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Developing and Qualifying Parameters for Closure Welding Overpacks Containing Research Reactor Spent Nuclear Fuel at Hanford

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ABSTRACT

Fluor engineers developed a Gas Tungsten Arc Welding (GTAW) technique and parameters, demonstrated requisite weld quality, and successfully closure-welded packaged spent nuclear fuel (SNF) overpacks at the Hanford Site. This paper reviews weld development and qualification activities associated with the overpack closure-welding and provides a summary of the production campaign.

The primary requirement of the closure weld is to provide leaktight confinement of the packaged material against release to the environment during interim storage (40-year design term). Required weld quality, in this case, was established through up-front development and qualification, and then verification of parameter compliance during production welding. This approach was implemented to allow for a simpler overpack design and more efficient production operations than possible with approaches using routine post-weld testing and nondestructive examination (NDE).

A series of welding trials were conducted to establish the desired welding technique and parameters. Qualification of the process included statistical evaluation and American Society of Mechanical Engineers (ASME) Section IX testing. In addition, pull testing with a weighted mockup, and thermal calculation/physical testing to identify the maximum temperature the packaged contents would be subject to during welding, was performed.

Thirteen overpacks were successfully packaged and placed into interim storage. The closure-welding development activities (including pull testing and thermal analysis) provided the needed confidence that the packaged SNF overpacks could be safely handled and placed into interim storage, and remain leaktight for the duration of the storage term.

INTRODUCTION

Spent nuclear fuel (SNF), from the Oregon State University (OSU) TRIGA®[1] Reactor, was stored in thirteen 55-gallon drums at the Hanford Site's low-level burial grounds for 20 years. The fuel was retrieved from buried storage and packaged into new containers (overpacks) for interim storage at the Hanford 200 Area Interim Storage Area (ISA) in 2006. One of the key activities associated with this effort was final closure of the overpacks by welding.

Weld quality, for typical welded fabrication, is established through post-weld testing and nondestructive examination (NDE); however, in this case, use of an alternate approach was desired to simplify overpack design and streamline production operations. An alternate approach is to develop and qualify the welding process/parameters, demonstrate beforehand that they produce the desired weld quality, and then verify parameter compliance during production welding.

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[1] *TRIGA* (*T*raining, *R*esearch, *I*sotopes, *G*eneral *A*tomics) is registered trademark of General Atomics

Using this alternate approach, Fluor engineers developed and qualified a Gas Tungsten Arc Welding (GTAW) process for closure of the packaged SNF overpacks. The following reviews the weld development and qualification activities for this effort and provides a summary of the production campaign.

OVERPACK DESCRIPTION, REQUIREMENTS AND CRITERIA

The overpack is designed to provide confinement of the packaged materials against release to the environment during interim storage over a 40-year design life. The overpack materials of construction are: Head, SA-240, Type 304L; Shell, SA-312, Grade TP304L; and Miscellaneous pieces (lift lugs and positioning ring), Type 304L. The heads are designed to fit into each end of the shell, forming a step at the head/shell interface where they are joined by a fillet weld (Figure 1). The head-to-shell weld was made with the overpack in the fixed, vertical upright position creating a horizontal or 2F welding position.

