MLM-3250(OP)

MLM--3250(OP)

DE85 011281

THE FORMING OF METAL COMPONENTS FOR RADIOISOTOPE HEAT SOURCES

Ernest W. Johnson

Monsanto Research Corporation (MRC)
Mound*
Miamisburg, Ohio 45342
Phone: 513-865-3311

Running head: Components for Radioisotope Heat Sources

*Mound is operated by Monsanto Research Corporation for the U. S. Department of Energy under Contract No. DE-AC04-76DP00053.

ABSTRACT

Use of refractories and noble metals to encapsulate the plutonium-238 fuel used to power radioisotope thermoelectric generators (RTGs) presents a series of problems for the fabricator. These alloys (Ta-10 W, T-111, Mo-Re, Pt-Rh, and Ir-0.3 W) permit the RTG a high operating temperature (which increases the Carnot efficiency) and minimize the risk of releasing plutonium dioxide in an accident.

The choice of materials for heat source construction has evolved from superalloys and refractory metal systems to iridium/carbon. This paper describes techniques employed at MRC to develop flight-quality iridium "Clad Vent Sets" (CVSs) to support production of the General Purpose Heat Source (GPHS). Techniques of forming, welding, and heat treating are addressed, as are the quality requirements necessary to justify employing the "DOP-26" iridium alloy parts as a primary encapsulation for $^{238}PuO_2$ fuel. The methods employed have enabled MRC to meet the DOE-defined requirements to support the CVS requirements for the Galileo (GLL) and International Solar-Polar (ISP) Missions.

INTRODUCTION

The GPHS RTG has been defined as the power generating system to be employed for the GLL and ISP spacecraft. This RTG is shown schematically in Figure 1. Figure 2 illustrates the heat source for this RTG.

Earlier, Monsanto Research Corporation, which operates Mound for the Department of Energy, had been charged with the production of primary containment components for plutonium-238 fuel used in various space missions. For the Viking and Pioneer Missions, molybdenum-47% rhenium, tantalum-10% tungston, T-111, and platinum-10% rhodium parts were produced. Wendeln et al. (1972). The next generator system, the Multi-Hundred Watt (MHW) RTG, featured a clad manufactured from iridium-0.3% tungsten. The technology incorporated in the fabrication of these components is described elsewhere. Wyder (1974); Wyder (1975).

As in the MHW Program, the supplier for the iridium alloy starting blanks and foil for the GPHS Program was the Oak Ridge National Laboratory (ORNL). ORNL had developed the original iridium-0.3% tungsten (DOP-4) alloy, which was used in the MHW Program. Liu and Inouye (1977). Further behavioral enhancement (better high-temperature impact ductility and reduced grain growth rate) was realized by the addition of ∿50 ppm of aluminum and ∿60 ppm of thorium. This alloy was designated DEP-26. Liu and David (1982). Components in various stages of production are shown in Figure 3.

METHODS

The fabrication processes for the various components are described as follows:

A. Cup - The blank is first sandwiched between two 0.08-mm tantalum barrier sheets and electron beam welded into Type 304 stainless steel waster sheets. The rolling direction of the waster sheet is oriented to ±45° with the final rolling direction of the iridium blank. This minimizes forming anisotropy. A two-step, deep-draw process employing heated tooling is performed at 925 → 650°C to transform the metal blank into a cup (Figure 4). The heated tooling is shown schematically in Figure 5.

There are several advantages to this process:

1. Controlled Lubrication - "Grafoil" washers provide good lubrication virtually without tooling wear.

2. Dimensional Control - Compensation inserts correct for wall thickening; final precision sizing is only a minor correction step.

3. Shielded Environment - EB welded pocket prevents unwanted compatibility problems.

4. Earring Neutralized - Waster sheets permit virtual elimination of nonuniform deformation due to sheet rolling processes.

5. Thermal Losses Minimized - Warm-forming temperature is retained by the blank due to the waster sheet insulating properties.

After forming, the barrier and waster sheets are removed, the cup lapped to length, rounded up, and grit blasted to an 0.8-3.2 μm finish. Dimensional and dye penetrant inspection are the principal quality requisités for this component.

The early cup production effort was plagued by the incidence of extremely small surface defects, which were found by the ultrasensitive fluorescent dye penetrant inspection technique being employed. To ascertain whether or not this effect could be done away with, a series of tests among LANL, Mound, and ORNL was performed. The techniques employed by the various participants did not result in reducing the flaking surface grains (Table I). Forming limit diagram analysis indicated that all methods were "in the same ball park" (Figure 6).

After a final one-hour 1500°C vacuum outgas (designed to remove all traces of volatile oxides which may be present after the process), the metal microstructure has changed from a highly wrought one to a material exhibiting an ASTM 6-8 grain size. Although retaining some grain anisotropy due to the warm rolling of the sheet, the as-produced cup grain structure is quite uniform (Figure 7).

B. Weld Shield - To protect the circumferential GTA weld from the plutonium fuel pellet, a weld shield is placed in one GPHS cup. This part is stamped from 0.13-mm iridium foil; the formed piece is rolled over a mandrel, and electron beam butt-welded into a continuous ring.

C. Decontamination Cover - As an assembly aid, the vent orifice must be protected from air and decontamination solutions during assembly. The decontamination cover provides this protection. This component is formed by blanking discs from 0.13-mm foil and pressure-pad forming to the proper configuration. Because a leak-tight seal is required, a fluorescent dye penetrant inspection is the main quality call-out.

