WM’00 Conference, February 27 – March 2, 2000, Tucson, AZ

WASTE-PACKAGE FABRICATION AND CLOSURE-WELD DEVELOPMENT FOR THE YUCCA MOUNTAIN PROJECT

Jerry A. Cogar
CRWMS-M&O/Framatome Technologies

William J. DeCooman
CRWMS-M&O/Framatome Technologies

Mark C. Knapp
CRWMS-M&O/Framatome Technologies

ABSTRACT

Framatome Technologies (FTG), as part of the Civilian Radioactive Waste Management System Management & Operating Contractor for the Department of Energy’s proposed repository at Yucca Mountain, is developing and demonstrating fabrication and remote welding techniques for the waste packages. The waste packages are being designed to contain bare spent nuclear fuel assemblies, canistered fuel, and other high-level waste, including solidified material from waste processing and immobilized plutonium.

In GFY 1999, the design for the waste package was a double-walled, thermally enhanced right circular cylinder with the outside cylinder material being approximately 25.400-mm (1.00 inches)-thick Alloy 22, and the inner reinforcement cylinder 60.325-mm (2.38 inches)-thick 316 NG stainless steel. For this waste-package design with a relatively thick outer-shell material, narrow-groove welding using a hot-wire, gas tungsten-arc (NG-GTAW) process was developed. However this approach, while allowing the closure lids to be welded using a single-pass per layer, induced residual weld stresses. The current waste package design has a thinner outer layer, which presents new opportunities and challenges. Thinner materials lend themselves to a less stress-inducing, more efficient technique of plasma-arc welding (PAW) using a keyhole process. The PAW keyhole process is faster than NG-GTAW welding, leaves less residual stress, provides full penetration of the back side of the weld contour, completely fills the crevice between the weld materials eliminating the potential for later oxidation/contamination, and makes the weld easier to inspect. Unfortunately, PAW has been limited to a maximum arc length of approximately 9.525 mm (0.38 inches), and so cannot readily be used for welding either the 25.400-mm (1.00 inches)-thick Alloy 22 or the inner 316 NG stainless steel.

This paper describes the fabrication of the double-walled waste packages. The fabrication involves applying a combination of narrow-groove weld designs incorporating NG-GTAW and PAW processes that still allow the closure lids to be welded using a single-pass per layer. Remote surface and volumetric nondestructive examination techniques are also discussed, with particular attention to real-time processes that use electromagnetic acoustic transducers and laser ultrasound to assess weld integrity. This work will ultimately result in a more robust waste package that will withstand the anticipated environment in the repository for thousands of years.

INTRODUCTION

Developing the closure welds is part of a larger engineering development program to develop waste-package designs. The purpose of this larger development program is to develop nuclear waste package fabrication and closure methods that the Nuclear Regulatory Commission will find acceptable and will license for disposal of spent nuclear fuel (SNF), non-fuel components, and vitrified high-level waste within a monitored geologic repository (MGR).

The WP closure development includes several major tasks, which, in turn, are divided into subtasks. There are four major development tasks: WP fabrication, WP closure weld, non-destructive examination (NDE), and remote in-service inspection. This report presents the objectives, technical information, and work scope relating to the WP closure weld development and NDE tasks and subtasks and reports results of the closure weld and NDE development programs for government fiscal year 1999 (GFY-99).

The objective of the GFY-99 WP closure weld development task was to develop requirements for closure-weld surface and volumetric NDE performance demonstrations; investigate alternative NDE inspection techniques; and develop specifications for integrating the welding, NDE, and handling systems. In addition, objectives included fabricating several flat plate mock-ups that could be used for NDE development, stress-relief peening, corrosion and residual-stress testing.

