PROCESSES, TECHNIQUES, AND SUCCESSES IN WELDING THE DRY SHIELDED CANISTERS OF THE TMI-2 REACTOR CORE DEBRIS

L.R. Zirker, R.A. Rankin, L.J. Ferrell
Idaho National Engineering and Environmental Laboratory
P.O. Box 1625, Idaho Falls, ID 83415

ABSTRACT

The Idaho National Engineering and Environmental Laboratory (INEEL) is operated by Bechtel-BWXT Idaho LLC (BBWI), which recently completed a very successful $100 million Three-Mile Island-2 (TMI-2) program for the Department of Energy (DOE). This complex and challenging program used an integrated multidisciplinary team approach that loaded, welded, and transported an unprecedented 27 dry shielded canisters (DSC) in seven-months, and did so ahead of schedule. The program moved over 340 canisters of TMI-2 core debris that had been in wet storage into a dry storage facility at the INEEL. The main thrust of this paper is relating the innovations, techniques, approaches, and lessons learned associated to welding of the DSCs . This paper shows the synergism of elements to meet program success and shares these lessons learned that will facilitate success with welding of dry shielded canisters in other DOE complex dry storage programs.

BACKGROUND AND DEFINITION OF TERMS

For years, Three-Mile Island-2 (TMI-2) reactor core debris had been held at the Idaho National Engineering and Environmental Laboratory (INEEL) in storage pools at the Test Area North (TAN) Hot Shop. In 1998, the DOE directed the operator at the INEEL to encapsulate all of this radioactive waste into dry storage by June 2001. A few attempts by the INEEL were made to purchase their own welding system to perform this encapsulation effort, but eventually a welding subcontractor, using their own semiautomatic rotary remote welding system, was selected to perform the DSC closure welds. The core of players involved with the welding of the DSC were an integral part of multidisciplinary team working the several aspects of the TMI-2 program in concert to achieve program success. After the waste was vacuum furnace dried, an unprecedented 27 dry shielded canisters (DSC), in seven-months, were loaded, welded, and transported ahead of schedule.

To aid in understanding, selected terms have been defined below.

- **Dry Shielded Canisters**: The dry shielded canister or DSC was fabricated from SA-517, grade 70 mild steel that was rolled into a 67-inch-diameter (170 cm), 168-inches-tall (426 cm) shell with a thick welded bottom plate and additional layers as a radiological shield. The shell has a 0.625-inch (1.6 cm) wall thickness; the radiological shield plug is 4.5-inch-thick (11.5 cm) laminated steel; and the top cover plate is 1.5-inches-thick (3.8 cm). The DSC shell was loaded with 12 debris canisters, seal welded, transported to the dry storage facility, and inserted into the storage vaults.
- **Gas Tungsten Arc Welding (GTAW)**: An arc welding process that coalesces metals by heating them with an arc between a tungsten (nonconsumable) electrode and the work (the metal). Shielding is obtained from an inert gas or gas mixture.
- **Governor's Agreement**: In 1995, the DOE, the state of Idaho and the U.S. Navy signed an historic settlement agreement. Part of the agreement was that the TMI-2 core debris stored in pools at INEEL had to be moved to dry storage by June 1, 2001 to await final disposal outside Idaho.

