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WANL-TME-2780
May 1971

ORIFICE JET BRAZING PROCESS
DEVELOPMENT, QUALIFICATION,
AND INITIAL APPLICATION (U)

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Development, Qualification, and Initial Application" (U)

Gentlemen:

Enclosed are ten (10) CRD copies of the subject document.

Respectfully,

R. F. Dickson, Manager
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Enclosure: Ten (10) CRD copies of TME-2780

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ABSTRACT

Experiments were carried out to develop acceptable procedures for brazing molybdenum alloy orifices to fuel element channel inlets of the NERVA R-1 reactor core. Results achieved with various procedures are described, and qualification tests of the selected process are documented. The recommended procedure includes preplacing of Au-Ni-Cr alloy washers and induction heating to 1600°F, holding two minutes, heating further to 2400°F, holding one minute, and allowing to cool. Inert atmosphere is used, and fixturing maintains proper positioning of the orifices. Leak testing of the joints has demonstrated reproducibly satisfactory sealing. Repair brazing is feasible if needed.

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1.0 INTRODUCTION

Methods of brazing TZM molybdenum alloy orifices into graphite fuel elements were studied and developed to support the early NERVA reactor design. The successful development of a reliable brazing process forms the principal subject of this report. This method has also been successfully applied to the brazing of TZM molybdenum alloy orifices into fueled graphite and UC-ZrC composite fuel elements.

The basic problem in brazing metal components to graphite is one of mismatched coefficients of thermal expansion. Graphite expansion is typically 2.5 to 3.0 microinches/in/ $^{\circ}$ F. Metals commonly exhibit expansivities of 12 microinches/in/ $^{\circ}$ F. The difference in expansivities must be minimized by a proper choice of (a) the orifice metal, (b) the braze alloy, which must have a thermal expansivity compatible with the orifice metal and the fuel element, and (c) the design of the orifice, a factor which is coupled with selection of the particular surfaces of the orifices which must be brazed. In these respects, the problem is treated as one involving a total orifice brazing system.

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2.0 PURPOSE OF PROGRAM AND PROGRAM REQUIREMENTS

The purpose of this program was to develop a brazing process and orifice jet configurations that will consistently make acceptable braze joints between TZM molybdenum alloy orifices and R-1 type AXM and/or AXF graphite fuel elements⁽¹⁾.

Several program requirements have been separately stated⁽¹⁾:

1) The braze process which is developed shall be applicable to both regular orifice jets* and threaded orifice jets*;

2) The braze process shall be adaptable to the production brazing requirements of the R-1 program;

3) Uncoated, unfueled elements are to be used for the braze development. Fueled elements are to be used to corroborate braze techniques and the data developed using unfueled elements;

4) Final qualification testing of the brazed joint shall be accomplished using only uncoated, unfueled elements*. The original work statement also required qualification of coated elements. This requirement was changed to reflect current R-1 fuel design⁽²⁾. Four elements are required for qualification testing, each element containing a full complement of 18 regular orifice jets and one threaded orifice⁽³⁾.

5) Each process qualification element shall be tested in the following sequence:

- (a) leak check
- (b) thermal cycle (60 cycles)
- (c) leak check
- (d) metallographic examination

6) A thermal cycle for process qualification shall consist in lowering the specimen temperature from room temperature to LN₂** , raising the specimen temperature from LN₂ to room temperature, then to 1000°R (540°F), followed by gas cooling to room temperature⁽⁴⁾. The specimen shall be held at each of the designated temperature plateaus for a sufficient length of time to allow for temperature equilibration.

* See Appendix C.

** The temperature of liquid nitrogen at ambient pressure.

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3.0 MATERIALS AND EQUIPMENT

3.1 BRAZING ALLOY

The brazing alloy used in this program is known commercially by two trade names, CRONIRO and PREMABRAZE 128*, and its composition is 72 percent gold, 22 percent nickel and 6 percent chromium (all percentages are by weight, to a tolerance of $\pm 1/2$ percent). The melting range is 1787°F (solidus) to 1832°F (liquidus)⁽⁵⁾.

This alloy was selected primarily because it will wet the NbC (GEM process) coating used on the fuel element channel walls** and its chromium content tends to form carbides with any possible free carbon particles in the brazed joint, which could otherwise cause a leak.

3.2 TEST ELEMENTS

The graphite used in the early stages of the process development was AXF type, machined to WANL drawing 388D807.

The graphite elements used in the verification of the developed process and for the qualification specimens were AXF type, POCO grade, obtained to PDS-30046-C from WNCO under WANL work order 14459, and (machined to) WANL drawing 577F509⁽³⁾.

For the purpose of this report, the basic difference between the two groups of elements is in the diameter of the flow channels accommodating the standard orifices. For the final process, this difference was unimportant.

3.3 ORIFICES

Both types of orifices, the regular (WANL drawing 388D437) and the threaded (WANL drawing 388D439) were machined from arc melted, warm rolled and stress-relieved TZM molybdenum alloy (0.5% Ti, 0.1% Zr, bal. Mo.) procured to WANL Purchasing

* CRONIRO is the trade name used by the Western Gold and Platinum Co., Belmont, California. PREMABRAZE-128 is the designation of Handy and Harman Corporation, New York.

** Since the start of this program, the fuel element design was modified by the specification of channel counterboring at the orifice end, resulting in brazing of the orifice to uncoated channels.

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Department Specification 30012-1 Rev. B. TZM molybdenum was selected as the orifice material principally because the carbide-forming braze alloy requires a relatively high brazing temperature, at which only molybdenum, with a coefficient of expansion of 3.0×10^{-6} in/in/ $^{\circ}$ F, is sufficiently matched to the expansivity of graphite to avoid joint breakage upon cooling. The TZM alloy was selected over unalloyed molybdenum primarily because of its lower ductile-to-brittle transition temperature and greater toughness at low temperature⁽⁷⁾.

3.4 BRAZING EQUIPMENT

The brazing of test elements was accomplished by an induction heating process. The power source used in the development program was a Westinghouse Industrial RF Generator of 10 Kw capacity. In addition, a Lepel RF Generator, rated at 55 Kw, was used in the brazing of PEWEE-2 test elements at the Los Alamos Scientific Laboratory (LASL)⁽⁸⁾.

In addition to the RF generator, the equipment necessary to perform the brazing process includes an induction coil; vycor braze chamber for vacua and inert gas containment; braze chamber end closures, gasketing, and hold-down bolts; optical pyrometry; vacuum pump and vacuum measuring equipment; and specimen fixturing.

A typical brazing setup is shown in Figure 1. A sketch of the specimen fixturing is shown in Figure 2 and a list of specific equipment items is given in Table 1.

3.5 LEAK TESTING EQUIPMENT

Two leak testing systems were used. In the first, a system was designed to show only the presence or absence of a leak in individual brazed orifice joints. The equipment for this purpose consisted simply of bottled inert gas, supplied under 25 psig pressure through tygon tubing to a small brass nozzle designed for placement within the open end of the orificed channel under test; an O-ring for placement between the nozzle face and the end of the test element; and a soap solution for leak detection.

A second, quantitative system was used to measure leak rates in imperfect braze joints detected initially by the qualitative test.

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TABLE 1
EQUIPMENT LIST

1. Two RF Generators were needed in the process development:
Westinghouse Industrial RF Generator, 10 Kw, 450 Kc, WANL
Identification Tag S-5116

Westinghouse Induction Heater RF Generator, 10 Kw, 450 Kc,
WANL Identification Tag AL-443.
2. Therm-dot Radiometer
Model TD-6BT70, Serial No. 6417.
3. Welch Vacuum Pump, Model 1402.
4. Graphite Susceptor (see Text).
5. Full Length Element Braze Chamber Extension (see Text).
6. Induction Coil - 8 turns of 1/4" Copper Tubing, 3" Coil ID.
7. Vycor Braze Chamber - 2-7/8" OD, 3/32" Wall, 12" Long.
8. Thermal Cycling, Furnace - Hevi-Duty Type MU-2018, Serial No. 99203,
WANL Identification Tag AL-60360.
9. Thermal Cycling, Strip Chart Recorder, L&N Model CD-1-1201M, Serial No. 0084,
WANL Identification Tag NWE-100.
10. Leak Detector (specially built on-site).

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Figure 1. Braze Chamber in Operation

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Figure 2. Element Braze Susceptor

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4.0 PRIOR RESULTS

Initial work was directed to development of a process to braze Type 416 stainless steel orifices, using a Ag-Cu braze alloy, into element channels coated with NbC by the GED (G End Diffusion) method. Later, the GEM (G End Methane) process was substituted for the GED method as a means of coating the fuel element channels with NbC. For the purposes of this report, the basic differences between the two channel coating techniques are in the characteristics of the coating itself; the GEM method results in a rougher coating surface consisting of finer grains of NbC than the GED process.

It was found that the Ag-Cu braze alloy would not wet GEM-coated elements; therefore a search was made for alternate braze metals. Initial studies showed that a Au-Ni-Cr alloy (Croniro) would satisfactorily wet the GEM process coating, but the required brazing temperature was 300-400°F higher than for the Ag-Cu alloy. At these temperatures, the expansivity differences between 416 stainless steel and graphite are too great. To decrease the dissimilarity in coefficients of thermal expansion, molybdenum and TZM molybdenum alloy were selected for study, with the TZM alloy ultimately being selected as the reference orifice material, as discussed above (Sec. 3.3).

In the preliminary development, it was found that both molybdenum and TZM molybdenum alloy orifices could be brazed to GEM-process NbC coating. Brazing temperature and orifice-channel gap were identified as the most important process parameters.

All early work was restricted to the brazing of the standard orifices. Two general methods of preplacement of the brazing alloy were attempted: preformed spiral rings (Figure 3) and powdered metal bonded in an acrylic binder. In neither case was the process completely acceptable. The preformed rings had a tendency to gouge the channel walls and the powder bonded method was not amenable to foreseeable development as a production process. Results of this work have been previously reported⁽⁹⁾.

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Figure 3. Orifice as Redesigned for Spiral Preform in Early Phase of Development

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5.0 SUMMARY OF RECENT RESULTS

5.1 STANDARD ORIFICE JETS

Since the range of acceptable brazing temperature and braze joint gaps had previously been adequately specified, the bulk of the final phase of development was concerned with methods of preplacing the braze alloy and further fine tuning of the brazing process as needed to achieve the optimistic goal of consistently producing full complements (18) of leak-tight standard orifice joints.

Four methods of preplacement of the braze alloy were investigated: adhesive transfer tape containing the powdered braze alloy; split rings; wire coil preforms and preformed washers.

The transfer tape method was considered as a potential improvement over the previously attempted method using bulk powdered metal within a binder since the tape could be accurately placed on the desired area and the amount of material could be quickly adjusted by adding to or deleting from the length of tape already placed, thereby allowing for a study of the relationship between joint quality and weight of tape (or metal) introduced. Although the tape is cumbersome to handle and is not amenable to mass production needs, it was felt that the quantitative aspects of this method would yield results applicable to a more efficient, production oriented technique.

The transfer tape is composed of a layer containing the powdered brazing alloy (CRONIRO) and an acrylic binder, temporarily attached to a plastic carrier film by an adhesive. In use, the brazing material is transferred to the desired surface by removing the carrier film and activating the pressure-sensitive adhesive coating deposited on the braze metal layer by finger pressure. During the brazing operation, the organic materials in the adhesive and binder decompose and a uniform, dense brazing material is left on the surfaces to be joined. In the best practice, therefore, the transfer tape is applied directly to the surfaces to be brazed. In the present application, the standard orifice jets were designed to receive the pre-placed braze alloy on a surface separate from the one to be brazed.*

* This is the surface shown in Figure 2 where a spiral ring was used as the braze material.

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Upon heating to the proper temperature, the braze metal theoretically flows to the portions of the system to be joined by capillary attraction.

In many cases where this was attempted, however, some braze metal bonded to the orifice at the areas of pre-placement (Figures 4 and 5), effectively starving the desired braze joint of braze metal, as shown in Figure 6. The amount of material thus lost to the braze joint varies with the speed of the brazing operation and significant quantities are thus "prebrazed" even at the highest heating rates used. Greater amounts of metal brazed in situ, as it were, with slower heating rates, due to increased time for diffusion of metallic constituents and bonding of the braze metal to the orifice surfaces. Sufficiently high heating rates could not be used to alleviate this effect, due to equipment limitations; therefore, three methods were suggested to increase the amount of pre-placed braze metal.

