UCRL 13839

Engineering Analyses and Tests

EVALUATION OF THE INTEGRITY OF EXISTING NFS WASTE TANKS

E.A.&T. Co.,Inc
4676 Admiralty Way,
Marina del Rey, Ca 90291

Project: 1016-1E

Date: DECEMBER 1977

EA & T CO., INC.
4676 ADMIRALTY WAY
SUITE 211
MARINA DEL REY, CA. 90291
TEL.: (213) 822-0931

ENGINEERING ANALYSES & TESTS

EVALUATION OF THE INTEGRITY OF EXISTING NFS WASTE TANKS

FORWARD

The special study carried out in this document was conducted under Purchase Order No. 7557303 with Lawrence Livermore Laboratory, University of California. Mr. Robert C. Murray of the Structural Mechanics Group, LLL, served as the technical representative for monitoring the project. Mr. Raymond Perez represented Engineering Analysis and Test Co., Inc., as principal investigator.

TABLE OF CONTENTS

ABSTRACT

Various means of investigating the integrity of the existing NFS waste tanks are presented including visual inspection, ultrasonic testing, acoustic emmission monitoring, radiography, and forced vibration testing. The experience which exists in performing such investigations of high level radioactive waste tanks is documented including visual inspections, photography, wall thickness measurements, and forced vibration testing. An evaluation is made on the relative merits of the presented inspection and testing alternatives.

1.0 Introduction

This study has been performed to investigate the inspection and testing techniques and procedures which exist for determining structural and material integrity, and to document the experience of others in performing such evaluations on high level radioactive waste tanks and vaults.

The primary objective of such an inspection and testing program would be to verify the containment capability of the existing NFS waste tanks and vaults. This would be accomplished by adopting those techniques and methodologies which have been developed for the surveillance of ERDA waste tanks of comparable design and content, and by utilizing existing technology for materials and structural integrity evaluation.

2.0 Summary and Conclusions

A survey of state of the art materials and structural integrity inspection and testing methodologies and a review of the actual inspection and testing experience which exist on high level waste tanks indicate that such a program could provide an immediate measure of the NFS Tank 8D-2 integrity. Visual inspections using existing hardware as developed by Savannah River Laboratory (SRL) and others is highly recommended. Forced vibration testing to establish the resonant frequencies and modes of vibration of the tank would provide the information necessary to validate theoretical models. Ultrasonic testing and acoustic emission technologies are available for in-depth analyses of any visually located anomolies in containment integrity.

3.0 Inspection and Testing Methodologies

The conceivable inspection and testing methodologies for materials and structural integrity determinations were evaluated for possible application to the seismic stability of the high level waste tanks at the Nuclear Fuel Services (NFS) site. Many of the conventional hands-on approaches had to be discarded due to the presence of the radiation field associated with the high level liquid waste. The inspection and testing methodologies outlined below have been found to have application to the evaluation of the structural integrity of pressure vessels containing high level radioactive material.

3.1 Ultrasonic Testing (UT)

Non-destructive inspection and testing of the waste tanks can be performed using established ultrasonic testing techniques. An echo-ranging technique using very short sound pulses (0.1 to 2.0 microseconds) of ultrafrequency (5 to 15 megacycles) has been used in the past to determine the presence of material discontinuities such as cracks, inclusions, or voids in casting, or welds up to 5 inches or more thick. The wall thickness of closed pressure vessels and tanks of similar design to those of NFS have been determined using ultrasonic techniques in which the time lag between initiation of the signal and its reflection from the inner wall surface is measured. This time interval is related to the wall thickness in the following manner.

Sound is a longitudinal wave phenomena representing the propagation of compressional waves in an elastic medium. The velocity of propagation, V, of these waves depends on the ratio of the elastic modulus, E, of the material to its density, ρ, as:

$$V = \sqrt{E/\rho}$$

The velocity of sound waves in the medium is then solely determined by the medium material properties. The relation between the frequency and wave length of the signal is then:

$$V = \nu \cdot \lambda$$

Thus at very high frequencies in the ultrasonic range, the wave length of the signal is very short which makes it possible to develop pulses of waves at the surface.

