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A Research Report for the
Rockwell Hanford Operations

Ultrasonic Inspection Techniques for Two Weld Closures Proposed for RSSF Waste Storage Casks

by
S. R. Doctor
C. J. Morris

January 1978

Prepared for the
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ULTRASONIC INSPECTION TECHNIQUES FOR TWO WELD CLOSURES PROPOSED FOR RSSF WASTE STORAGE CASKS

to
Rockwell Hanford Operations
Richland, Washington

by
S. R. Doctor
C. J. Morris

January 1978

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Richland, Washington 99352

SUMMARY

One method being considered for interim storage of high-level radioactive waste materials is to place these materials in large sealed stainless steel canisters and subsequently store these canisters in a second sealed steel storage cask. Weld procedures are proposed as the closure or seal for these vessels. Inspection of these closures to assure initial and long-term integrity of the closure welds presents a challenge to nondestructive testing. The environment is thermally (400-1000°F) and radioactively (10^5 R/hr) hot necessitating remote inspection procedures.

Under canister development and demonstration programs sponsored by the Department of Energy (formerly the Energy Research and Development Administration) at Rockwell Hanford Operations (formerly ARHCO) and Pacific Northwest Laboratory (PNL), research was performed to develop an ultrasonic test method that could be employed in the environment. As a result of the work, ultrasonic test techniques were developed for inspecting the final weld closure of the waste cask. Special transducers, coupling techniques and fixturing were developed and demonstrated in a mockup test facility by remotely examining a 2-in. full penetration weld closure. The examination was performed at room ambient and at a temperature of 200°F. Testing at the desired temperature of 400°F was not completed due to a loss in transducer performance at temperatures in excess of 200°F. However, PNL has recently conducted a series of long-term thermal tests at 350°F, and with an additional design alteration the transducers will be capable of long-term operation at 400°F.

Several features of the inspection system performed successfully. The three-point ball system to support the transducers did an excellent job for a prototype system. The pressurized ultrasonic couplant and feed system performed satisfactorily and should not require further development. The couplant spreading concept was effective, producing a good signal to noise ratio at operating temperatures. The spring loading of the transducers also performed well.

Upon completion of the mockup test demonstration, the cask was subjected to a drop test. The ultrasonic results of the pre- and post-examination of two weld closures (the 2-in. full penetration weld and the threaded plug with seal weld) are presented. After the completion of the drop test, both weld closures were radiographed. The radiographs verified the ultrasonic examination and the presence of weld defects in the same areas. Sectioning of the cask closure welds with metallographic verification was not completed at the time of this writing.

As a result of the experience gained from the Retrievable Surface Storage Facility (RSSF) storage cask program, recommendations pertaining to the nondestructive engineering development program for Spent Unreprocessed Fuel (SURF) storage casks are presented.

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ULTRASONIC INSPECTION TECHNIQUES FOR TWO WELD CLOSURES PROPOSED FOR RSSF WASTE STORAGE CASKS

INTRODUCTION

The 2-in. full penetration weld closure technique is the fourth in the series of proposed Retrievable Surface Storage Facility (RSSF) waste cask closure concepts. In this study, the 2-in. full penetration weld closure, shown in Figure 1, was inspected with ultrasound. Before this research was carried out, ultrasonic inspection techniques were developed for three other weld closures. They were a full penetration butt joint closure, a multi-plate fillet closure, and a threaded plug with seal closure weld.[1]

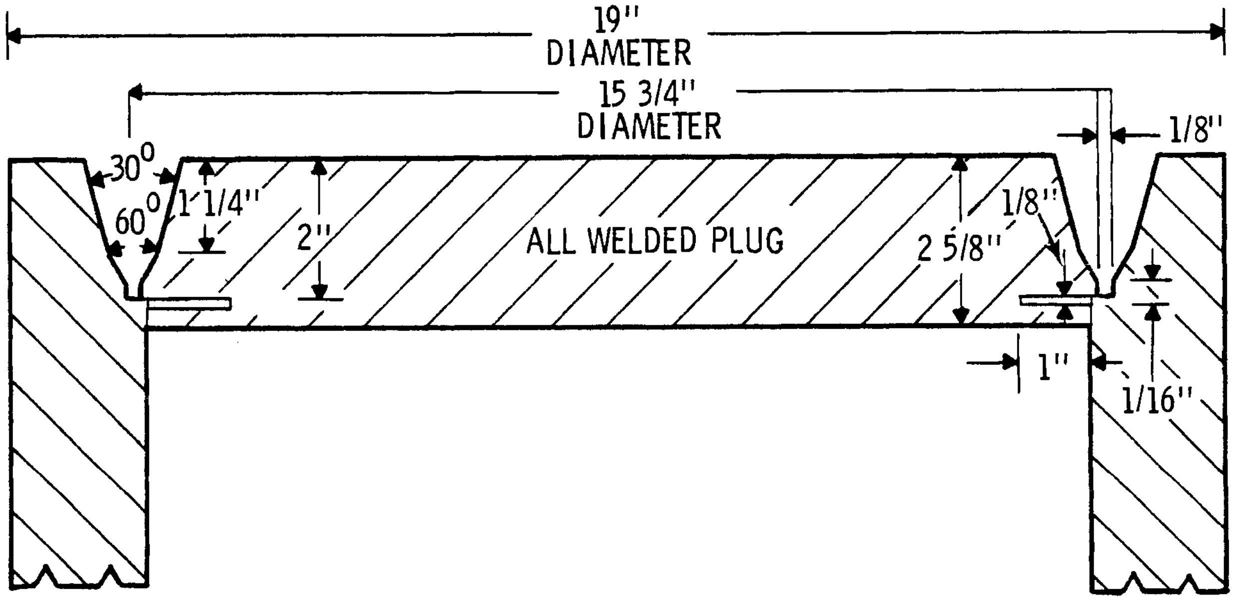


FIGURE 1. Full Penetration Weld for RSSF Cask

The ultrasonic examination of the butt joint, fillet, and seal closure welds was limited to laboratory contact testing at room ambient using a representative closure specimen. In addition to the laboratory testing of the 2-in. full penetration weld, Pacific Northwest Laboratory (PNL) was contracted to develop an ultrasonic inspection system capable of remote operation at temperatures between 400 and 500°F. This would be the anticipated cask temperature in air if the cask were filled with high-level radioactive waste. To accomplish the ultrasonic inspection PNL fabricated special high-temperature transducers and a special mechanical fixture which positioned and coupled the transducers to the RSSF cask. Upon completion of the remote high-temperature inspection, the RSSF cask was drop tested and again inspected to evaluate closure integrity. Two drop tests were conducted by Rockwell Hanford Operations (Rockwell) with the 2-in. full penetration weld and the threaded plug with seal closure weld inspected after each drop. (One closure type was on each end of the cask.)

