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CHARACTERIZATION OF ^{238}Pu HEAT SOURCE GRANULE CONTAINMENT

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ABSTRACT

The Milliwatt Radioisotopic Thermoelectric Generator (RTG) provides power for permissive-action links. These nuclear batteries convert thermal energy to electrical energy using a doped silicon-germanium thermopile. The thermal energy is provided by a heat source made of ^{238}Pu, in the form of $^{238}PuO_2$ granules. The granules are contained in 3 layers of encapsulation. A thin T-111 liner surrounds the $^{238}PuO_2$ granules and protects the second layer (strength member) from exposure to the fuel granules. The T-111 strength member contains the fuel under impact condition. An outer clad of Hastelloy-C protects the T-111 from oxygen embrittlement.

The T-111 strength member is considered the critical component in this $^{238}PuO_2$ containment system. Any compromise in the strength member is something that needs to be characterized. Consequently, the T-111 strength member is characterized upon it's decommissioning through Scanning Electron Microscopy (SEM), and Metallography. SEM is used in Secondary Electron mode to reveal possible grain boundary deformation and/or cracking in the region of the strength member weld. Deformation and cracking uncovered by SEM are further characterized by Metallography. Metallography sections are mounted and polished, observed using optical microscopy, then documented in the form of photomicrographs. SEM may further be used to examine polished Metallography mounts to characterize elements using the SEM mode of Energy Dispersive X-ray Spectroscopy (EDS).

INTRODUCTION

This paper describes the characterization of the metallurgical condition of decommissioned Radioisotopic Thermoelectric Generator (RTG) heat sources. The heat generating component of the heat source is $^{238}PuO_2$ in the form of granules. Due to the emission of radiation and its highly corrosive nature the metal selected for its containment was T-111, an alloy of Tantalum and Hafnium. A thin layer of T-111 called a liner surrounds the $^{238}PuO_2$ granules and protects the second thicker layer of T-111 called a strength member. Since T-111 can be subject to oxygen embrittlement, a layer of Hastelloy C is a third layer of containment to protect the T-111 from this. The strength member is the critical component in the containment system and is the focus for characterization of its metallurgical condition.

The techniques used for characterization are Scanning Electron Microscopy (SEM) and Metallography. The heat source is dismantled, and the $^{238}PuO_2$ granules are removed. The strength member weld is characterized by SEM used in Secondary Electron mode to reveal possible grain boundary deformation and/or cracking in the region of the strength member weld. The weld only is characterized since the weld is considered the weakest part of the strength member. If deformation and/or cracking are found, the weld is further characterized by

Metallography. The polished metal surfaces in the Metallography mounts may be subject to elemental analysis of the metal surface using SEM in the Energy Dispersive X-ray Spectroscopy (EDS).

HEAT SOURCE DISASSEMBLY

The first step in the disassembly process is to remove the Hastelloy C outer clad. This is accomplished by using a high speed saw with a carborundum blade to cut the outer clad off circumferentially. The cut is made only deep enough to penetrate the outer clad of the heat source so that the second layer (strength member) is intact. Optical photographs are taken of the strength member exterior. The strength member and liner are de-fueled by drilling through the strength member and liner with a drill press while the strength member is held in a fixture. Once both layers of containment have been penetrated the fuel can be emptied from the strength member and liner. The resultant fuel is weighed, and placed in a fuel storage container. A cut is made through the circumference of the second layer (strength member) in order to remove it from the liner leaving the liner intact. Optical photographs are taken of the third layer (liner) exterior after which the liner is cut in half circumferentially. Optical photographs are taken of the strength member and liner interiors.

Figures 1, 2, and 3 are optical images of the outer clad, strength member, and liner respectively.

