Guidelines for Development of Structural Integrity Programs for DOE High-Level Waste Storage Tanks

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OUTLINE

- Overview of TSIP Process
- Summary of NDE Considerations
- Changes in and Impact of NDE Capabilities Since 1997

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HIGH LEVEL WASTE TANK STRUCTURAL INTEGRITY PANEL

- Panel Composition
  - Bandyopadhyay (chair), Bush, Kassir, Mather, Shewmon, Thompson, Streicher, Weeks
- Input
  - 17 Tank Structural Integrity Workshops involving panel and personnel from 4 sites (October 1991 – January 1997)
  - Written material provided by sites

HIGH LEVEL WASTE TANK STRUCTURAL INTEGRITY PANEL

- Initial Panel Charge
  - Review information about operations, aging, degradation mechanisms, and maintenance and encourage exchange between sites
  - Evaluate existing programs on aging management and tank system structural integrity
  - Provide comments and recommendations for improvement
  - Provide guidance for estimation of end-of-life
  - Review generic issues (e.g., applicability of ASME Section XI – type inspection rules)
  - Advise management regarding permanent waste disposal and need for new tanks
- Final Panel Output
  - *Guidelines for Development of Structural Integrity Programs for DOE High Level Waste Storage Tanks,* BNL-52527, UC-406 (January 1997)

SCOPE OF CHARGE

- System Structural Integrity
  - Characterize degradation mechanisms
  - Identify methods to determine extent of degradation
  - Define surveillance and monitoring requirements
- Seismic Design and Qualification
- Safety Issues
- Safety Envelope
- Waste Characterization
- Conduct of Operations
- Staffing

SCOPE OF STRUCTURAL INTEGRITY DISCUSSIONS

- Components
  - Steel tank
  - Reinforced concrete tank or vault
  - Steel liner
  - Transfer piping
  - Cooling tubes
- Areas
  - Structure
  - Materials/Metallurgy
  - Corrosion
  - Concrete degradation
  - Crack initiation and growth
  - In-service inspection
  - Nondestructive examination

“PERMANENT” RECORD OF WORKSHOPS

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NDE TOPICS DISCUSSED

- 2/92 Planned Exams
  Visual Inspections
- 4/92 In-service Inspection of Existing Tanks
- 8/92 Outline of ISI Guidelines Developed
- 10/92 Site Input on ISI
  Discussion of Draft Guidelines
- 12/92 Discussion of Draft Guidelines
- 3/93 Inspection of Double-Shell Tanks
- 5/93 Guideline Status
- 6/93 Guideline Status
- 9/93 Guideline Discussion
- 12/93 Guideline Discussion
- 3/94 Site Comments on Guidelines
- 9/94 Guidelines to Sites for Formal Comment
- 3/95 PVRC Formal Comments on Guidelines
- 1/97 Hanford DST UT Examination
  Guidelines Formally Released

GUIDELINES FOR DEVELOPMENT OF STRUCTURAL INTEGRITY PROGRAMS FOR DOE HIGH-LEVEL WASTE STORAGE TANKS

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CHAPTER 5 NONDESTRUCTIVE EXAMINATION (NDE)

5.1 Introduction and Scope

- The NDE is intended primarily to detect degradation due to generic mechanisms that cause damage such as pitting, wall thinning, or cracking of steel materials.
- No claim is made that the program will detect random development of cracks or leaks
  - Use of leak detectors most reliable way to detect random leaks
  - The role of NDE, on the other hand, is to detect conditions such as potentially unstable cracks in the steel shells, or *generic* evidence of degradation (pitting, thinning, cracking) that might lead to leakage in the future.

CHAPTER 5 NONDESTRUCTIVE EXAMINATION (NDE): STEEL TANKS

- The NDE plan described selectively chooses segments of ASME Boiler & Pressure Vessel Code Section XI, "Rules for In-service Inspection of Nuclear Power Plant Components," to formalize the NDE procedure.
  - Section XI is the only definitive document in the United States covering nuclear in-service inspection (ISI)
  - There is no intent to invoke Section XI per se. Rather, the intent is to use applicable Articles relevant to high-level waste storage tanks.
  - The latest edition of appropriate ASME Codes and their addenda, such as Section XI, shall be used.