D. Vent - The vent is a critical component from safety and operational standpoints. The vent permits the helium which results from alpha decay of plutonium-238 to exit the clad, yet retains solid plutonium particulates. The two vent discs are stamped from 0.13-mm foil. A thin layer (72.5 mg) of iridium powder (-325, +400) is sintered between the two discs. The final part is then less than 0.41-mm thick. The flow rate is 0.075-0.125 cm^3/sec at 7 kPa pressure differential. The general appearance of this component is given in Figure 8.

After piece-part fabricatión, electron beam welds are performed to produce the completed "Clad Vent Sets" shown in Figure 3. Inspections are made for cracks, voids, pores, and penetration; the vent and decontamination cover welds must be leak-tight and fusion continuous. Appearance of the EB welds are shown in Figure 8 (vent) and Figure 9 (decontamination cover and weld shield tab).

QUALITY CONTROL

For the purpose of quality and reliability, a set of GPHS cups undergoes the following in-process and post-processing inspections:

(a) 64 dimensional inspections

(b) 2 flow tests

(c) 2 fluorescent dye penetrant checks

(d) 1 helium leak check

(e) 5 visual checks

(f) Destructive testing (~1 in 50) for metallography, microhardness, and chemical analyses.

As a function of part, Table II compares discrete process steps versus inspection points in the processing of one set of GPHS hardware. This close surveillance of parts throughout the total process has resulted in a very low reject rate in foil and subassembled parts. The major production problem remains that related to the inherent difficulty in achieving a uniform material from which to form cups without delaminated or flaked structure.

MRC has produced ~1900 iridium cups since 1980. The 74 percent "flight-quality" yield testifies to the difficulty of manufacturing the component. The 98% usable product resulted in a quite satisfactory process assessment, however.

Piece-part efficiencies were somewhat better: The weld shield yielded 85% prime parts, decontamination cover success was 92% prime, and 91% of the vents produced were of prime quality. Approximately 98% of the subassemblies were acceptable for prime use after the electron beam welding was completed.

SUMMARY

In summary, flight-quality iridium components can be fabricated from iridium alloys by modifying standard production processes. A large quantity of metrological and NDE data support the quality of these devices, which, in turn, justify their use in containing plutonium fuel for space system applications.

REFERENCES

1. Wendeln, D. E. et al. (1972) "Heat Source Capsule Fabrication Technology Program: Final Report January 1971-March 1972," MLM-1935.

2. Wyder, W. C. "Iridium Hardware Fabrication for the MHW Heat Source," in TRANSACTIONS OF THE AMERICAN NUCLEAR SOCIETY 1974 WINTER MEETING, October 27-31, 1974, Washington, D. C., pp. 36-37.

3. Wyder, W. C. (1976) "Warm Hydroforming of Iridium +0.3 Wt% Tungsten Hemishells," MLM-2203.

4. Liu, C. T. and H. Inouye (1977) "Development and Characterization of an Improved Ir-0.3% W Alloy for Space Radioisotopic Heat Sources," ORNL-5290.

5. Liu, C. T. and S. A. David (1982) "Weld Metal Grain Structure and Mechanical Properties of Iridium Alloy DOP-26," ORNL-5857.

TABLE I - As part of the Iridium Production Technology Program, candidate cup fabrication processes were reviewed. Dye penetrant indications were believed to be the most significant pass-fail criterion; all cup manufacturing processes exhibit this effect to some extent.

Variable	LANL	MRC	ORNL
Blank Temperature	1000°C	925 → 650°C	600°C
Tool Temperature	1000°C	250°C	600°C
Number of Draws	1	2	1
Forming Load	~1800 lb	~8000 lb	~10500 lb
Hold-down Force	600 lb	0	3000 lb
Punch Speed	3 in./min	24 in./min	0.5 in./min
Lubricant	Si_3N_4	C[a]	BN
Dye Penetrant	Yes	Yes	Yes

[a]Waster sheet only.

TABLE II - Numerous inspections are performed on a set or iridium GPHS cups throughout and after processing.

	Process Steps	Inspection Steps
Cup	20	3
Vent	20	3
Weld Shield	9	2
Decontamination Cover	9	3
Subassembly	12	8
Total	70	19

