracks, or measure wall thinning.

By using a coordinate feedback system in P-Scan the wall crawler could relocate indications post baseline. The TSAFT system could determine the distance around a knuckle that a crack would be from the transducers.

4.3 Schedule Risks

Initial deployment by Fiscal Year 2002 was determined to be an important criterion. It is believed that the earlier an alternative is ready for deployment the easier it would be to finish the designated number of tanks by Fiscal Year 2005. The FORCE Y-arm scored the highest in this area because it is readily adaptable to the existing system. Since the TSAFT and floor crawler are new approaches, proof of concept testing, acceptance testing and operational testing would be required.

4.4 Operability

FORCE received the highest subtotal in this category because of the prior experience that operators have with the existing FORCE system in use. Since the Y-arm module is a bolt-on modification of the current system, operators are trained and familiar with the motorized crawler. Efficiency in deployment is maximized, and learning curve risk is minimized.

4.5 Reliability

The floor crawler appears to be a robust system, but operator manipulation would involve a potentially high learning curve. However, these crawlers have been deployed in tank annuli numerous times in the past.

Because of the manipulating arm's proprietary design, a failure would require the product to be sent off-site and repaired at the vendor's facilities in California. Spare parts are another concern with the Python arm since it takes 4 months to build a new unit should catastrophic failure occur. TEK does advertise that they have never received reports of a manipulator arm failure from any of their customers to date. This indicates good reliability. TEK Engineering doesn't build additional units until they are purchased.

The FORCE wall crawler Y-Arm can be repaired on-site. A worst case scenario with the metal band is that it gets impacted and deflects past its yield point, requiring replacement. The replacement can be made in house within a matter of days if a spare is not available at the time. Also, the feasibility of having spares on hand is increased since the metal band is a single part that can be ordered and stored for future use. The entire Y-arm module would not have to be purchased, at a cost of $25,000 each, as long as catastrophic failure to the entire unit is not encountered.

Reliability of the TSAFT system cannot be confidently evaluated at this point, due in large part to its' early stage of maturity.

4.6 Versatility

All three of the alternatives are limited in riser sizes that can be used. A 24" riser is most desirable for each alternative. Also, limitations exist when encountering obstructions. The existence of installed thermocouples, for example, on the walls of the primary tanks causes concern. The wiring protruding from the thermocouples hangs in the annulus and could become entangled with any of the three alternatives.

Adapting the FORCE Y-arm to the current system of ultrasonic scanning would require nothing more than bolting the new Y-arm to the scanning bridge of the current magnetic wall crawler and software modifications. Current operating practice would be followed to limit the stroke length so as not to impact the concrete pad with the transducer. This is accomplished with the aid of video cameras providing feedback to the NDE operator in controlling the movement of the crawler and scanning arm.

The TSAFT system could also mount to the current wall crawler, but would more likely be adapted to another type of off-the-shelf magnetic crawler device. Development of software to control crawler movement and/or collect and process data could be significant.

The floor crawler could require a different data processing approach to scan and interpret the results.

Table 1. Alternative Comparison Matrix

ALTERNATIVES	RANK (1 to 100)
Annulus Floor Crawler with Manipulating Arm	55.9
FORCE Institute Flexible Y-Arm	86.0
TSAFT Imaging Technology	55.7

RELATIVE VALUE(rv) of CRITERIA GROUPED by CATEGORY

% rv	CATEGORY	% rv	CRITERIA DESCRIPTION	% rv	A	B	C
5	Life-Cycle Cost	33	Initial Costs	1.7	5	10	3
		33	Annual Costs	1.7	3	9	7
		34	Spare Parts Costs	1.7	4	9	7
		100	Subtotals ▸		2.0	4.7	2.8
35	Diagnostic Capabilities	15	Reliably Detect and Size Pits	5.3	10	10	0
		20	Reliably Detect and Size Cracks	7.0	10	10	2
		10	Measure Wall Thickness	3.5	10	10	2
		15	Ability to Relocate Indications	5.3	3	8	7
		20	Data Process Storage Capabilities	7.0	0	10	5
		20	Knuckle Radius Coverage	7.0	6	6	10
		100	Subtotals ▸		21.5	31.2	15.6
10	Schedule Risks	80	Initial Deployment by FY 02	8.0	5	8	3
		20	Completion by FY 05 w/o heroic efforts	2.0	10	10	8
		100	Subtotals ▸		6.0	8.4	4.0
15	Operability	35	Ease of Deployment Use	5.3	3	9	9
		35	Safe Operation	5.3	9	10	10
		10	ALARA	1.5	10	10	10
		20	Training/Qualifications	3.0	6	10	5
		100	Subtotals ▸		9.6	14.5	13.0
25	Reliability	20	Availability of Spare Parts	5.0	5	10	3
		15	Performance Speculation	3.8	5	7	6
		15	Robustness	3.8	6	10	9
		15	Simplicity of Design	3.8	7	10	8
		15	Vendor Support	3.8	8	10	5
		20	Repairability	5.0	4	8	8
		100	Subtotals ▸		14.3	22.9	16.0
10	Versatility	20	Able to Handle Unexpected Geometry	2.0	7	7	7
		20	Smaller Riser Access	2.0	1	1	1
		30	Overcome Obstructions	3.0	2	4	4
		30	Adaptable to Existing System	3.0	1	10	5
100		100	Subtotals ▸		2.5	4.4	4.3