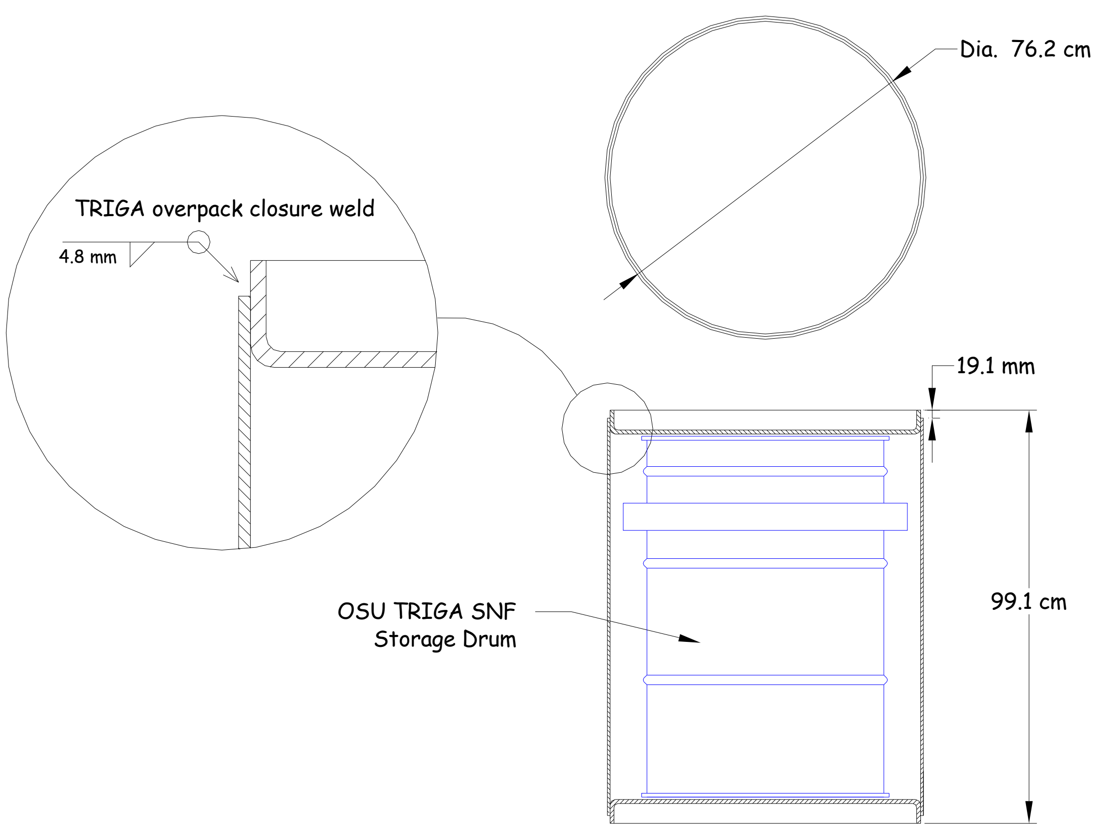


Fig. 1. Overpack sketch and closure weld joint design.

Qualification of the welding process, procedure and Welding Operators met the requirements of American Society of Mechanical Engineers (ASME) Section IX. In addition, storage facility criteria required the welded overpack to be leaktight per ANSI N14.5 ($\leq 1 \times 10^{-7}$ atm cc/sec air).

WELDING PROCESS, EQUIPMENT AND FIXTURING

The welding process, Gas Tungsten Arc Welding (GTAW), incorporated the machine-welding mode; i.e., equipment that performs the welding operation under constant observation and control of a welding operator. Welding equipment included a full-function, microprocessor controlled system (Gold Track V) manufactured by Liburdi Dimetrics®[2]. Welding was performed remote to the overpack with the aid of a video console and cameras at the weld head. A fixture designed and fabricated to support and align the weld head, with respect to the closure, was used during welding – See Figure 2.

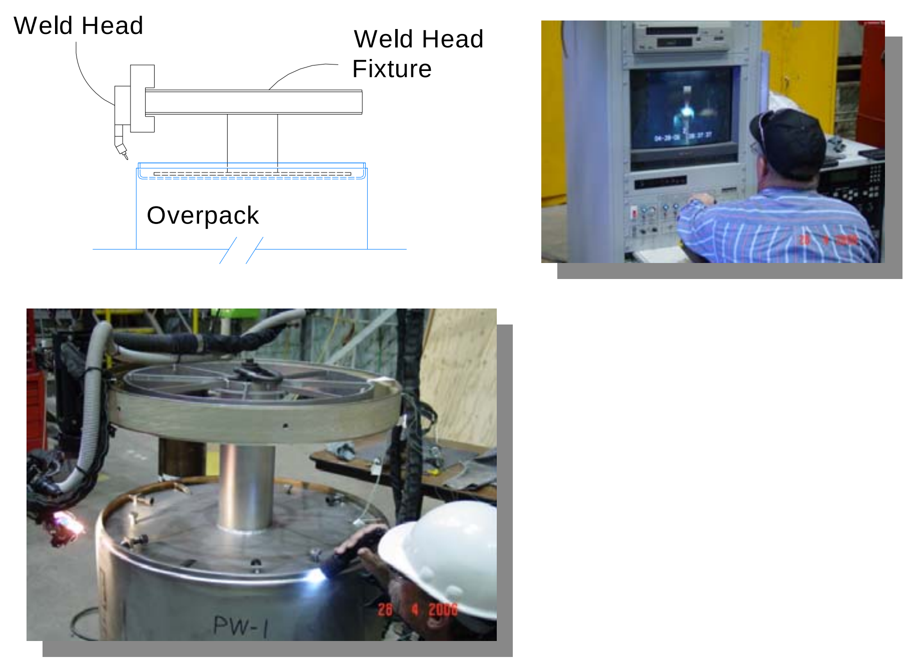


Fig. 2. Weld head fixture and Welder Video Console.