WORK DESCRIPTION

NON-DESTRUCTIVE EXAMINATION

Surface and Volumetric NDE Performance

This task involved developing of a specification, *Performance-Based Ultrasonic Examination Requirements for Waste Package Closure Welds* (FTI 1999a), to assess the effectiveness of ultrasonic examinations of WP closure welds and provide requirements for qualifying ultrasonic testing (UT) equipment, procedures, and personnel to perform these examinations. The closure welds will require both surface and volumetric examinations for two reasons: the assure the integrity of the weld and verify that the welding process did not adversely affect the adjacent base metal. Over the past 10 years, NDE requirements for applications in commercial nuclear reactors have shifted from prescriptive fabrication-type standards to performance-based NDE. Performance-based NDE provides high confidence in the integrity of the welds examined because these techniques have been successfully demonstrated on flawed and non-flawed mock-ups representative of the flaws of concern and the components to be examined. With this approach, not only can the presence of a flaw be accurately detected (percentage) and its size be accurately measured, but also, the false-call (false-positive) rates can be assessed.

Design and Build Two Test Samples for NDE Process Evaluation

This task involved the fabrication of two mock-ups for assessing NDE methods applicable to the waste package closure welds. These mock-ups were constructed of the same materials and weld joint design used for the government fiscal year 1999 (GFY-99) welding project (Alloy 22 and titanium). The mock-ups contained welding flaws of known dimensions and included lack of fusion, porosities, and crater cracking. The target flaw size for this project is 5.000 mm (0.197 inches). The mock-ups contained flaws slightly above and below this size so that the NDE capability could be accurately assessed. Due to the late delivery of the mock-ups, a thorough ultrasonic examination could not be performed in time for the results to be included in this report. However, initial scanning using manual UT techniques indicated that all of the lack-of-fusion flaws can be easily detected in the titanium and Alloy 22 materials.

Alternate Surface Examination Techniques

This task investigated alternate surface examination techniques as a replacement for liquid-penetrant examination as a way to avoid generating hazardous waste. The alternate techniques included methods such as eddy current, thermal imaging, and magneto-optic imaging. The mock-ups used for this task were developed in the NDE Process Evaluation; however, due to the late delivery of these mock-ups, the tests could not be conducted in time for this report. This task can be performed during the GFY-00 development program.

Couplant-Free Ultrasonic Examination Techniques

This task evaluated alternative UT inspection techniques that do not require couplant. The alternative techniques evaluated included electro-magnetic acoustic transducers (EMAT), EMAT with phased array, laser excitation, laser excitation and reception, and thermal imaging.

EMAT induces eddy currents in the material in the presence of a strong magnetic field to induce ultrasound by means of the Lorenz force. In addition to the advantage of couplant free operation, the EMAT technology can generate propagation modes such as the horizontal shear mode not available with piezo-electric transducers. This technique is highly dependent on the conductivity and the ferromagnetic properties of the material and has been successfully used on aluminum, where the conductivity is high, or on ferritic steels, where moderate conductivity is found in conjunction with high ferromagnetism.

Austenitic steels, however, have lower conductivity typically 1% that of copper and near zero ferromagnetism. For some time, it had been assumed that EMAT techniques could not be used for these materials. However, recent research has shown that the phased array technology with multiple EMAT transducers can be used to achieve a usable signal. In this application, the phased pulsing of the transducers is used to enhance the signal above what could be achieved with a single transducer. With a usable signal strength, the horizontal shear propagation mode allows better penetration of the weld material.

Hybrid laser-EMAT systems use laser pulses to excite ultrasonic waves into material, with the returning signal detected by a standard EMAT transducer. As with the standard EMAT technology, the receiver will work best on highly conductive or ferromagnetic materials. Without the enhancement of either the horizontal shear propagation mode or the phased-array technology, the hybrid laser-EMAT system would not appear as applicable to the austenitic materials.

Laser emission-laser reception systems use the laser pulse to excite an ultrasonic signal in the material. The return signal is detected as surface vibration with a laser interferometer. The most significant advantage of this technique is its ability to follow complex geometries. Its primary limitation is that it only readily generates a normal (0-degree) pressure wave unless thin materials are being examined. Because of the lack of an angle beam mode, there may be limitations on the areas that can be reached for anything but extended open surfaces. Commercial systems are available.