This report presents a discussion of the work effort for the development of the remote high-temperature ultrasonic inspection system. Areas of concern pertaining to this development effort were:

- reference specimen,
- ultrasonic test technique,
- high-temperature transducer fabrication,
- remote mechanical fixture,
- ultrasonic system operation, and
- ultrasonic data resulting from the testing program.

REFERENCE BLOCK PREPARATION

The calibration notches were made in a representative weld sample provided by Rockwell. A study was conducted to determine the most cost-effective means of producing representative machined notches. The notches fabricated by the use of slit saws, end mills, and electro-discharge machining (EDM) were very similar ultrasonically; however, the slit saw notches are considerably less expensive to machine.

A series of five representative slit saw notches were machined into the test specimen at the crown and the root of the weld. Figure 2 shows the location and orientation of the notches. The orientation of the machined notches was selected on the metallurgical basis that flaws and weld defects are likely to occur along the heat-affected zone (i.e., weld interface). As a result of cask closure geometry, the heat-affected zone is at an angular orientation of ±15° at the crown (referenced to a 0° weld centerline) and ±30° at the root of the weld. In addition to flaws occurring in the heat-affected transition zone, fracture mechanics analysis has shown that flaws of equal

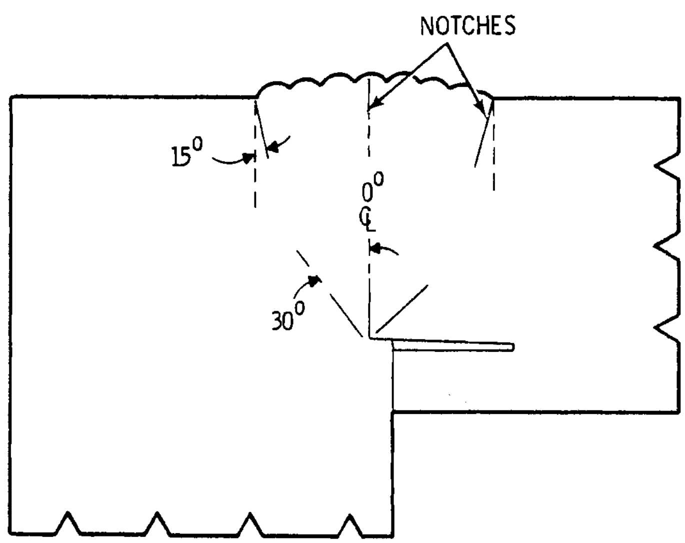


FIGURE 2. Location and Orientation of Slit Saw Notches in the Reference Weld Sample

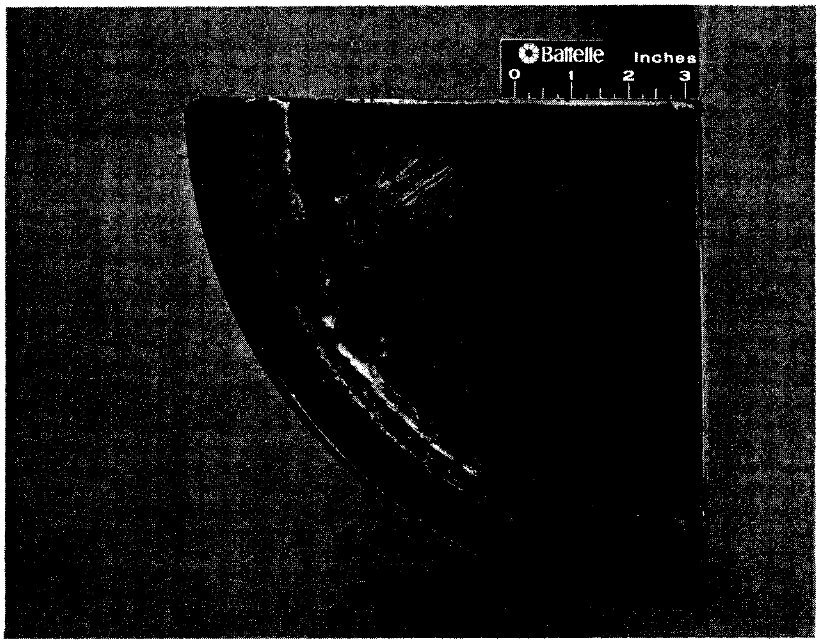
severity could result at the center of the weld crown and root areas. With the information derived from the fracture mechanics analysis, PNL constructed a representative reference block (Figure 3). The reference block contained slit saw notches at angle orientations of ±15° and ±30° at a depth of 0.3 in. at the crown and root of the weld, respectively. In addition, three machined notches, at depths of 0.1, 0.3 and 0.5 in. along the 0° centerline position, were added to the reference block to provide defect sizing information and a level of system sensitivity.

LABORATORY TESTING

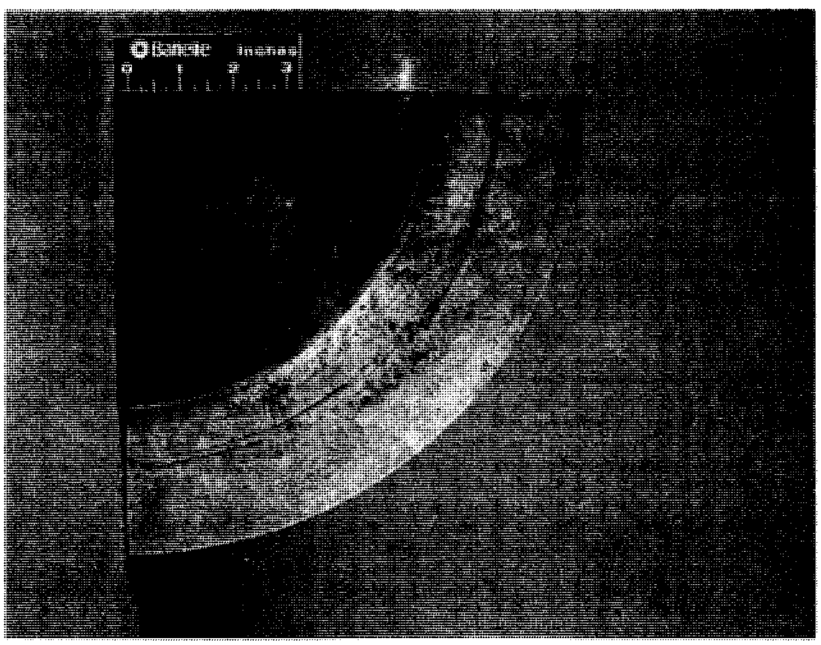
Using the developed reference block, tests were conducted to determine the optimum inspection technique for crown and root examination. Both longitudinal and shear mode techniques were investigated using 2.25 MHz and 5 MHz transducers of the sizes listed in Table 1. A Sperry 771 Reflectoscope with a 10N P/R was used as the ultrasonic pulser/receiver for the laboratory testing.