- **Idaho National Engineering and Environmental Laboratory**: The Idaho National Engineering and Environmental Laboratory (INEEL) is a multi-program National laboratory that supports the U. S. Department of Energy's (DOE) missions and business lines of environmental quality, energy resources, science and technology, and national security. INEEL's focus is to: Deliver science-based, engineered solutions to the challenges of DOE's missions areas, other federal agencies, and industrial clients; Complete environmental cleanup responsibly and cost-effectively using innovative science and engineering capabilities; Provide leadership and support to optimize the value of EM investments and strategic partnerships throughout the DOE complex, and to; Enhance scientific and technical talent, facilities, and equipment to best serve national and regional interests.
- **Semiautomatic Remote Rotary Welding System**: This rugged system was designed for remote work in a radioactive environment. Dual GTAW welding torch heads, mounted on a central rotary track, were controlled via cables that penetrated the hot shop shielding walls. Camera mounted on the torch heads aided a remote operator to run system and perform the welding.
- **TMI-2 Reactor**: TMI Unit 2 was located outside of Harrisburg, PA along the Susquehanna River. The reactor system was a Babcock and Wilcox 900-MWe PWR
- **TMI-2 Reactor Accident**: On March 28, 1979 at 4:00 AM, a minor malfunction occurred in the system that feeds water to the steam generators. This caused the core to eventually overheat to the point where over 90% of the reactor core was damaged. This event led eventually to the most serious commercial nuclear accident in U.S. history and fundamental changes in the way nuclear power plants were operated and regulated.
- **TMI-2 Debris**: After the reactor core of the TMI-2 reactor melted down, it was chopped up and sized to fit into the TMI defueling debris canisters. This included everything from floor sweepings to fuel rods to pieces of the melted morass.
- **TMI-2 Defueling Debris Canisters**: Also called debris canisters. These are 14-inch-diameter (35.6 cm), 145-inch-long (268 cm) stainless steel tubes with a welded bottom plate and a removable top head assembly to facilitate loading and unloading of the TMI-2 debris. These canisters were processed, after years of wet storage, with a vacuum drying operation prior to placing into the dry shield canister to ensure dryness in storage.
- **TMI-2 Independent Spent Fuel Storage Installation**: The TMI-2 Independent Spent Fuel Storage Installation or ISFSI is a Nuclear Regulatory Commission licensed facility at the INEEL. The ISFSI was designed, built, and licensed to store 29 DSCs of TMI-2 core debris in an aboveground dry storage configuration.

INTRODUCTION

The Idaho National Engineering and Environmental Laboratory (INEEL) operated by Bechtel-BWXT Idaho, LLC (BBWI) recently completed a very successful Three-Mile Island-2 (TMI-2) program for the Department of Energy (DOE). The following are noteworthy highlights of the project:

- Twenty-five dry shielded canisters (DSCs) were loaded, welded, transported, and placed into a dry storage facility over a seven months (eight-day average cycle time)
- About 3500 linear feet of weld was performed with no weld defects
- A 417% increase in productivity was achieved between the first and last welded DSCs
- A 99% efficiency or online productivity was achieved with the welding system

- The program was completed six weeks ahead of schedule, meeting the Governor's Agreement for moving all TMI-2 core debris into a dry storage facility by June 1, 2001.

Four physical or hardware systems of the TMI-2 program were worked in concert to achieve program success:

- The availability of the DSC transporter
- The remote radiological assay system
- The heated-vacuum drying systems
- The remote semiautomatic welding system.

All four were essential, and their roles were paramount in the overall program plan, as were the Test Area North (TAN) facility, crews, and equipment. But the main purpose of this paper is to describe and outline the many innovations, techniques, and approaches that were germane to the welding of the DSCs. This includes selecting a remote welding system and vendor operator/owner, ensuring readiness of the welding system, proofing the operating procedures using mockup coupons, and accomplishing the welding in a radioactive environment. Welded DSCs, or any nuclear waste container, are the primary barriers between the waste and the public or environment, and the public and stakeholders demand the absolute highest quality of welds.

INNOVATIONS, TECHNIQUES, AND APPROACHES

Many innovations, techniques, and approaches developed at the INEEL were relevant to the welding of DSCs. Noteworthy aspects included the following:

- A systems approach to managing the proposal and specification requirements was implemented to select the welding system, to conduct the welding system readiness assessments, and to ensure that design requirements were met.
- An innovative in situ cracking technique was developed to generate cracks on mockup assembly and workmanship sample welds, validating that the remote inspection systems could discern weld defect indications.
- A validation, or readiness assessment, of the welding system on a mockup DSC weld-out with complete destructive and nondestructive evaluation of the welds was performed prior to purchase of welding services.
- Dry-run procedure validation, performed during a mockup assembly weld-out, enhanced the operating procedure prior to start-up.
- Personnel earmarked to interface between the facility operators and the welding subcontractor crews were essential in meeting program success.
- A subcontract welding service was employed to perform the welding, furnish the welding system, and provide the system spare parts with a full-time service technician and most of the weld operators. See Figure 1 for a photograph of the welding system.