PROCESS TECHNIQUE AND PARAMETER DEVELOPMENT / QUALIFICATION

Initial Welding Trials

GTAW closure of the production overpack required a multi-pass weld to achieve the design weld size. Since the overriding quality criterion associated with the closure weld is leaktight integrity, development focus was directed at the first or root pass of the weld. It was important that this pass create the proper seal, penetrate into the root of the joint, and be of sound quality. Optimum fill-pass parameters were also

[2] Liburdi Dimetrics is a registered trademark of Liburdi Dimetrics Corporation

identified, but not investigated to the same extent as for the root pass. The following describes welding development associated with the root pass for the overpack closure.

Initial welding trials consisted of identifying a baseline set of parameters and then making a series of welds with iterative evaluation and parameter adjustment until the desired results were achieved – sound weld metal and complete fusion. These welds were made on flat plate test coupons representative of the overpack weld joint with regard to material type, thickness, weld joint design and welding position. In addition, welds were made on round sections simulating the actual overpack. Table I identifies the optimized set of welding parameters, referred to as the nominal or target parameters.

Table I. Initial Welding Parameter Development Nominal Welding Parameters

	WFS	PriV	PriA	PriW	BckV	BckA	BckW	IPM	J/I	Wire Dia	Freq	Torch Angle
Nom	30/20	10.0	240	40%	9.0	170	60%	3.60	28693	0.035	1.3	40

Note:

Nom = Nominal Welding Parameter
WFS = Wire Feed Speed (inches/minute)
PriV = Primary Voltage (volts)
PriA = Primary Amps (amps)
PriW = Primary Pulse Width (% of a single pulse cycle)
BckV = Background Voltage (volts)
BckA = Background Amps (amps)
BckW = Background Pulse Width (% of a single pulse cycle)
IPM = Inches Per Minute (travel speed)
J/I = Joules Per Inch (heat input)
Wire Dia = Filler Wire Diameter
Freq = Pulse Frequency (pulse cycles/second)
Torch Angle = Degrees Torch Tilted Up from Horizontal

Cells that are shaded are the Critical Parameters

One of the constraints considered during parameter development was weld-joint fitup, i.e., the potential for a gap at the shell / head interface. Per the design drawing, the gap could range from 0 to 2.4 mm (3/32-inch). To ensure the nominal parameters would accommodate fitup within this range, several test coupons were welded in which gaps varied from 0 to 4.0 mm (5/32-inch). It was determined that a 2.4 mm (3/32-inch) gap could be successfully welded (bridged) with these parameters.

Welding Process/Parameter Qualification

With the nominal parameters set and confidence that design weld-joint fitup (gaps) could be successfully welded, a simple statistical experiment was designed to evaluate bounding limits for two of the welding parameters – primary welding current and primary travel speed. These parameters were judged to be of primary importance in determining weld bead shape, puddle control and fusion at the root of the joint.

The purpose of the experiment was to identify a suitable range for the critical parameters in which variation within the range limits would produce the desired weld. Bounding values were set at the Welding Engineers discretion to bracket anticipated variability of the welding and measuring equipment and to accommodate potential upset conditions.

The experiment, a two-factor, two-level factorial with replication at the high and low limit values (See Table II), was first performed on round sections simulating the actual overpack, and then transferred to an actual production overpack for qualification. Table III lists the parameter settings for the test, identified as SW-1. The weld controller was programmed to create 8 equal-length weld segments, for the 76.2 mm (30-inch) test sample, in which the 8 parameter settings noted in the table were deposited. The completed weld was subjected to Visual Inspection (VT), Liquid Penetrant examination (PT), Helium Leak testing (LT) and metallographic evaluation (metallography). Table IV provides the test results and photomicrographs from three of the weld sections, representing the low, high, and nominal heat-input settings.