As a result of the laboratory testing program, an optimum inspection technique was established which requires a transducer positioned on the side of the cask and on top of the cover plate. The inspection of the weld crown is performed using a 0.5-in. diameter transducer, at 2.25 MHz, with a longitudinal wave propagating at an angle of 15° into the crown of the weld. This examination is accomplished with a transducer located on the side of the cask. The root inspection is achieved using a 0.25- by 1.0-in. transducer, at 2.25 MHz, with a shear wave propagating at an angle of 60° into the root of the weld. This examination is accomplished with a transducer located on top of the cover plate. The results of the longitudinal and shear tests on the reference block are presented in Figure 4.

Figure 4 shows a plot of the relative amplitude response versus notch depth. The amplitude response to 0.3-in. notches is 60% or greater regardless of angular orientation. For 0.5-in. notches a minimum reponse of 80% is



A. Crown Notches

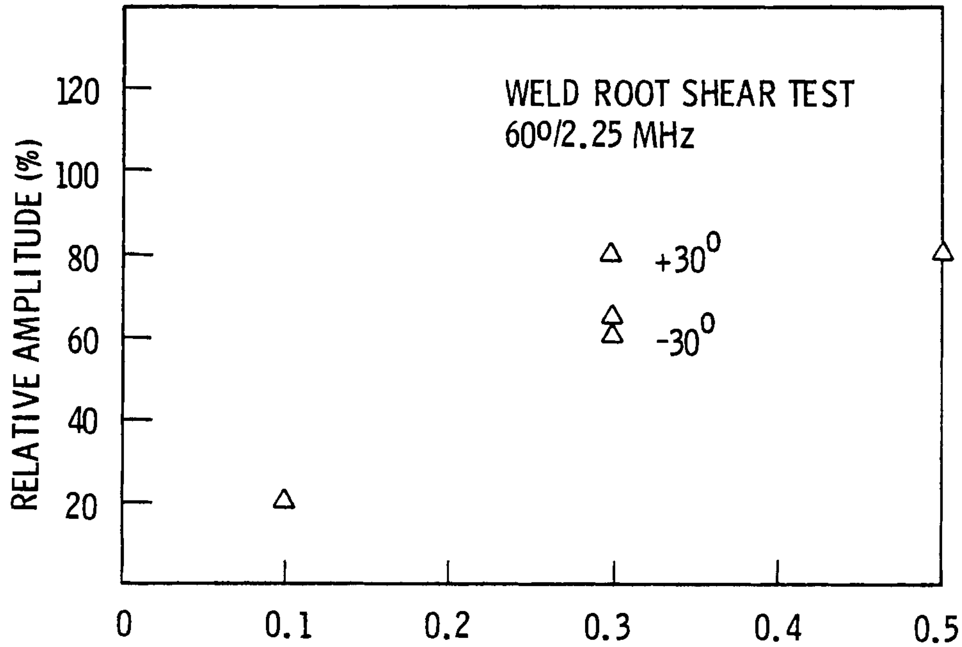


B. Root Notches

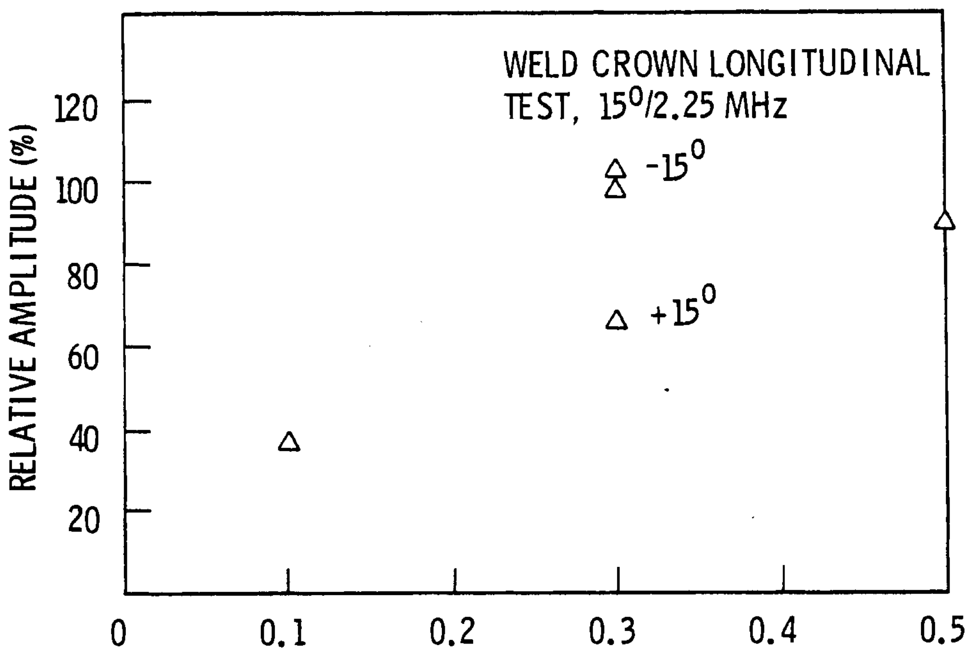
FIGURE 3. Ultrasonic Reference Block

TABLE 1. Size and Frequency of Piezoelectric Elements Investigated

	Propagation Angle	Size	Frequency	Wedge Material
Longitudinal Technique	43°	0.5 in. x 1.0 in.	2.25 MHz	Macor®
	45°	0.75 in. x 1.0 in.	2.25 MHz	plastic
	15°	0.25 in. x 1.0 in.	2.25 MHz	plastic
	15°	0.25 in. x 0.3125 in.	2.25 MHz	plastic
	15°	0.5-in. diameter	5.0 MHz	plastic
Shear Mode Technique	45°	0.75 in. x 1.0 in.	2.25 MHz	plastic and vespel
	45°	0.5-in. diameter	2.25 MHz	plastic
	35°	0.5-in. diameter	2.25 MHz	plastic
	23°	0.75 in. x 1.0 in.	2.25 MHz	plastic
	45°	0.25 in. x 1.0 in.	2.25 MHz	plastic
	35°	0.25 in. x 1.0 in.	2.25 MHz	plastic
	60°	0.5-in. diameter	2.25 MHz	plastic
	60°	0.25 in. x 1.0 in.	2.25 MHz	plastic