One method, in which the length of the shank upon which the braze tape is placed is increased, thereby supporting wider sections of transfer tape, was considered undesirable because if the increase in shank length was added to the existing orifice length, the cost of extra molybdenum and additional machining would be high. If the added shank length was obtained by reducing the length of the section to be joined to the element (see Figure 3), potential problems in orifice seating or alignment within the channel could arise. However, several runs were nevertheless made to determine the overall feasibility of this approach.

No improvements in braze quality were noted, as braze metal continued to wet the orifice in the pre-placement position, starving the braze joint.

A second method which was attempted consisted in increasing the width of the transfer tape without changing the orifice length, so that the wrapped tape envelope actually extended beyond the inner end of the orifice. It was expected that during melting, surface tension effects would cause the ends of the tape to shrink back toward the main body of braze metal. The minimum width of tape for brazing leak-tight joints with a high degree of reliability was found to be 0.125-inch with a maximum diametral orifice-element gap of 0.003 inch to 0.005 inch.

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Bottom Arrows Show Areas Where Preplaced Brazed Material Bonds in Situ.
Starved Joint is shown on Left (Top Arrow).

Figure 4. Photomacrograph of Orifices Brazed with Transfer Tape

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Note Alloying with Molybdenum, Effectively Reducing Orifice Wall. The Metallographic Technique is Described in Appendix B.

Figure 5. Photomicrograph of Orifice in Figure 4 (Left) Showing Braze Metal Bonded in Area of Preplacement Rather than Flowing to Braze Joint

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Figure 6. Photomicrograph of Orifice in Figure 4 (Left) Showing Starved Braze Joint

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A specimen with 0.003 in. gap (diametral) and one with 0.005 in. gap (diametral) were brazed with the above optimum tape measurements, each with a full complement of 18 standard orifices and for the first time with the complete standard orifice loading arrangement, no leaks were observed in either sample. A typical braze joint from this specimen is shown in Figure 7. With larger diametral gaps, 7-8 mils, a 33 percent leakage rate was observed, using the same techniques.

The dummy orifices in this series of experiments measured 0.096-inch diameter at the braze joint. The braze tape was 0.002-inch thick and 13/16-inch long. All test pieces were brazed in the inverted position, i. e., the exposed heads of the orifices were bottom-most in the fixture. It was expected that the flow of metal and the escape of entrapped gases would be enhanced in this position.

The brazing process for the optimum runs consisted in induction heating under an argon flow after a triple evacuation and backfill. The test assemblies were held at 1600°F for 2 minutes to allow for outgassing and temperature equilibration, then raised to 2400°F and held for 1 minute to effect the braze. The assemblies were allowed to cool slowly within the fixture.

Although leak tight braze joints could be produced by the above method, it was found that the braze metal showed a tendency to flow around the end of the orifice and within the orifice through-hole as shown in Figure 8.

Since the brazing process had been otherwise successful, attempts were made to reduce the flow effect by chamfering the end of the orifice, thereby adding an extra corner as a flow barrier. Several tests were made, using dummy orifices*. Metallographic inspection of the results showed that the braze metal still had a tendency to flow completely around the orifice end, although the effect was greatly diminished (Figure 9). (The effect was more noticeable under the microscope due to color differences, than is evident in the given figure.) The use of a braze-resisting material was also considered and a few specimens were brazed after coating the ends with an MgO paste in advance of the receipt of an order of commercial

* Dummy orifices, i. e., orifices without through-holes were used in most of the preliminary trials in order to conserve the more expensive standard orifices.

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Figure 7. Typical Braze Joint in Leak-Free Test Element Using Transfer Tape as a Method of Braze Preplacement

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Figure 8. Illustration of Flow of Braze Metal Within Orifice Through-Hole

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Figure 9. Dummy Orifice with Chamfered End, Showing Slight Flow of Braze Metal Around Corners

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braze-resisting materials. However, there was no discernible improvement in the end condition of the orifices. Further work along these lines, and in fact, the concept of using the braze transfer tape was suspended since it was found that the quality of the transfer tape could not be reproduced.

All test runs described above were made using a single batch of transfer tape as the braze metal medium. In order to replace the diminishing supply an order was placed with the tape supplier for another roll of material, manufactured to the same thickness and using the same binder and adhesives as the first, successfully utilized batch.

Upon receipt of this batch, however, it was found that the adhesive was too tacky, causing difficulties in handling, and the distribution of powdered braze material within the binder was grossly non-homogeneous. Discussions with the supplier resulted in the conclusion that the adhesive in the first batch, which had been in-house for at least 6 months prior to use for this test, had dried sufficiently to allow for easy handling yet retained sufficient adhesiveness for adherence to the orifice. (Normal shelf life for this material is 3 months.)⁽¹⁰⁾

The braze material was reclaimed and a repeat order was placed, with the exception that a less tacky adhesive be used* and an attempt be made to improve the homogeneity of particle distribution. This material, although less tacky, was also too difficult to handle without damage. Again, the powder density was extremely non-uniform. Further discussions with the tape and powder suppliers resulted in the conclusion that a particle size of 10 or 12 microns was desirable for homogeneous suspension within the binder material as shown by the vendor's successful manufacture of other powder transfer tapes, such as molybdenum. However, because of the high degree of malleability of the braze metal, particles of this fineness could not be prepared by the ball-milling process, as normally used. It was, therefore, concluded that reproducibility of the transfer tape could be assured only after a tape manufacturing development phase but this was undesirable from the viewpoints of costs and schedule. Therefore, the tape method of braze metal placement was shelved and the use of solid pre-forms

* The supplier's designation of the original adhesive, unacceptable unless aged, is Y-1. The low tack adhesive is designated as X-4.

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in the shape of rings was reinvestigated. A summary of results, using the transfer tape method, is given in Table 2.

A solid metal pre-form has the advantage of greater density and ease of assembly over the powder-tape method.

In advance of the receipt of an order for full rings, a supply of split rings was made from available CRONIRO sheet stock and seven braze runs were made using this method of introducing the braze metal. These rings were made from nominally 0.100 in. wide, 0.006 in. thick, 0.293 inch long strips. Special care was taken to deburr each ring and to minimize the gap. While deburring was successful, some rings had a gap of up to 5 mils between the split ends.

The best run showed only one leaking braze joint from a total of 18. Examination of the leak test results (Table 3) shows that, in general, the leak tight brazes were realized in the cases where the greatest weight of material was available. Some of the braze ring preforms were installed in specific, recorded orientations in an effort to determine if the split in the ring was contributory to the observed leaks. Post-braze leak testing and metallography showed no unique relationship between the actual leak position and the pre-braze ring orientation. However, metallographic observations showed that a large amount of braze metal had bonded to the element and the orifice at the area of pre-placement, similar to the situation described above for transfer tape. Figure 10 shows a transverse section taken across the area of braze-ring pre-placement, where it is evident that brazing has taken place. In addition to starvation of the intended braze joint, this condition of relatively large localized mass of braze metal (compared to smaller mass at the designed braze joint), results in a differential thermal contraction between the fuel element and braze metal capable of initiating cracks. Beaded-fuel samples brazed in this manner show circumferential cracks after brazing associated with the brazed area (Figures 11 and 12), but unfueled graphite samples do not (Figure 10). Also, Figures 10 and 12 show that considerable alloying of the orifice takes place, which reduces the original orifice wall thickness in the most severe cases (Figure 12). Increasing the brazing temperature up to 2700°F results in melting of much of the pre-brazed material,

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TABLE 2

TRANSFER TAPE RESULTS

Run	Weight Tape (gm)	Nominal Gap (in.)	Braze Temp/Time	Leaks	Remarks
SM-1	0.016 (avg. of 4)	0.001	1600°F/2 min.,	None	
SM-2	0.016 (avg. of 4)	0.002	2400°F/1 min.	All	
SM-3	0.016 (avg. of 4)	0.003		All	
SM-5	0.023	0.002	1200°F/2 min.,	No	
	0.031	0.002	2300°F/1 min.	No	
	0.033	0.002		No	
	0.039	0.002		No	
SM-6	0.023	0.003	1600°F/2 min.,	Yes	
	0.031	0.003	2350°F/1 min.	No	
	0.034	0.003		No	
	0.042	0.003		No	
SM-8	0.034	0.003	1600°F/2 min.,	No	
	0.034	0.003	2400°F/1 min.	No	
	0.031	0.003		No	
	0.039	0.003		No	
SM-9	0.028	0.003	1600°F/2 min.,	No	
	0.027	0.003	2400°F/1 min.	No	
	0.031	0.003		No	
	0.027	0.003		Yes	
SM-10	0.026	0.002	1600°F/2 min.,	No	
	0.026	0.002	2400°F/1 min.	No	MgO Stop-off
	0.026	0.002		No	MgO Stop-off
	0.026	0.002		No	
SM-11	0.027	0.002	1600°F/2 min.,	No	
	0.028	0.002	2400°F/1 min.	No	
	0.030	0.002		No	
	0.028	0.002		No	
	0.031	0.002		No	
	0.028	0.002		No	
	0.027	0.002		No	
	0.028	0.002		No	

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TABLE 2 (CONTINUED)

<u>Run</u>	<u>Weight Tape (gm)</u>	<u>Nominal Gap (in.)</u>	<u>Braze Temp/Time</u>	<u>Leaks</u>	<u>Remarks</u>
SM-11	0.026	0.002		No	
	0.031	0.002		No	
	0.031	0.002		No	
	0.027	0.002		No	
	0.029	0.002		No	
	0.030	0.002		No	
	0.030	0.002		No	
	0.027	0.002		No	
	0.029	0.002		No	
	0.030	0.002		No	
SM-12 (fueled)	0.040	0.004	1600°F/2 min.,	No	209g weight used in this run, and also subsequent runs
	0.040	0.004	2400°F/1 min.	No	
	0.037	0.004		Yes	
	0.039	0.004		Yes	
	0.041	0.004		No	
	0.036	0.004		Yes	
	0.037	0.004		No	
	0.037	0.004		No	
	0.038	0.004		No	
	0.039	0.004		No	
	0.034	0.004		Yes	
	0.034	0.004		No	
	0.037	0.004		No	
	0.041	0.004		No	
	0.039	0.004		No	
	0.036	0.004		Yes	
	0.036	0.004		No	
	0.039	0.004		Yes	
SM-13	0.030	0.003	1600°F/2 min.,	Yes	PW type
	0.027	0.003	2400°F/1 min.	Yes	PW type
	0.037	0.003		No	
	0.036	0.003		Yes	

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TABLE 2 (CONTINUED)

<u>Run</u>	<u>Weight Tape (gm)</u>	<u>Nominal Gap (in.)</u>	<u>Braze Temp/Time</u>	<u>Leaks</u>	<u>Remarks</u>
SM-14	0.028	0.002	1600°F/2 min.,	No	PW type
	0.027	0.002	2400°F/1 min.	No	PW type
	0.029	0.002		No	
	0.027	0.002		No	
	0.027	0.002		No	
	0.028	0.002		No	Orifice bevel
SM-15	0.026	0.003	1600°F/2 min.,	No	PW type
	0.028	0.003	2400°F/1 min.	No	PW type
	0.036	0.003		No	
	0.035	0.003		No	
	0.037	0.003		No	Long Shank
	0.038	0.003		Yes	Long Shank Orifice Bevelled
SM-16	0.028	0.003	1600°F/2 min.,	No	
	0.028	0.003	2400°F/1 min.	No	
	0.027	0.003		No	
	0.028	0.003		No	
	0.027	0.003		No	
	0.029	0.003		No	
	0.025	0.003		No	
	0.029	0.003		No	
	0.029	0.003		No	
	0.029	0.003		No	
	0.028	0.003		No	
	0.027	0.003		No	
	0.030	0.003		No	
	0.029	0.003		No	
	0.025	0.003		No	
	0.027	0.003		No	
	0.029	0.003		No	
	0.029	0.003		No	
SM-17	0.026	0.003	1600°F/2 min.,	No	
	0.025	0.003	2400°F/1 min.	Yes	

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TABLE 2 (CONTINUED)