LIST OF FIGURES

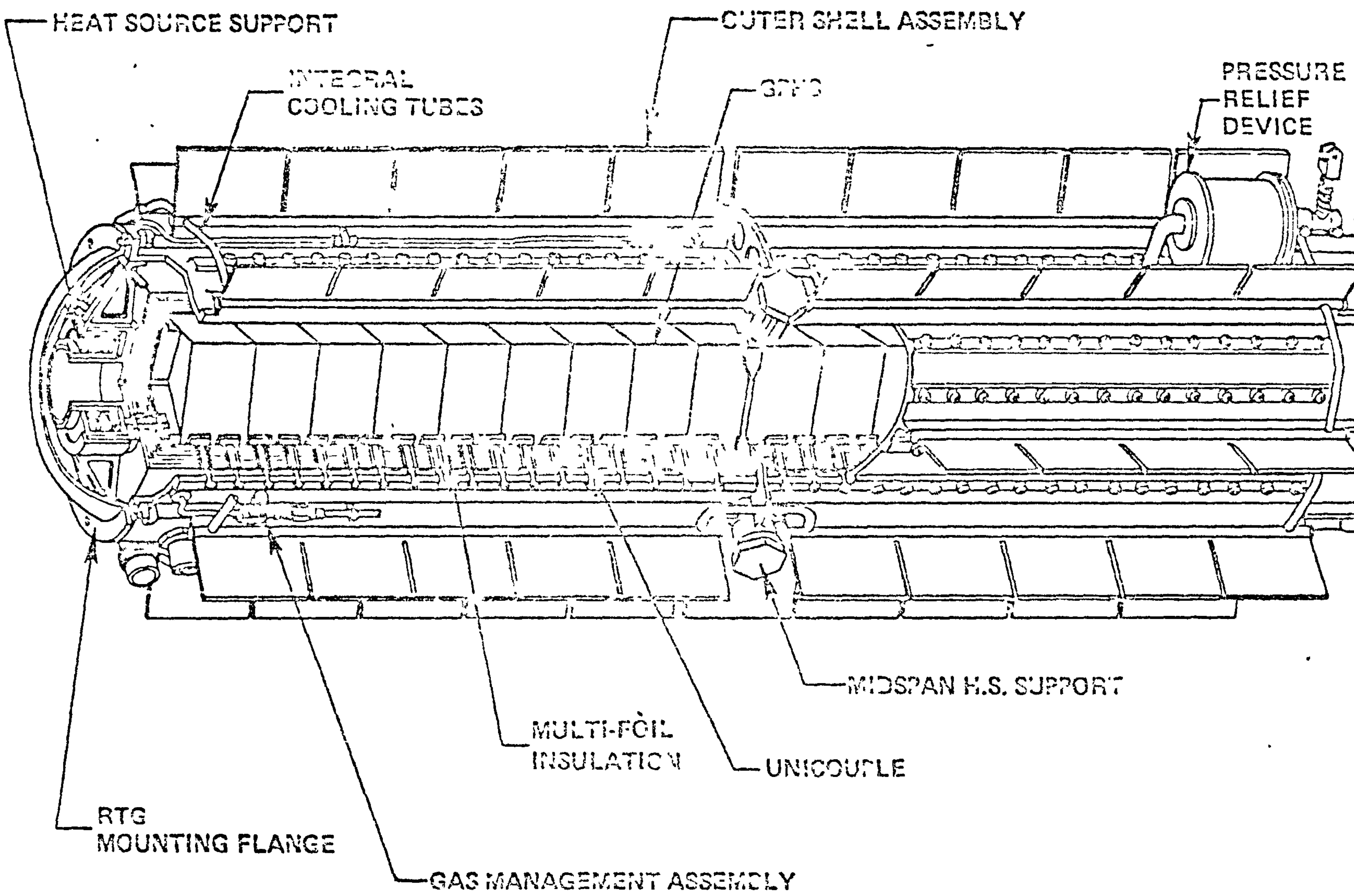


FIGURE 1: THE GPHS RTG IS ASSEMBLED USING 18 250-W HEAT SOURCE MODULES.