A. Weld Root Notch Depth (inches)



B. Weld Crown Notch Depth (inches)

FIGURE 4. Ultrasonic Response to Slit Saw Notch Depth for the 2-in. Full Penetration Weld

achievable. Notches in the range of 0.1 in. are detectable, and serve to evaluate test sensitivity. However, a 0.1-in. flaw has a very low probability of growth that might threaten the integrity of the cask. The data show a nonlinear response that assures a high degree of test confidence for detecting the larger flaws of interest.

TRANSDUCER DEVELOPMENT

High temperature transducers were designed to withstand thermal surface temperatures between 400 and 500°F. Special bonding agents were used to bond the piezoelectric elements to the selected wedge material. In addition, special transducer backing and damping material was used to achieve optimum transducer performance.

The transducer wedges were fabricated from high density graphite, Macor®[a] (a ceramic), and Aerotherm®.[b] The graphite exhibits the best high temperature performance with essentially no change in ultrasonic velocity up to 600°F. The high density graphite was selected as the primary wedge material for the demonstration test with backup transducer wedges constructed using Macor® and Aerotherm®.

MECHANICAL FIXTURE DEVELOPMENT

A mechanical fixture was developed which was used to position and hold the transducers as the waste cask rotated. The fixture was designed with the knowledge that horizontal, vertical, and angular positioning was available if the fixture could be attached to the weld head assembly system. A dovetail bracket was constructed to adapt the fixture to the weld head assembly. Figure 5 shows the mechanical fixture with associated transducers. Also shown in Figure 5 is the three-point rolling ball transducer support system, which adjusts for desired couplant layer thickness. In addition, spring loading was provided to pressure couple the transducers to the cask. Figure 6 shows the mechanical fixture positioned for inspection of the cask.

(a) Trademark of the Corning Glass Co.
(b) Trademark of the Aerotect Corporation.