Systems Approach

The welding engineer of the TMI-2 program used a systems approach on several welding related tasks of this program. The systems approach was to use a simple tool developed and applied by system engineers to track requirement and requirement compliance. Essentially, the tool is a matrix—a requirements matrix. It is a chart that lists each individual requirement, after each of which a performance or compliance measure statement is written. The performance or compliance of each requirement must be verified. An example of the requirements matrix is included in appendix A.

When the initial automatic welding system was delivered to Idaho, it was discovered that the system was ill-conceived, dysfunctional, defective, untested, poorly designed, and did not meet design or system requirements. To avoid a repeat of this situation, we applied a systems approach (matrix template) several times during the program with great success to receive equipment that met the program requirements.

The significance of using a systems approach for requirements tracking stems from the following:

- Time was running out on developing a welding system from scratch and still meet the June 1 deadline.
- Because of the deadline, TMI-2 program engineers focused on identifying system requirements to ensure that the welding contractor knew the design and end-use requirements. The welding system had to be right the first time because time remaining was limited, and it needed to interface with other aspects of the program.
- This allowed the TMI-2 program to track the welding system requirements to ensure compliance. As a result, the second or selected welding system worked and was sufficiently robust for this remote welding application.
- The requirements matrix tool was shared with the welding system contractor to ensure they understood the requirements, knew what was expected of them, and knew what constituted compliance.
- This ensured that the readiness reviews and welding contractor equipment tests considered and met all of the design requirements.

The lessons learned regarding the system approach would be

- The systems approach ensured that the welding equipment met the design requirements, and as a result there were no surprises. It functioned as required, and the program was a success.

In Situ Cracking

Producing repeatable high-quality welds—barriers between the radioactive waste and the public—was critical to this welding effort. Next to the process of producing high-quality welding, ensuring that quality welds were produced was paramount. The nondestructive examination (NDE) process of choice was magnetic particle testing (MT), since the DSCs were fabricated from mild steel.

During the initial readiness review, a paradox occurred during the mockup welding and inspection system demonstrations. Since the welding was flawless, the semiautomatic remote MT system had no defects to find. The MT system was calibrated, as per the welding code with calibration blocks, but we did not know if the inspection system truly functioned in the DSC weld joint configuration or if the system could detect cracks within the various weld layers.

To validate the MT system during this mockup welding demonstration, we artificially generated in situ defects. Two-inch-long (5.1-cm) copper wire segments were placed into the weld groove joint and consumed into the weld metal during welding. This in situ crack generation technique proved very successful, providing physical defects for both the MT system and the managers/regulators to observe, thus validating the inspection system. See Figures 2 and 3. The event was published June 2001 in *Practical Failure Analysis,* an American Society of Metals International publication.

The in situ cracking technique was applied in another occasion during the TMI-2 program. Essentially, a remote inspection system was designed and built to inspect the purge-and-vent port welds after the DSCs were transported and placed in dry storage. The problem was that the inspection equipment operators needed to demonstrate that the fiber optics and monitors of the inspection system could discern a crack in the weld. The project welding engineer designed and built a portable workmanship sample coupon mimicking actual weld conditions (thickness, shape, and orientation), which included induced cracks in the weld of the coupon. Multiple cracks were generated by inserting a 1-inch-long (2.54-cm), 0.25-inch-wide (0.6-cm) strip of aluminum sheet metal into the weld joint and subsequently consuming it into the weld metal during welding.