The velocity of sound in iron and soft steel is approximately 16,500 feet per second. Therefore, if the frequency used is 15 megacycles, the wavelength of a single vibration is on the order of 10^{-2} inches, and the reflection time interval for the NFS tank is on the order of 10^{-5} to 10^{-6} seconds.

The instrumentation required to perform ultrasonic testing consists of a megahertz sonic signal generator, a transducer of comparable frequency response, an amplifier, and an oscilloscope or electronic clock from which the reflection time interval can be determined. These tests have reportedly been used to establish corrosion rates of exposed canisters of high level waste at Battle-Northwest. A test consists of scanning the surface with the horn of the signal generator and transducer and determining the reflection time from the inner surface or from a material discontinuity which might be present.

3.2 Ultrasonic Wall Thickness Measurements

The principal ultrasonic measurement systems in use today for the determination of metallic wall thickness rely on either resonance or pulse echo techniques. The major factors affecting the ultrasonic measurements are grain size, metallurgical condition, and the presence of welds. Experimental programs have determined that ultrasonic measurement techniques using commercially available instrumentation are capable of measuring wall thickness of 0.25 to

2.00 inches within 2 to 5% accuracy.

In the reported experimental work, two basic instruments were used; the Magnflux Model PS-702 and the Magnaflux Model SO-300 Sonizon. The first of these relies on pulse echo technique while the latter is based on resonance.

In the pulse echo method, the crystal in the transducer is made to vibrate at its own natural frequency, and the resulting energy is coupled directly into the wall. Frequency changes are made by changing transducers. The energy travels through the metal in the form of a sound wave. Upon striking the opposite side of the wall, the energy is reflected back to the transducer energizing it.

If the metal wall has low attenuation and dispersion characteristics (i.e., if the metal is mild carbon steel or stainless steel), the sound wave will continue traveling back and forth between walls, energizing the transducer each cycle.

3.3 Ultrasonic Testing of Welds

In 1969, the American Welding Society issued new editions of the Code for Welding in Building Constructions (AWS D1.0-69) (4), and Specifications for Welded Highway and Railway Bridge (AWS D2.0-69). Appendix C - Ultrasonic Testing of Welds (4) was part of these documents. This is the first ultrasonic testing procedure issued by the Society and it covers the ultrasonic testing of groove welds between the thicknesses of 5/16 and 8 inches, inclusive. The welds may be either butt, tee, or corner welds, and may be either full or partial penetration welds.

The procedure outlined is based on the monitoring of induced shear wave vibrations in the transverse direction of signal passage due to the greater sensitivities and resolving power. If a weld discontinuity has enough surface roughness to reflect sound energy to some degree at angles other than perfect reflection angles, the amplitude response is highest when its major dimensions are oriented at an angle of exactly 90 degrees to the direction of sound beam travel. For this reason, a shear wave transducer with the angle nearest to 90 degrees would normally return the highest amplitude response from discontinuities whose major orientation direction is most detrimental to the weld structure. A 70 degree transducer angle is the largest angle of transducer used in the application of Appendix C because larger angles create difficulties in surface wave mode conversion and discontinuity depth perception.

The acceptance criteria for welds as indicated in Appendix C is based on the length of the discontinuity relative to the depth of the weld.

3.4 Acoustic Emission (AE)

Acoustic emission refers to the transient sonic signals produced by materials undergoing plastic deformation. A microcrack which is growing due to stress concentration or corrosive attack does so in sporadic steps. Each growth step is accompanied by the emission of sonic waves in the 100 KHz to 1 MHz range. These sonic waves, upon amplification with typically a 10^4 to 10^6 gain factor, produce on the order of 10^5 counts per second of acoustic emission.