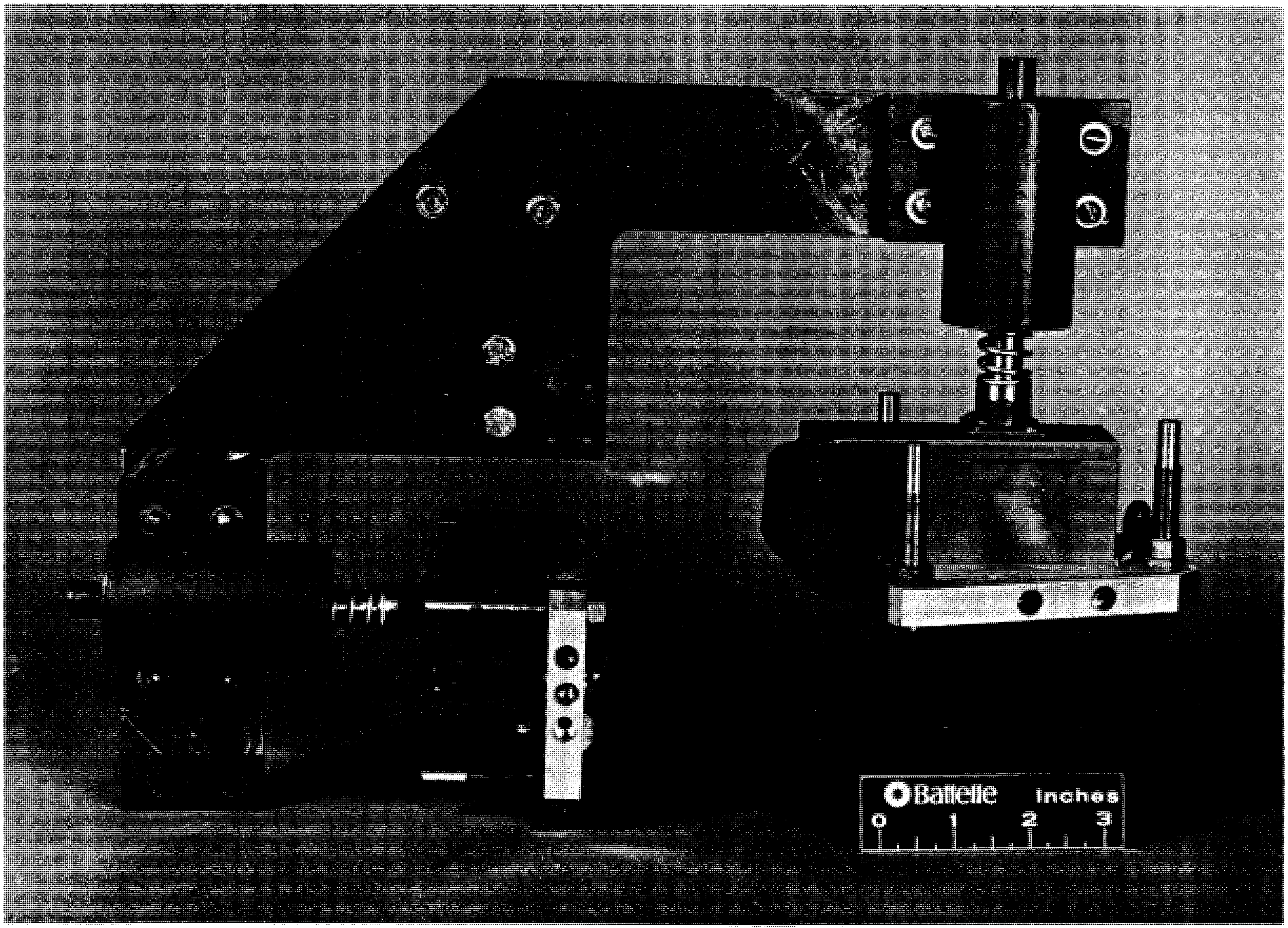


FIGURE 5. Mechanical Fixture with High Temperature Transducers

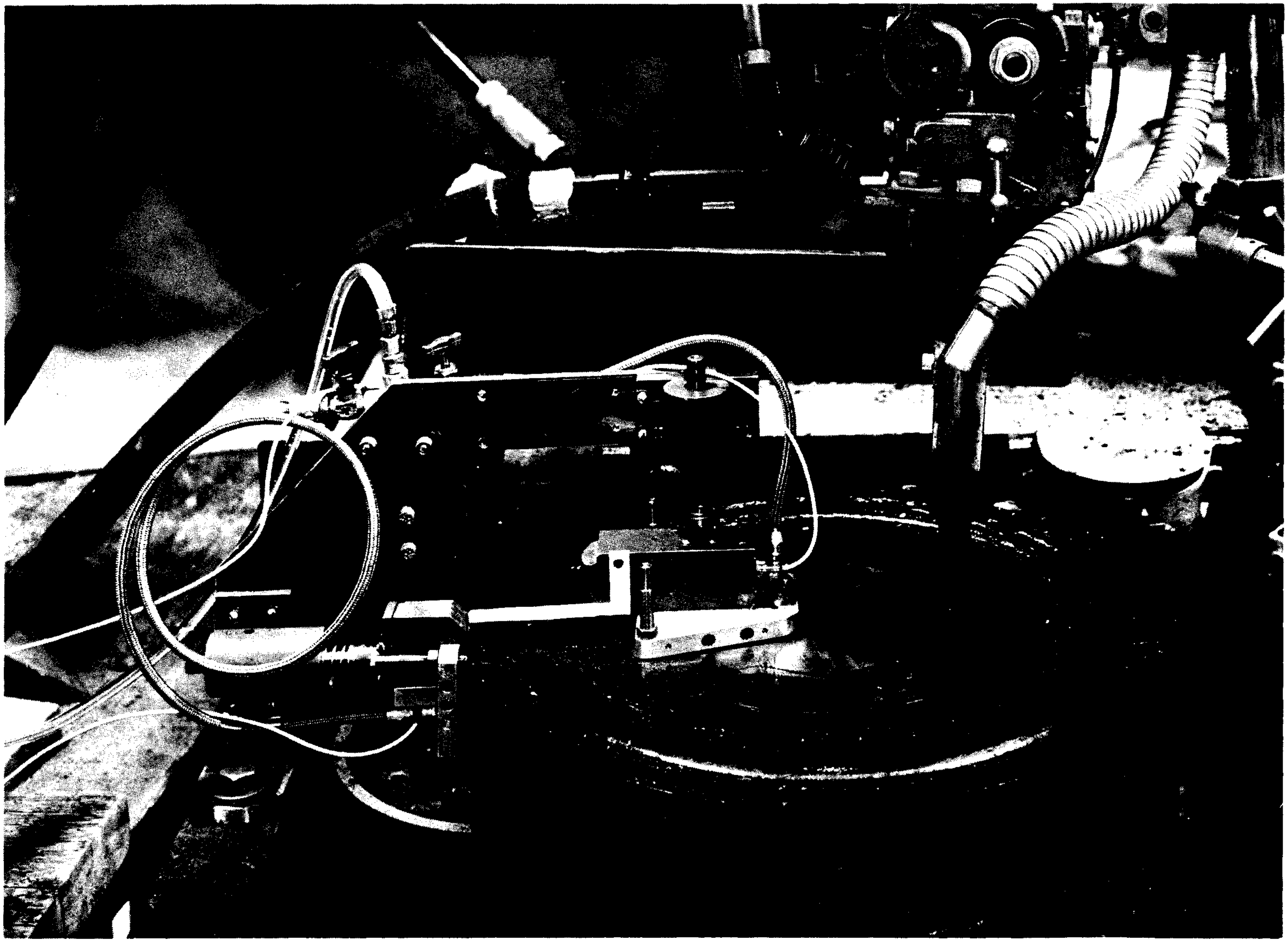


FIGURE 6. Mechanical Fixture Positioned for Inspection

ULTRASONIC TEST SYSTEM

Figure 7 shows a schematic representation of the demonstration ultrasonic test system for RSSF Cask inspection. The system consists of a Branson 303 ultrasonic pulser/receiver with a Hewlett-Packard two-channel strip chart recorder connected to the gated output of the Branson 303. A Tektronix 454 oscilloscope is connected to the Branson 303 for photographing specific ultrasonic reponse data. The two-channel chart recorder provided an on-line record of the ultrasonic response during the remote scanning operation. The second channel indicated the response from defects which were greater than the 50% accept/reject threshold. The air supply provided 30 psi of pressure to the high temperature ultrasonic couplant (Pyrogel®[a]) holding tank. During operation, appropriate valves are sequentially opened and couplant is fed to the transducers and uniformly spread about the cask surface. Figure 8 shows the mockup hot cell test facility with the ultrasonic test system.

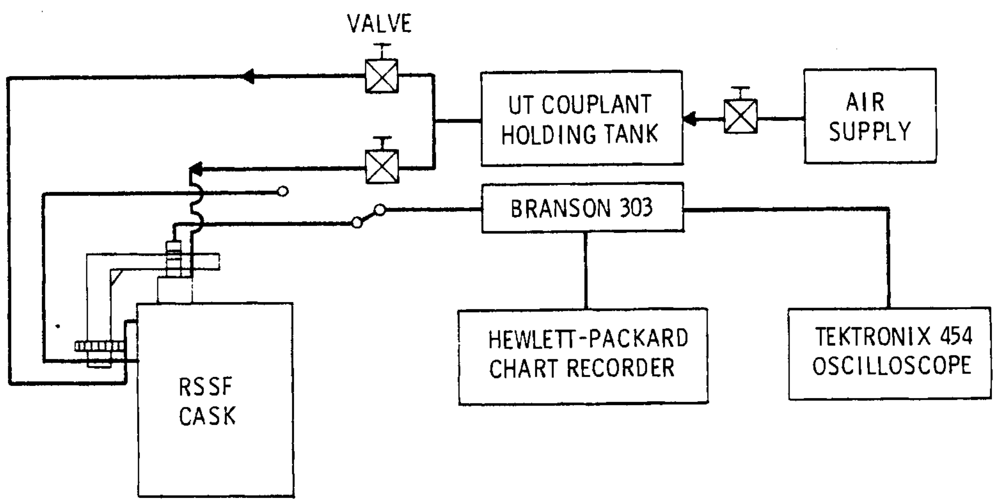


FIGURE 7. Block Diagram of the Demonstration System Used for the Ultrasonic Test

(a) Trademark of the Echo Laboratories.