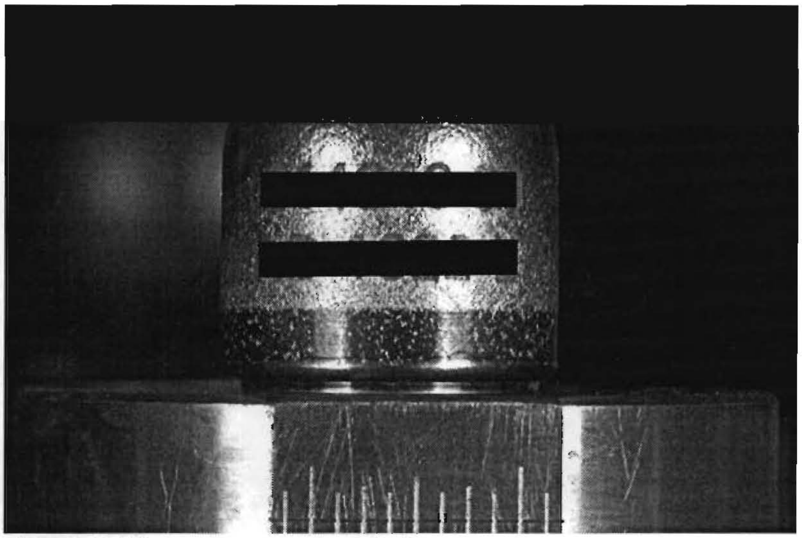

Figure 1. Heat source outer clad.