The thermal wave imaging method maps the response of the material surface to fast thermal transients. The presence of flaws or other discontinuities at, or near, the surface cause changes in the thermal decay. These differences in thermal decay rates are used to form images of the discontinuity. The impulse for the thermal transient is often a laser pulse, but in the case of welding, the welding torch itself can be the source. The thermal wave technique has some sensitivity to near-subsurface flaws; its sensitivity decreases exponentially with depth, much as does eddy current testing. As such, this technique would appear to be excluded by the primary assumption that the selected techniques should provide volumetric examinations. However, if the welding torch is used as the source for the thermal transient, this method can be used as a real-time monitor of the welding process on each pass. This approach requires a closed-loop coupling between the welding and imaging system.

Two technologies, phased array-EMAT and laser-based ultrasonics, are mature enough technologies to warrant further evaluation, with primary emphasis on the EMAT technology. These techniques would be used in much the same manner as conventional UT in that the inspection would occur after the weld was complete. The other technique of interest is the thermal wave imaging. The greatest advantage for this technique would be for continuous inspection during the welding process. The primary question for this method is the ability of the proposed welding system to use such a closed-loop inspection system.

This task consisted of two phases. The first task included a scoping evaluation of the technologies including EMAT and laser-generated ultrasound. The results of the evaluation suggest that EMAT is the most promising couplant-free ultrasonic method. However, a direct comparison to conventional ultrasonic methods is required. Phase two would involve applying the most promising technologies to the mock-ups developed for the NDE Process Evaluation. This would provide a direct comparison to evaluate these technologies.

Phased-Array Ultrasonic Examination Techniques

This task was evaluated the effectiveness and efficiency of using phased-array ultrasonic examination techniques to assess the closure welds versus conventional ultrasonic examination. The mock-ups developed for the NDE Process Evaluation were used for this evaluation; however, due to the late arrival of the mock-ups, this was not completed in time for inclusion in this report. This task can be performed during the GFY-00 development program.

Specifications for Integrated Welding and NDE Manipulator

This task involved the preparation of a specification that outlines tool controller issues associated with automated and remote NDE applications. This document discusses the various types of control systems available and considerations for selecting various controller designs that are compatible with "low-noise" environments required for these NDE applications.

This specification deals with the interface between the tooling hardware design and the motion-control system. The intent is to summarize the tooling control options currently available to the tool designer. The general characteristics of the interface are as follows:

- The interface must provide controlled motion giving repeatable scan speeds and step increments. Manual control is not sufficient for data acquisition.
- The system must provide near real-time reporting of the scanner position as input to the welding and data-acquisition processes.

Diverse ranges of controllers are currently available and must be considered for the applications required for closure welding and NDE processes. Because of the various applications within the system, selecting one or two types of controllers is not practical. Each individual application must be evaluated for the type of controller best suited for that application. The tool designer must select a tooling control based on the needs and constraints of the application. The types of controllers currently available include stepper motors, analog demand, position integral derivative (PID) analog controllers, and PID with coordinated motion. Each type of controller has strengths and limitations.

The stepper-motor controller is attractive because it is the simplest tool to control and does not require any active control to hold a given position. However, actual implementation, the control problem is more complicated. Without the addition of separate passive encoders, open loop without feedback would exist. It is far too easy for the motor to lose a few steps on each motion, which results in significant errors during a multi-stroke raster scan. Other limitations are power and speed. High-power, stepper-motor controllers tend to generate significant electrical noise that is unacceptable during data acquisition. The speed is further limited due to the pulse nature of the motor steps. The controller has a limitation on the rate of sending steps, and the motor has a torque curve that decreases with increasing step rate.

Design Inputs

- Step resolution, must meet resolution needs of the scan increments

- Encoder resolution, should be equal to or better than step resolution
- Maximum current
- Maximum step rate

Signal Connections

- From controller to motor/encoders: multi-wire cabling
- From controller to operator's station: serial or local area network (LAN), either can be extended by fiber optics
- From controller to acquisition: sync pulse or encoder ouput

Controller Location

- Less than 500 ft from the scanner

Simple analog demand controllers use analog servomotor controllers. These controllers have much lower electrical noise for a given motor torque. Further, servomotors have a greater torque for a given package size. The result is that for a given application, the servomotor has greater torque and power than the stepper motor; however, the servomotor must be actively controlled. For the stepper motor, the acquisition system only needs to check the final position after a motion is requested, while for a servomotor, the position must be monitored during the motion. The simple analog demand controllers use simple and minimal electronics. The controller hardware itself has an open-loop, speed demand. The system uses the acquisition hardware to read the encoder and provides a coarse, closed-loop control on position. The controller hardware can synthesize an encoder signal from motor commutation. This controller cannot react to variations in mechanical resistance or load.

