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EVALUATION AND CHARACTERIZATION OF GENERAL PURPOSE HEAT SOURCE GIRTH WELDS FOR THE CASSINI MISSION

ABSTRACT: General Purpose Heat Sources (GPHSs) are components of Radioisotopic Thermoelectric Generators (RTGs) which provide electric power for deep space missions. Each GPHS consists of a ^{238}Pu oxide ceramic pellet encapsulated in a welded iridium alloy shell which forms a protective barrier against the release of plutonia in the unlikely event of a launch-pad failure or reentry incident. GPHS fueled clad girth weld flaw detection was paramount to ensuring this safety function, and was accomplished using both destructive and non-destructive evaluation techniques. The first girth weld produced from each welding campaign was metallographically examined for flaws such as incomplete weld penetration, cracks, or porosity which would render a GPHS unacceptable for flight applications. After an acceptable example weld was produced, the subsequently welded heat sources were evaluated non-destructively for flaws using ultrasonic immersion testing. Selected heat sources which failed ultrasonic testing would be radiographed, and/or, destructively evaluated to further characterize and document anomalous indications. Metallography was also performed on impacted heat sources to determine the condition of the welds.

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INTRODUCTION

The Cassini spacecraft to Saturn was launched on October 15, 1997 containing two-hundred and sixteen General Purpose Heat Sources (GPHSs). These heat sources were manufactured from ^{238}Pu oxide ceramic material at Los Alamos National Laboratory (Figure 1). Each GPHS produces approximately 61 watts of thermal energy from the alpha decay of the 238 isotope of plutonium. This heat is used to generate the electrical power Cassini will require to complete its ten and one-half year mission. Each heat source is a plutonia dioxide pellet (PuO_2) encapsulated in a iridium shell or clad (Figures 2 and 3). A thin metal band, or weld shield, was placed around the girth of each fuel pellet to isolate it from the weld. The iridium cladding was then tungsten inert gas welded around it's girth in a glovebox using a Hobart welder and a Jetstar controller (Figure 4).

FIGURE 1
PLUTONIA FUEL PELLET

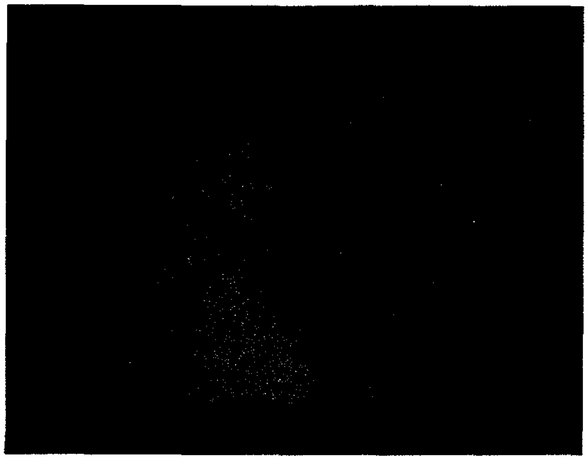


FIGURE 2
GPHS DETAIL

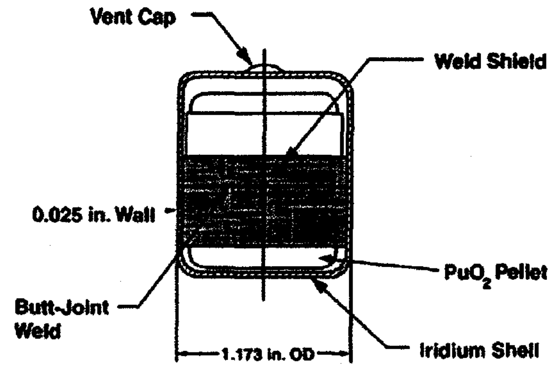
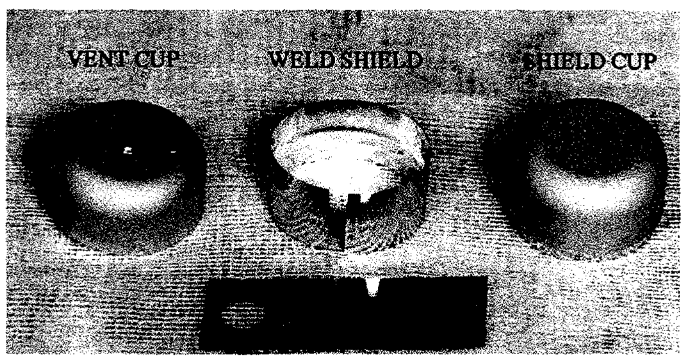