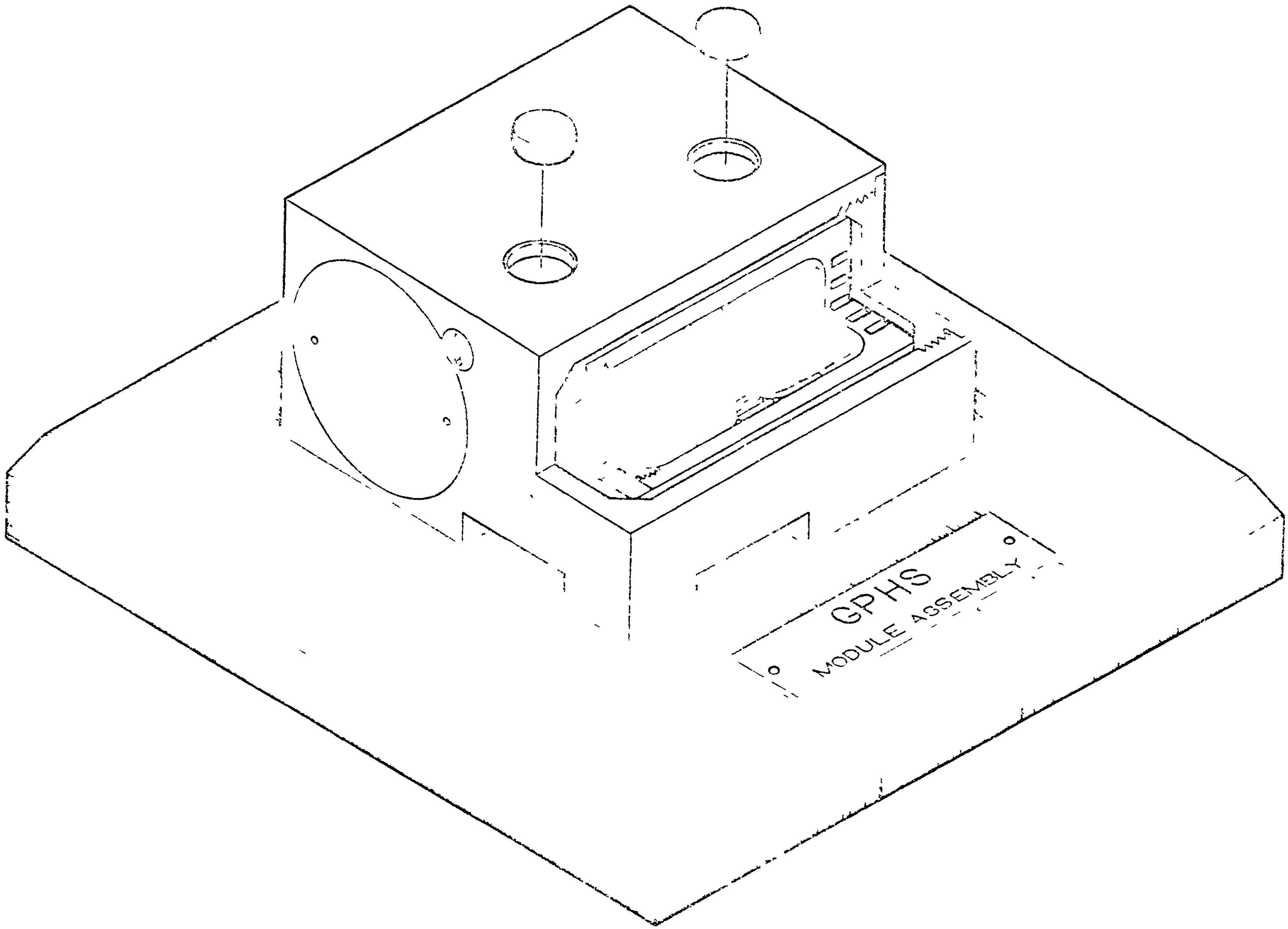


FIGURE 2: ONE GPHS MODULE CONTAINS FOUR FUELED CLADS.

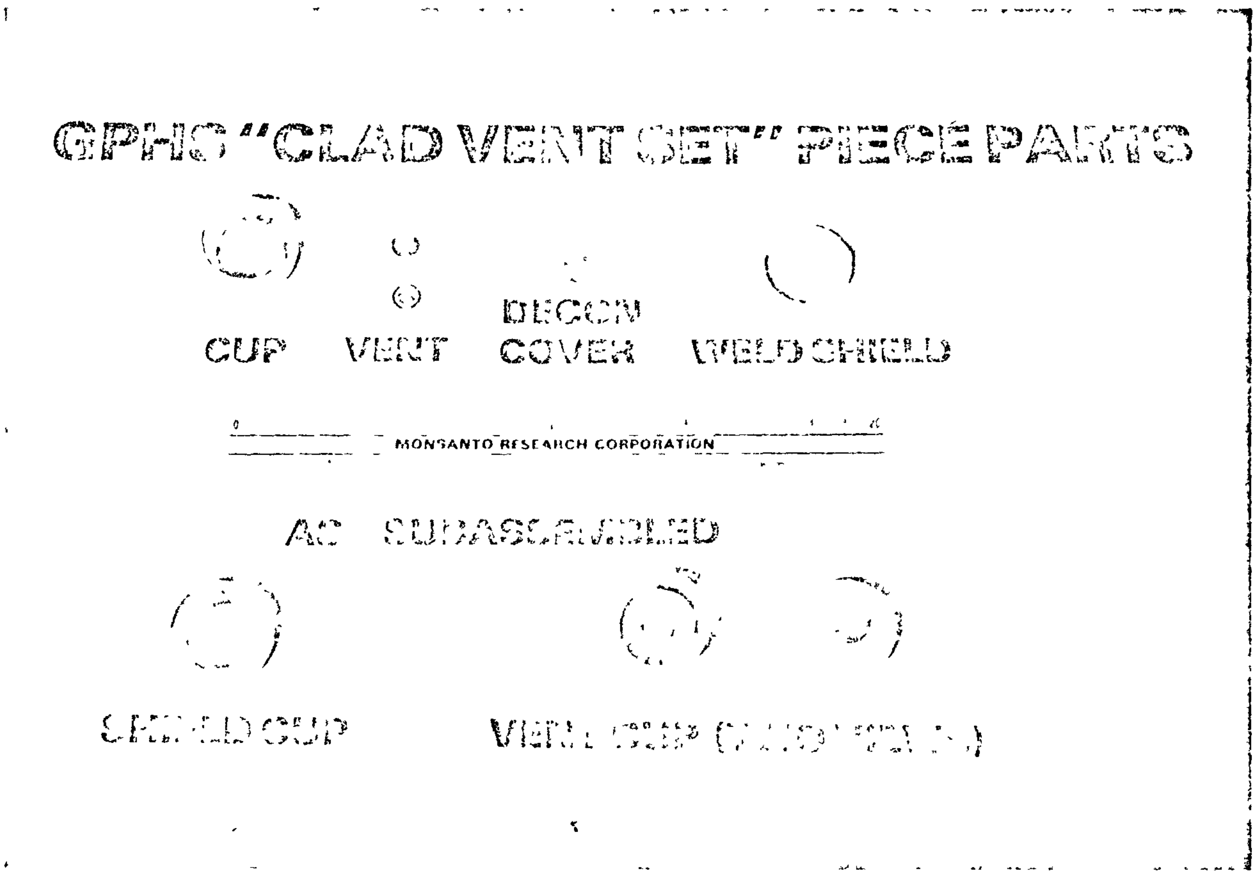


FIGURE 3: PRODUCTION OF IRIDIUM GPHS "CVS" HARDWARE INCLUDES THE ELECTRON BEAM (EB) SUBASSEMBLY OF THE VENT, DECON COVER AND WELD SHIELD TO THE CUPS.