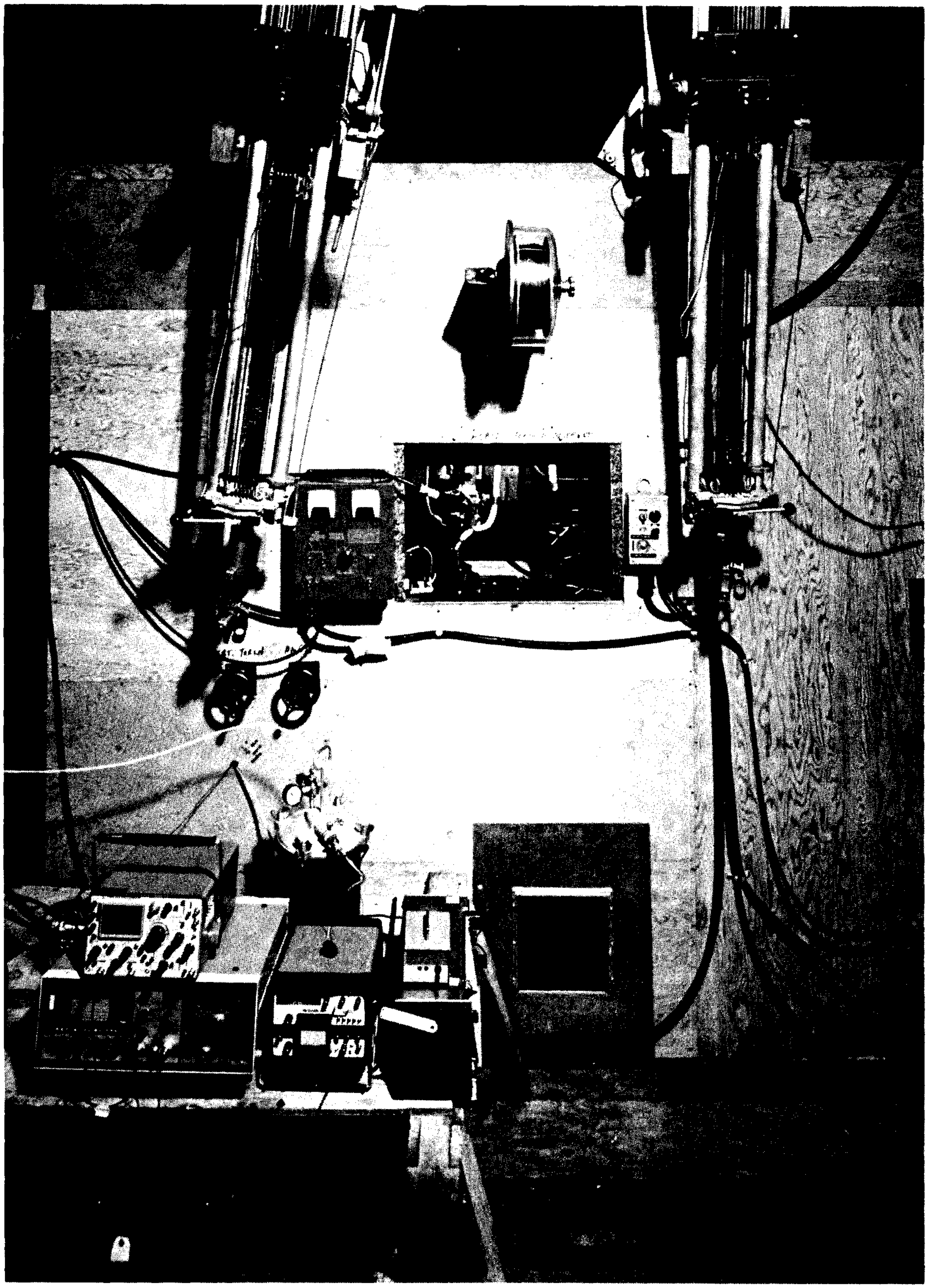


FIGURE 8. Demonstration Setup Showing the Ultrasonic Inspection System

SYSTEM EVALUATION

The major problem encountered in the program was the failure to obtain a sufficient bond between the lead metaniobate piezoelectric element and the selected wedge material. Silver conductive epoxy, rated at 500°F, was used for this bond. Previous work of similar application at Westinghouse Hanford demonstrated that the silver epoxy performed satisfactorily at temperatures between 400 and 500°F. However, in this particular application, significant loss of ultrasound occurred after short exposures to temperatures ranging from 200 to 450°F. Because of this signal loss, inspection of the cask weld at 400°F was not completed. A scan of the cask weld was successfully performed at a temperature of 200°F. Due to the time constraints of the program, laboratory testing of the transducers at temperature did not take place before the mockup demonstration. Recently, PNL has tested transducers using Stycast 2762 FT®,[a] a high-temperature epoxy. The tests have shown that the present transducers perform satisfactorily at 350°F during a 72-hr test period. With an additional design alteration, the transducer will be capable of long-term operation at 400°F.

Another key problem that surfaced during the demonstration phase was that the attempt to calibrate the system using a reference target resulted in a totally unsatisfactory referencing procedure. A dynamic reference system is needed. The ideal system would consist of a reference block, a turntable for rotation, and a heating system which enables dynamic target referencing at temperature. This suggestion is discussed further in the section on future recommendations.

Several features of the inspection system performed successfully. The three-point ball system to support the transducers did an excellent job for a prototype system. The pressurized ultrasonic couplant and feed system performed satisfactorily and should not require further development. The couplant spreading concept was effective, producing a good signal to noise ratio at operating temperatures. The spring loading of the transducers also

(a) Trademark of Emerson and Cuming, Inc.

performed well, although the fixture did have a tendency to twist counter-clockwise under pressure and thus cause the transducer on the surface of the cask to lift slightly. However, this was alleviated by reducing the spring load.

TEST RESULTS

The test results for the 2-in. full penetration weld, and the threaded plug and seal weld are presented in Figures 9 and 10, respectively. Figures 9 and 10 show the pre-drop and post-drop data with the impact area designated for each weld closure.

The 2-in. full penetration weld inspection results were produced using both the contact hand inspection and the remote inspection technique. The results obtained using the remote inspection technique with on-line strip chart recording were identical to the data produced with the contact tests. The post-drop results (from the full penetration closure), show that the cracks detected prior to the drop had apparently closed slightly as a result of the drop test.