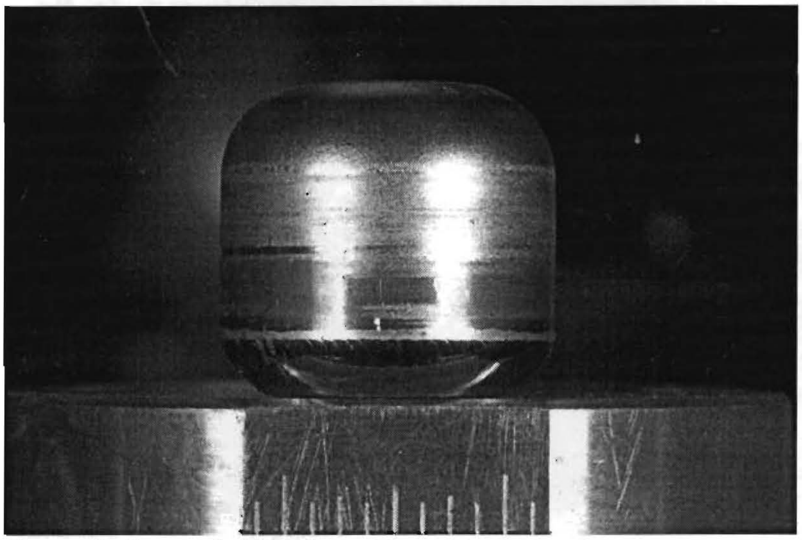

Figure 2. Strength Member

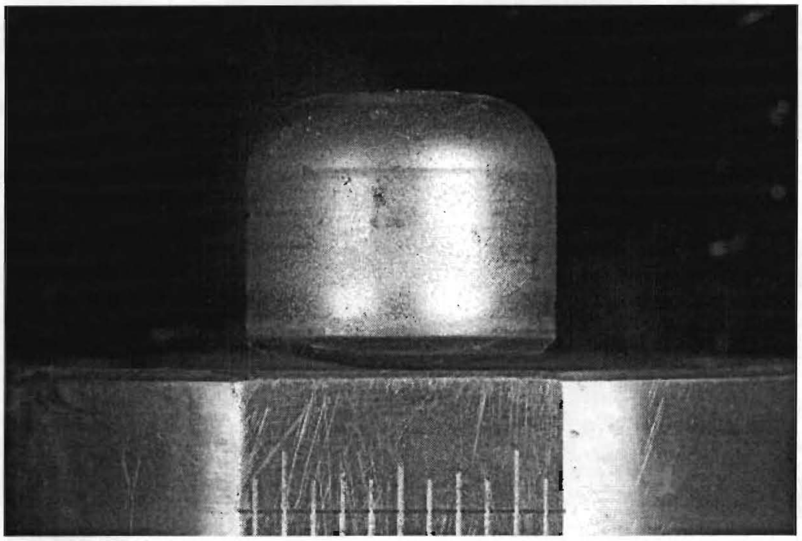

Figure 3. Liner

STRENGTH MEMBER PREPARATION FOR SEM ANALYSIS

The lid portion of the strength member is separated from the side wall as close as possible to the weld connecting the respective components. This is done in order for the SEM mount positioning system to be adjusted to allow the detector to analyze the weld and a small portion of the sidewall without remounting the part several times (remounting the part is avoided due to $^{238}PuO_2$ contamination). The interior weld surface (which would be exposed to the $^{238}PuO_2$ granules in the case of a liner failure) will be examined in its entirety with SEM (in secondary electron mode). The separated lid is submitted to the Interfacial Science team of our Materials Science & Technology division for the SEM analysis.

Figure 4 identifies exterior strength member components, while figures 5 and 6 are optical photos of the interior and exterior strength member lid.

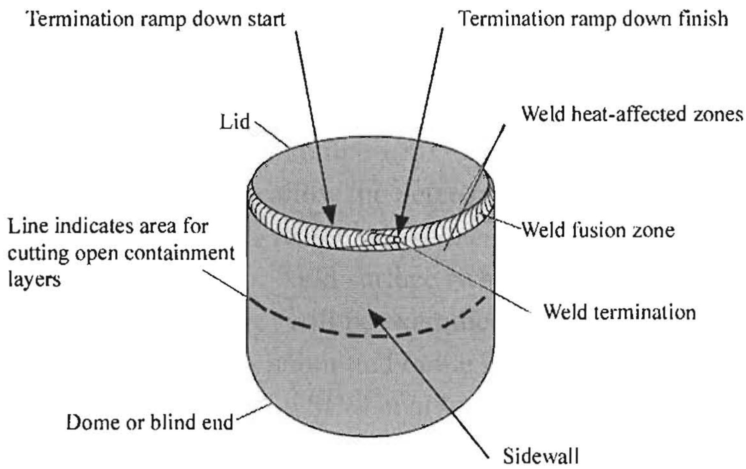

Figure 4. Identification of strength member components

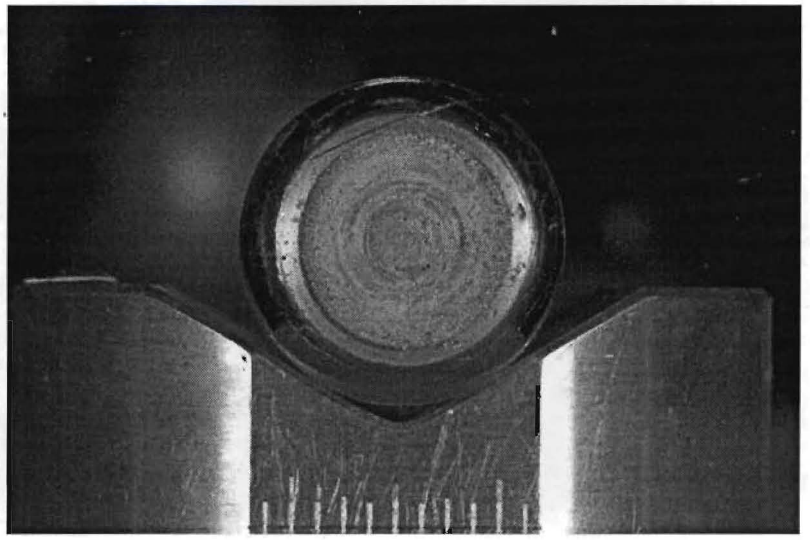

Figure 5. The exterior of the strength member showing the lid and exterior weld surface.