FIGURE 4: PRIOR TO FORMING GPHS CUPS FROM DOP-26 IRIDIUM THE BLANKS ARE SEALED IN A WASTER SHEET PACKET.

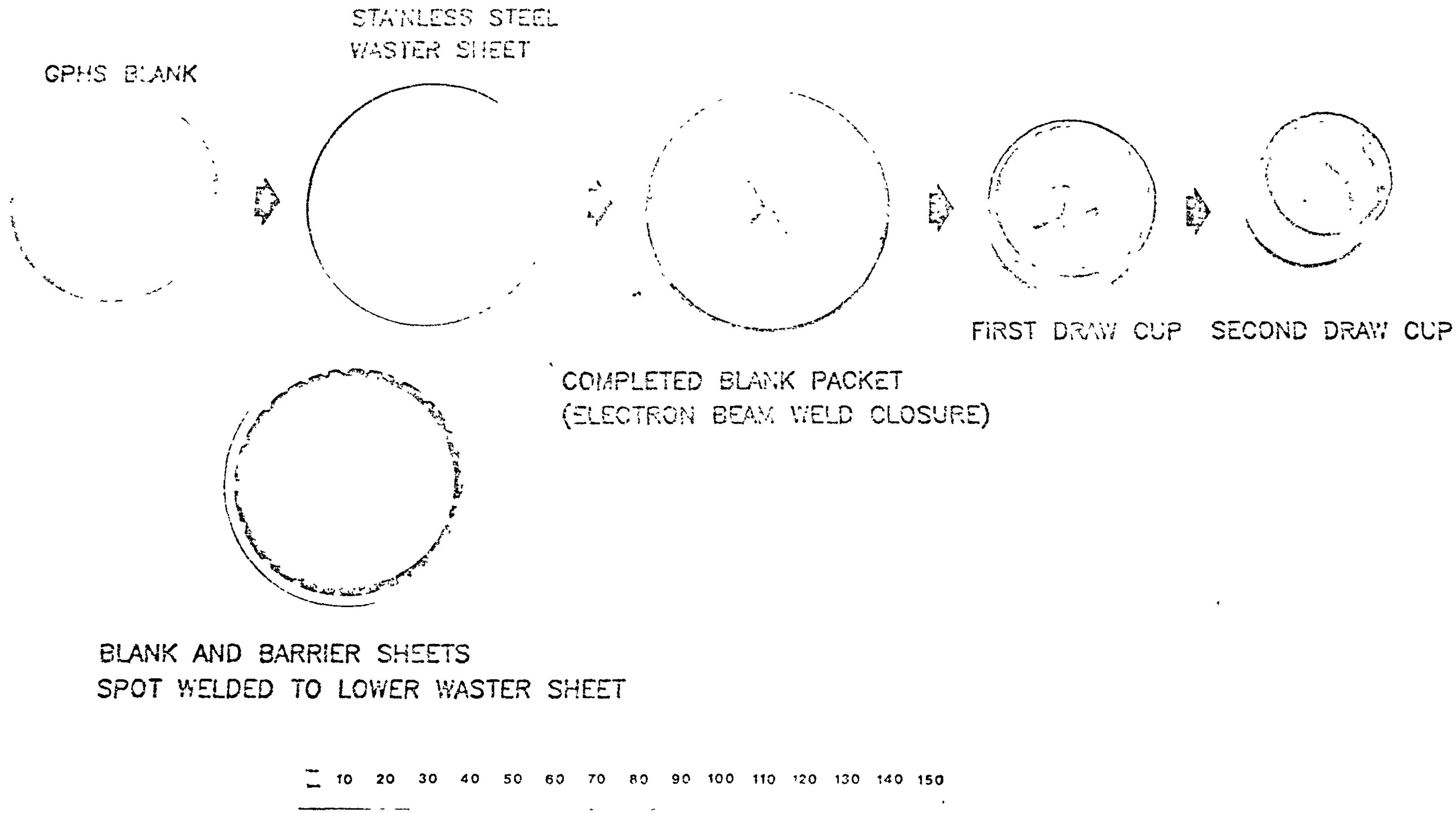


FIGURE 5: HEATED GPHS CUP DRAWING TOOLING RESULTS IN QUALITY PARTS AFTER A TWO-STEP OPERATION.