CHAPTER 5 NONDESTRUCTIVE EXAMINATION (NDE): STEEL TANKS

5.2 Exemptions

- It is recognized that several tanks or tank designs have limited accessibility because of limited head penetrations, lack of access due to cooling coils, or to other geometric considerations. In such instances the site should prepare the program and incorporate specific requests for exemption, or alternative approaches to achieve compliance. These requests for exemption should be resolved by appropriate DOE organizations at the local or headquarters level.

STEEL TANK NDE

5.3 Inspection Requirement

- Primary recommendation in Table 5.1 to follow
  - Elaboration of Philosophy and Interpretation in Appendix A
- Alternative examination procedures
  - Eddy current (most appropriate for non-magnetic material)
  - EMAT-based UT

TABLE 5.1 EXAMINATIONS OF CARBON OR LOW-ALLOY AND AUSTENITIC STAINLESS STEEL OR HIGH-ALLOY TANK CONTAINING HIGH-LEVEL WASTE

REGION EXAMINED	EXAMINATION REQUIREMENTS	EXAMINATION METHODS	ACCEPTANCE LEVELS	EXTENT OF EXAMINATION	FREQUENCY OF EXAMINATION
LIQUID-VAPOR INTERFACE	± ONE FOOT OF INTERFACE	VOLUMETRIC (0° UT)	PITS, (<50%t)	5% OF INTERFACE LENGTH OF EACH TANK TO BE EXAMINED*	EACH INSPECTION INTERVAL (DIVIDED INTO TWO PERIODS)
LIQUID-SLUDGE INTERFACE, IF SUCH EXISTS	± ONE FOOT OF INTERFACE	VOLUMETRIC (UT) FROM OUTER SURFACE	PITS (<50%), CRACKS (<50%t)*** (<20%t)** GROSS CORROSION (<20%t)	5% OF INTERFACE LENGTH OF EACH TANK TO BE EXAMINED	EACH INSPECTION INTERVAL
LOWER KNUCKLE OF PRIMARY TANK	UPPER WELD	VOLUMETRIC	CRACKS (<20%t)** (<50%t)***	5% OF LENGTH DIVIDED INTO TWO OR MORE SEGMENTS IF ACCESSIBLE	EACH INSPECTION INTERVAL
LOWER KNUCKLE OF PRIMARY TANK	PREDICTED MAXIMUM STRESS REGION OF BASE METAL PLUS LOWER	VOLUMETRIC	CRACKS (<20%t)** (<50%t)	5% DIVIDED BETWEEN KNUCKLE BASE METAL AND LOWER WELD IF ACCESSIBLE OTHERWISE 5% OF KNUCKLE DIVIDED	EACH INSPECTION INTERVAL

TABLE 5.1 (CONTINUED) EXAMINATIONS OF CARBON OR LOW-ALLOY AND AUSTENITIC STAINLESS STEEL FOR HIGH-ALLOY TANK CONTAINING HIGH-LEVEL WASTE