Table II. Basic Design of the 2-Factor, 2-Level Factorial

Current (Primary Pulse)	Travel Speed	Welding Heat Input
Low	High	Low
Nominal (target)	Nominal (target)	Nominal (target)
High	High	Intermediate
High	Low	High
Low	High	Low (replication)
Nominal (target)	Nominal (target)	Nominal (target)
Low	Low	Intermediate
High	Low	High (replication)

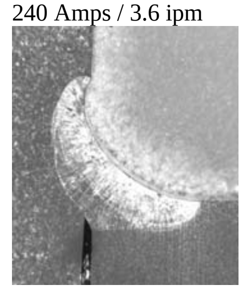
Table III. Welding Parameters for the Statistical Experiment (Root-Pass Weld)

Test ID	Seg-ment	WFS	PriV	PriA	PriW	BckV	BckA	BckW	IPM	J/I	Heat	Freq	Torch Angle
SW-1-1	LH	30/20	10.0	210	30%	9.0	155	N/A	4.00	23720	Low	1.3	40
SW-1-2	Nom	30/20	10.0	240	20%	9.0	170	N/A	3.60	28693	Nom	1.3	40
SW-1-3	HH	30/20	10.0	270	20%	9.0	185	N/A	4.00	28968	Int	1.3	40
SW-1-4	HL	30/20	10.0	270	15%	9.0	185	N/A	3.20	35309	High	1.3	40
SW-1-5	LH	30/20	10.0	210	30%	9.0	155	N/A	4.00	23720	Low	1.3	40
SW-1-6	Nom	30/20	10.0	240	20%	9.0	170	N/A	3.60	28693	Nom	1.3	40
SW-1-7	LL	30/20	10.0	210	20%	9.0	155	N/A	3.20	29730	Int	1.3	40
SW-1-8	HL	30/20	10.0	270	15%	9.0	185	N/A	3.20	35309	High	1.3	40

Note:

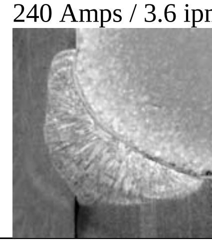
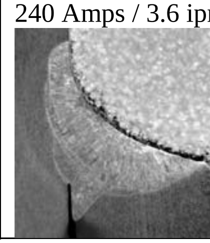
1. See Table 1 for Parameter Heading definitions
2. Cells that are shaded are the Critical Parameters

Table IV. Evaluation Results for the Statistical Experiment Weld – (SW-1)

Test ID	VT	PT	LT	Metallography		
SW-1-1 **SW-1-2** **SW-1-3** **SW-1-4** **SW-1-5** **SW-1-6** **SW-1-7** **SW-1-8**	Accept No Indications	Accept No Indications	Accept Leak Rate: $< 1x10^{-7}$ atm-cc/sec	Accept SW-1-1 (Low Heat) 210 Amps / 4 ipm 	Accept SW-1-4 (High Heat) 270 Amps / 3.2 ipm 	Accept SW-1-6 (Nom Heat) 240 Amps / 3.6 ipm 

With successful results from the experimental test, the nominal parameter values were designated as the production parameters. The production parameters were then applied to one additional production overpack in which the entire weld was made with these parameters. This weld (identified as PW-1) was subjected to the same evaluation testing as the experimental test – See Table V for results and photomicrographs.

Table V. Evaluation Results Production Test Weld – (PW-1)

Test ID	VT	PT	LT	Metallography	
PW-1 (90^0) **PW-1 (270^0)**	Accept No Indications	Accept No Indications	Accept Leak Rate: $< 1x10^{-7}$ atm-cc/sec	Accept PW-1 (90) 240 Amps / 3.6 ipm 	Accept PW-1 (270) 240 Amps / 3.6 ipm 

ADDITIONAL TESTING AND EVALUATION

Integrated Proof Testing

With successful evaluation of the final qualification weld, PW-1, and conformance to the ASME Section IX requirements, the production Welding Procedure Specification (WPS) was certified and issued. The production WPS was used to weld an overpack in which both heads were fitted with lifting lugs (in production, only the top head receives these lugs). This overpack was subjected to a pull test of 1.25 times the design lifting load [1,554 kg (3,425 lbs.)] – See Figure 3. The tested overpack was visually examined and liquid penetrant tested for damage and one of the head-to-shell welds was helium leak tested. Test criteria were met with no indications disclosed. In addition, no signs of physical damage were observed and the helium-tested, head-to-shell weld was found to be leaktight.