Changes in the inertia of the tool from one application to the next are also a problem. This controller cannot implement a PID loop because the controller uses the encoder information from the acquisition system. The rate of acquisition will not be high enough to support a PID control.

Design Inputs

- Encoder resolution
- Maximum current
- Maximum motor speed
- Minimum motor speed (stall speed based on torque curve and mechanical resistance)

Signal Connections

- From controller to scanner: cabling for motor power and encoder signals
- From controller to operator's station: serial that can be extended by fiber optics
- From controller to acquisition: encoder output

Controller Location

- Within 500 ft of the scanner

PID analog controllers provide truly closed-loop control of both speed and position. This enables the controller to handle a much wider range of conditions. This improved control comes at the cost of requiring real-time computer control of the motion. The controller must directly read the encoders and react to the changes in resistance, load, etc. This requires a larger, more complicated, more expensive computer. In addition, this tool requires a trained operator to establish and adjust the PID parameters.

Design Inputs
- Motor characteristics of torque and power
- Tool inertia
- Current limits
- Position sampling rates

Signal Connections
- From controller to scanner: cabling for motor power and encoder signals
- From controller to operaror's station: LAN
- From controller to acquisition: encoder output, LAN

Controller Location
- Within 500 ft of the scanner

PID controllers with coordinated motion are the closest to the ideal universal controller. It is highly adaptive to very general problems of scanning motion geometries. This adaptability comes at the cost of a tool with a high degree of complexity in design, implementation, and operation. This really should be the controller of last resort, to be used only when none of the above will work.

The design inputs for this style controller are really beyond the scope of this document.

The type of controller used for a particular application must be based on the design requirements of the application as well as the advantages and limitations of the controllers. As system requirements become better defined, these selection criteria will be evaluated on a case-by-case basis and the appropriate hardware employed for each application.

WELD SYSTEM DEVELOPMENT

This task involved the development of interface control specifications required for the Surface Facilities Operations/Waste Package Operations closure weld interface in the hot cell welding configuration. This specification describes the system components and their interactions as part of a system diagram. The specification, *System Diagram of the Yucca Mountain Waste Package Closure System* (FTI 1999b), identifies the system's main components and provides a road map for the integration of the system.

WELD TEST SPECIMENS

Peening Specimens

A study was used to evaluate the possibility of using laser peening to reduce surface tensile stresses in welded joints. Two Alloy 22 plates, each 25.4-mm (1.00 inches) thick, were welded with narrow-groove hot wire GTAW. These plates were fully restrained using strongbacks to prevent distortion in the joints. Preliminary results of the laser-shot peening demonstrate that compressive surface stresses can be imparted into the weld region to a depth of 5 to 7 mm (0.197 to 0.276 inches).

Welding of Corrosion and Residual Stress Coupons

The welding requirements for these coupons were not related to the type of coupon being welded. The type of coupon only specifies the type of test that will be performed after the completion of welding and NDE have been completed. Three processes were used to weld residual stress and corrosion coupons. The purpose of the coupons was to compare and contrast plasma arc welding with cold wire GTAW and hot wire GTAW. The welding procedures and joint designs were based on the process used for each coupon. Both types of coupons used the same procedure and joint designs for each individual process. All of the coupons were either a 22.225-mm (0.88 inches) full-penetration Alloy 22 weld or a 15.875-mm (0.63 inches) full-penetration titanium weld. The following figures show the joint design for the coupons; the following tables summarize of the welding parameters used for each process and material used.