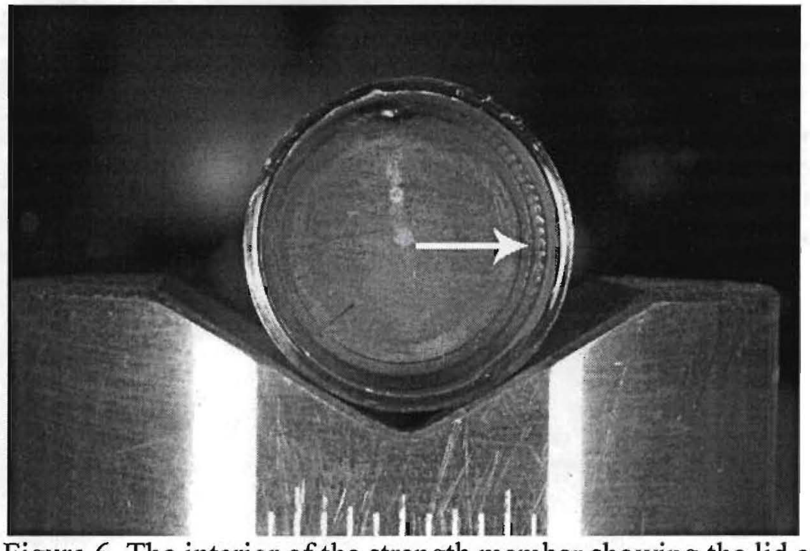

Figure 6. The interior of the strength member showing the lid and interior weld surface. Arrow indicates the interior weld surface which will be examined by SEM.

SEM ANALYSIS

Examination of the interior weld surface will indicate anomalous areas such as cracks and other degradation of the weld surface. The types of cracking that may be expected to occur are: intergranular stress-rupture cracks, intergranular fracture, intergranular secondary cracking, and subcritical cracking. The relative positions of anomalous cracking are noted within the following areas: weld fusion zone, weld heat affected zone, and the area within a position defined by the weld ramp down termination start and the weld ramp down termination finish. The weld heat affected zone extends from both sides of the weld fusion zone into the strength member lid, and the strength member sidewall. Results are reported back to our team and are used to indicate positions where the strength member lid can be sectioned for metallography.

Figures 7 and 8 are examples of SEM images; in this case portions of non-anomalous results for a strength member.