Acoustic emission measurements are capable of detecting and locating flaws with greater resolution than can be obtained with ultrasonic or radiographic techniques. An additional advantage of AE inspections is that the object being tested (i.e. waste tank and associated piping) does not have to be scanned as is required in ultrasonic or radiographic inspections to detect or locate flaws.

A disadvantage of AE techniques is that only active flaws can be detected. A crack which is not currently growing will not emit sonic radiation. Furthermore, the size or significance of a located flaw must be determined using conventional methods such as ultrasonics or radiography.

To locate active flaws in materials, two or more transducers are placed on the object and an electronic clock is used to determine the time of arrival of a signal pulse to the different transducers. As in ultrasonic transmissions, the velocity of the pulse is solely dependent on the material properties; therefore, the time of arrival of the signal is directly related to the distance. Thus, triangulation methods can be used to locate the flaw.

The instrumentation used to perform AE inspection and tests is somewhat more sophisticated than that used for UT. It consists of transducers, amplifiers, clocks, a counter and normally a minicomputer used to perform the triangulation calculations. AE instrumentation has been designed to maintain continuous surveillance of nuclear reactor pressure vessels and other pressure vessels containing chemically toxic materials.

3.5 Forced Vibration Testing (FVT)

At much lower frequencies (0-100 Hz), vibration tests could be carried out which would determine the resonant frequencies, vibrational mode shapes, damping values, and, in general, the system response to vibrational excitation such as would occur as a result of an earthquake or severe ground motion due to an impact or explosion. From such measurements, the inertial forces present during such events can be readily computed resulting in known values of stress and strain at critical points such as the emergency transfer lines, waste coolant lines, neutralized waste concentrator system and the waste tanks themselves.

To perform a FVT of the tank vault system, sinusoidal shakers would be mounted at various points on the system which would produce uni-directional vibrational excitation. A sweep of the frequency range of interest (typically 1 Hz to 30 Hz) would be performed to locate the resonant frequencies. These frequencies would be recorded using a data acquisition system consisting of accelerometer transducers of milli "g" (10^{-3} g's) range, strip chart recorders and a spectrum analyzer which produces hard copies of the resonant frequency band width from which the damping values are determined.

The modes of vibration at these resonant frequencies of the tank vault system would then be determined. This is accomplished by placing transducers along the three orthogonal directions of the exposed surfaces and "mapping" the manner in which the surface vibrates at each resonant frequency. Such information is then used to compute the stresses and strains at critical points in the system.

3.6 Radiographic Inspections (X-Ray)

Radiography, or x-ray analysis, is accomplished using a source of x or gamma radiation (frequently a cobalt-60 source) and a fluorescent screen or film. Inhomogeneities such as cracks, voids, or inclusions, show up on the film in the form of under- or over-exposed areas in relation to the general background. As in the interpretation of ordinary x-ray films, the resolution of images obtained from radiographic films in industrial applications in rather poor, requiring the use of a well trained technician.

Application of radiographic inspection of the tank vault system components is rather limited due to the high radiation field associated with the contained high level waste.

4.0 Inspection and Testing Experience

Inspection of buried high level waste tanks is difficult because of radiation and contamination problems. However, techniques have been developed for remote inspection and evaluation of the condition of waste tanks at the Savannah River Plant (SRP), Hanford Reservation, and at the Idaho National Engineering

Laboratory (INEL). These include visual inspection by means of a periscope, photography, ultrasonic measurements of wall thickness, and corrosion specimens.

4.1 Optical Periscope Experience

A portable optical periscope composed of up to 4 ten-foot sections is extended from grade into the annular space or tank with the objective lens relatively close to the location of interest. Incandescent lights mounted below the objective lens on the periscope provide illumination for direct viewing and for periscope photography, using fairly long exposures. Alternate objective lenses (1x and 5x) and an adjustable objective mirror provide viewing angles of 40 and 8 degrees, respectively, centered horizontally, below horizontal, or vertically downward. Used in a tank annulus at various elevations in a given riser, the periscope permits surveillance of the full height of the primary tank wall from one tangent point to the other (ordinarily twenty to twenty-five feet of tank circumference) at each location. The cooler annular type tanks have four risers at 90° intervals around the annulus. These risers allow periscope surveillance of 30 to 40% of the wall area of these tanks.