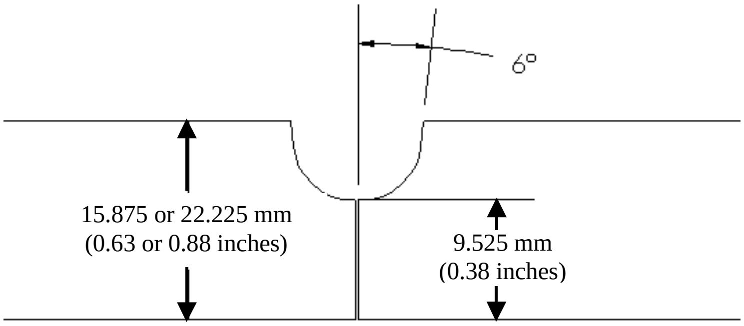

Figure 1. Plasma Arc Coupons

Figure 1 shows the basic weld geometry and dimensions used for the plasma arc coupons. Titanium plates, were 15.875-mm (0.63 inches) thick; the Alloy 22 plates, 22.225-mm (0.88 inches) thick.

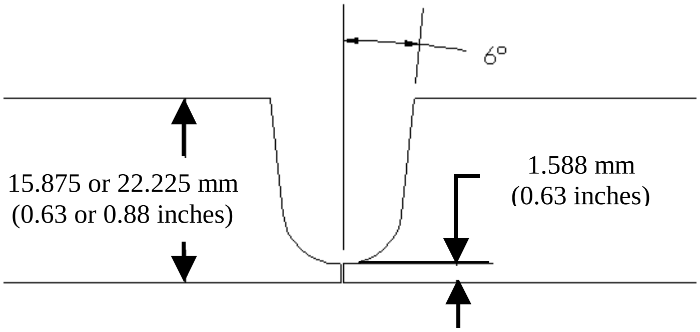

Figure 2. Hot Wire and Cold Wire GTAW Coupons

Figure 2 shows the basic weld geometry and dimensions used for the Hot Wire and Cold Wire GTAW coupons. Titanium plates were 15.875-mm (0.63 inches) thick; the Alloy 22 plates, 22.225-mm (0.88 inches) thick.

Table 1. Cold Wire GTAW Welding Parameters

Parameter	Alloy 22
Torch Amperage	275/175
Torch Voltage	11.5-12
Travel Speed (IPM)	4.0
Wire Feed Speed (IPM)	60-110/30-54
Shield Gas Flow (CFH)	50
Trailing Gas Flow (CFH)	50
Shielding Gas Composition	75% He / 25% Ar

IPM = inches per minute
CFH = cubic feet per hour

Table 2. Hot Wire GTAW Welding Parameters

Parameter	Alloy 22	Titanium
Torch Amperage	330-335	305-330
Torch Voltage	12.5-13.0	10.5-11.0
Travel Speed (IPM)	8	6.4-8
Wire Feed Speed (IPM)	160	120-160
Shield Gas Flow (CFH)	40	45
Trailing Gas Flow (CFH)	40	50
Shielding Gas	75% He / 25% Ar	99.9% Argon
Hot Wire Voltage	2-3	2-3
Hot Wire Amperage	55-65	55-65

Table 3. Plasma Arc Welding Parameters

Parameter	Titanium Keyhole	Titanium Melt-in
Torch Amperage	200/100	300/150
Torch Voltage	Locked at fixed distance	Locked at fixed distance
Travel Speed (IPM)	4.0	5.5
Wire Feed Speed (IPM)	N/A	60
Shield Gas Flow (CFH)	40	40
Shield Gas	Argon	Argon
Plasma Gas Flow (CFH)	6.5	0.5
Plasma Gas	50% Ar / 50% He	50% Ar / 50% He
Trailing Gas Flow (CFH)	30	30
Trailing Gas	Argon	Argon

The introduction of Alloy 22 and titanium materials and different welding processes from those used in previous year's development programs required new procedures. Two new procedures were developed to complete the titanium coupons: plasma arc welding and hot wire GTAW. A procedure to plasma arc weld Alloy 22 could not to be developed due to limitations of the process for welding thick joints.