FIGURE 3
IRIDIUM GPHS HARDWARE



It was important for mission safety that each girth weld completely penetrated the iridium cladding and was free from defects which might degrade the strength of the clad. This is because the cladding provides a protective shell around the plutonia, minimizing the amount released into the environment if a launch pad or reentry accident were to occur. GPHS girth weld flaw detection was accomplished using non-destructive evaluation. Flawed welds were further characterized with non-destructive and destructive evaluations.

EXAMPLE WELD EXAMINATION AND INSPECTION

Before the beginning of each weld campaign, a test, or example weld was produced on GPHS iridium hardware containing a simulant fuel pellet. This example weld unit was inspected for dimensions and exterior weld condition. It was then opened using an *Isomet*™ saw and a rotary chuck (Figure 5), and the interior of the weld visually examined with a hand lens. The presence of

FIGURE 4
GENERAL PURPOSE HEAT SOURCE
FUELED CLAD

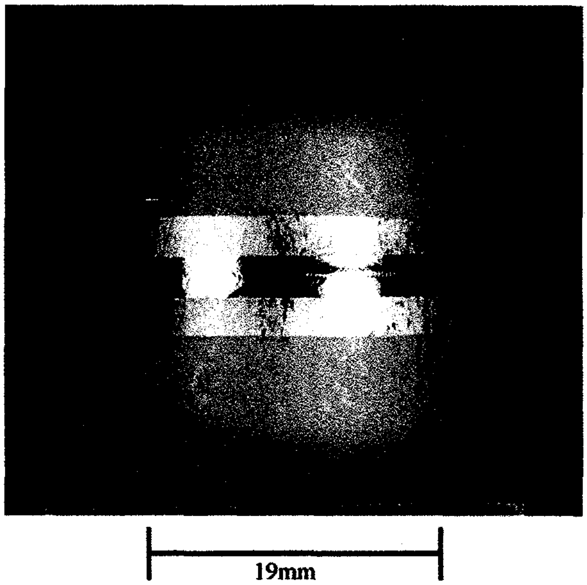
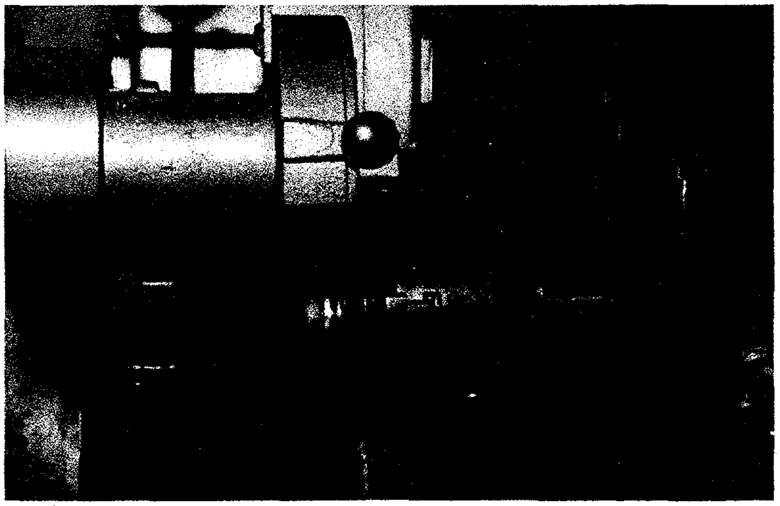