<u>Run</u>	<u>Weight Tape (gm)</u>	<u>Nominal Gap (in.)</u>	<u>Braze Temp/Time</u>	<u>Leaks</u>	<u>Remarks</u>
SM-18	0.027	0.004	1600°F/2 min.	Yes	
	0.028	0.004	2400°F/1 min.	Yes	
	0.026	0.004		No	
	0.026	0.004		No	
	0.026	0.004		No	
	0.026	0.004		No	
	0.026	0.004		No	
	0.029	0.004		No	
	0.027	0.004		No	
	0.027	0.004		No	
	0.026	0.004		No	
	0.025	0.004		No	
	0.027	0.004		No	
	0.026	0.004		No	
	0.025	0.004		No	
	0.027	0.004		No	
	0.030	0.004		No	
	0.028	0.004		No	
SM-19	0.026	0.003	1600°F/2 min.	No	Final temp. overshoot to 2530°F. Used modified susceptor.
	0.026	0.003	2400°F/1 min.	No	
	0.027	0.003		No	
	0.026	0.003		No	
	0.027	0.003		No	
	0.025	0.003		No	

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TABLE 3

BRAZE RUN DATA - USING SPLIT BRAZE RINGS ON STANDARD ORIFICES

<u>Run No.</u>	<u>Max. Temp. °F and Time at Temp.</u>	<u>Weight of Ring (gm)</u>	<u>Presence of Post- Braze Leak</u>
HEB-1	2400°F 1 min.	0.0231	Yes
		0.0235	Yes
		0.0230	No
		0.0323	No
		0.0225	Yes
		0.0332	No
		0.0318	No
		0.0238	Yes
		0.0237	No
		0.0312	No
		0.0327	No
		0.0328	No
		0.0302	No
HEB-2	2700°F 1 min.	0.0340	No
		0.0319	No
		0.0317	No
		0.0329	No
		0.0332	No
		0.0306	Yes
		0.0328	No
		0.0319	No
		0.0314	No
		0.0317	No
		0.0315	No
		0.0325	No
		0.0328	No
		0.0322	No
		0.0329	No
		0.0323	No
		0.0335	No
		0.0325	No

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TABLE 3 (CONTINUED)

<u>Run No.</u>	<u>Max. Temp. of and Time at Temp.</u>	<u>Weight of Ring (gm)</u>	<u>Presence of Post- Braze Leak</u>
HEB-3	2400°F 1 min.	0.0309	No
		0.0316	Yes
		0.0332	Yes
		0.0326	Yes
HEB-3	2400°F 4 min. rerun	0.0328	No
		0.0314	Yes
HEB-4	2400°F 1 min. (52 min. 1600 - 2400°F)	0.0332	No
		0.0327	No
		0.0337	No
		0.0327	No
HEB-5	2400°F 2 min.	0.0326	Yes
		0.0323	No
		0.0313	No
		0.0315	No
HEB-8*	2400°F 2 min.	0.0245	Yes
		0.0244	Yes
		0.0217	Yes
		0.0233	Yes
HEB-9	2100°F 2 min.	0.0237	No
		0.0247	Yes
		0.0224	No
		0.0242	Yes

* No holding period at 1600°F. All other runs this table held at 1600°F for 2 minutes.

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100X

Figure 10. Transverse Section of Dummy Orifice with Split-Ring Preform
Brazed In-Situ

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MAGNIFICATION: APPROXIMATELY 20X

Figure 11. Fueled Graphite - Showing Cracking Resulting from Split-Ring Preforms Brazed In-Situ

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MAGNIFICATION 50X

Figure 12. Fueled Graphite - Showing Cracks and Eroded Orifice Wall from Split-Ring Preforms Brazed In-Situ

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sealing the designed orifice-channel joint against leaks in some cases but not in others. In the high temperature runs, the non-uniformly, but considerably eroded orifice walls, were revealed (Figure 12).

In general, the amount of metal brazed in-situ and the consequent starvation of the design braze joint was greater in the case of split-ring preforms than with braze transfer tape. The large number of cases where braze metal was found in contact with the graphite suggests that "spring-back" caused the unannealed rings as the temperature is increased to open up sufficiently to contact the graphite channel wall, allowing diffusion of atomic species to proceed, and forming a bond with the test element (Figures 11 and 12), bridging the intended braze joint. Partial melting of the rest of the braze metal then occurs as the temperature is raised through the braze metal's two-phase region ($1787-1832^{\circ}\text{F}$)⁽⁶⁾, but since passage to the braze joint is partially blocked, the "spongy" metal is forced to contact the orifice wall in the area of blockage, effecting a braze bond with the orifice. In other areas, where the ring of metal does not contact the element channel wall, melting and flow into the braze joint proceeds in a normal, unimpeded fashion. The mechanism as suggested here is offered as a tentative explanation of the one-sided nature of the in-situ brazing, which invariably occurs as shown in Figure 11.

A supply of solid rings was not available to test the mechanism proposed above. However, it was felt that a wire-coil preform would provide much less contact area for pre-brazing in-situ than a solid ring. Six-mil diameter wire coils were wound around a #50 drill (which is nominally 0.070-inch in diameter, or about 0.015-inch smaller in diameter than the orifice pre-placement shank) and installed on the orifices as shown in Figure 13. Care was taken to bend back and deburr the ends of the wire coil as needed to prevent scoring of the element channels during insertion of the orifice. The results of these runs are shown in Table IV. The results for runs held at 1600°F for 2 minutes before heating to the brazing temperature of 2400°F for 1 minute were excellent as expected, with only one leak found in 23 brazed joints. At this point in the program, an attempt was made to further simplify the process by heating to 2400°F as fast as possible without the 1600°F holding period. The results

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Figure 13. Wire-Coil Braze Preform Installed on a Dummy Orifice

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TABLE 4

BRAZE RUN DATA - USING WIRE COIL PREFORMS ON STANDARD ORIFICES

<u>Weight of Wire Wrap on Std. Orifice (gms)</u>	<u>Run No.</u>	<u>Max. Temp. and Time at Temperature</u>	<u>Presence of Post-Braze Leak</u>
0.0217	HEB-6	2400°F	No
0.0189	HEB-6	2 min.	No
0.0247	HEB-6		No
0.0206	HEB-6		No
0.0204	HEB-7	2400°F	No
0.0227	HEB-7	2 min.	No
0.0212	HEB-7		No
0.0206	HEB-7		No
0.0215	HEB-7		No
0.0206	HEB-7		No
0.0217	HEB-7		No
0.0221	HEB-7		No
0.0201	HEB-7		No
0.0211	HEB-7		No
0.0191	HEB-7		No
0.0203	HEB-7		No
0.0214	HEB-7		No
0.0208	HEB-7		No
0.0216	HEB-7		No
0.0220	HEB-7		No
0.0215	HEB-7		No
0.0218	HEB-7		Yes
0.0199	HEB-7		No
0.0213	HEB-8	2400°F*	Yes
0.0219	HEB-8	2 min.	No
0.0215	HEB-8		Yes
0.0215	HEB-8		Yes
0.0209	HEB-9	2100°F	Yes
0.0206	HEB-9	2 min.	No
0.0219	HEB-9		Yes
0.0210	HEB-9		No

* No holding period at 1600°F. All other runs this table held at 1600°F for 2 min.

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were negative (see Tables 3 and 4, Run HEB-8). Of a total of 8 brazed joints, including wire-coil and split-ring braze preforms, only one joint was leak tight. The actual mechanism of the need for the holding period was not discernible from the results but the intermediate holding period is apparently necessary either for temperature (and hence stress) equilibration or for outgassing. All further runs were, therefore, made with the 1600°F, 2-minute holding period.

An attempt was made to repair the single leak in run HEB-7 by rebrazing, but at 2100°F for 60 minutes. The leaking joint (from HEB-7) was leak-tight after the rebraze but a leak was found in one of the previously leak-tight joints. This run showed the possibility of lowering the braze temperature, thereby, reducing the thermal expansion differences and possibly improving braze joint quality. Some leaks were found in this run as shown in Tables 3 and 4, Run HEB-9; however, results from two of the brazed orifices suggested the use of still another pre-form method. One orifice with a wire preform was also brazed with a double turn of braze wire at the outer, or head end of the orifice. Another orifice had no braze metal other than a double wrap of braze wire around the head. An example (from another run) is shown in Figure 14. In both cases, the brazed joint was leaktight and a small, uniform braze fillet was observed on the top surface of the test element around the orifice heads. These results suggested a new method of applying braze preforms as well as a repair technique for leaking brazed joints. Accordingly, the braze repair technique was attempted and it was found that 2-1/4 wraps of 0.006-inch CRONIRO wire are sufficient to successfully repair imperfect brazes, using the same braze process of holding at 1600°F for two minutes and heating to 2100°F for one minute. Four repair brazes were successfully attempted with this technique, which is described in the Appendices under DRM 51291.

The successful application of wire wrap braze metal to the top surface of the orifices suggested the possibility of using an even more convenient form of preform, namely, a CRONIRO washer to be placed between the orifice heads and the top surface of the elements. This method had been suggested earlier in the program but was rejected by WANL Reactor Design on the grounds that braze metal was undesirable in the area between the top surface of the element and the bottom surface of the head of the orifice primarily because of potential

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Orifices Shown by Arrows Had Been Originally Brazed in Run HEB-9 Using the Same Coil Technique (See Text, p. 5-24). Orifices with Coils as Shown Had Leaks After Run HEB-9.

Figure 14. Test Element Surface Showing Method of Leak Repair Using Wire Coils

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bridging of braze metal across the top of the element, which was considered to be a stress problem, and because of potential problems in maintaining a close tolerance in the heights of the orifices above the element surface. However, even in the early experiments using braze tape, braze metal was invariably observed under the head of the orifice in those cases where adequate braze-joint fill was obtained to achieve full joint integrity (leak-tightness), as shown in Figure 7. The use of weights (up to approximately 200 grams atop the assembly did not prevent the flow of metal to the outside orifice-element surface, where a small braze ring was usually observed.

Upon reappraisal, however, the Design Group approved trial braze runs using 5-mil thick, 0.136-in. OD and 0.099 in. ID washer preforms. The use of braze washer preforms was found to be completely successful from a metallurgical point of view. The process is described in the Appendices under DRM 51263 Rev. A. In a total of 455 orifices brazed by this technique, two orifices were incorrectly handled and did not braze properly. One orifice was not restrained during the braze by the cover weight (in this particular run, the element was brazed with the orifices topmost), and was found lying on the top surface of the element, while the washer was brazed to the graphite. Another orifice was cocked within the element channel and, therefore, did not braze. This orifice was physically removed from the element and rebrazed successfully without introducing leaks into any of the previously brazed orifices. A total of 453 orifices was, therefore, brazed with leak-tight joints to unfueled graphite, beaded-fuel, and composite fuel, in 4-inch as well as full-length elements (see Table 5). When the materials were properly assembled, therefore, the process, using washer preforms, was 100 percent successful in producing leak-free joints. The process was used to braze full length PEWEE-2 elements at LASL for a field test, and for the WANL Test Scope 160, "Threaded Orifice Pullout Test" elements⁽¹¹⁾. Details of the process and washer dimensions are given for both of these applications in the Appendices under DRM's 51291 and 51263, respectively. A representative photomicrograph of an element brazed using a washer preform is shown in Figure 15. A view of the top surface of a brazed Test Scope 160 element, (Figure 16) shows the braze fillets typical of a single washer process. Conformance of the braze metal to the machining grooves further demonstrates the metal's wettability.

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TABLE 5

BRAZE RUN DATA - USING WASHER PREFORMS ON STANDARD ORIFICES

No. of Orifices Braze	Run No.	Single Washer	Two Washers	Beaded Fuel	Non- Fueled	Final TS 033 Development	Test Scope 160 Specimens
5	HEB-10	X			X	X	
5	HEB-11	X			X	X	
2	HEB-12	X			X	X	
1	HEB-12		X		X	X	
6	HEB-13	X			X	X	
5	HEB-14	X			X	X	
5	HEB-15		X		X	X	
5	HEB-16	X			X	X	
7	HEB-17		X		X	X	
19	HEB-18		X		X	X	
18	HEB-19		X	X		X	
5	HEB-20		X	X		X	
6	HEB-21		X		X	X	
6	HEB-22	X			X		X
6	HEB-22-1	X			X		X
6	HEB-22-2	X			X		X
6	HEB-22-3	X			X		X
6	HEB-22-4	X			X		X
6	HEB-22-5	X			X		X
6	HEB-22-6	X			X		X
6	HEB-22-7	X			X		X
6	HEB-22-8	X			X		X
6	HEB-22-9	X			X		X
6	HEB-22-10	X			X		X
6	HEB-22-11	X			X		X
6	HEB-22-12	X			X		X
6	HEB-22-13	X			X		X
6	HEB-22-14	X			X		X
6	HEB-22-15	X			X		X
6	HEB-22-16	X			X		X
6	HEB-22-17	X			X		X
6	HEB-22-18	X			X		X
6	HEB-22-19	X			X		X
6	HEB-22-20	X			X		X
6	HEB-22-21	X			X		X
6	HEB-22-22	X			X		X
6	HEB-22-23	X			X		X
6	HEB-22-24	X			X		X
6	HEB-22-25	X			X		X
6	HEB-22-26	X			X		X
6	HEB-22-27	X			X		X
6	HEB-22-28	X			X		X
6	HEB-22-29	X			X		X
6	HEB-22-30	X			X		X
6	HEB-22-31	X			X		X
6	HEB-22-32	X			X		X

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Figure 15. Representative Standard Orifice Braze Joint in Graphite Element Using Washer Preforms (Qualification Element)

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ELEMENT 19024-10
BRAZE RUN HEB22-48

8X

Figure 16. Orifices Brazed with Preformed Washers.
Note Conformance of Braze Fillets to Machining Grooves

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It should be noted here that use of both a single and a double set of 5-mil thick washers was investigated. A double set of washers under an orifice resulted in braze fillets of larger diameter, and the braze metal flowed further into the originally designed joint than with single washer runs (see Reference 8). However, since the single washer concept adequately produced leak-tight joints and no strength requirements were imposed on standard orifice brazed joints, the final process, adopted for TS-160, used the single washer concept. Double washers were used on the PEWEE-2 brazes, which were performed early in the "washer phase" of development, for added reliability.