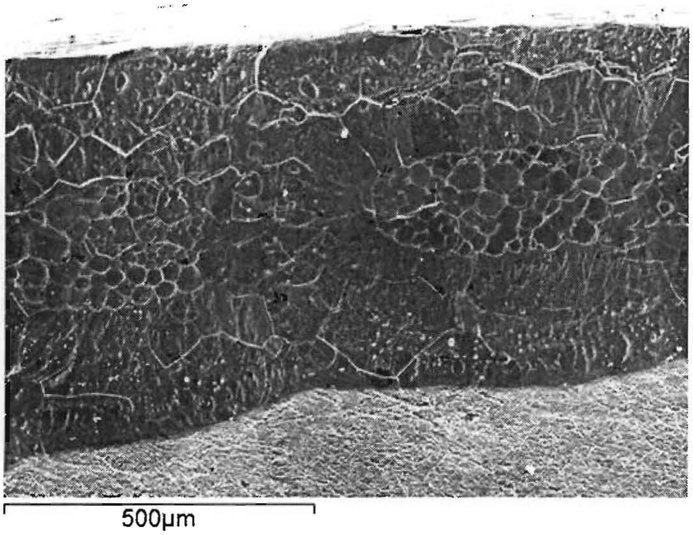

Figure 7. SEM image of a strength member non-anomalous weld fusion zone

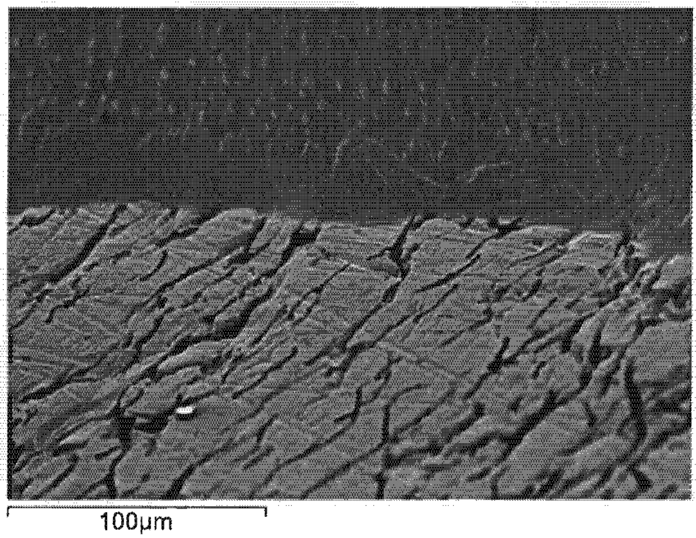

Figure 8. SEM image of a strength member non-anomalous weld fusion zone with part of the weld heat affected zone.

METALLOGRAPHY

Anomalous areas indicated by SEM analysis are sectioned out of the strength member lid, mounted in epoxy, ground, polished and etched following a metallographic preparation procedure developed for T-111 alloy. Photomicrographs of the prepared mounted surfaces will produced to document the metallography results.

Figures 9 and 10 are examples of non-anomalous metallography photomicrographs from a strength member, while figure 11 is an anomalous metallography photomicrograph from a strength member.

Figure 9. Metallography microphotograph of a strength member non-anomalous weld heat affected zone with part of the weld fusion zone.

Figure 10. A metallograph microphotograph of a non-anomalous weld fusion zone with the weld heat affected zones.

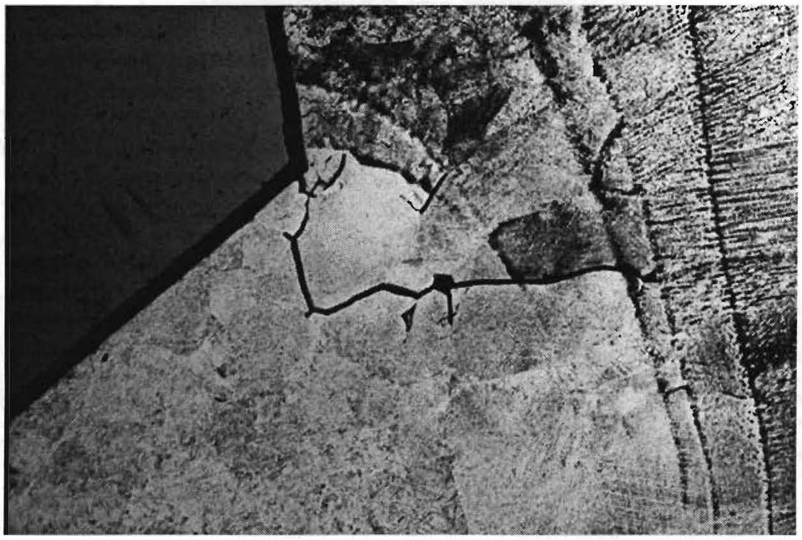

Figure 11. A metallography microphotograph of an anomalous strength member weld fusion zone.

SEM ENERGY DISPERSIVE X-RAY SPECTROSCOPY (EDS)

Anomalous areas seen in the photomicrographs require the metallography mounts to be resubmitted to the Interfacial Science team of our Materials Science & Technology division for SEM Energy Dispersive X-ray Spectroscopy (EDS) to characterize possible contaminates. An elemental distribution map of up to four elements or contaminants is provided to our team.

Figures 12 and 13 are examples of EDS results from a strength member.