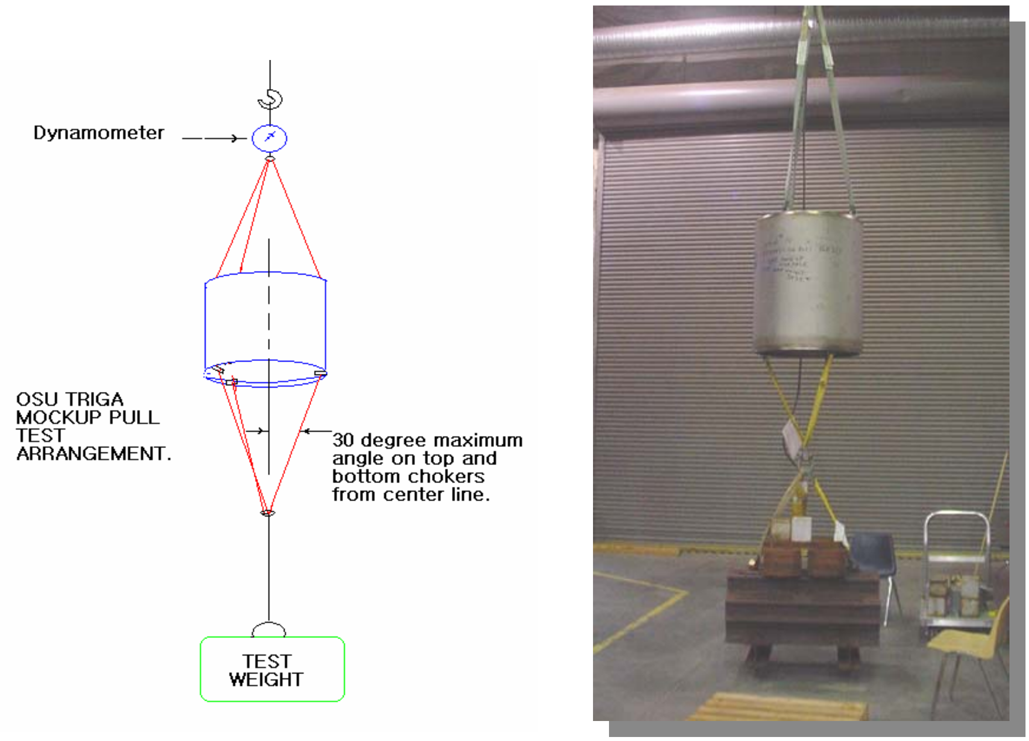


Fig. 3. Setup for pull testing.

Maximum Temperature of Packaged Contents Resulting from Closure Welding

To understand the impact the heat of closure welding may have on the overpack contents, a temperature calculation, using the computer code FLUENT^{TM}[3], was performed [1]. This calculation incorporated large margins and is considered conservative. The maximum calculated temperature the packaged contents will experience is 35.8^o C (96.4^o F) at the drum surface. This is based on an initial or ambient temperature of 26.8^o C (80.2^o F), creating a modest 9^o C (16.2^o F) temperature increase. The maximum calculated temperature the overpack will experience, at approximately 7.6 cm (3 inches) from the weld (on the shell), is 153^o C (307^o F).

[3] Fluent is a registered trademark of Fluent Incorporated

To confirm results of the model, thermocouples were attached to the overpack just prior to welding the final qualification mockup (PW-1) to measure actual maximum temperatures. Temperature values were recorded using a vendor-calibrated data logger; thermocouple attachment locations and results are shown in Figure 4. A comparison of the calculated value at 7.6 cm (3 inches) from the weld (on the shell) to the measured value at the same location, confirms the conservative nature of the calculation. That is, 153^{o} C (307^{o} F) and 80^{o} C (176^{o} F) for the calculated vs. the measured values, respectively.