FIGURE 5
OPENING OF A SIMULANT FUELED
GPHS FOR WELD INSPECTION

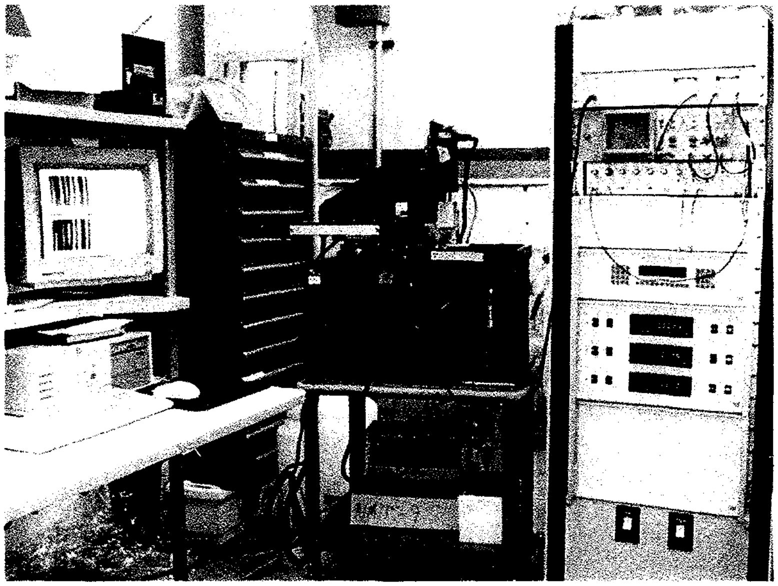


anomalies such as incomplete weld penetration, cracks, or porosity, would render the weld unacceptable for use and require another example-weld to be made. If no defects were observed, it was assumed that the weld was of good quality and a series of GPHSs would be welded using the same welding parameters and conditions. After welding and exterior inspection, each heat source was decontaminated and removed from the glovebox line for ultrasonic inspection (UT).

UT INSPECTION

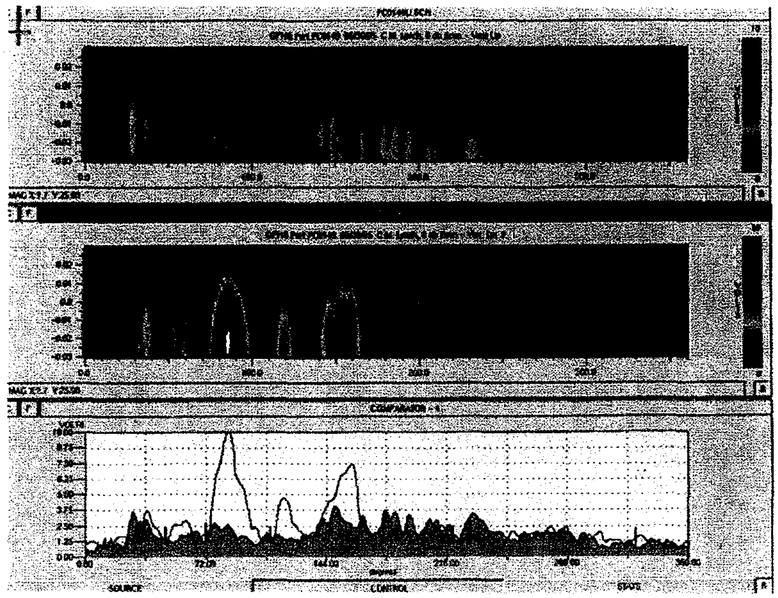
Each GPHS girth weld was inspected using a custom-designed Panametrics Multiscan UT immersion inspection system (Figure 6). If the UT scan produced an indication above a set

FIGURE 6
PANAMETRICS MULTISCAN UT
INSPECTION SYSTEM



threshold value, it would be rejected for flight applications (Figure 7). During the Cassini production phase it was discovered that either a fusion of the weld to the weld shield, called weld shield fusion, or a mismatch in the iridium cup diameters, called cup mismatch (or a step), could produce a reflector large enough to cause UT rejection. Since neither condition compromised the quality or integrity of the weld, additional ultrasonic tests, and radiography, would be used to further characterize these welds. If a preponderance of evidence indicated that the rejectable indication was caused by one of these two conditions this heat source was released for flight applications. Destructive testing was performed on a number of rejected heat sources to positively identify the morphology of the rejectable UT reflector, to verify UT results, and to provide data for an artificial intelligence program database we are developing in collaboration with Westinghouse Savannah River Company to classify UT indications.