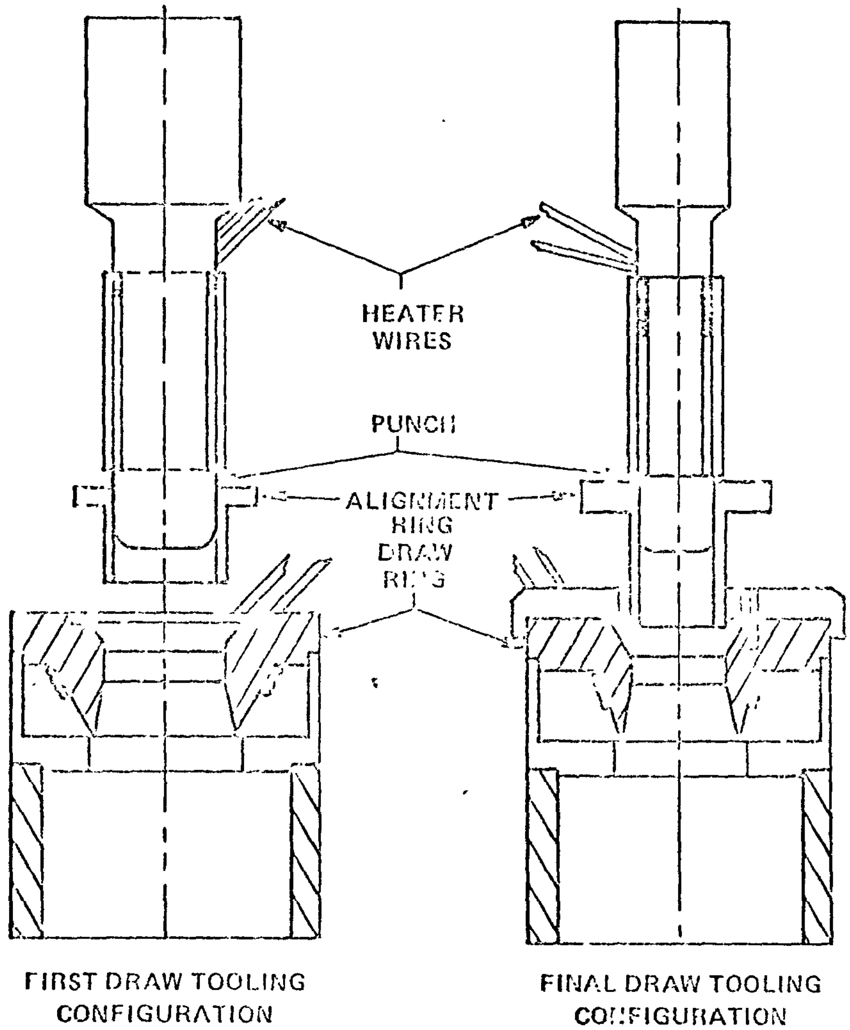
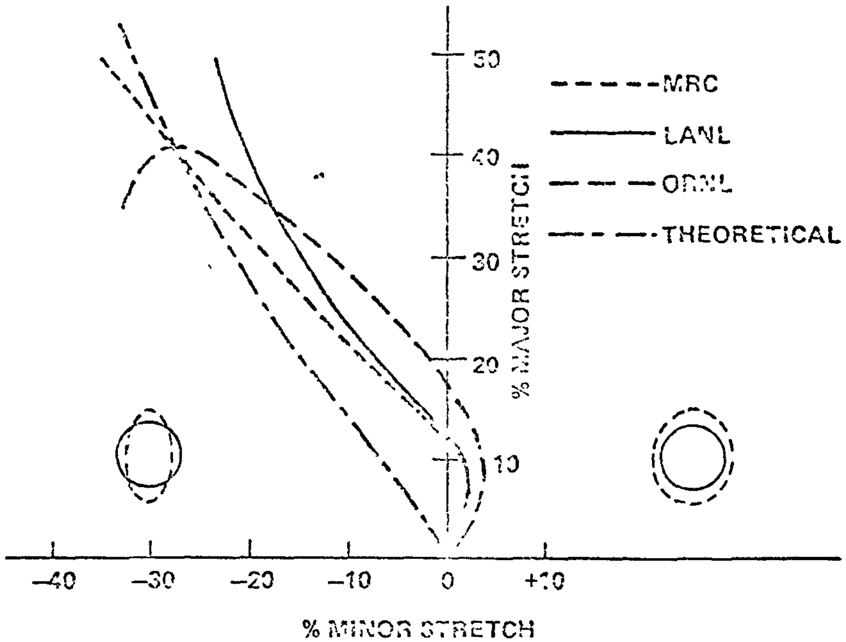


FIGURE 6: EMPLOYING THE FORMING LIMIT DIAGRAM FORMAT, THE MEASURED STRAINS INVOLVED IN GPHS CUP FABRICATION AT MOUND, LANL AND ORNL ARE COMPARED.