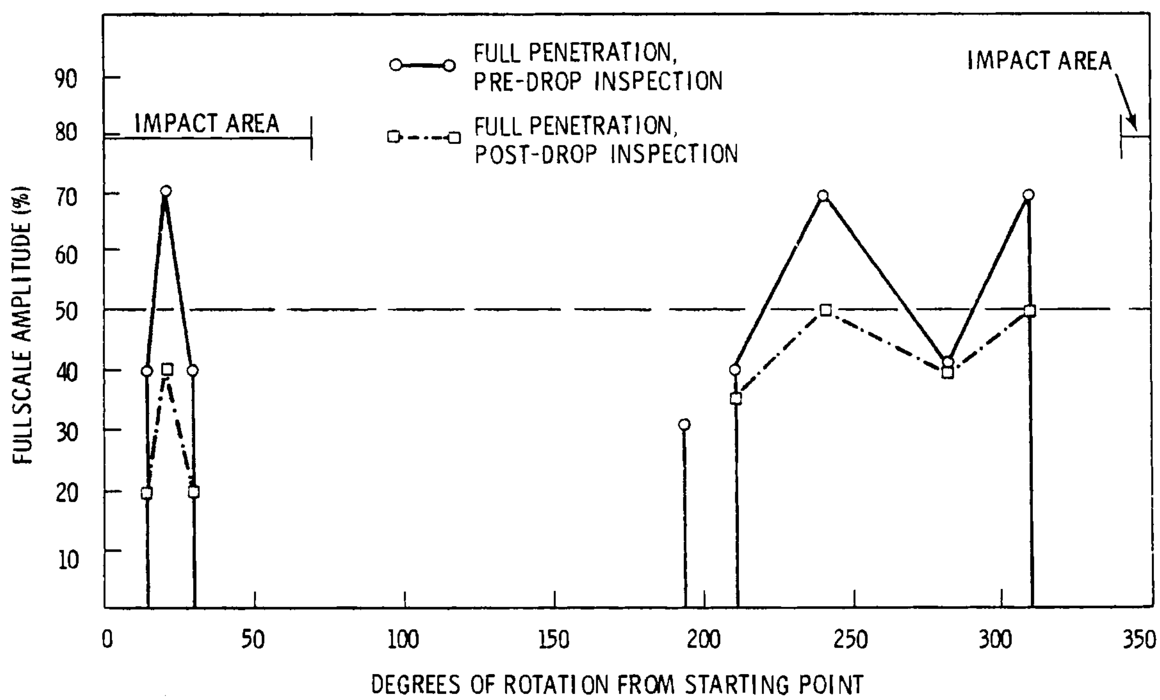


FIGURE 9. Ultrasonic Examination Results for the Full Penetration Weld

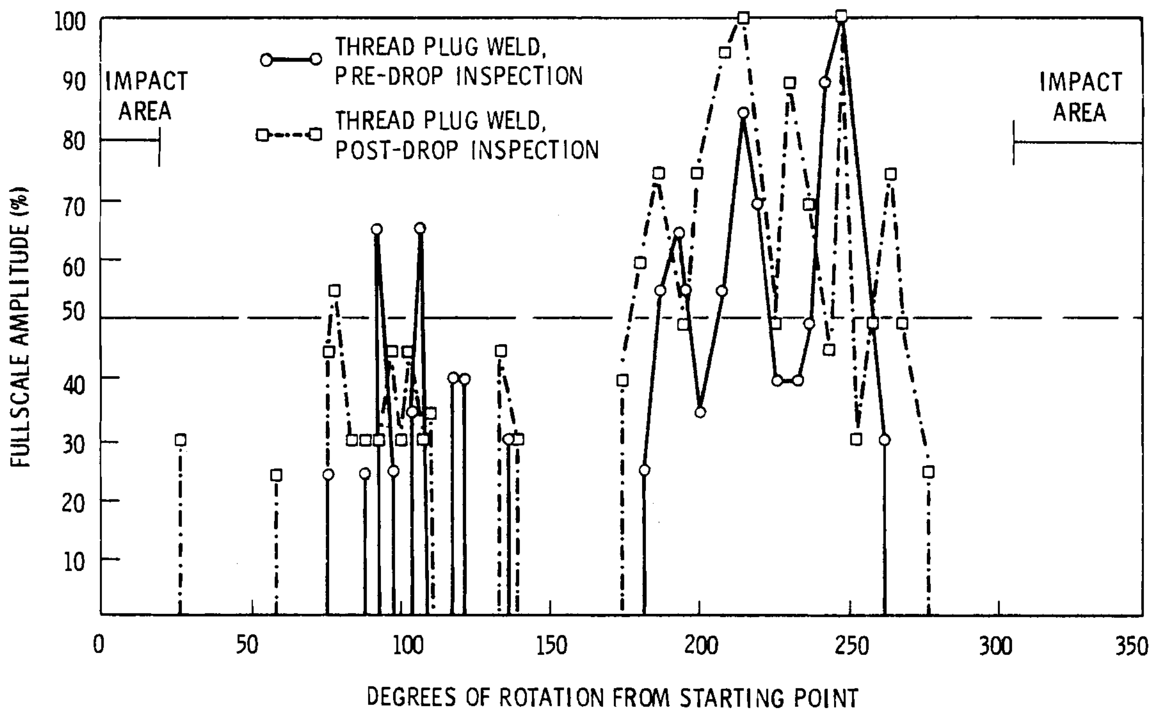


FIGURE 10. Ultrasonic Examination Results for the Threaded Plug Closure

The ultrasonic testing of the threaded plug and seal closure weld (shown in Figure 11) was carried out using a 60° shear propagation angle with a 0.5-in. diameter and 2.25-MHz transducer. The testing was performed using the hand contact inspection technique. The post-drop results of Figure 10 show that a slight crack growth produced an increase in amplitude response. However, the changes shown are minor and reflect, in part, variations in transducers used, couplant layer thickness, and operator dependence.