FIGURE 7
UT SCAN OF A REJECTED
GPHS GIRTH WELD



METALLOGRAPHY

Metallography was performed on the GPHS example welds to ensure they were of good quality and free from anomalies that could compromise their integral strength. Metallography was also performed to characterize rejected welds for research purposes and to document the weld condition of GPHSs impacted in our safety verification and testing program.

Example Weld Metallographic Preparation and Examination

Example welds were prepared for metallographic examination at both the single-pass (180 degrees) and overlap weld (0 degree) regions to verify complete weld penetration and the absence of defects. This was accomplished by sectioning the iridium clads at the indicated locations and any other areas of interest, using an *Isomet*™ low-speed saw in the glovebox (Figure 8).

Metallographic Section Mounting

Each metallographic section was cold-mounted by positioning it with a *Uniclip*™ inside a mold and pouring *Durofix*™ mounting media over it. This product produces a iridium mount hard enough for good edge retention, while not requiring an excessive amount of grinding time. This material also has the advantage of curing rapidly, allowing grinding and polishing operations to begin within a few hours of mounting (Figure 9).

FIGURE 8
SECTIONING OF AN IRIDIUM GPHS CLAD

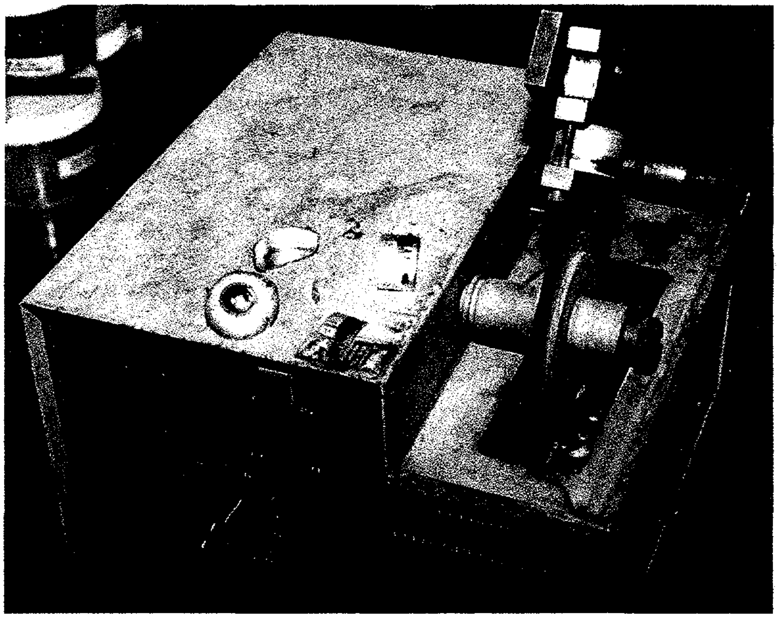
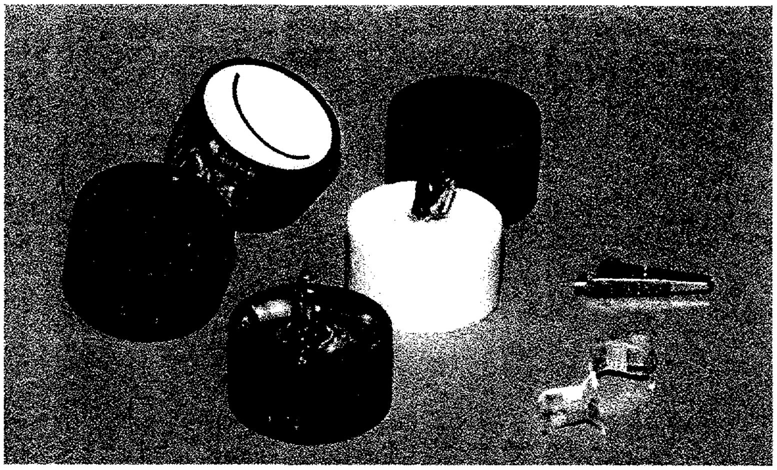