The BBWI level III inspector confirmed detection of the crack using ASME BPVC, Sec V, Article 9, "Direct Visual Examination Methods." The coupon was satisfactory for demonstrating and qualifying equipment used for remote or indirect examination of DSC welds. The operators of the remote inspection system could readily ascertain the cracks, and both the equipment and the coupon functioned as designed. Benefits of this workmanship coupon include

- Training and qualifying inspection and operations personnel
- Simulation of actual conditions but performed in a nonradiation area
- Validation of the operating procedure (a dry run) prior to field inspection
- Verifying readiness of the system, the camera, and the digital image screens before mobilizing for a field inspection or after system maintenance
- Compliance with ASME procedure and equipment demonstration requirements: clear and repeatable.

These benefits were significant, considering the

- Cost of in-service inspections
- Cost of mobilizing crews
- Efforts to maintain radiation exposures as low as reasonably achievable
- Avoiding disassembly of the storage containment system of obtain access to the welds.

Although expensive to fabricate, the workmanship coupon has multiple end uses. A lessons learned regarding workmanship coupons would be

- Due to the unique and hazardous conditions germane to the nuclear industry, workmanship coupons can be fabricated to replicate unique configurations, to use for training and qualification of workers, to validate inspection systems or processes, and to enhance efficiency.

DSC Mockups

Use of full-scale mockups played an important role in the success of the TMI-2 program. The mockups were essentially identical to actual DSCs, except that they were only three feet tall, and the weld joint configurations were prepared on both ends of the shell to double the use of the mockup. They were indispensable during the readiness assessments of the welding system, the inspection equipment, and during the validation of the operating procedures.

Although the first remote welding system functioned during the computer diagnostic programs of the readiness assessment, the system failed to complete the first two weld passes over a 3-day period. The second and final welding system performed perfectly, producing welds in an actual production condition and demonstrating the required rigor.

The mockup welds were 207-inch-long (526-cm) circumferential single and double bevel welds. See Figure 4 for the joint detail. Each weld takes about sixty minutes to complete with a total weld-out time of seven to nine hours. The total weld metal deposited for each canister is about 30 pounds (13.6 kg). During the production welding a secondary weld head was attached to the rotary welding system, which essentially doubled the efficiency—cutting the welding time in half and ensured that the welding could continue if one system went down.

Lessons learned regarding full-scale mockup would include

- Full-scale mockups test and validate both the equipment and personnel to the fullest extent possible, thus ensuring the capabilities of both.
- The cost of full-scale mockups for equipment debugging and validation pales in comparison to costs involved fixing a welding system in a radioactive environment, repairing defective welds, or reclaiming nuclear waste from a substandard welded DSC.

Dry-run Procedure Validation

Use of full-scale mockups during validation of the operating procedure also played an important role in the success of the TMI-2 program. The work of this program was new and unique to the INEEL, since most previous work in the TAN Hot Shop had revolved around loading and unloading radioactive waste and fuel. This work involved a complex operating procedure that required the TAN Operations personnel to interface with non-INEEL personnel, to move sophisticated remote welding and inspections systems, and to lift DSC parts. The dry-run procedure validation accomplished multiple tasks:

- Red-line the initial procedure version to met actual working steps
- Refine the coordinating steps between the operations and non-INEEL personnel
- Develop the interfaces between the operation supervisors and welding subcontractor superintendent
- Train the operators and technicians on their tasks and duties.

A lessons learned regarding dry-run procedure validation would be

- On complex projects, dry-run procedure validation using full-scale mockups gives true validation of operating procedures, enhances training, and readily identifies the bottlenecks and problems often missed with table-top exercises.