RECOMMENDATIONS FOR CONTINUED DEVELOPMENT

This program originated under the Atlantic Richfield Hanford Company RSSF Storage Cask Program. Since that time the program has shifted emphasis and is now being conducted by Rockwell. The RSSF program has been delayed and the new emphasis is on spent unreprocessed fuel (SURF) facilities. The SURF storage requires a container with performance criteria which are quite

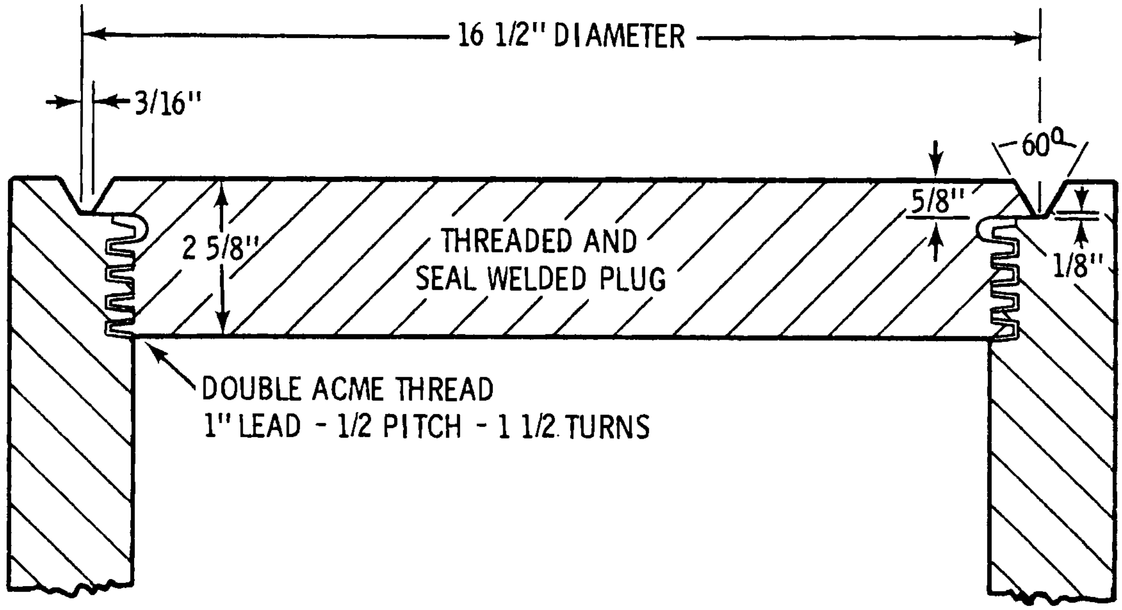


FIGURE 11. Threaded Plug with Seal Closure Weld for RSSF Cask

similar to the RSSF performance standards. As a result of the experience gained from the RSSF storage cask program, recommendations pertaining to the nondestructive engineering development for the SURF program are presented.

The anticipated licensing requirements have been the guide for assessing the different nondestructive examination (NDE) techniques. All NDE techniques were reviewed as to their applicability in performing the inspection. As a result of the review, radiography, ultrasonics, and helium leak testing showed the highest potential for success in inspecting the weld closure. However, radiography was ruled out because of the anticipated thermal environment and high background radiation encountered in the process cell and the weld designs. The only other known licensable alternative is a two-technique system consisting of helium leak testing and ultrasonic test inspection. The helium leak test indicates the level of gas-tightness of the weld and the ultrasonic test indicates the size, location and orientation of defects within the weld. These techniques complement one another and will detect all weld flaws of concern. For example, a worm hole through the weld would be found with the helium leak test and possibly missed with the ultrasonic test. However, any subsurface flaw would be missed by the helium leak test and located with the ultrasonic test.

The helium leak test has not been addressed in this study, but should be considered at an early date in future work. The problems of high temperature, high radiation doses, remote operation, and vacuum seals for the helium test should be incorporated with the philosophy of containment and processing. Other important considerations include weld-surface preparation requirements and total time to perform all NDE inspections. Decisions must also be made as to whether to have one containment barrier or two, and whether to include closure weld testing only or complete overpack examination as well as periodic in-service weld examination.

The recommendations that follow are designed to summarize the problem areas that exist and provide solutions that will insure a developed ultrasonic inspection system. The inspection system will proceed through three developmental stages: a) the determination of the feasibility of the inspection, b) laboratory development of the inspection technique, and c) mockup proof testing of the remote ultrasonic system.

PNL proposes that a three-phase program be established. The three phases of the development program are:

- Phase 1 - SURF cask inspectability
- Phase 2 - Development of ultrasonic test technique and test procedure
- Phase 3 - Development of an ultrasonic test system to demonstrate inspection capability.

SURF CASK INSPECTABILITY

The work in this phase is to define the inspection criteria and list all constraints, assess the applicability of the NDE methods, initiate some preliminary material testing, and make the requirements for NDE known to the weld closure designers to assure inspectability.

The following parameters must be established to guide the NDE design: a) maximum temperature of the cask surface during the NDE inspection, b) anticipated radiation dosage, c) cask configuration, d) closure technique, and e) time to perform all the NDE inspections (ultrasonic test and helium leak test) with a performance requirement for each NDE method.

Once the parameters have been established, then those anticipated materials proposed for the NDE development can be evaluated. For example, the ultrasonic bonding agent Stycast 2762 FT works well at high temperatures and is radiation resistant.[2] Will it continue to perform at high temperatures after accumulating significant radiation dosage? Laboratory tests can begin immediately to answer the material performance questions.

The work detailed in the next two phases is specified for ultrasonic inspection, although the development of any other NDE method would follow the same format.

DEVELOPMENT OF ULTRASONIC TEST TECHNIQUES AND PROCEDURES

The baseline data developed for Phase 1 is utilized as input for the laboratory development and testing of Phase 2. The Phase 2 work effort is divided into four tasks.

- A laboratory test standard representative of the closure weld will be developed to establish instrumentation sensitivity.
- The ultrasonic test techniques will be established.
- High-temperature and radiation-resistant transducers will be developed with sufficient performance data to predict lifetime in the anticipated SURF test environment.
- The performance capability of the test will be demonstrated.

Transducer unbonding arising from high temperature stresses was the major problem encountered in the RSSF program. Recent testing at PNL has demonstrated successful transducer performance at temperatures of 400°F for three hours.

DEVELOPMENT OF AN ULTRASONIC TEST SYSTEM TO DEMONSTRATE INSPECTION CAPABILITY

The Phase 3 effort would involve a laboratory mockup facility for system development and testing. A special mechanical fixture will be designed, constructed, and tested by PNL at this laboratory mockup facility. Upon completion of the mockup testing and debugging, a performance demonstration of the inspection system, at the designated SURF facility or demonstration SURF facility, will commence. The Phase 3 work effort is divided into four tasks.

- A laboratory mockup facility will be established for prototype-system testing and debugging.
- Mechanical fixtures will be developed (or the RSSF fixture will be modified) for cask inspection.
- The performance capability of the remote ultrasonic inspection system will be demonstrated using the laboratory mockup facility.
- Actual proof testing of the prototype ultrasonic system will be performed at the designated test facility.

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