REGION EXAMINED	EXAMINATION REQUIREMENTS	EXAMINATION METHODS	ACCEPTANCE LEVELS+	EXTENT OF EXAMINATION	FREQUENCY OF EXAMINATION
EXTERNAL SURFACE OF PRIMARY TANK IF ACCESSIBLE	BELOW NOMINAL VAPOR-LIQUID INTERFACE	VOLUMETRIC (O°) UT	WALL THINNING (<20%t)	EACH INSPECTION INTERVAL	EACH INSPECTION INTERVAL
VAPOR REGION AT TOP OF PRIMARY TANK	CONFIRM VT WITH PT OR UT IF ATTACK IS FOUND	REMOTE VISUAL	EVIDENCE OF ATTACK SHOULD BE EVALUATED	REMOTE SCAN OF VAPOR REGION	EACH INSPECTION INTERVAL
PLATE MAKING UP BOTTOM OF TANK IF ACCESSIBLE	"BEST EFFORT" NDE EXAMINATION	VOLUMETRIC	CRACKING (<20%t)** (<50%t)*** THINNING (<20%t) PITTING (<50%t)	PRIMARILY FOR NEW TANKS DESIGNED FOR ACCESSIBILITY; HOWEVER, LIMITED SCANS SHOULD BE CONDUCTED IF FEASIBLE	EACH INSPECTION INTERVAL
OVERALL SCAN OF INTERNAL SURFACE	WHEN TANK IS ESSENTIALLY EMPTY	REMOTE VISUAL	EVIDENCE OF DEGRADATION SHOULD BE EVALUATED	GENERAL SCAN OF INSIDE OF PRIMARY TANK	WHEN TANK IS EMPTY

* TANK POPULATION TO BE EXAMINED IS 10% OF TANKS, BUT NOT LESS THAN ONE; ALTERNATIVELY, THE POPULATION EXAMINED MAY BE GREATER THAN 10% WITH A COMPARABLE REDUCTION IN THE AMOUNT EXAMINED IN EACH TANK, PROVIDED THE TOTALS ARE THE SAME AS FOR THE 10% POPULATION.

** <20%t FOR CRACKING APPLIES WITH FLAW LENGTHS ≥ ONE FOOT.

*** <50%t FOR CRACKING APPLIES WITH FLAW LENGTHS < ONE FOOT WITH LOWER BOUND LENGTHS ABOUT 0.5-INCH.

THE INSPECTION INTERVAL IS 10 YEARS; THE INSPECTION PERIOD IS APPROXIMATELY 5 YEARS.

SPECIAL EMPHASIS MUST BE PLACED ON WELDMENTS, WHERE LEAKS ARE MOST LIKELY TO

APPENDIX A – PHILOSOPHY AND INTERPRETATION OF BASES USED IN NONDESTRUCTIVE EXAMINATION (NDE) GUIDELINES

- A.1 Introduction
- A.2 Scope
- A.3 Purpose of Generic NDE Guidelines
- A.4 Approach Taken
- A.5 Bases Used for Evaluating Degradation
- A.5.1 Bases for Flaw Sizes
- A.5.2 Bases for Examination Percentages
- A.5.3 Reasons for Selection of NDE Angles
- A.5.4 Implication of Section XI Articles Cited
- A.5.5 Exemption Mechanism with Examples

OPTION 1
STAND-ALONG APPROACH

X

- Such an approach could have used existing inspection “standards” such as those of the American Petroleum Institute for thin-walled tanks. This approach was discarded for the following reasons:
  - The API “standards” are not true consensus standards; therefore, all values would require justification.
  - While the API standards have a good technical basis, they lack any tie to nuclear. This was considered a possible limitation.
  - A complete stand-along NDE guideline documents would be about 100 pages in length and require 3-5 years to develop.

OPTION 2
CONSENSUS CODE APPROACH

- It is recognized that Section XI was developed for thicker wa vessels; however, piping examinations with ultrasonics ofter thicknesses less than those of the waste tanks. The principal differences are in the diameter-to-thickness ratios. This approach was selected because:
  - Section XI is a consensus Code approved for use in commercial nuclear power plants by the USNRC.
  - About 25 years experience and thousands of man-days effort have been expended I the development of Section XI.
  - The sampling approach used in Section XI represents the only viable NDE option for high-level waste tanks because of time/manpower limitations.
  - Many articles can be cited by reference without further justification.
  - NDE techniques, including both equipment and NDE operator qualification are well defined.
  - Section XI relies heavily on feedback from utilities, regulators and other interested parties to modify and upgrade the Code continuously so that real problems can be soled.
  - The use of relevant parts of Section XI permits a concise and defensible guideline document.