Tank interior viewing with the telescope has been less useful than annulus inspection for evaluation of primary tank leaks and mechanical and metallurgical condition because of greater visual distances, higher lighting demands, and (frequently) poor visual transmissivity (fog) in the tank vapor space. However, in-tank surveillance via telescope has been invaluable in studying the manner, degree, and effects of sludge removal and salt accumulation and removal.

4.2 Direct Photography Experience

Apparatus and techniques are in use and under continuing development to supplement periscopic inspections with direct photography using shielded camera and electronic flash (strobe) lamps lowered directly into the tank vapor space or annulus. Most work to date has utilized a camera which has a spring powered advance, and permits multiple successive exposures without manual access to the camera.

The camera assembly, including close fitting lead shielding, a shutter release solenoid, and one or more remotely rechargeable strobe lamps, is tailored for passage through a 5 inch diameter access port. It is suspended by a flexible, reinforced rubber steam hose which allows enough flexibility for easy handling on the tank top and enough torsional rigidity to provide positive orientation (azimuth) control of the camera line of sight. An azimuth-indexed support bearing at grade level and detachable stops along the supporting hose facilitate rapid entry, positioning, and removal of the assembly in and from the tank or annulus. This is needed to minimize film fogging due to the often intense gamma field that is encountered. Swinging of the camera on its flexible support hose does not affect picture clarity because of the short duration of the strobe flashes.

Picture resolution, clarity, and color are generally superior to the best picture taken through the periscope. They are much superior where film fogging is not serious or where low light levels, degradation of optics, and/or poor focusing result in low quality periscope pictures.

The chief disadvantage of the direct photography inspection technique is the delay before finished photographs are available. This disadvantage is not serious for ordinary prescheduled inspections; any unusual conditions which show up in the photographs can be re-examined by periscope in the detail warranted, with or without further direct photography of the specific area of interest.

A wide angle camera in an articulated mounting to give a downward field of view was developed in 1974-75 for scanning service. A single picture from the camera, fitted with four electronic flash units, encompasses almost all of the tank wall area covered by a score or more of close-up pictures obtained by panning the horizontal-looking camera at several elevations. Use of the wide-angle camera for routine annulus inspections substantially increases the practical frequency of inspections.

4.3 Wall Thickness Measurement Experience

Ultrasonic equipment has been used to measure the thickness of the primary wall of the double-wall waste tanks at SRL. Two types of instruments have been used: (1) in 1967 and 1969, an analog-type instrument was used with which the reading was interpreted from a display on a cathode ray tube, and (2) in 1972 through 1975, a similar, but more accurate, digital thickness gage was used. The measurements on all 30 tanks, indicated no significant thinning of the tank walls. The presence of pits or stress-corrosion cracking would not likely be detected by this technique.

Equipment has also been designed and demonstrated for penetrating waste salt or sludge at the bottom of tanks and obtaining bottom thickness measurements. Measurements have been taken on the bottom of SRP tanks 21, 22 and 23, with all measurements indicating no thinning of the bottom plate.

4.4 Forced Vibration Testing Experience

The only documented FVT of a buried tank vault system was conducted at the SRL in 1975. The test was reportedly conducted using elctromagnetic shakers (as opposed to sinusoidal shakers) which normally do not have the force levels at low frequencies necessary to excite the natural frequencies of such massive objects. However, several resonant frequencies and their respective mode shapes were reportedly measured (18).