Table 2. Alternative Cost Comparison Summary

	Initial Cost	Transducers with Assembly	Misc. Fabrication / Assembly	Spare Parts
Alternative 1: Floor Crawler	$26,500	$10,000	$10,000	$26,500
Alternative 2: Wall Crawler	$25,000	$0	$10,000	$25,000
Alternative 3: TSAFT	$100,000	$2,000	$10,000	$4,000

An informal sensitivity analysis was performed on the results, using a standard military diagnostic program (MAPP). The purpose of this analysis was to determine if inherent bias in the evaluation affected any of the criterion weighting results with enough significance to affect the final value. The sensitivity analysis demonstrated that any bias in the evaluation did not significantly affect the final values for each of the three alternatives.

5.0 Summary / Recommendations

The purpose of this report is to document the evaluation for the three alternatives for Ultrasonic Testing on the primary tank lower knuckle region from within the annulus. The alternatives were rated against consistent criteria to assure a fair comparison and then ranked on the weighting set for each criterion.

All three alternatives use crawlers to position the ultrasonic transducers. The primary difference is that alternative 1 uses a unique tracked platform to navigate the floor of the annulus space while alternatives 2 and 3 use magnetic based platforms that navigate the vertical walls of the primary tank.

Although not discussed in detail in the AGA meeting, the location of the "predicted maximum stress region" of the primary tank lower knuckle is relevant to the selection of the appropriate technology for examining this region. The predicted magnitude and location of maximum stress is dependent on the accuracy of the structural model, the loading conditions and load combinations considered, steel plate thicknesses, and material property assumptions. The predicted stress profiles along the tank wall vary in a complex manner, particularly in the lower knuckle region, as indicated in Figures 5.1 through 5.4 of *Double-Shell Tank Useful Life Analysis*, WHC-SD-WM-ER-556. Evaluation of the data files for these figures indicate the region of maximum meridional tensile stress on the inside tank surface coincides approximately with the point where the lower knuckle rests on the concrete insulating slab, while the point of maximum hoop stress on the inside surface occurs in the lower wall plate immediately above top of the curved lower knuckle. However, these analyses have not been finalized, and the location of predicted maximum stress in the lower knuckle region cannot presently be defined with certainty. Therefore, for purposes of selecting among the three NDE technologies

evaluated in this AGA, a robust approach is needed. 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 AGA process (i.e., the FORCE Institue Y-Arm Module). The FORCE Y-arm approach can be used in combination with the technology already in-place (RUTI) for examination of tank bottoms through air slots. These two technologies collectively provide the capability to measure material thickness, and to detect and size pits and cracks in the regions of the tank knuckle that are directly accessible. However, only the RUTI can examine the location of predicted maximum meridional tensile stress, based on present un-released structural analysis, and only where this region is exposed through the air slots. Accordingly, if and when the TSAFT technology is proven, it will be deployed to gain supplemental data in regions of the lower knuckle not accessible by either RUTI or the FORCE crawler with flexible Y-arm.

The analyses of the three alternatives evaluated in the AGA have been summarized in Table 3. Table 3 lists each alternative's subtotal for each criterion then summed to produce a cumulative score for each alternative. Based on its overall ranking the FORCE Institute Y-Arm Module is the preferred choice for the initial phase of lower knuckle NDE, and will provide the most reliable and cost effective means to perform the required functions. However, as noted, the FORCE Institute Y-Arm cannot examine the portion of the knuckle in contact with the insulating concrete slab. Accordingly, the FORCE Institute Y-arm is not a stand-alone technology, and will need to be supplemented with RUTI or TSAFT.

Table 3. Summary of Alternative Comparison Results

Criteria	Alt. 1 Floor Crawler	Alt. 2 Wall Crawler	Alt. 3 TSAFT
Life-Cycle Cost	2.0	4.7	2.8
Diagnostic Capabilities	21.5	31.2	15.6
Schedule Risks	6.0	8.4	4.0
Operability	9.6	14.5	13.0
Reliability	14.3	22.9	16.0
Versatility	2.5	4.4	4.3
Total	55.9	86.0	55.7