A.5.1
BASES FOR FLAW SIZES

- Because of low loads and thin sections triaxial stresses are eliminated so that an unstable flaw should be quite long, even under Level D seismic loads. Therefore the intent of NDE programs is to:
  - Detect generic failure mechanisms
  - Provide early warning of such failure mechanisms within the limitations inherent in a sampling program
- In contrast to Section XI where the cut-off for flaw sizes requiring no additional actions is 2.5%t, the low loads of the tanks and the biaxial stresses inherent in thin sections permit much larger permissible flaw sizes before there is a need to increase the examination sample size
  - Justification for the values of 20%t and 50%t

A.5.2
BASES FOR EXAMINATION PERCENTAGES

- The approach was to select regions for examination that were believed to be most susceptible to the anticipated mechanisms of pitting, crevice, bulk, or stress corrosion
  - Sample size was selected to provide a reasonable confidence of detecting generic degradation
  - Sample size was a compromise based on complexity of remote automated NDE
  - Sample represents a lower bound for reliable detection of generic degradation; it is roughly comparable to Section XI IWC values.

A.5.3
REASONS FOR SELECTION OF NDE ANGLES

- The lack of success in detection and sizing of flaws with single angle UT in the early years of Section XI and the statistically validated results of the Program for the Inspection of Steel components led to the decision in Section XI to require four angles (0°, 45°, 60°, and 75°
L-wave)
  - The 0° choice is obvious for pits and for wall thinning
  - With stress corrosion, the lack of success in the absence of a definite qualification program and in detecting intergranular stress corrosion in wall thicknesses of 0.2 to ~1.5 inches was confirmed in the IGSCC occurring in BWRs and in PISC programs using implanted fatigue and stress-corrosion cracks

A.5.4 IMPLICATION OF SECTION XI ARTICLE CITED

- Several articles/appendices of Section XI are cited
  - The examination interval of ten years in IWA-2430 was selected as a reasonable interval. This was divided into two inspection periods of five years rather than the three of Section XI
  - Appendix III is usually used for piping. The procedure in the appendix has been revised to include more examination angles. The three angles required represent a conservative position
  - Appendix VIII represents a performance demonstration using samples comparable in thickness to the tank and containing the most probable flaws (pits, thinning, SCC). Use of these specimens should qualify the UT equipment and establish the reliability of flaw detection and flaw sizing

A.5.5
EXEMPTION MECHANISM WITH EXAMPLES

- The Section XI Code is made up of a number of requirements In some instances a utility cannot comply
- An example of the high-level waste storage tanks is cited below. This example, it is believed, represents a valid exemption and should be accepted
- At one site, some waste storage tanks were not stress relieved and have experienced through-wall SCC.
  - The number of through-wall cracks range from a few in some tanks to a large number in others.
  - There is a high probability that these tanks contain SCC that has not penetrated the wall.

BASES FOR FLAW SIZES

- The purpose of the NDE guidelines program should be to detect new generic degradation, not to trigger more examinations with a known and well documented problem
  - "New" SCC detected should comply with IWC-2420 regarding successive examinations. If three successive examinations confirm no crack growth, further UT is not required per
    IWC-2420 (inhibitor working)
  - "New" SCC detected should not invoke IWC-2430 regarding additional examinations. It is known that SCC has occurred. Invoking IWC-2430 has a high probability of expanding the sample to 100% of accessible welds. This would require an expenditure of time and resources out of proportion to the value added information

CONCRETE NDE

- Approach should be employed on a case-by-case basis depending on
  - Accessibility
  - Anticipated degradation mechanism
  - Prior evidence of degradation
  - 5-10 year interval
  - Only tanks where degradation expected
  - Only regions where degradation expected
- Applicable segments of ACI 201.1R and Subsection ISL of Section XI are relied on to develop the necessary procedures and tests

CONCRETE NDE

- Methods
  - Direct visual
    - Hole drilling outside zones of reinforcing steel
  - Ultrasonic Pulse Velocity Method
  - Rebound Number Test
  - Acoustic Emission Test
  - Electrochemical Testing
  - Radiography Testing