5.0 Recommendations For Existing NFS Tanks

On the basis of the information presented, it is concluded that visual, photographic, ultrasonic wall thickness, and forced vibration testing of the high level radioactive tanks at the NFS site are all feasible options which may be employed in an inspection of the existing tanks. The application of radiographic surveys of the tanks and piping network as part of this program would appear to be quite limited due to the presence of the high radiation background field. The application of acoustic emission technologies to the evaluation of the existing tanks would require the performance of an R&D effort to establish the feasibility and to develop the testing techniques.

As a result of the analyses conducted, it is recommended that an inspection and testing program be implemented which includes visual and photographic inspections as a minimum for the detection of cracks and/or leaks in the tank liner, piping, etc. Forced vibration testing as a means of evaluating the structural integrity of the tank liner is stongly recommended. As a final measure, it is suggested that ultrasonic wall thickness measurements be employed in the event that accelerated corrosion of the piping network or tank liner is suspected.

REFERENCES

1. NUREG-0043, "Alternate Processes for Managing Existing Commercial High Level Radioactive Wastes," Battelle Northwest Laboratory Under Energy Research and Development Administration Contract for the US Nuclear Regulatory Commission.

2. Lyman, Taylor, Metals Handbook, Metals Handbook Committee, The American Society for Metals, "Mechanical Testing of Weld Metal and Welded Joints," p. 137, 1948.

3. Holby, Eric, "Measuring Wall Thicknesses of Installed Values," Welding Engineer, p. 9, November 1974.

4. Shenefelt, George A., "Ultrasonic Testing Requirements of the AWS 1969 Building Code and Bridge Specifications," p. 342, May 1971.

5. Rosenstein, A.H. and Lubahn, J.D., "Brittle Fracture of Welded Steel Plates" Welding Reserach Council of the Engineering Foundation, Supplement to Welding Journal, p. 481-5, Nov. 1967.

6. ASME Pressure Vessel Code, Section VIII, Part UG-General Requirements Impact Test Requirements for Carbon and Low Alloy Steel, p. UG-84, 1976 Edition.

7. ASTM A 652-1973, Standard Specification for Special Requirements for Wrought Steel Welding Fittings for Nuclear and Other Special Applications.

8. Levenson, Milton, "Advanced Acoustic Testing Techniques," R & D Status Report Nuclear Power Division EPRI, Journal, p. 52, Aug. 1977.

9. Reinhart, Eugene R., "Evaluating the Performance fo Inservice Inspectors of Reactor Piping and Pie Welds," EPRI Journal, p. 61, Aug. 1977.

10. BNWL-B-103, "Development and Design of an Ultrasonic Inspection System for Rad Waste Containers," Battelle Northwest, Richland, WA, June 1971.

11. Docket -50332-B SAR Amendment No. 4 to the Application by Allied Chemical Nuclear Products, Inc. For a Construction Permit and Operating License for the Barnwell Nuclear Fuel Plant.

12. ERDA-1553-D, Draft Environmental Statement-Management of Intermediate Level Radioactive Waste, Oak Ridge National Laboratory, Oak Ridge, Tenn, Jan. 1977.

13. EPA-520/3-75-003 "Preliminary Environmental Analysis of a Generic Fuel Reprocessing Facility," US Environmental Protection Agency, Office of Radiation Programs.

14. ERDA-1536, Draft Environmental Statement-waste Management Operations-Idaho National Engineering Laboratory, Idaho Fall, Idaho, June 1976.

15. ERDA-1537, Draft Environmental Statement-Waste Management Operations, Savannah River Plant, Aiken, So. Carolina, Oct. 1976.

16. ERDA-76-43, Alternatives for Managing Wastes from Reactors and Post Fission Operations in the LWR Fuel Cycle, vol. 3 of 5: Alternatives for Interior Storage and Transportation.

17. McElroy, J.L., et. al. Status of the Waste Solidification Demonstration Program, Nucl. Tech., vol. 12, p. 78, Sept. 1971.

18. Personal Communications with Paul Turkheimer, Wiley Laboratory, Norco, California.