The heights of the orifice heads from the element surface were measured by the WANL Quality Assurance Department on four elements (from the qualification samples, discussed below), each with a full complement of 18 standard orifices. The results, given in Table 6 show that the heights in any one element were within 1 mil. The variation from one element to another was ± 1 mil. These data show that the process as described in DRM 51263 is capable of maintaining close tolerances and is in this respect, as well as in the use of simple braze preforms, directly amenable to production requirements and techniques.

Figures 17 and 18 show representative standard orifice brazes, using transfer tape, in a beaded fuel element. The wettability is demonstrated in Figure 17, where the braze metal has entered a cavity, probably occupied previously by a fuel bead. In Figure 18, alloying with the fuel material is evident. (The straightness of the braze metal wall - at the hole in the graphite matrix at the bottom of this figure - suggests that the hole is probably due to pullout of a fuel bead during post-braze metallographic preparation, and does not indicate lack of ability of the braze metal to fill a pre-existing hole. Similar observations were noted with braze washer preforms. Figure 19 shows results of a practice composite-fuel run using a spare LASL* 30% ZrC composite element brazed with washer preforms. In general, the quality of bonding in brazes in the relatively small number of composite fuel brazes thus far observed seems to be superior even to those observed in graphite or beaded

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TABLE 6
ORIFICE DIMENSIONAL INSPECTION OF FULL-COMPLEMENT,
BRAZED GRAPHITE ELEMENTS

<u>Element Identification</u>	<u>Height of Orifices from Element Face</u>	<u>Height of Threaded Orifice from Element Face</u>
LB 19022-5	0.101 in.	0.893 in.
LB 19022-9	0.101 in.	0.880 in.
LB 19023-10	0.100 in.	0.881 in.
LB 19024-2	0.102 in.	0.920 in.

All Measurements are to ± 0.001 -inch.

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Figure 17. Brazed Standard Orifice Joint in Beaded-Fuel Element

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100X

Figure 18. Brazed Standard Orifice Joint in Beaded Fuel Element

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100X

Figure 19. Brazed Standard Orifice Joint in LASL Composite Fuel Element
No. 166-60592

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fuel elements (Figure 19). However, it was noted that cracks invariably appear in the braze metal where sharp corners are found in composite material (Figure 20). As seen in Figure 19, these cracks do not occur with rounded element corners. The crack did not lead to any observable leaks⁽⁸⁾ since sufficiently continuous bonded interfaces exist. However, the possibility exists that thermal cycling conditions could lead to crack propagation within the orifice itself, as already seen in threaded orifice joints after severe shock (see Section 5.3 below). It is, therefore, suggested that results of the PEWEE-2 test be closely studied to determine if these cracks do indeed appear in the orifice. It is also suggested that the composite fuel channels be chamfered in future tests to avoid the initiation of cracks. Comparison of Figures 19 and 20 also demonstrates the differences in depth of braze metal travel down the orifice element gap. Due to non-centering of the orifice within the channel, the braze metal flows to a greater length in the side with the narrow gap, as expected. With proper centering, the two brazed joint lengths should be practically identical.

5.2 CENTRAL THREADED ORIFICE

The first design requirement for brazing the threaded orifice was for effecting a braze joint in the unthreaded portion of the orifice between the top surface of the element and the concavity⁽³⁾ provided for the preplacement of the braze alloy, rather than in the threaded joint. When results showed that at least six or seven threads, and with sufficient braze metal the entire threaded length could be brazed, the design criterion was revised to require brazing of the threaded joints and not in the previously specified area⁽¹²⁾.

The latter method was used for brazing of all threaded orifices for the Test Scope 160, Threaded Orifice Pullout Test, specimens.

In experiments to meet the early design requirement, braze metal in the form of transfer tape was wrapped in the concavity of the threaded orifices. These early specimens were brazed upside down, i. e., with the orifices facing downward, in order to use the force of gravity to aid in filling the design braze joint. Qualitative leak tests of the brazed joints showed gross leaks in all cases.

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100X

Figure 20. Brazed Standard Orifice Joint in LASL Composite Fuel Element No. 166-60592, Showing Crack Due to High Stress Intensity at the Sharp Element Corner

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In the latest experiments, designed to braze the threaded joints, the test elements were brazed with the orifices facing upward, and braze metal in the form of 0.006-inch diameter CRONIRO wire was wrapped within each preplacement concavity. As can be expected, the method of wire wrapping required a greater learning period and degree of skill than was required for the washer-preform method of brazing the standard orifices described in the preceding section. In order to accomplish the wire wrapping successfully, the orifice is chucked in a lathe and the initial end of the CRONIRO wire is spot welded to the orifice with a capacitance-discharge welder. The lathe is run at a very slow speed and the wire is carefully fed onto the orifice to completely fill the preplacement area. Care must be taken not to overwind the braze metal so that the orifice OD is exceeded by the mass of wire. When the maximum amount of metal (120-125 milligrams) has been wound, as determined by the above dimensional criterion, the final wire end is secured by a half-hitch knot. A skilled operator can consistently maintain a mass of metal weighing 100 to 120 milligrams after winding two or three orifices (see Table 7).

Breaks in the consistency of wire weights, seen in Table 7, as weights less than 100 milligrams, are a result of "re-learning" after brief periods of inactivity in the brazing schedule. With a few exceptions, the leaks are found in threaded orifice joints with the least amount of braze metal, as well as in the heaviest, where it was noted that the orifices were inserted only with difficulty.

The brazing time-temperature parameters are identical for all runs shown in Table 7 and are the same as those shown in Table 5, for the standard orifice since both types of orifices were brazed simultaneously. The process details are given in DRM 51263, Rev. A. The method thus described is obviously less adaptable to production requirements than the simpler technique for standard orifices. However, this disadvantage is partially offset by the smaller ratio of the total number of threaded-to-standard orifices (1:18) within each element.

From a total of 49 threaded orifices brazed by the above method, only 7 show any evidence of leaks, all of which are less than the maximum leak rates of 6 cc air/minute, under a pressure head of 10 psi as specified by WANL Design⁽¹²⁾. Figure 21 shows a section from one of the first threaded orifices brazed with the wire pre-form. The leak in this brazement, as in the other threaded orifices which were not leaktight, probably follows a helical

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TABLE 7

DATA SHEET - ELEMENTS BRAZED FOR TEST SCOPE 160 (THREADED ORIFICE PULLOUT TESTS), WIRE WRAPPED THREADED ORIFICES

Brazing Run Identification	Weight of Brazing Wire (gms)	Post-Brazing Thread Qualification Joint Leak Test (1)			Remarks
		Helium 20 psi (2)	Air 15 psi	Air 10 psi	
HEB-22-1	0.0995	No	-	-	
HEB-22-2	0.1064	No	-	-	
HEB-22-3	0.1200	No	-	-	
HEB-22-4	0.1203	No	-	-	
HEB-22-5	0.1287	VSL	0	-	
HEB-22-6	0.1048	No	-	-	
HEB-22-7	0.1142	SL	0	-	Tight in installation showed no leak on recheck.
HEB-22-8	0.1049	No	-	-	
HEB-22-9	0.1093	No	-	-	
HEB-22-10	0.0972	No	-	-	
HEB-22-11	0.1160	L	6 cc/min	-	
HEB-22-12	0.0960	SL	0	-	
HEB-22-13	0.1040	VSL	0	-	
HEB-22-14	0.1030	SL	0	-	
HEB-22-15	0.1199	No	-	-	
HEB-22-16	0.1114	No	-	-	
HEB-22-17	0.1242	No	-	-	
HEB-22-18	0.1009	No	-	-	
HEB-22-19	0.1085	No	-	-	
HEB-22-20	0.1096	No	-	-	
HEB-22-21	0.1019	No	-	-	
HEB-22-22	0.1107	No	-	-	
HEB-22-23	0.1094	No	-	-	
HEB-22-24	0.1078	SL	-	-	
HEB-22-25	0.1131	No	-	-	
HEB-22-26	0.1201	No	-	-	
HEB-22-27	0.1225	SL	0	0	Full Complement Qualification Sample
HEB-22-28	0.1168	No	-	-	
HEB-22-29	0.1044	No	-	-	
HEB-22-30	0.1082	No	-	-	
HEB-22-31	0.1079	No	0	0	Full Complement Qualification Sample
HEB-22-32	0.1049	No	-	-	
HEB-22-33	0.1113	VSL	-	-	Tight in installation
HEB-22-34	0.1072	No	-	-	
HEB-22-35	0.0973	No	-	-	
HEB-22-36	0.1019	VSL	-	-	
HEB-22-37	0.1055	No	-	-	
HEB-22-38	0.1150	No	-	-	
HEB-22-39	0.1068	No	-	-	
HEB-22-40	0.1120	SL	<1 cc/min	0	Full Complement Qualification Sample
HEB-22-41	0.1109	SL	2 cc/min	0	Full Complement Qualification Sample
HEB-22-42	0.1164	No	-	-	
HEB-22-43	0.1098	SL	-	-	
HEB-22-44	0.1213	No	-	-	
HEB-22-45	0.0963	No	-	0	Full Complement
HEB-22-46	0.1143	No	-	-	
HEB-22-47	0.1079	No	-	0	Full Complement
HEB-22-48	0.0989	No	-	-	
HEB-22-49	0.1302	No	-	-	Tight in installation.

* Notes: (1) The 20 psi leak check was qualitative. Only those samples as indicated were retested quantitatively after brazing.
 (2) In order of increasing severity the leaks under 20 psi Helium were classified as follows:

VSL Very small leak
 SL Small Leak
 L Leak

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50X

Figure 21. Section Through Brazed Threaded Central Orifice Showing Uniformity of Braze and Probable Leak Path

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path at the apex of the orifice threads, as shown in the figure. Otherwise, the braze metal adequately fills the root areas of the orifice threads and is uniform from one thread to another.

No attempt was made to maintain a definite threaded orifice height, from the element surface. The orifices were simply threaded into the central channels until seating was established, as judged by resistance to further finger pressure. However, measurements were taken on four orifices, as given in Table 6.

Inspection of Figure 21 suggests that redesign of the graphite thread to allow more room for braze metal at the graphite thread root (or orifice thread apex), coupled with redesign of the braze metal preplacement concavity by extending it in length or by forming a right angle cut at its uppermost end, would increase the reliability of the described technique in producing leak-tight threaded joints.

Alternatively, the process can be shortened for production purposes by redesigning the preplacement concavity to allow for installation of a split, cylindrical preform which could be installed using an adhesive similar to those used for braze transfer tapes.

5.3 PROCESS QUALIFICATION TESTS

Test Scope 033 (see Appendix C) required the leaktight brazing of four full-complement (18 standard and one threaded orifice) elements for qualification of the brazing process. Actually, seven fully-sealed full complement assemblies were brazed.

The Test Scope also required the thermal cycling and releak check of four full-complement brazes. The thermal cycling of the qualification samples consisted of 60 alternate cooling and heating cycles as follows: RT to LN₂ to RT to 612°F to RT.