FIGURE 9
MOUNTING PRODUCTS

Grinding and Polishing

The mounts were ground and polished using an automated variable speed grinder/polisher machine in a glovebox (Figure 10). *Carbimet*™ grinding discs were used with a automated water drip, for grinding and rough polishing from 240 grit down to 600 grit. Then 6- and 1-micron

FIGURE 10
METALLOGRAPHIC MOUNTS



water-based diamond suspensions were used on a nylon cloth for fine polishing. Polishing progress was determined between each step by visually inspecting with a hand lens. Occasionally we observed scratches on our sample mounts caused by the cross-contamination of the polishing media with particulates present in the glovebox atmosphere, or from failure of our cleaning process to adequately remove contaminants from earlier grinding/polishing steps. Since these tasks must be accomplished within the glovebox environment, we are unable to rinse our mounts under running water or dry them by conventional methods which would minimize this problem. Our procedure is to clean the mounts between each step in a water-filled ultrasonic cleaner. We run a line of industrial water through a filter and into the glovebox to provide a relatively clean water source. After initial rinsing in the ultrasonic cleaner, each mount is further hand-rinsed with filtered water and dried with clean cheesecloth. We strive to keep the glovebox where grinding and polishing operations are performed as clean as possible and separated from other operations such as sectioning that spread airborne debris. This reduces the potential for cross-contamination of the polishing media. For final polishing we use 0.3-micron alumina in a water slurry on a *Vibromet*™ vibratory polisher (Figure 11).

Metallographic Etching

Polished sample mounts containing interesting features are photodocumented to provide a permanent record of the mount's orientation and macroscopic characteristics (Figure 12). Then they are electrolytically etched. This process selectively removes the metal in the grain boundaries to reveal the grain structure of the metal. This is done in an open-front hood attached to our glovebox line, by using a tungsten probe to transmit AC current to the metal surface while it is immersed in a hydrochloric acid solution.

FIGURE 11
VIBROMET POLISHER

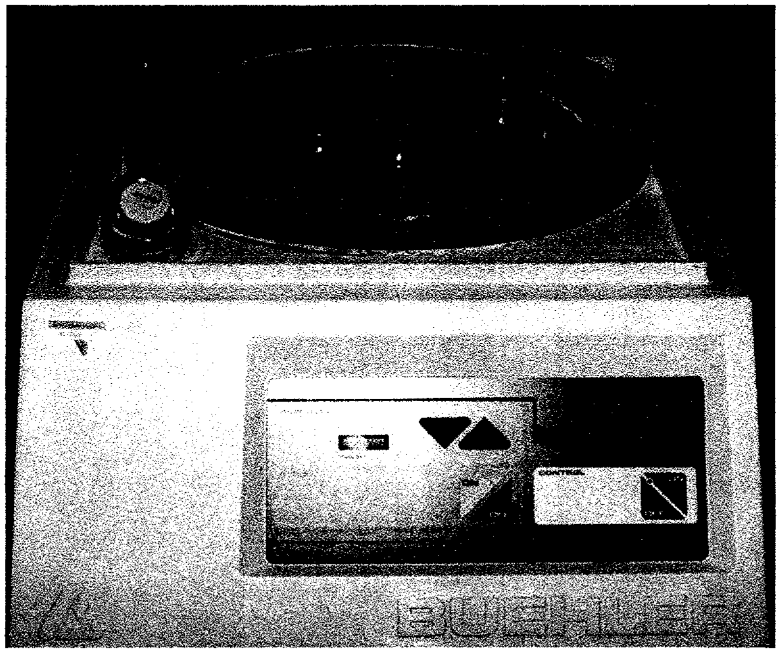
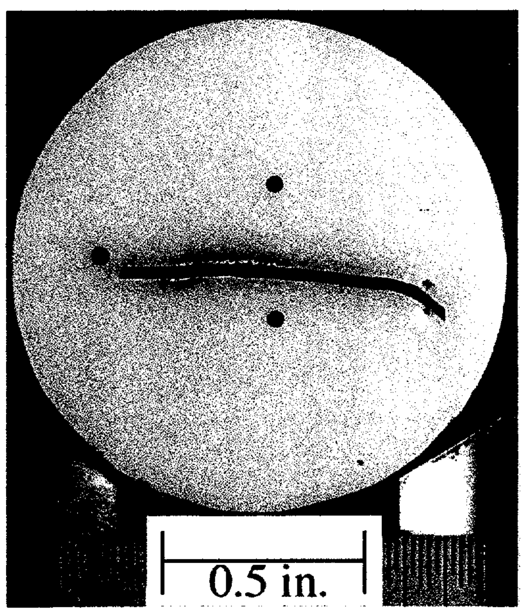