Cold Wire GTAW

The cold wire GTAW process was used in the GFY-97 development program to weld a narrow-groove geometry. The welding of these coupons was relatively easy because procedures had already been developed. All Alloy 22 plates used for the coupons were restrained using strongbacks. These were thick plates welded to the back of the Alloy 22 plate with Alloy 22 welding rods.

Hot Wire GTAW

Hot wire GTAW applies electrical current to the filler metal to help melt in the wire, thus achieving higher wire feed rates than cold wire GTAW. The process was used in the GFY-98 development program and has been proven to produce excellent results on the welded samples. Alloy 22 coupons were successfully welded without difficulty using procedures developed in the GFY-98 program. However, challenges were encountered while completing the titanium welds.

The most significant difference between welding Alloy 22 and welding titanium is that titanium requires much better shielding to produce acceptable welds. Most of the welds produced had some level of surface contamination. It is very easy to see a lack of shielding in titanium weld by examining the color of the welded surface. A silver or gray color indicates the area was totally shielded from contamination. As the surface becomes contaminated, the metal will turn gold, then red and blue with increased contamination. These levels of surface contamination may be acceptable if they are brushed off between passes. The titanium weldments were not ultrasonically tested, but the welds with these levels of contamination did pass transverse bend tests and performed adequately on tensile tests. If the weld has a flaky white appearance, the contamination has probably affected more than the surface, and the weld is probably unacceptable. Trailing gas shielding boxes were used to weld titanium and adequately shielded the titanium weld.

The most common problem experienced was jamming of the filler metal wire. The titanium wire (ERTi-7) is very soft and malleable compared to the Alloy 22 wire. These wire characteristics caused a problem at high feed rates. The location where the wire contacted the molten weld pool was unpredictable because the wire would move from side to side as well as up and down. When the wire was fed into a solidified area, it caused the feeder to jam. This problem can be eliminated by redesigning the wire feeding system. Five slide on strongbacks were used to fully restrain the titanium coupons over the 812.80-mm (32.00 inches) long plates to prevent distortion. With proper shielding, titanium was readily welded with the process except for wire-feed problems.

Plasma Arc Welding

Plasma Arc Welding (PAW) is beneficial for the closure lid welding because it can produce faster welds with less distortion and reduced residual stresses. These benefits are accomplished by PAW's ability to fully penetrate 9.525 mm (0.38 inches) or greater root pass using a keyhole technique. The process uses a constricted orifice that produces a hotter, more concentrated arc. A narrow stream of plasma gas flows through the constricted orifice at a high velocity and punches a keyhole through the molten base metal. As the weld progresses, the molten metal solidifies behind the keyhole leaving a fully penetrated weld with an acceptable backside and root face bead.

Keyhole welds were made with Alloy 22 and titanium with a 9.525-mm (0.38 inches) penetration in a single pass. With additional development, 9.525-mm (0.38 inches) keyhole welds in these materials may be possible. Because of the low density of titanium it could be possible to produce 19.050-mm (0.75 inches) keyhole welds. Stainless steel is limited to a 9.525-mm (0.38 inches) keyhole. Several attempts were made to keyhole a 12.700-mm (0.50 inches) section, but none were successful.

The Alloy 22 coupons were unable to be completed because the joint design required a minimum arc length of 14.288 mm (0.56 inches) for the keyhole pass. With this long arc gap, the process was very unstable and did not consistently produce a sound root pass. Using this long arc length on the second pass while feeding wire did not allow smooth flow of the wire in the joint and thus left holes and side wall lack of fusion. For this reason, the PAW Alloy 22 Corrosion and Residual Stress coupons were unable to be completed. A successful keyhole was welded from the backside of the joint. By welding on this side, a shorter arc length could be used. This work was for information purposes only; therefore, no procedure was written for it.

Titanium welding with PAW was successful, and procedures were developed to weld the coupon. The welding of the PAW titanium coupon was completed, but the plasma torch was experiencing problems while completing the keyhole pass. This probably left several indications in the full penetration weld. UT of this plate has not been completed at this time. This coupon was restrained with the same type of strongbacks used for the Hot Wire GTAW coupons. A purge chamber on the backside of the weld was added to the setup to completely shield the backside of the weld.