Two of the four full leak tight, full complement brazes (identified as 19022-5 and 19022-9) were selected at random for thermal cycling along with two of the full complement assemblies showing threaded orifice leaks (identified as 19023-10 and 19024-2). The two elements showing leaks were selected for thermal cycling to determine whether or not the leak paths would enlarge, as determined by greater post thermal cycle leak rates.

The four elements were tested simultaneously in a specially-designed test rig as shown in Figures 22 and 23.

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Figure 22. Thermal Cycling Equipment

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Figure 23. Closeup View of Specimens During Thermal Cycling Qualification Testing

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The four elements are secured in a circular pattern by thin stainless steel plates at each end. One plate fits over the threaded jets. Spacers were placed over each of the four threaded orifices between the plate and the top surfaces of the elements. The top plate was secured by loose fitting nuts over the end of each threaded orifice. The lower end plate was secured by 8-32 threaded bolts that loosely fit the threaded central channel in the bottom of the elements.

In one of the elements, a sheathed chromel-alumel thermocouple, about 1/16 in. in diameter was placed within one of the channels near the center of the assembly, with the couple junction placed just within the inner end of a standard orifice. The entire assembly was placed within a vycor chamber for protection from oxidation during heating.

The specimens were cycled from room temperature to 1072R (612°F)* under flowing argon, removed from the furnace and cooled to room temperature within the vycor chamber. Cooling was aided by replacing the argon with helium, and by the use of a small electric fan.

When room temperature was reached, the assembly was removed from the vycor chamber and lowered into a liquid nitrogen bath, with the orifices oriented topmost. The assembly was judged to be at the ambient LN₂ temperature when the bubbling (due to boiling) of the liquid nitrogen ceased. At this point, the assembly was lifted rapidly out of the liquid bath and replaced within the vycor chamber under flowing argon to prevent moisture pickup from the atmosphere. The four-element assembly then reached room temperature under ambient thermal conditions.

The time history for each portion of the cycle was:

- a) Heating from room temperature to 612°F, 15 minutes average (12-18 minute range);
- b) Cooling to room temperature, 15 minutes average (12-18 minute range);
- c) Cooling from room temperature to liquid N₂ temperature, 2 minute average (1-3 minute range);

* The maximum temperature specified by the TS-033 document was 1000°R (540°F). The thermal cycling as actually performed, is therefore, more severe than required.

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d) Heating from LN₂ to room temperature, 30 minute average (24-48 minute range). Each specimen was leak checked before thermal cycling, after 31 cycle, and after the full 60 cycles. In addition, one element (#LB 19022-5) had previously experienced 60 cycles from room temperature to liquid nitrogen temperature. (The first thermal cycling plan was to perform the total 60 cooling cycles before starting the 60 heating cycles. This plan was modified as described above).

The results of the quantitative leak check of the central threaded orifice are given in Table 8, and show that the thermal cycling did not initiate leaks in previously sealed threaded orifices. Also, pre-thermal cycling leaks were not significantly affected by the cycling stresses. The standard orifices in each of the four qualification samples were leak checked both by a qualitative bubble test and with the quantitative flowmeter test. All standard orifices were leak tight after thermal cycling.

A representative photomicrograph of cross sections from one of the thermal cycled specimens (No. 19023-10) is shown in Figure 24.

The thermal cycling results demonstrate the resistance of the brazed joints to thermal cyclic stresses and show that the brazing process meets the requirements of the Test Scope.

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TABLE 8

THREADED ORIFICE LEAK TEST RESULTS - BRAZING PROCESS
QUALIFICATION SAMPLES

Element Identification	Pressure Head (psi)	Element History ⁽¹⁾		
		A	B	C
		Leak Rate (cc/min.)	Leak Rate (cc/min.)	Leak Rate (cc/min.)
19022-5 ⁽²⁾	5	0	-	-
	10	0	0	0
	15	0	0	-
19022-9	5	0	-	-
	10	0	0	0
	15	0	0	-
19023-10	5	0	-	-
	10	0	2	2.5
	15	2	4	-
19024-2	5	0	-	-
	10	0	1	1 ⁽³⁾
	15	1 ⁽³⁾	2	-

NOTES: (1) Element Histories:

A - Post Braze, Prior to Thermal Cycling

B - After 31 Thermal Cycles,

612°F → R. T. → LN₂ → R. T. → 612°F

C - After Full 60 Cycles

(2) This element had been previously thermal cycled 60 times from

R. T. → LN₂ → R. T.

(3) Barely readable.

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Figure 24. CRONIRO Braze Within Thread of Central Orifice.
Shown After Severe Thermal Shock.

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6.0 SUMMARY AND CONCLUSIONS

Early work had identified the basic materials needed to form orifice-element brazes. Final development work was aimed toward the realization of a fully-reliable process for brazing leaktight orifice-element joints. Specific phases of development included the investigation of several methods of braze metal preplacement on the standard orifice as follows:

- 1) Transfer Tape
- 2) Split Ring Preforms
- 3) Wire Coil Preforms
- 4) Washer Preforms

Several design modifications of the basic standard orifice design were also studied in parallel with the first three methods listed above. These are:

- 1) Extension of the braze preform shank length,
- 2) Chamfering of the 0.085 in. diameter shank, and
- 3) Chamfering of the 0.097" diameter shank.

The development of the transfer tape method was carried out to the point where full complement, leak-tight standard orifice joints were brazed, but handling of the tape appears to be unwieldy for tight-schedule production requirements. In addition, extreme batch-to-batch variations in tape quality were found.

The use of split-ring preforms was more amenable to production requirements, but braze joint quality was less and process reliability was lower than for the transfer tape method. The method of wire coil preforms showed promise of being an effective compromise between the requirements of reliability and production adaptability, but was dropped in favor of washer preforms.

A fully reliable process, yielding sealed standard orifice joints was developed using the washer preform concept. Only two assembly errors, easily correctable, were committed in brazing over 450 standard orifices to non-fueled, beaded-fuel, and composite elements, including full length elements of both types.

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The developed process was successfully applied to the brazing of thirty orifices into PEWEE-2 reactor fuel elements, and into 49 specimens for the Threaded Orifice Pullout Test (TS-160).

The design modifications which were studied in parallel with the braze metal application methods, were not sufficiently effective in improving process reliability. However, successful use of the washer preform suggests the design modification of shortening the orifice length, saving material and machining costs, and chamfering the element channel, reducing braze joint crack initiation.

The transfer tape method was tried for the brazing of the threaded orifice, but was found to be unreliable. A process using wire braze metal was successfully developed for brazing the threaded orifice joints. The degree of reliability was less than perfect for this braze joint, but all leaks were within WANL Reactor Design limits for acceptable joints. Modifications to the existing threaded orifice design were suggested by the developmental results.

A repair technique utilizing wire preforms was developed for standard orifice joints showing leaks. Repair of unsealed threaded orifice joints was not attempted, but it is highly probable that the same technique used for standard orifices would also be effective in this case.

Process qualification samples successfully withstood a minimum of 60 thermal cycles from 1072R (612°F) to R. T. to liquid N₂ temperatures without introducing leaks into sealed orifices or significantly enlarging leaks in existing (threaded) orifices.

It is concluded that the brazing process for both types of orifices, as described in DRM 51263, Revision A, successfully meets the requirements imposed by Test Scope DM-033 with additional requirements and modifications presented by WANL Reactor Design Engineering.

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7.0 REFERENCES

- (1) Scope of Test for Orifice Seal-Braze Development and Testing, 58 DM-033-3, December 16, 1969 (CRD).
- (2) Personal Communication, R. J. Garey to C. J. Kubit, July 27, 1970.
- (3) WANL Drawing 577F509GO1, "Orifice Element Assembly Test Specimen", January 9, 1969.
- (4) Scope of Test for Orifice Seal-Braze Development and Testing, 58 DM-033-4, July 27, 1970.
- (5) "Brazing Alloys", Data Sheet, Western Gold and Platinum Company, Belmont, California, March 1969.
- (6) Aerospace Structural Metals Handbook, AFML-TR-68-115, Belfour Stulen, Inc., Traverse City, Michigan, Code 5303, Page 1.
- (7) "Brazing of Fuel Element Orifices for the PW-2 Reactor at LASL", DRM 51296, January 15, 1971 (CRD).
- (8) "The Relationship Between Brazing Process Variables and GEM-Molybdenum Joint Quality for a Chromium-Nickel-Gold Braze Alloy", F. D. Seaman, WANL-TME-1904, March 17, 1969.
- (9) Telephone Communication from G. R. CASTLES-VITTA Corporation, Wilton, Connecticut, April 20, 1970.
- (10) Test Scope 58DE-160-1, "Threaded Orifice Pullout Test" (CRD).
- (11) Telephone Communication from R. Garey, WANL Reactor Design Group, October 21, 1970.

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APPENDIX A

BRAZE JOINT PHASE MORPHOLOGIES AND CHEMISTRY

It can be seen in the preceding photomicrographs that the braze joint metal presents a distinctive morphological aspect: a more or less centrally located, generally continuous, sinuous phase which, in some cases, actually form a cylindrical envelope within the braze joint; an irregular, and often dendritic or "Chinese script-like" phase on the side nearest the TZM molybdenum orifice; and a somewhat elongated or blocky phase nearest the element channel wall. Thus, at first hand the braze joint appears to consist of three distinct phases within an otherwise homogeneous matrix (see especially Figure 24). The separate elongated phase, like the continuous serpentine phase, polishes in relief and is probably a hard carbide. The dendritic phase polishes flat in the plane of the matrix and is probably a non-carbide.

By themselves, the isolated phases are of no great practical interest. However, the continuous, serpentine phase is particularly interesting, since under the microscope, it is seen to be in relief against the matrix, suggesting a hard, and possibly brittle nature, which combined with its continuity, extending even to the elements' exterior, presents a potential crack path, or leak source.

A brief study of the nature of the various phases was, therefore, made to aid in interpreting the brazing mechanism and in assessing the quality of the braze, itself, and some special experiments were conducted to isolate the various phases.

Metallographic examination of the CRONIRO metal, in the as-received condition reveals a single-phase solid solution (Figure 1A). A CRONIRO washer preform, brazed to a graphite element surface in the absence of molybdenum, shows only an isolated phase in a homogeneous matrix and a similar phase at the graphite interface. These phases polish metallographically in relief, suggesting a hard material. Since only graphite is added to the system, the hard phases observed are most likely carbides and correlate with the hard elongated particles observed in the proximity of the graphite in Figure 2A.

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In another experiment, CRONIRO metal, in the form of transfer tape, was brazed within a hole drilled into a TZM molybdenum orifice, out of contact with graphite. As shown in Figure 3A, a plane-polishing, dendritic phase is generally formed.

These results indicate, therefore, that the flat-polishing, usually dendritic phases close to the orifice are associated with the TZM molybdenum-CRONIRO system, the relief-polishing, separated phases nearest the element wall are associated with the graphite-CRONIRO system, and the complete graphite-CRONIRO-molybdenum system is necessary for formation of the continuous, serpentine phase.

A further point should be mentioned here in reference to the generally continuous, serpentine phase. Upon close examination under the microscope, a subtle but distinct difference in color was noted between the side of the phase facing the graphite and the side facing the orifice. The appearance suggested a bifurcation in composition, extending the full length of the phase. Unfortunately, this apparent difference is not easily seen in the photomicrographs. Rather than attempting to develop optical metallographic procedures to demonstrate the observation, an electron microprobe examination was made.

An area similar to that shown in Figure 4A was studied at a magnification of 600 X on an ARL Electron-Microprobe, Model AMX. A series of element distribution photographs were taken of the oscilloscope presentation of the x-ray images. To aid in their interpretation, a sample current image was photographed, showing the distribution of the various phases (Figure 5A), and the background x-radiation was recorded (Figure 6A).

The element distribution photographs are shown in pairs, each pair corresponding to one of the elements Ni, Au, Mo, and Cr. One of each pair is the x-ray image of the particular element distribution within the field of study, and the other is a superimposition of the x-ray image upon the sample current photograph. Inspection of each pair shows clearly how the elements are distributed within each phase:

Ni - Generally distributed except in graphite-side of the "serpentine" phase.
(Compare Figures 7A(a) and 7A(b).

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- Au - Generally distributed except in the graphite side of the "snake" phase - less Au than Ni in the Mo side of the snake phase; low gold in the dendritic phases (compare Figures 8A(a) and 8A(b).
- Mo - High in the serpentine phase, also high in phases close to Mo orifice, low elsewhere (compare Figures 9A(a) and 9A(b).
- Cr - Generally distributed but low on Mo side of snake phase, where it is largely replaced by Ni (major) and Au (minor) (compare Figures 10A(a) and 10A(b).