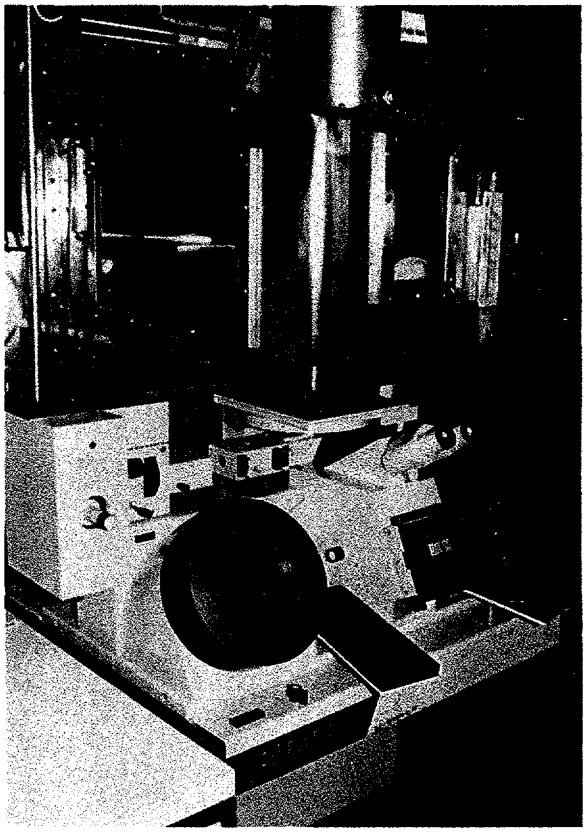
FIGURE 12
MACRO PHOTOGRAPH OF
METALLOGRAPHIC MOUNT



Metallographic Examination and Photodocumentation

The mounts are transferred into a glovebox extension suspended over a LECO metallograph (Figure 13). The sample is thoroughly examined, especially in the weld region, for anomalous conditions such as porosity, incomplete weld penetration, cracks, unusual grain structure, deposits, a step or cup mismatch condition, or weld shield fusion. The weld area and any interesting features or anomalies are photographed with a digital camera mounted to the metallograph. We recently converted from film photography to digital imaging which vastly decreased our turnaround time and improved our archival ability.

FIGURE 13
METALLOGRAPH AND
GLOVEBOX EXTENTION

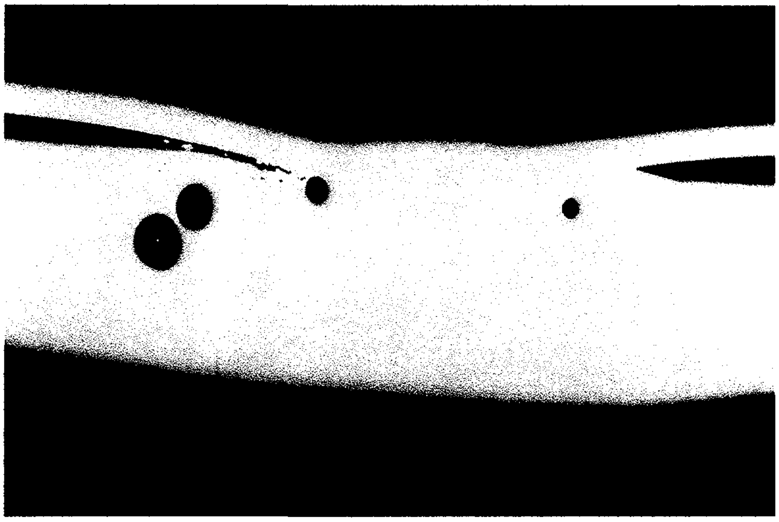


Metallography of UT Failures and Impact-test units

Metallography was performed on selected heat sources which failed UT inspection and on heat sources subjected to impact studies. This enabled a positive determination to be made as to what condition caused the UT failure. It was important to determine if a particular UT failure was caused by weld shield fusion (Figures 14-16) or a cup mismatch (Figure 17), as opposed to a