The plasma arc welding process in the keyhole mode is very sensitive to small changes in environment or parameters that can leave holes in the root pass of the weld. The arc sometimes becomes unstable due to an inconsistent flow of plasma gas or a change in airflow patterns in the work area. A very small orifice was used to qualify the procedure to weld the titanium. A larger orifice could help reduce the sensitivity of the arc in the keyhole mode.

The use of PAW on closure lid welding has potential; however, more development is required to determine if the process will be beneficial for this application. A narrow-groove torch needs to be designed to fully utilize PAW on thick sections. The current torch design limits it to welding 19.050 mm (0.75 inches) or thinner materials. The arc length becomes too long to successfully keyhole the root pass when used on thicker materials. A narrow-groove torch design will enable a 9.525-mm (0.38 inches) to 12.700-mm (0.50 inches) keyhole root pass and then several filler passes to complete a thicker joint. Because plasma has so many variables, fully developing a good procedure to weld with this process requires more time. The current Welding Procedure Specifications and Procedure Qualifications do not consistently produce acceptable welds. Fit-up criteria for keyhole welds will be necessary to specify fit-up tolerances in the system diagram. Upslope and downslope of the plasma gas also must be further developed. These parameters will leave a hole at the start and finish of the keyhole section if they are not set properly.

Ultrasonic Examination Results

As part of the GFY-99 development program, the Alloy 22 and titanium welded plate samples were ultrasonically examined for weld integrity. The plates examined are the Alloy 22, 25.400-mm (1.00 inches) plates and the titanium grade 7, 15.875-mm (0.63 inches) plates. Both the Alloy 22 and titanium plate samples were ultrasonically examined in the as-welded condition, i.e., full penetration welds with no grinding or machining of weld crowns or weld root.

Ultrasonic examination of the plate samples was performed in accordance with the *American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code,* Section III (ASME 1989a) and Section V, 1989 Edition (ASME 1989b). Each plate was ultrasonically examined using the Framatome designed "X/Y" scanner and data acquisition and analysis systems, Accusonex. The scanner was used for positioning the ultrasonic probe in a controlled manner relative to the weld axis. The scanner was attached to a stationary platform, and each plate was subsequently positioned adjacent to the scanner for performing the examination. The "X/Y" coordinates of the scanner were oriented parallel and perpendicular to the weld axis respectively. As the probe was scanned over the plate's surface, data was acquired at specified intervals. This data was subsequently filtered, digitized, and stored on optical media for storage and data analysis. After completion of data acquisition, the ultrasonic data was analyzed for weld defects, lack of fusion, porosity, etc. in accordance with the ASME Code, Sections III and V.

Currently, three Alloy 22 samples have been ultrasonically examined - two residual stress coupons and one corrosion coupon. Each plate was ultrasonically examined for indications oriented parallel, or near parallel, to the weld axis. This was accomplished by pointing the probe perpendicular to the weld axis. Three separate transducers were used for performing the examination, a 45° shear wave, a 60° shear wave, and a 70° longitudinal wave. The 45° and 60° angles each used single-element
2.25 MHz, 12.700-mm (0.5 inches) diameter, composite probes. The 70° angle used dual-element 7.620-mm x 15.240 (0.3 inches x 0.6 inches per element) 5 MHz probes. Each plate coupon was required to be examined in the as-welded condition. The weld crown on each coupon limited how closely the probe could get to the weld. To offset this limitation, the 45° probe was used in both the half-vee and full-vee configurations (half-vee travels from the top surface to the bottom surface, full-vee travels from the top surface to the bottom and back to the top surface). The half-vee technique examined the base, or root area of the weld, and the full-vee technique examined the upper portion of the weld by bouncing the ultrasound off the inside diameter surface. The 60° and 70° angles supplemented the 45° coverage with the 60° providing coverage from the root upwards and the 70° covering the upper part of the weld. Calibration of the ultrasonic system was performed using ASME Code calibration blocks, one for the Alloy 22 and one for the titanium material.