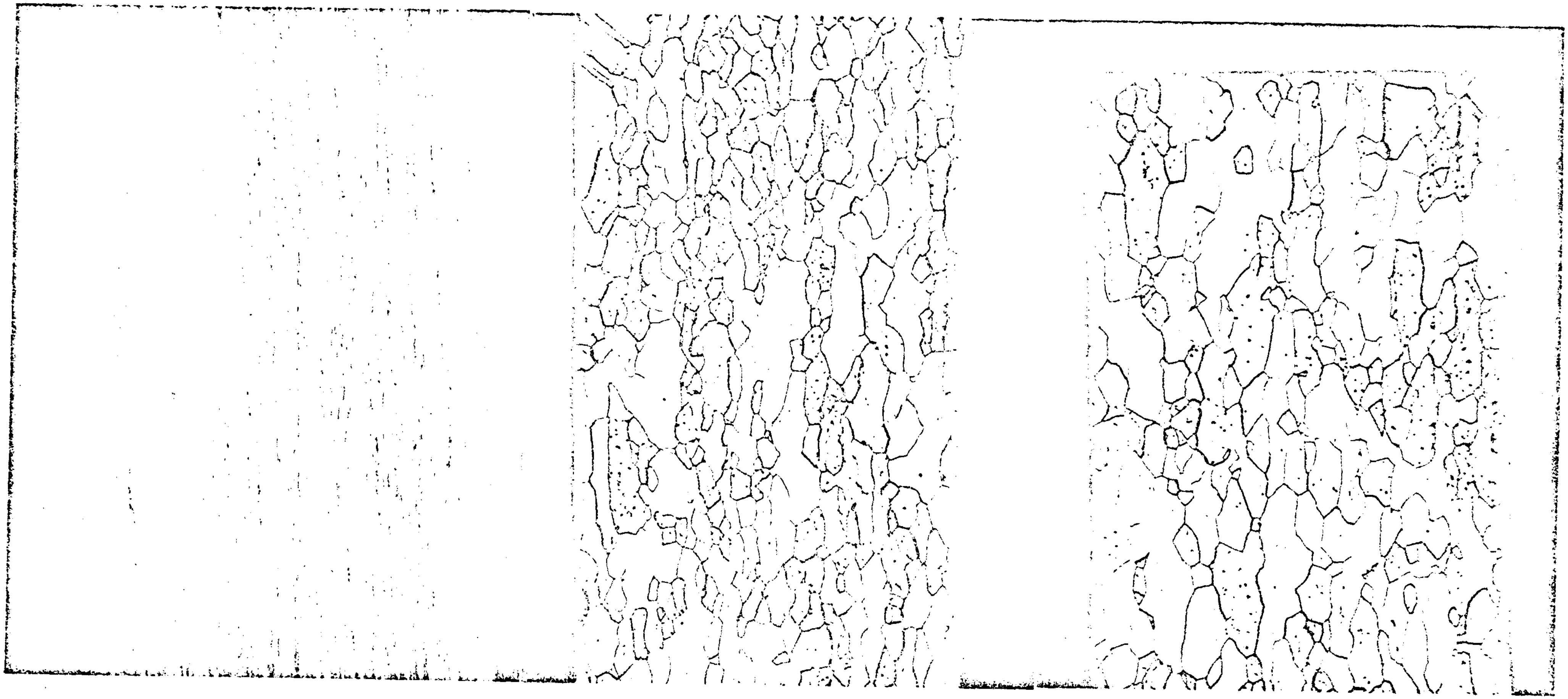


FIGURE 7: THE IRIDIUM MICROSTRUCTURE IS MONITORED BY PERFORMING METALLOGRAPHIC INSPECTION OF THE ORNL-PRODUCED BLANK (LEFT) AND MRC-PROCESSED CUPS (CENTER UNWORKED PORTION IS THE MIDDLE PHOTOGRAPH AND CUP LIP IS ON THE RIGHT). PHOTOS ARE 100X.