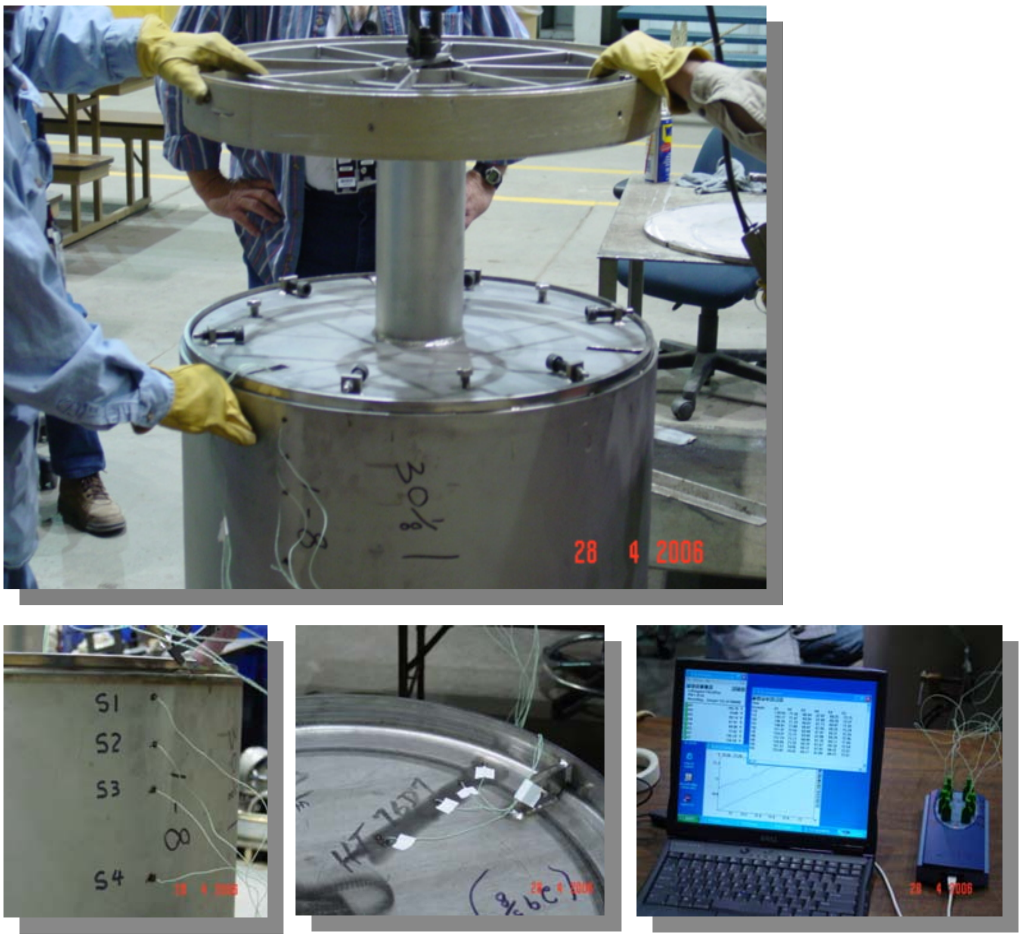


Fig. 4. Temperature measurement test setup.

DISCUSSION

In addition to the ASME Section IX certifications, the Welding Operators scheduled for production welding were those that performed the development work. This provided opportunity to become thoroughly familiar with the process and the specific technique developed. The “machine-welding” mode relies, to a degree, on the skill of the Welding Operator. The overall strategy for providing high confidence in the overpack closure welding includes both the development qualification activities reported herein and the skill of the qualified Welding Operators.

It is noted that the bottom head-to-shell weld is identical to that of the top or closure weld. This weld is made prior to placing the contents into the overpack, and technically could be examined/tested by typical post-weld activities. However, because of equivalency between the developed closure approach and what would otherwise be typical post-weld examination and testing, the bottom head-to-shell production welds were made using the developed closure process.

PRODUCTION CAMPAIGN

After completion of welding qualifications, the production campaign was successfully conducted. The campaign, which started in November 2006 and completed in December 2006, included receipt of the existing drums containing SNF in an on-site shipping system from the burial grounds, emplacement of the drums in the storage overpacks, welding the overpacks, and transfer of the welded overpacks to RadVaults in the 200 Area Interim Storage Area. The welding operation was performed in the Canister Storage Building, which is adjacent to the 200 Area Interim Storage Area, and utilized existing welding equipment from previous SNF container closure welding operations. Welding operations for individual overpacks were achievable within a work day, but the overall schedule was limited by receipt rate of TRIGA drums, due to weather conditions and competing site priorities for shipping resources. After welding, emplacement of the loaded overpacks into RadVaults for interim storage was completed using a lifting fixture designed to interface with the overpack lid – See Figure 5.

Fig. 5. Packaged overpack placement into the RadVaults.

CONCLUSION

Routine post-weld examination and testing was not performed on the packaged, TRIGA SNF overpacks discussed herein. Instead, Fluor engineers applied a GTAW process technique that was developed, qualified and demonstrated to provide high confidence that weld requirements would be met without the benefit of performing post-weld examination. Requirements specified in ASME Section IX, for procedure and performance qualification were met. Successful proof testing of a completed mockup was performed, establishing adequacy of both the overpack design and fabrication. In addition, the maximum temperature of the overpack contents, resulting from closure welding, was identified and determined to have no significant impact on the packaged materials.

ACKNOWLEDGMENTS

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ACKNOWLEDGMENTS

[1] M.G. Piepho, “Time-Dependent Temperatures of OSU TRIGA Overpack and Drum During the Welding of Overpack Head”, HNF-29769, Fluor Government Group, September 30, 2005