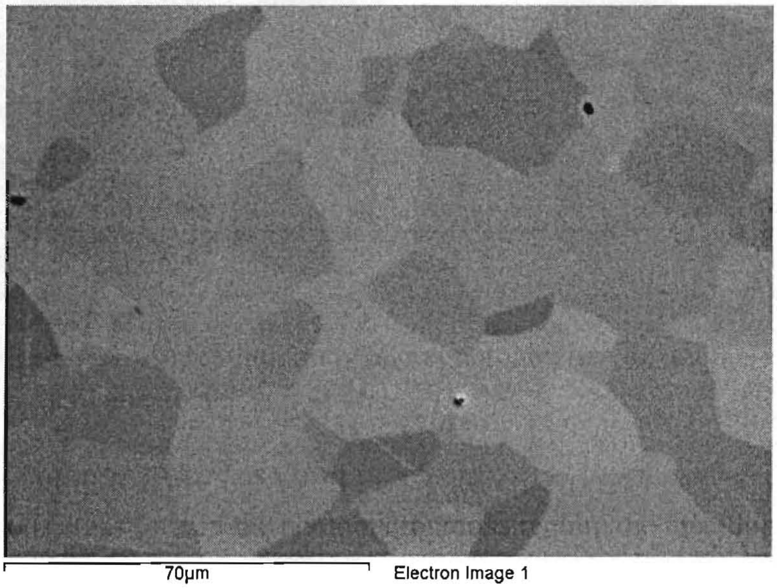

Figure 12. SEM EDS electron image

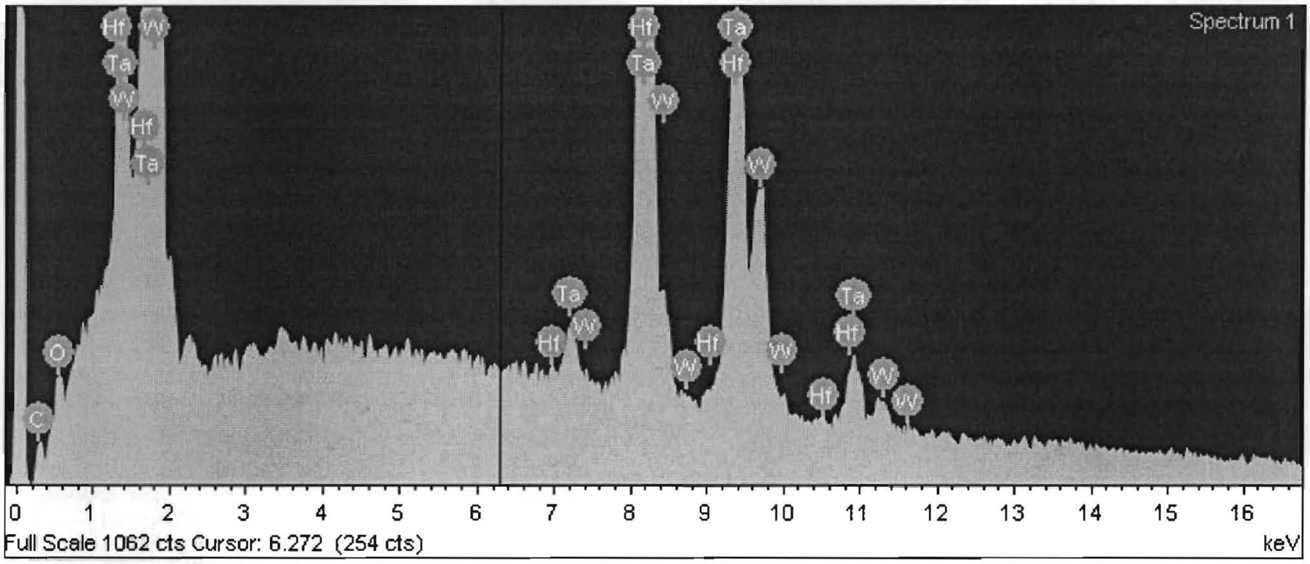

Figure 13. SEM EDS elemental distribution indicating high concentrations of Tantalum and Hafnium

CONCLUSION

Scanning Electron Microscopy (SEM) and Metallography are the techniques used in the characterization of the metallurgical condition of decommissioned Radioisotopic Thermoelectric Generator (RTG) heat sources. The T-111 heat source strength member weld is characterized by SEM used in Secondary Electron mode to reveal possible grain boundary deformation and/or cracking in the region of the strength member weld. If deformation and/or cracking are found, the weld is further characterized by Metallography. The polished metal surfaces in the Metallography mounts may be subject to elemental analysis of the metal surface using SEM in the Energy Dispersive X-ray Spectroscopy (EDS).