These observations were substantiated by microprobe traverses taken across selected areas and recorded on an X-Y recorder as a trace of x-ray intensity versus distance traversed for each of the four elements Mo, Cr, Ni and Au. The distribution of carbon could not be determined from an x-ray image oscillogram or from a microprobe traverse as were the other elemental distributions.

Thus, the serpentine phase is seen to be a complex carbide composed of molybdenum, with a partition of chromium on the side facing the graphite element, and nickel on the side facing the orifice. Gold is associated with the nickel in this phase and is present here in smaller quantities than in the matrix phase.

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100 X

Figure 1A. Photomicrograph of CRONIRO Braze Metal, in As-Received Condition (Cold Rolled and Bright Annealed)

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Figure 2A. Cross Section of Washer Preform Brazed to Graphite Element Surface

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75X

Figure 3A. CRONIRO Braze Within Cavity in TZM Molybdenum Orifice
No Graphite is Present.

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200X

Figure 4A. Optical Photomicrograph Showing Structure Typical of Braze
Subjected to Microprobe Analysis

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Figure 5A. Sample Current Electron Microprobe Photograph of Braze
in Threaded Joint

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600X

Figure 6A. Electron Microprobe Photograph, Threaded Joint Braze,
Background X-Radiation
 $\lambda = 1.750$

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GRAPHITE METAL

GRAPHITE

ORIFICE

(a) Nickel Distribution 600X

BRAZE METAL

GRAPHITE

ORIFICE

(b) Nickel Distribution Superimposed
Upon Specimen Current Display 600X

Figure 7A. Electron Microprobe Oscillographs - Nickel Distribution
in Threaded Orifice Braze Joint

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(a) Gold Distribution 600X

(b) Gold Distribution 600X

Superimposed Upon Specimen Current Display

Figure 8A. Electron Microprobe Oscillographs-Gold Distribution in
Threaded Orifice Braze Joint

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BRAZE METAL

GRAPHITE

ORIFICE

(a) Molybdenum Distribution 600X
BRAZE METAL

GRAPHITE

(b) Molybdenum Distribution Super-
Imposed Upon Current Display 600X

Figure 9A. Electron Microprobe Oscillographs - Molybdenum Distribution in
Threaded Orifice Braze Joint

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(a) Chromium Distribution 600X

(b) Chromium Distribution Super-
imposed Upon Specimen Current
Display 600X

Figure 10A. Electron Microprobe Oscillographs - Chromium Distribution in
Threaded Orifice Braze Joint

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APPENDIX B

METALLOGRAPHIC PROCEDURE

Proper metallographic procedure must be followed in the preparation of CRONIRO-TZM molybdenum - fuel element braze joints in order to avoid artifacts. As shown in Figure 1B, the use of excessive amounts of Cr_2O_3 solution, used normally to remove fine scratches in the final polishing stage, results in etching out of the Mo-Cr-Ni serpentine phase. The resulting artifact can be misinterpreted as a crack or separation in the braze metal. Proper technique, where the amount of chromic acid in the polishing solution is kept to a minimal amount, results in photomicrographs such as shown in the text, e.g., see Figures 17 and 19.

The procedure used for satisfactory metallographic results is described as follows:

- 1) Grind through 400 grit paper with water as lubricant.
- 2) Grind through 600 grit paper with wax as lubricant.
- 3) Polish on silk cloth with a solution of 1 gram Cr_2O_3 in 300 ml water -Linde B slurry.
- 4) Repeat step 3 on Microcloth.

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ARTIFACT
SHOWN BY
ARROW

100X

Figure 1B. Orifice Braze Joint Showing Artifact Caused by Overetching

Note Continuation of the Etched-Out Phase at the End
Points of the Artifact.

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APPENDIX C

The following drawings are included in the appendix:

- 1) WANL Drawing 388D842, "Orifice Jet-Cluster Assembly".
- 2) WANL Drawing 388D439, "Jet, Threaded-Cluster Assembly".
- 3) WANL Drawing 388D437, "Orifice Jet-Cluster Assembly".

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SCOPE OF TEST FOR
ORIFICE SEAL-BRAZE DEVELOPMENT & TESTING

58DM-033-3

This document supersedes 58DM-033-2.

1. PURPOSE OF TEST (U)

- (CRD) The purpose of this program is to develop orifice jet configurations and a brazing process that will consistently make acceptable braze joints between molybdenum orifices and R-1 type graphite fuel elements. The braze process developed shall be applicable to both regular orifice jets and threaded orifice jets. All development effort and tests are to be considered within the scope of this document.
- (U) The purpose of this revision is to modify the development program to include the cyclic conditions identified in SNPO Change Order 70-1.
- (U) This effort provides development data in support of Paragraphs 3.1.1.1.8, 3.1.1.2.1 and 3.3.1 of EC 677558.

2. REQUIRED TESTS (U)

- (U) The development effort and tests specified in this document shall include, but not be limited to, the following:

2.1 Development Effort (U)

- (CRD) 2.1.1 Materials Department shall develop a satisfactory process for brazing orifice jets of molybdenum (PDS 30012) to AXM and/or AXF graphite fuel elements. The process developed is to be adaptable to the production brazing requirements of the R-1 program.
- (U) 2.1.2 Initial braze development may be accomplished with uncoated, unfueled elements. Code three graphite elements with AXF or AXM material certification may be used.
- (U) 2.1.3 Backup initial braze development may be accomplished with coated, unfueled elements. Code three graphite elements with AXF or AXM material certification may be used.

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- (U) 2.1.4 Final braze development shall be accomplished using both fueled and unfueled elements. The fueled elements are to be used to corroborate braze techniques and data developed using unfueled elements.
- (CRD) 2.1.5 Final development testing of the braze joint shall be accomplished using both coated and uncoated unfueled elements. Four elements of each type are required for testing. Each element shall contain 18 orifice jets and one threaded orifices jet as described in 577F509 G01.
- 2.2 Test Effort (U)
- (U) 2.2.1 Metallographic Examination - The brazed joints shall be examined as required to determine the acceptability of the braze.
- (U) 2.2.2 Helium Leak Tests - The brazed joints shall be leak tested at 20 psig using bubble leak detection techniques and helium gas. An acceptable braze will show no bubbles after three minutes. All leak tests shall be performed at room temperature.
- (U) 2.2.3 Thermal-Cyclic Tests - The brazed joints shall be cycled through sixty (60) thermal cycles. Each cycle shall consist of raising the specimen temperature from LN₂ to 1700°R and then returning it to LN₂ temperature. The specimen shall be held at each temperature for a period that will assure a constant temperature throughout.
- (CRD) 2.2.4 Testing shall be accomplished on eight (8) specimens to verify the acceptability of the braze joint. This testing shall be accomplished on elements containing the full compliment of orifices (18 orifice jets and 1 centrally located threaded orifice). Each specimen shall be tested in the following sequence:
- (1) leak check
 - (2) thermo-cycle (60 cycles)
 - (3) leak check
 - (4) metallographic examination

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Page 3 of 3

- (CRD) 2.2.5 Three (3) specimens meeting the requirements of Paragraph 2.2.4 with the exception of metallographic examination, shall be forwarded to EML to support part of the threaded orifice pullout test, 58DE-160-0.

3. REQUIRED TEST COMPLETION DATE (U)

- (U) 3.1 Required Date - February 15, 1970.

4. DATA REQUIRED (U)

- (U) 4.1 The braze alloy, brazing temperature, joint clearance, tolerance range and other process data required to produce a satisfactory braze joint.
- (U) 4.2 Metallurgical sections to show the effect of thermo-cycling on brazed joint integrity.
- (U) 4.3 Statistical results of leak tests.
- (U) 4.4 Effect of UC₂ on brazed joint if any.
- (U) 4.5 Effect of brazing to coated and uncoated surfaces.

5. TEST HARDWARE (U)

- (CRD) 5.1 Manufacturing Engineering is to provide orifice jets and threaded orifices for this braze effort as developed per Scope of Test document 58DC-202.
- (U) 5.2 Element braze specimens per Drawing Nos. 577F509, 388D807, and 981D357 shall be ordered by Reactor Design.
- (U) 5.3 Materials shall provide braze alloy and all fabrication and test hardware required.

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58DM-033-4
Page 1 of 1

SCOPE OF TEST FOR
ORIFICE SEAL-BRAZE DEVELOPMENT & TEST (U)

58DM-033-4

Reason for Change:

To bring cyclic temperature test requirements into line with maximum reactor conditions.

Revise Paragraph 2.2.3 to read:

Thermal-Cyclic Tests - The brazed joints shall be cycled through 60 thermal cycles. Each cycle shall consist of raising the specimen temperature from LN_2 temperature to room temperature, to $1000^{\circ}R$ then forced air cooled to room temperature followed by cooling to LN_2 temperature.

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SECURITY CLASS CONFIDENTIAL RESTRICTED DATA ATOMIC ENERGY ACT OF 1954 Cp-1		DATA RELEASE MEMORANDUM Westinghouse Astronuclear Laboratory CODE IDENT NO. 14683 (THIS PAGE UNCLASSIFIED) SHEET <u>1</u> OF <u>5</u>				DRM NO 51291	REV (1)	
SUBJECT (120) BRAZING - MOLYBDENUM ORIFICE JETS TO PEWEE 2 FUEL ELEMENTS						DRM TYPE (13) Process Description DEPARTMENT (13) MATERIALS DATE (6) 8-7-70		REACTOR Pewee 2
PARA NO	CEI	PARA NO	CEI	PARA NO	CEI	TEST SCOPE NO	DATA ITEM	
1.							1.	2.
2.							3.	4.
3.							5.	6.
DOCUMENT REFERENCES (DWGNO/PART NO/COMPUTER CODES/DRMS/MTLS SPECS/CORRESPONDENCE)								
WANL								
1.		2.		3.		4.		5.
6.		7.		8.		9.		10.
1. PURPOSE 2. ASSUMPTIONS/METHODS 3. CONCLUSIONS (USE CONTINUATION SHEET IF NECESSARY)								
<p>1. <u>PURPOSE</u></p> <p>To provide description of a) process for brazing of orifices to Pewee 2 fuel elements, and b) inspection procedure for the braze joint quality.</p> <p>2. <u>ASSUMPTIONS/METHODS</u></p> <p>The process, as described, represents the most reliable brazing technique developed to date under Test Scope No. 58DM-033, as determined by using the same types of materials as those specified for the Pewee 2 brazed elements.</p> <p>3. <u>CONCLUSIONS</u></p> <p>(Not Applicable)</p>								
APPROVALS <div style="border-bottom: 1px solid black; margin-bottom: 5px;"> C. Kubit 8/7/70 </div> PREPARED BY DATE				INFORMATION CATEGORY <div style="border-bottom: 1px solid black; margin-bottom: 5px;"> Unclassified </div> CLASSIFICATION				SECURITY CLASS CONFIDENTIAL RESTRICTED DATA ATOMIC ENERGY ACT OF 1954 Cp-1
<div style="border-bottom: 1px solid black; margin-bottom: 5px;"> E. Clayton 8/7/70 </div> APPROVED BY DATE				<div style="border-bottom: 1px solid black; margin-bottom: 5px;"> E. Clayton 8/7/70 </div> AUTHORIZED CLASSIFIER DATE				

 WANL FORM NO. 59919A

SECURITY CLASS

UNCLASSIFIED

DATA RELEASE MEMORANDUM
CONTINUATION SHEET

DRM NO.

51291

REV

SHEET 2 OF 5

BRAZING - MOLYBDENUM ORIFICE JETS TO PEWEE 2 FUEL ELEMENTS

PROCESS DESCRIPTION1. MATERIALS

- 1.1 Pewee 2 fuel elements.
- 1.2 Molybdenum orifices per 910E130.
- 1.3 Braze alloy washers of the following composition and dimensions:

Composition

72% gold)
22% nickel) - (All percentages by weight, to $\pm 1/2\%$)
6% chromium)

This material is known by the trade names
"CRONIRO"* and "PREMABRAZE 128."**

Dimensions

0.140" $\begin{matrix} +0.002" \\ -0.000" \end{matrix}$ O. D.
0.110" $\begin{matrix} +0.002" \\ -0.000" \end{matrix}$ I. D.
0.005" $\pm 0.001"$ Thick

* Western Gold and Platinum Company, Belmont, California.

** Hardy and Harman Corporation, New York, N. Y.

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DATA RELEASE MEMORANDUM
CONTINUATION SHEET

DRM NO.