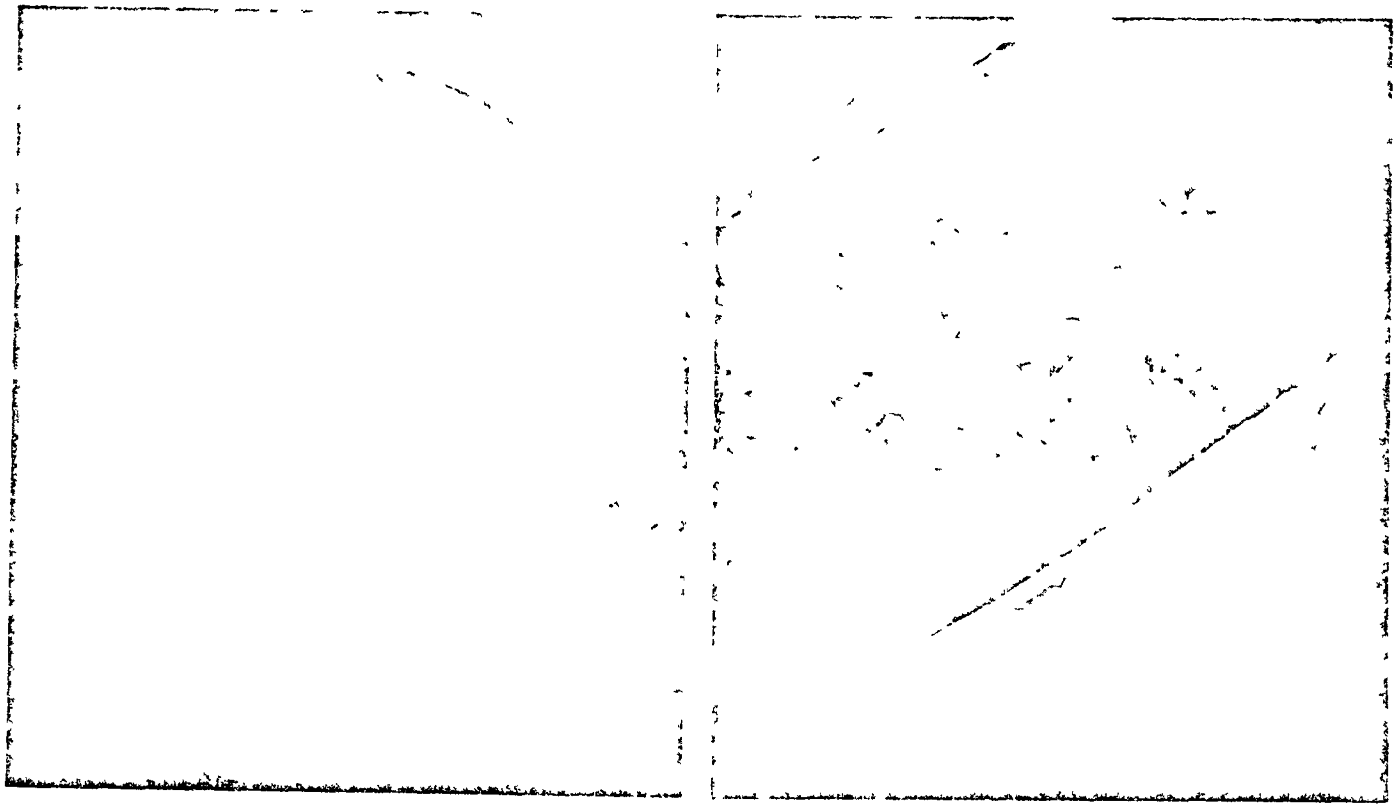


FIGURE 8: SEM SHOTS OF THE IRIDIUM GPHS FRIT VENT SHOWS THE OVERALL GENERAL APPEARANCE (INCLUDING THE EB WELD) ON THE LEFT AT 10X AND DETAIL OF THE SINTERED IRIDIUM POWDER IN THE FRIT AREA ON THE RIGHT AT 100X.

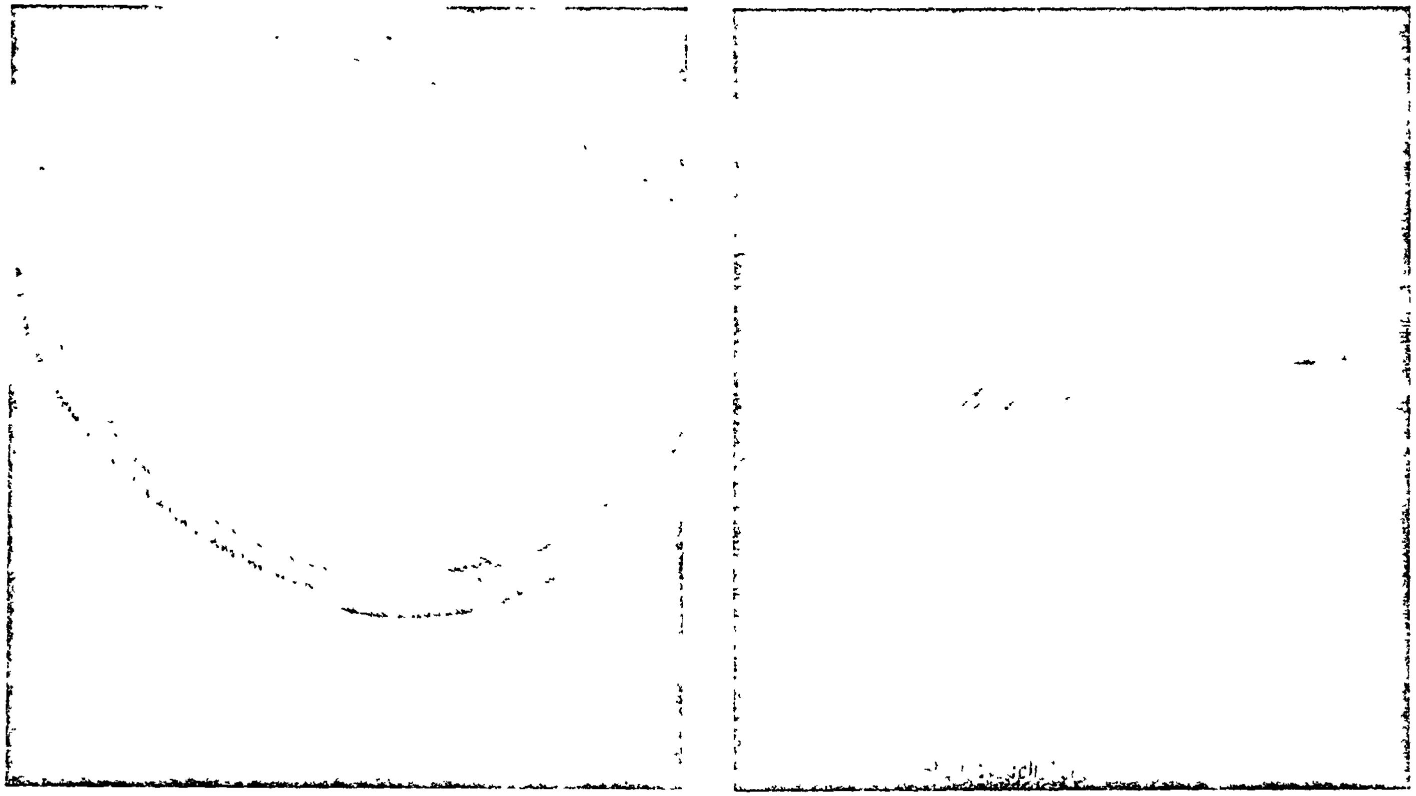


FIGURE 9: EXAMPLES OF GPHS IRIDIUM EB SUBASSEMBLY WELDING ARE THE DECONTAMINATION COVER (ON THE LEFT AT 10X) AND THE WELD SHIELD TAB-TO-CUP (ON THE RIGHT AT 20X).