Earmarked Personnel

Use of personnel earmarked to interface between the facility operators and the welding subcontractor crews also assisted in achieving program success. Heretofore, the facility operations and the operations supervisor conducted the radioactive waste and fuel handling operations in the hot shops themselves. With the complexity of this work and the multiple interfaces between the several program entities, it was essential that additional personnel be added to the work equation. The two essential personnel or positions were a job supervisor and subcontractor technical representative. The job supervisor was a mid-level supervisor and performed as a liaison between the operations crews, the shift supervisor, and the subcontractor technical representative. The subcontractor technical representative was an INEEL employee but acted as liaison between the job supervisor and the welding subcontractor crew/supervisor. These two worked flawlessly to solve problems as they arose, thus enhancing efficiency. The first two DSCs took 50-hours to complete, but as these two worked with the various crews and solved production problems, the last several DSC welds were completed in one shift, or less than 12 hours.

A lessons learned regarding earmarked personnel would be

- On complex projects using personnel earmarked to interface between operations, the subcontractors can enhance operational efficiency.

Subcontract Welding Service

There are always trade-offs between using in-house versus subcontract labor. In our case, the reasons for using a subcontract welding service out-weighed those for using our in-house welding crews. Although the initial costs may appear to be more costly, the hidden costs and constraints working with the DOE environment sways the decision. Benefits of using a subcontract welding service included their providing

- Their own proprietary semiautomatic remote rotary welding system (a GTAW process.)
- Redundant operating systems—one for hot cell work, the other for training and backup
- Crews with experience welding DSCs
- Crews that reported to work within six-hour notice
- A full-time onsite welding system electronic technician
- A full compliment of welding system spare parts.

At the end of the project, the downtime for the welding system was calculated and it had a 99% efficiency or online productivity. This efficiency enhanced productivity of the facility operations and made meeting the milestone possible. They also welded 3500 linear feet of weld with no weld defects. Prior to bringing in the subcontract welding service with their welding system, the first four INEEL DSCs were welded by manual welding process. With the manual welding the efficiency was about 50% caused by equipment failure and repairing of weld defects.

A lessons learned regarding subcontract welding services and equipment would be

- A subcontract welding service provided efficiencies greater that what the in-house welders could provide.

CONCLUSIONS

Many innovations, techniques, and approaches, germane to the welding of the DSCs were applied on the TMI-2 program. Highlights of the program included the following:

- Twenty-five dry shielded canisters (DSCs) were loaded, welded, transported, and placed into a dry storage facility over seven months (eight-day average cycle time)
- About 3500 linear feet of weld was performed with no weld defects
- A 417% increase in productivity was achieved between the first and last DSCs
- A 99% efficiency of online productivity was achieved with the welding system
- The program was completed six weeks ahead of schedule, meeting the Governors Agreement for moving all TMI-2 core debris into a dry storage facility by June 1, 2001.

The following elements of the program provided synergism and promoted success:

- Implementing a systems approach ensured that the proposal and specification requirements for the welding system were met
- Using an in situ cracking technique validated the remote inspection systems
- Using mockup DSCs validated and assessed the welding system prior to contracting of the welding services
- Validating the procedure by performing a dry-run using DSC mockups enhanced the operating procedure, training, and coordination prior to start-up
- Using personnel earmarked to interface between the facility operators and the welding subcontractor crews increased efficiency
- Hiring a subcontract welding service with their crews and equipment was more efficient and cost effective than using in-house personnel.

Applying these elements of the program and the lessons learned to any program involving DSC welding will assist in achieving success.

Fig. 1. Photograph of semiautomatic rotary remote welding system

Appendix A, A Sample Page from the Requirements Matrix

Legend of the Heading to the Requirements Matrix:

No.: This is the number assigned to each row and item in the chart.
Source: This states the source of the requirement.
Item: The item that which is to be to be provided, performed, and/or included with the welding system and service.
Performance: Measure This is the measurement on how performance to the requirement is achieved or reached.
Verification: Verification of compliance to the requirement is performed by the following: inspection, demonstration, or test.
Acceptance: If the item has be verified that it meets the requirement, then the tester will acknowledge acceptance by signing and dating. *LZ is Larry Zirker.*
Notes: Notes are any additional information that is helpful or needed. Notes in "italics" are made during the demonstration.