51291

REV

SHEET 3 OF 5

2. PREPARATION OF COMPONENTS

- 2.1 Clean the molybdenum orifice jets in acetone. Flush with liquid Freon followed by a flush in Freon gas.
- 2.2 Clean the braze alloy washers using the same technique as in 2.1 (The braze alloy sheet material has been previously annealed in hydrogen at 1600°F for 30-60 minutes and the washers are made from this annealed sheet by stamping.).
- 2.3 Prepare the fuel elements by flowing argon, helium, or nitrogen gas through the channels, followed by a Freon gas flush.
- 2.4 Handle all prepared components with clean linen gloves or equivalent.

3. ASSEMBLY OF COMPONENTS

- 3.1 Install the selected fuel element in the fuel element holder.
- 3.2 Obtain orifice assembly "recipe."
- 3.3 Install two (2) braze washers on the proper orifice jet, as determined by the "recipe."
- 3.4 Install the washer-orifice jet assembly into the proper element flow channel, as determined by the "recipe."
- 3.5 Repeat 3.3 and 3.4, as required, for each channel assigned a 910E130 orifice.
- 3.6 Attach the element holder, with the orifice jets topmost, to the braze chamber. Lower insulation collar and susceptor over exposed end of element. Position pyrometer sight hole in susceptor to reveal the element at a point 0.125-0.250 from braze position. Place small section of unfueled element on top of orifices. Load this small section with a steel cylinder weighing 200-210 grams.
- 3.7 Seal braze chamber and prepare for braze cycle.

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SECURITY CLASS UNCLASSIFIED	DATA RELEASE MEMORANDUM CONTINUATION SHEET	DRM NO. 51291
REV		
SHEET <u>4</u> OF <u>5</u>		

4. BRAZING CYCLE

- 4.1 Evacuate the braze chamber to a vacuum of at least 100 microns. Backfill with argon (welding grade) to a slight positive pressure. Repeat the evacuation and backfill cycle three (3) times.
- 4.2 After the third backfill of argon, adjust the argon flow to a flow rate of 3 to 5 cu. ft. per hour. Be sure the gas outlet is within an operating exhaust hood usable for radioactive materials.
- 4.3 Using induction heating, heat the region of the element containing the orifices to $1000 \pm 50^{\circ}\text{F}$. Start to evacuate the braze chamber and stop the argon flow. Hold at this temperature until the pressure is reduced to 60-80 microns.
- 4.4 Reinststate the argon flow to a flow rate of 3 to 5 cu. ft. per hour and shut off the vacuum pump.
- 4.5 Heat to $1600 \pm 25^{\circ}\text{F}$ and hold at this temperature for two (2) minutes.
- 4.6 Increase temperature to $2100^{\circ}\text{F} \pm 50^{\circ}\text{F}$ and hold at this temperature for one (1) minute.
- 4.7 Shut off power. Increase argon flow rate to 10 to 15 cu. ft. per hour. Maintain the argon flow rate for fifteen (15) minutes. Replace the argon with helium at a flow rate of 10 to 15 cu. ft. per hour until the brazed element is cool.
- 4.8 Stop gas flow and remove fuel element holder from braze chamber.

5. INSPECTION PROCEDURE

- 5.1 Visually inspect element for evidence of braze fillet around the brazed orifices.
- 5.2 Remove element from element holder.
- 5.3 Check each brazed orifice for leaks using a flow meter as follows (Do not use a liquid leak detector.):
 - 5.3.1 Place a temporary seal over the flow hole of the orifice jet under test.

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DATA RELEASE MEMORANDUM
CONTINUATION SHEET

DRM NO.

51291

REV

SHEET 5 OF 5

5. INSPECTION PROCEDURE (cont'd)

- 5.3.2 Insert the leak check probe into the open end of the channel containing the orifice under inspection.
- 5.3.3 Pressurize the channel with helium (welding grade) to 20-25 psi.
- 5.3.4 Observe the leak rate, if any. Consider all orifices showing a leak rate equal to or less than 10 cc. per minute as acceptably brazed. Recycle if necessary.
- 5.3.5 Move acceptable elements to designated area.

6. BRAZE REPAIR PROCEDURE

- 6.1 Repair all brazed orifices showing a leak rate of greater than 10 cc. per minute as follows:
 - 6.1.1 Place a tightly wound spiral of 6-mil diameter wire of the braze composition over the exposed head of the orifice to be repaired. The bottom of the wire spiral must be placed at the point of contact of the orifice jet with the fuel element surface. Prior to insertion, the spiral is prefabricated by wrapping the wire 3 - 3-1/2 times around a #36 or #37 drill.
 - 6.1.2 Braze as per section 4.0.
 - 6.1.3 Repeat Inspection Procedure 5.0.

SECURITY CLASS

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SECURITY CLASS <i>Unclassified</i>		DATA RELEASE MEMORANDUM Westinghouse Astronuclear Laboratory CODE IDENT NO. 14683				DRM NO 51263	REV (1) A
SUBJECT (120) Brazing Molybdenum Orifice Jets to Unfueled Graphite Elements						SHEET <u>1</u> OF <u>5</u>	
						PROC DSCRPTN Materials	
						DATE (6) 091670	REACTOR R-1
PARA NO	CEI	PARA NO	CEI	PARA NO	CEI	TEST SCOPE NO	DATA ITEM
1.						58DE-160	1. 2.
2.							3. 4.
3.							5. 6.
DOCUMENT REFERENCES (DWGNO/PART NO/COMPUTER CODES/DRMS/MTLS SPECS/CORRESPONDENCE)							
1. 388D437	2. 388D439	3. 577F509	4.	5.			
6.	7.	8.	9.	10.			
1. PURPOSE 2. ASSUMPTIONS/METHODS 3. CONCLUSIONS (USE CONTINUATION SHEET IF NECESSARY)							
<p>1. PURPOSE</p> <p>To provide description of process for brazing of test specimens to be used for threaded orifice pull-out test (TS 58DE-160).</p> <p>2. ASSUMPTIONS/METHODS</p> <p>The process, as described, represents the best brazing technique developed to date under Test Scope No. 58DM-033, and has been qualified by leak-tight brazes using the same types of materials as those to be used for the specimens in Test Scope 58DE-160. The process is described in the attached pages.</p> <p>3. CONCLUSIONS</p> <p>(Not Applicable)</p>							
APPROVALS <i>P. J. Kulbit</i> 9/22/70 PREPARED BY DATE <i>J. T. Thompson</i> 9/22/70 APPROVED BY DATE				INFORMATION CATEGORY <i>Unclassified</i> CLASSIFICATION <i>J. T. Thompson</i> 9/22/70 AUTHORIZED CLASSIFIER DATE		SECURITY CLASS <i>Unclassified</i>	

Re: BRAZING MOLYBDENUM ORIFICE JETS TO UNFUELED GRAPHITE ELEMENTS

PROCESS DESCRIPTION1. MATERIALS

- 1.1 Graphite elements (per 577F509H01 (A, B, or C))
- 1.2 Molybdenum orifices per { 388D439H01B (H02B thru H15B is acceptable)
388D437H01A (H02A thru H15 is acceptable)
- 1.3 Braze alloy washers of the following composition and dimensions:

Composition	
72% gold 22% nickel 6% chromium	(all percentages, by weight, to $\pm 1/2\%$)

This material is known by the trade names
"CRONIRO"* and "PREMABRAZE 128."**

Dimensions	
0.136" $\begin{matrix} +0.002" \\ -0.000" \end{matrix}$	- O. D.
0.099" $\begin{matrix} +0.002" \\ -0.000" \end{matrix}$	- I. D.
0.005" $\pm 0.001"$	- Thick

- 1.4 Braze alloy wire of the same composition as the washers, and of the following dimensions:

Diameter: 5-6 mils

NOTE: The braze alloy material (sheet and wire) has been previously annealed in hydrogen at 1600°F for 30-60 minutes. The washers were made from the annealed sheet by die stamping. The wire was annealed after final drawing to size.

* Western Gold and Platinum Company, Belmont, California.

** Hardy and Harman Corporation, New York, N. Y.

Re: BRAZING MOLYBDENUM ORIFICE JETS TO UNFUELED GRAPHITE ELEMENTS

PROCESS DESCRIPTION2. PREPARATION OF COMPONENTS

- 2.1 Visually inspect the regular and threaded molybdenum orifice jets. Remove any loose powdered material on the outside diameters by brushing with a nylon bristle brush under running water.
- 2.2 Clean the regular and threaded molybdenum orifice jets and the braze alloy washers with acetone.
- 2.3 Weigh the clean and dry threaded orifice to the nearest milligram, and record the weight.
- 2.4 Clean the graphite elements by flowing argon, helium, or nitrogen gas through the channels. Use gas of welding grade, minimum purity. Follow by a Freon gas flush.
- 2.5 Cut sections of braze alloy wire to the length listed in 3.2. Wipe with cloth saturated with acetone.
- 2.6 Avoid handling cleaned braze alloy washers, braze alloy wire, and brazing surfaces of the orifices and graphite element with bare hands.

3. ASSEMBLY OF COMPONENTS3.1 Orifice Jets

- 3.1.1 - Place a single braze washer on a small orifice jet (388D437H01A thru H15A).
- 3.1.2 - Install the orifice jet-washer assembly into one of the six graphite element channels immediately adjacent the central channel, as per appropriate drawing.
- 3.1.3 - Repeat 2.1 and 2.2 for the total required orifice jet-washer assemblies.

3.2 Threaded Orifices (388D439H01B thru H15B)

- 3.2.1 - Wrap a sufficient length (13-1/2 inches minimum) of braze alloy wire around the machined cavity immediately adjacent to the 0.500-inch long threaded portion of the orifice (see appropriate drawing) until the wire surface is approximately flush with the outer diameter of the orifice. * Tack-weld the wire ends, using a capacitance welder or equivalent, to facilitate handling.

*As a guide, approximately 17-1/2" (length) of wire will fully fill the appropriate cavity when tightly wound.

Re: BRAZING MOLYBDENUM ORIFICE JETS TO UNFUELED GRAPHITE ELEMENTS

3. ASSEMBLY OF COMPONENTS (cont' d)

- 3.2.2 - Clean the wire-wrapped orifice by flushing with Freon gas.
 - 3.2.3 - Weigh the wire-wrapped orifice to the nearest milligram. Obtain the weight of wire by difference and record. The minimum weight of wire metal required is 95 milligrams. Repeat 3.2.1, 3.2.2, and 3.2.3, if necessary, to obtain the required minimum.
 - 3.2.4 - Install wire-wrapped orifice into the central channel of a graphite element, per appropriate drawing. Turn the orifice within the channel until the orifice is fully threaded, as determined by meeting slight resistance. Do not force orifice into channel. Record serial number of threaded orifice and graphite element.
- 3.3 Attach the element holder, with the orifice jets topmost, to the braze chamber. Lower insulation collar and susceptor over exposed end of element. Position pyrometer sight hole in susceptor to reveal the element at a point 0.125-0.250" from braze position. Place small section of graphite or unfueled element on top of orifices. Load this small section with a steel cylinder weighing 200-210 grams.
- 3.4 Seal braze chamber and prepare for braze cycle.

4. BRAZING CYCLE*

- 4.1 Evacuate the braze chamber to a vacuum of at least 100 microns. Backfill with argon (welding grade) to a slight positive pressure. Repeat the evacuation and backfill cycle three (3) times.
- 4.2 After the third backfill of argon, re-evacuate to at least 100 microns pressure.
- 4.3 Using induction heating, heat the region of the element containing the orifices to $1000 \pm 50^\circ\text{F}$. Continue to evacuate the braze chamber. Hold at this temperature for a minimum of 30 minutes until the pressure is reduced to 60-80 microns (to outgas the system).
- 4.4 Reinstate the argon flow to a flow rate of 3-5 cu. ft. per hour and shut off the vacuum pump.

*NOTE: The temperatures indicated are as read by a calibrated optical pyrometer through the clean vycor brazing chamber. The optical pyrometer shall be corrected for the emissivity of graphite of 0.90 ± 0.02 by manual adjustment.

Re: BRAZING MOLYBDENUM ORIFICE JETS TO UNFUELED GRAPHITE ELEMENTS

PROCESS DESCRIPTION

4. BRAZING CYCLE (cont'd)

4.5 Heat to $1600 \pm 25^{\circ}\text{F}$ and hold at this temperature for two (2) minutes.

4.6 Increase temperature to $2100^{\circ}\text{F} \pm 50^{\circ}\text{F}$ and hold at this temperature for one (1) minute.