FIGURE 14
MICROGRAPH OF REJECTED IRIDIUM WELD WITH WELD SHIELD FUSION AND POROSITY

FIGURE 15
MICROGRAPH OF REJECTED IRIDIUM WELD WITH WELD SHIELD FUSION AND POROSITY



defect such as a crack. A GPHS with weld shield fusion or a cup mismatch might still be suitable for flight applications. A GPHS with a condition adversely affecting it's strength or integrity, such as a crack in the weld, would not. Figure 18 is a micrograph of a normal fully penetrating weld without anomalies. In collaboration with Westinghouse Savannah River Company, the metallography was correlated with the UT data to build a database for flaw classification. This was used in conjunction with artificial intelligence software. Although this was nascent technology during Cassini production, it could prove to be very valuable for verifying future heat source acceptability. Since each GPHS costs approximately $300,000.00 to produce, saving previously rejected heat sources could result in significant cost benefits to future missions.

FIGURE 16
MICROGRAPH OF REJECTED IRIDIUM WELD
WITH WELD SHIELD FUSION AND POROSITY

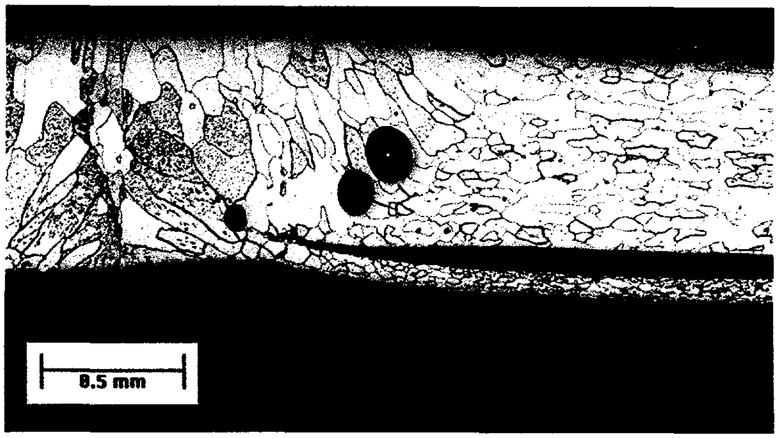


FIGURE 17
MICROGRAPH OF REJECTED IRIDIUM WELD
WITH STEP CONDITION

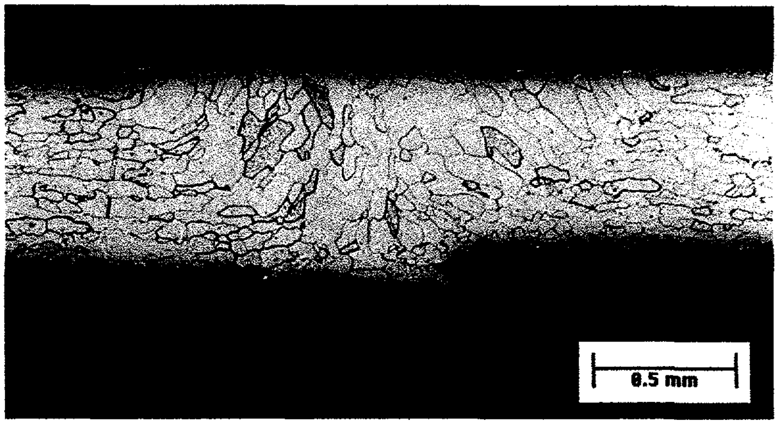


FIGURE 18
MICROGRAPH OF NORMAL IRIDIUM WELD