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ADVANCES IN NDE EQUIPMENT/TECHNIQUES SINCE 1997

- Inspection Techniques
  - Ultrasonics
    - Phased array probes
    - Air coupled probes
    - Guided wave NDE Techniques
  - Radiography
    - Digital detectors
  - Eddy Currents
    - Array detectors
    - High sensitivity solid state detectors (e.g., GMR)
    - Pulsed eddy current systems
  - Fluorescent Penetrant Inspection
    - Better understanding of influence of process parameters

ADVANCES IN NDE EQUIPMENT/TECHNIQUES SINCE 1997

- Magnetic NDE
  - Improved instrumentation and theories of interpreting magnetic Barkhausen effect
- Infrared
  - Significant camera improvement
- Vibrothermography (Sonic IR)
  - Detection of IR radiation excited by vibration (rubbing crack faces)
- Terahertz NDE
  - Time domain measurements of electromagnetic reflectivity at 10^{12} Hz

ADVANCES IN NDE EQUIPMENT/TECHNIQUES SINCE 1997

- Data Processing
  - Increases in computational capability
    - Enables much more sophisticated data storage and processing
- Simulation
  - Increasingly sophisticated tool to simulate results of major inspection modality
    - Guided set-up and interpretation of inspection
    - Assist in assessment of probability of detection

ADVANCES IN NDE EQUIPMENT/TECHNIQUES SINCE 1997

- Advances in Concrete NDE
  - New techniques driven by increased interest in infrastructure problems
  - Better scientific understanding of technique performance

IMPLICATIONS OF NDE ADVANCES ON GUIDELINES

- A number of these techniques have the potential to improve the ability to inspect the tanks
- They have different levels of maturity
- Unknown to the author are
  - The degree to which they are recognized in current ASME codes
  - The degree to which such recognition is viewed important by the governing bodies
- Lists of high maturity and emerging techniques with potential application to the tanks follow

NDE ADVANCES WITH HIGH MATURITY AND CLEAR POTENTIAL TO IMPACT TANK INSPECTION

- Inspection Techniques
  - Ultrasonics
    - Phased array probes
      - *Sweep angle of beam while probe is mechanically scanned* over liner
    - Guided wave NDE Techniques
      - *Rapidly scan areas and identify suspect regions for further detailed evaluation*
- Data Processing
  - Increases in computational capability
    - Enables much more sophisticated data storage and processing
      - *Better images of cracks and corrosion using current technology*
      - *Enables phase array improvements*
- Simulation
  - Increasingly sophisticated tool to simulate results of major inspection modality
    - Guide set-up and interpretation of inspections
      - *Response of flaws under different NDE scenarios*
      - *Interpretation of guided wave NDE signals*

EMERGING NDE ADVANCES WORTHY OF FURTHER CONSIDERATION

- Inspection Techniques
  - Radiography
    - Digital detectors
      - *Avoids need for film development and storage with permanent digital record*
      - *Would be of value if radiography needed for concrete*
  - Eddy Currents
    - Most appropriate for non-ferrous materials
    - Array detectors
      - *Faster coverage of a given area*
    - High sensitivity solid state detectors (e.g., GMR)
  - Vibrothermography (Sonic IR)
    - Detection of IR radiation excited by vibration (rubbing crack faces)
      - *Emerging technique receiving a lot of attention*
      - *Whole field detection/characterization of tight cracks*

EMERGING NDE ADVANCES WORTHY OF FURTHER CONSIDERATION

- Terahertz NDE
  - Time domain measurements of electromagnetic reflectivity at 10^{12} Hz
    - *Emerging technique whose properties are just beginning to be understood.*
    - *Played a key role in inspection of Spayed on Foam Insulation in Space Shuttle*
    - *Has been used in preliminary studies on concrete*
- Advances In Concrete NDE
  - New techniques driven by increased interest in infrastructure problems
  - Better scientific understanding of technique performance
    - As influenced by the heterogeneous nature of the concrete

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