Table 4. Results of the Ultrasonic Examinations

Scan	**Corrosion Plate Coupon**	**Residual Stress Coupon #1**	**Residual Stress Coupon #2**
45RS.Y+	NRI	NRI	NRI
60RS.Y+	NRI	NRI	NRI
70RL.Y+	NRI	NRI	NRI
45RS.Y-	NRI	Indication adjacent to weld root	NRI
60RS.Y-	NRI	NRI	NRI
70RL.Y-	NRI	NRI	NRI

NRI = No Recordable Indications

The unacceptable indication located in the residual stress coupon #1 is a 54% distance amplitude correction (DAC) indication located adjacent to the root and measuring 81.28-mm (3.2 inches) in length. No through-wall measurement was taken since the amplitude was less than 100% DAC. By procedure this indication would be unacceptable if characterized as a crack, lack of fusion, or incomplete penetration. Most likely, being near the root the indication can be characterized as incomplete penetration.

CONCLUSIONS

The late start on the project and the long-lead time for the current materials did not permit all the work required by the Technical Guidelines Document to be accomplished in the depth required. These tasks will continue to be performed and reported in the GFY-00 closure document. Many assumptions were made to complete this year's system diagram. More development in welding and NDE is required to accurately complete the system diagram so assumptions will not have to be made. If the design of the PAW narrow-groove torch is successful in next year's workscope, PAW could be very beneficial to closure lid welding, saving time, and reducing residual stress.

Weld samples created in this year's program will allow a number of tests to be conducted by Lawrence Livermore National Laboratory and other organizations. These tests include magnesium chloride, residual stress, as well as corrosion and aging.

ACKNOWLEDGMENTS

This work was supported by the Yucca Mountain Site Characterization Office as part of the Civilian Radioactive Waste Management Program. This project is managed by the U.S. Department of Energy, Yucca Mountain Site Characterization Office. The technical work was funded under DOE Contract No. DE-AC08-91RW00134.

REFERENCES

Civilian Radioactive Waste Management System (CRWMS) Management and Operating Contractor (M&O) 1998. *Disposal Container Handling System Description Document.* BCB000000-01717-1705-00026 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980910.0676

CRWMS M&O 1999a. *Uncanistered Spent Nuclear Fuel Disposal Container System Description Document.* BBA000000-01717-1705-00004 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990608.0160

CRWMS M&O 1999b. *Classification of the Preliminary MGDS Repository Design.* B00000000-01717-0200-00134 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981103.0546

CRWMS M&O 1999c. QAP-2-0 Activity Evaluation *WP Engineering and Fabrication*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990330.0490

CRWMS M&O 1999d. *Waste Package Operations FY-99 Closure Weld Development Technical Guidelines Document.* BBA000000-01717-2500-00017 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990511.0239

FTI 1999a. Performance-Based Ultrasonic Examination Requirements for Waste Package Closure Welds. Lynchburg, Virginia: FTI. ACC: MOL.19990903.0111

FTI 1999b. System Diagram of the Yucca Mountain Waste Package Closure System. Lynchburg, Virginia: FTI. ACC: MOL.19990903.0112

Office of Civilian Radioactive Waste Management (OCRWM) 1998. *Quality Assurance Requirements and Description.* DOE/RW-0333P REV 08. Washington D.C.: U.S. Department of Energy (DOE). ACC: MOL.19980601.0022

OCRWM 1999a. *Monitored Geologic Repository Requirements Document*. YMP/CM-0025 REV 3. DCN01. Las Vegas, Nevada: DOE. ACC: MOL.19990429.0228

OCRWM 1999b. *Supplier Evaluation Report.* Framatome Technologies Inc. Dated 6/21/99. Las Vegas, Nevada: DOE. ACC: MOL.19990712.0089

CODES, STANDARDS, REGULATIONS, AND PROCEDURES

ASME 1989a. *ASME Boiler and Pressure Vessel Code.* Section III, Rules for Construction of Nuclear Power Plant Components. Division 1 – Subsection NB. New York, New York: ASME. TIC: 232801

ASME 1989b. *ASME Boiler and Pressure Vessel Code.* Section V, Nondestructive Examination New York, New York: ASME. TIC: 245342