No.	**Source**	**Item:** to be provided, performed, and/or included	**Performance or Compliance Measure**	**Verification: Inspection, Demonstration or Test**	**Acceptance: Sign and Date**	**Notes**
1	Appendix D, Note	The actual welding of the DSC mock-up shall be performed remotely.	Observe if work was remotely performed.	Demonstration	*LZ, 5/24/00*	*Not truly "remote". Needs some tuning before remote.*
2	Appendix D, Note	The welding operator shall perform all of the welding operations without direct visual interaction with the DSC mock-up.	Observe if work was performed with visual interaction.	Inspection	*LZ, 5/24/00*	
3	Appendix D, Note	Once the remote welding unit has been installed and set up, except for the changing of electrodes and wire spools, all of the welding operations shall be accomplished from a remote location.	Observe if welding system needed tweaking during operation.	Demonstration	*LZ, 5/24/00*	*One time the wire guide had to be adjusted, but overall, no fine tuning was ever required.*
4	D-1.1	Set-up the welding system on the DSC/cask mock-ups, and make the necessary hose and cable connections.	Position and connect the welding system	Demonstration	*LZ, 5/24/00*	
5	D-1.2	Verify that the weld joint areas of the weld coupon and the DSC mockup are ready for welding.	Was the cleanliness and root gaps weld ready?	Inspection	*LZ, 5/24/00*	*No INEEL coupon was welded.*
6	D-2.1	Weld the root pass, in the 45-degree, single groove joint, on a 12-inch coupon.	Complete the weld with no workmanship defects.	Demonstration	*No INEEL coupon was welded.*	*This was performed prior to this.*
7	D-2.2	The subcontractor shall furnish the weld parameters.	Review the parameter sheets.	Inspection	*LZ, 5/24/00*	
8	D-2.3	Inspect root pass weld to the visual inspection criteria	Pass inspection	Inspection	*No INEEL coupon was welded*	*This was performed prior to this.*

Fig. 2. Copper wire in joint

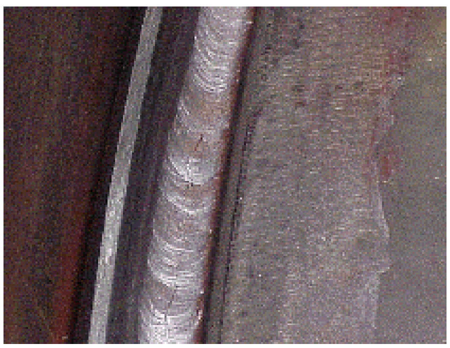
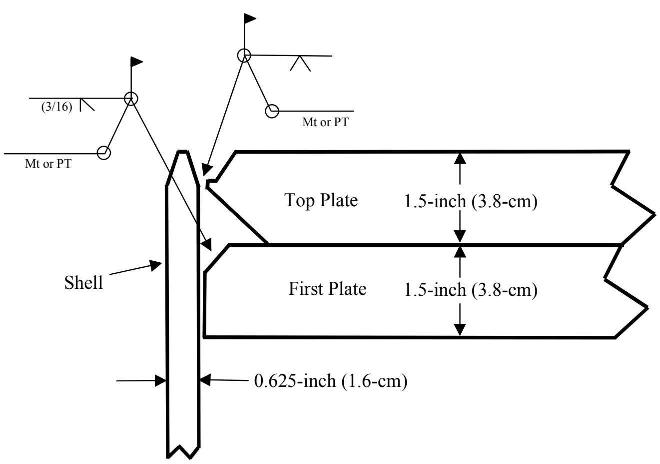


Fig. 3. Cracks in weld metal



NOTES:
- Drawing is not to scale.
- In the welding sequence, the First Plate is welded first and inspected.
- The Top Plate is set into place after the First Plate is inspected and then welded.

Fig. 4. Joint Detail