4.7 Shut off power. Increase argon flow rate to 10-15 cu. ft. per hour. Maintain the argon flow rate for fifteen (15) minutes. Replace the argon with helium at a flow rate of 10-15 cu. ft. per hour until the brazed element is cool.

4.8 Stop gas flow and remove fuel element holder from braze chamber.

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
D6	A	ADDED 3/2 TO "A" DIA HOLE PART NO. REV OF ITEMS 1 THRU 15 WAS - ECO 16,582	J.W.W 2-25-69 3-11-69 3-11-69 3-11-69	<i>[Signature]</i> <i>[Signature]</i> <i>[Signature]</i> <i>[Signature]</i>

ITEM NO	"A" DIA	"A" DIA TOLERANCE	"B" RADIUS MAX
1	.0190	±.0002	.0002
2	.0200	±.0002	.0002
3	.0210	±.0002	.0002
4	.0225	±.0002	.0002
5	.0240	±.0002	.0002
6	.0255	±.0003	.0003
7	.0275	±.0003	.0003
8	.0300	±.0003	.0003
9	.0330	±.0003	.0003
10	.0360	±.0004	.0004
11	.0400	±.0004	.0004
12	.0450	±.0005	.0005
13	.0500	±.0005	.0005
14	.0600	±.0005	.0006
15	.0700	±.0005	.0007

- 3 - THIS DIMENSION APPLIES FOR FULL LENGTH OF PART.
- 2 - REMOVE ALL BURRS AND BREAK ALL SHARP EDGES .005 MAX RADIUS OR CHAMFER UNLESS OTHERWISE SPECIFIED.
- 1 - MARK PART NUMBER ON CONTAINER PER P294517-1.

1	15	ORIFICE, JET		388D437H15A	Mo	PDS 30012-1		
1	14			H14A				
1	13			H13A				
1	12			H12A				
1	11			H11A				
1	10			H10A				
1	9			H09A				
1	8			H08A				
1	7			H07A				
1	6			H06A				
1	5			H05A				
1	4			H04A				
1	3			H03A				
1	2			H02A				
1	1	ORIFICE, JET		388D437H01A	Mo	PDS 30012-1		
QTY. REQD.	SYM	ITEM NO.	NOMENCLATURE OR DESCRIPTION	CODE IDENT NO.	PART OR IDENTIFYING NO.	MATERIAL	SPECIFICATION	ZONE

LIST OF MATERIALS

			UNLESS OTHERWISE SPECIFIED			CONTRACT NO. NP-1			Westinghouse Astronuclear Laboratory Pittsburgh, Pennsylvania					
			INTERPRET DWG PER MIL-D-1000 DIM IN INCHES BASED ON 68°F			DATE OF DWG 12-2-68			ORIFICE, JET - CLUSTER ASSEMBLY (U)					
			TOLERANCES - DO NOT SCALE			CHECKER 12-7-68 12-13-68 RWT						RELIAB & Q. A.		
			2PL DEC 3PL DEC ANGLES 1/25			DESIGN 12-7-68						MFG		
			±.02 ±.005 ± 1°			ANALYSIS						STRESS		
			- 1 003TIR			MAYL			DFT SUPV W.P. March 12/69					
NEXT ASSY		USED ON		P294517-1		IDENT		INFORMATION CATEGORY C-RD						
G APPLICATION		SPECIFICATION		TYPE		James W. Funch 12/13/68 AUTHORIZED CLASSIFIER DATE								
DWG CODE NO.		3		L/O 939J698										
SCALE 10/1		WT ACT		WT CALC		SHEET 1		OF 1						

Figure 1C. Orifice, Jet-Cluster Assembly

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REVISIONS			
ZONE	LTR	DESCRIPTION	DATE
C7	A	ADDED LAPPED FINISH 8	J.W.W.
C7		ADDED 3 FINISH SYMBOL	02-26-68
C5		ADDED 3 FINISH SYMBOL	3-11-69
		DELETED 1.520 DIM SHOWING DEPTH OF .085 DIA HOLE	
C7		ADDED .060 ± .015 DIM TO SHOW LENGTH OF "A" DIA HOLE	
		ADDED VIEW A TO SHOW DRILL POINT	
		ADDED NOTE 3	
		PART NO. REV OF ITEMS 1 THRU 15 WAS - ECO 16,582	3/11/69 M.P. Lucken
A6		ADDED NOTE 4	KRAWCZAK
A4	B	ADDED P 294564-2 CLASS O INSPECTION PART NO. REV OF ITEMS 1 THRU 15 WAS A	6/16/69 E.D. Parake
		ECO 16,641	6-12-69 M.P. Lucken

ITEM NO	"A" DIA	"A" DIA TOLERANCE	"B" RADIUS MAX
1	.0190	±.0002	.0002
2	.0200	±.0002	.0002
3	.0210	±.0002	.0002
4	.0225	±.0002	.0002
5	.0240	±.0002	.0002
6	.0255	±.0003	.0003
7	.0275	±.0003	.0003
8	.0300	±.0003	.0003
9	.0330	±.0003	.0003
10	.0360	±.0004	.0004
11	.0400	±.0004	.0004
12	.0450	±.0005	.0005
13	.0500	±.0005	.0005
14	.0600	±.0005	.0006
15	.0700	±.0005	.0007

- 4 - LIQUID PENETRANT INSPECTION PER P294564-2 CLASS O SHALL BE PERFORMED ON O.D. SURFACE OF UNTHREADED LENGTH INCLUDING 2 THREAD RELIEFS.
- 3 - TRANSITION FROM .085 DIA TO "A" DIA MAY BE OPTIONALLY FLAT BOTTOM OR DRILL ANGLE
- 2 - REMOVE ALL BURRS AND BREAK ALL SHARP EDGES .005 MAX RADIUS OR CHAMFER UNLESS OTHERWISE SPECIFIED.
- 1 - TAG PART NUMBER PER P294517-1

	1	15	JET, THREADED		388D439H15B	MO	PDS 30012-1	
1		14			H14B			
1		13			H13B			
1		12			H12B			
1		11			H11B			
1		10			H10B			
1		9			H09B			
1		8			H08B			
1		7			H07B			
1		6			H06B			
1		5			H05B			
1		4			H04B			
1		3			H03B			
1		2			H02B			
1	1	1	JET, THREADED		388D439H01B	MO	PDS 30012-1	
QTY. REQD	SYM	ITEM NO.	NOMENCLATURE OR DESCRIPTION	CODE IDENT NO.	PART OR IDENTIFYING NO.	MATERIAL	SPECIFICATION	ZONE
LIST OF MATERIALS								
			UNLESS OTHERWISE SPECIFIED	CONTRACT NO. NP-1		Westinghouse Astronuclear Laboratory		
			INTERPRET DWG PER MIL-D-1000 DIM IN INCHES BASED ON 68°F	DATE OF DWG 11/1/68		Pittsburgh, Pennsylvania		
			TOLERANCES - DO NOT SCALE	CHECKER: J.W.W. DESIGNED BY: J.W.W.		RELIAB & Q.A.		
			2PL DEC 3PL DEC ANGLES 125	DESIGN 1-27-68		NFG		
			±.02 ±.005 ± 5°	ANALYSIS		STRESS		
			AA	MATL		DRY SUPPLY 11/1/68		
P294564-2	CLASS 0 INSPECTION					JET, THREADED - CLUSTER ASSEMBLY		
P 294517-1	IDENT							
	SPECIFICATION	TYPE						
L/O 939J698								
			INFORMATION CATEGORY					
			UNCLASSIFIED					
			APPROVED AUTHORIZED CLASSIFIER	DATE				
DWG SIZE D		CODE IDENT NO. 14683		DWG NO. 388D439				
SCALE 4/1		WT ACT -		WT CALC -		SHEET 1		OF 1

Figure 2C. Jet, Threaded-Cluster Assembly

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	AT TRANSITION OF .084 $\pm$.000 DIA AND .109 $\pm$.000 DIA, ADDED 45° $\pm$ 1° CHAMFER PART NO REV OF ITEMS 1 THRU 16 WAS - ERCO 20,079 J.W.WILLIAMS III	7-21-70 7-21-70	R. J. R. [Signature]

ITEM NO	A DIA	A DIA TOLERANCE	B RADIUS MAX
1	.0190	$\pm$.0002	.0002
2	.0200	$\pm$.0002	.0002
3	.0210	$\pm$.0002	.0002
4	.0225	$\pm$.0002	.0002
5	.0240	$\pm$.0002	.0002
6	.0255	$\pm$.0003	.0003
7	.0275	$\pm$.0003	.0003
8	.0300	$\pm$.0003	.0003
9	.0330	$\pm$.0003	.0003
10	.0360	$\pm$.0004	.0004
11	.0400	$\pm$.0004	.0004
12	.0450	$\pm$.0005	.0005
13	.0500	$\pm$.0005	.0005
14	.0600	$\pm$.0005	.0006
15	.0700	$\pm$.0005	.0007
16			

- 4 ∇ A .003 APPLIES TO ALL DIAMETERS COAXIAL TO A.
- 3 ∇ THIS DIMENSION APPLIES FOR FULL LENGTH OF PART.
- 2 — REMOVE ALL BURRS AND BREAK ALL SHARP EDGES .005 MAX RADIUS OR CHAMFER UNLESS OTHERWISE SPECIFIED.
- 1 — MARK PART NUMBER ON CONTAINER PER P294517-1

1	16	ORIFICE, JET	388D842H16A	MO	PDS30012-1
1	15		H15A		
1	14		H14A		
1	13		H13A		
1	12		H12A		
1	11		H11A		
1	10		H10A		
1	9		H09A		
1	8		H08A		
1	7		H07A		
1	6		H06A		
1	5		H05A		
1	4		H04A		
1	3		H03A		
1	2		H02A		
1	1	ORIFICE, JET	388D842H01A	MO	PDS30012-1

QTY REQD	SYM	ITEM NO.	NOMENCLATURE OR DESCRIPTION	CODE IDENT NO.	PART OR IDENTIFYING NO.	MATERIAL	SPECIFICATION	ZONE
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UNLESS OTHERWISE SPECIFIED				CONTRACT NO. NP-1	
INTERPRET DWG PER MIL-D-1000 DIM IN INCHES BASED ON 68°F				DATE OF DWG 5-18-70	
TOLERANCES - DO NOT SCALE				CHECKED BY M.L. MOWRY	
2PL DEC 3PL DEC ANGLES 1/25				DESIGNER R. J. R.	
$\pm$.02 $\pm$.005 $\pm$				ANALYSIS	
— 1 —				MATERIAL	
NEXT ASSY		USED ON P294517-1	IDENT	INFORMATION CATEGORY UNCLASSIFIED	
G APPLICATION		SPECIFICATION	TYPE	DATE 5-18-70	
DWG CODE NO. 3				AUTHORIZED CLASSIFIER	
				DATE	
Westinghouse Astronuclear Laboratory Pittsburgh, Pennsylvania				ORIFICE, JET CLUSTER ASSEMBLY	
DWG SIZE D		CODE IDENT NO. 14683		DWG NO. 388D842	
SCALE 10/1		WT ACT.		WT CALC	
				SHEET 1 OF 1	

Figure 3C. Orifice, Jet-Cluster Assembly

Fold
— — —
or Cut

TITLE Orifice Jet Brazing Process Development, Qualification, and Initial Application	
	DOCUMENT NO. WANL-TME-2780	DATE May 1971
ABSTRACT Experiments were carried out to develop acceptable procedures for brazing molybdenum alloy orifices to fuel element channel inlets of the NERVA R-1 reactor core. Results achieved with various procedures are described, and qualification tests of the selected process are documented. The recommended procedure includes preplacing of Au-Ni-Cr alloy washers and induction heating to 1600°F, holding two minutes, heating further to 2400°F, holding one minute, and allowing to cool. Inert atmosphere is used, and fixturing maintains proper positioning of the orifices. Leak testing of the joints has demonstrated reproducibly satisfactory sealing. Repair brazing is feasible if needed.		
DATA ITEM NO. N. A.	SECURITY CLASSIFICATION OF DOCUMENT C-RD	
CDRL LINE NO.	TOTAL NO. OF PAGES	
KEY WORDS <p style="text-align: center;">Pressing, Fuel Element, Orifice</p>		
AUTHOR/EDITOR C. J. Kubit/J. B. McAndrew		PREPARING DEPT. Materials
W Form 59943 DOCUMENT INFORMATION SUMMARY		

Fold
— — —
or Cut