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MILLIWATT GENERATOR HEAT SOURCE
PROGRESS REPORT

April 16, 1977 - July 15, 1977

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Miamisburg, Ohio

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MILLIWATT GENERATOR HEAT SOURCE
PROGRESS REPORT

I. Introduction

Activities at MRC associated with the Milliwatt Generator Heat Source efforts over the period April 16, 1977, to July 15, 1977, are presented below.

II. Inconel 600/T-111 Compatibility (P. E. Teaney)

Metallography was completed for the nine Inconel 600/T-111 alloy compatibility specimens which were heated according to the following test matrix:

<u>Temperature</u> (°C)	<u>Time</u> (Hr)		
1225	1	4	16
1100	10	40	160
1000	100	400	1600

Metallographic examination of the specimens revealed a reaction which increased with time and temperature. The widths of the reaction zones were measured from photomicrographs and are given in the following tables:

<u>Temperature</u> (°C)	<u>1 Hr.</u> (μm)	<u>4 Hr.</u> (μm)	<u>16 Hr.</u> (μm)
1225	25.7	40.7	73.3
1100	<u>10 Hr.</u> (μm)	<u>40 Hr.</u> (μm)	<u>160 Hr.</u> (μm)
	26	38.7	70
1000	<u>100 Hr.</u> (μm)	<u>400 Hr.</u> (μm)	<u>1600 Hr.</u> (μm)
	26	42	83.3

Although diffusion occurred in both directions, diffusion of the Inconel 600 alloy components into the T-111 alloy predominated. As a result, a line of Kirkendall type voids existed along the Inconel 600 side of the reaction zone. The reaction zone of one of the specimens tested at 1225°C for 16 hours, is shown in Figure 1. The other samples appeared similar

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300X (as polished)

Reaction between Inconel 600 and T-111 alloy
after 16 hrs. at 1225°C

FIGURE 1

except for differing reaction zone widths. When reaction rate and activation energy determinations are completed, a report will be written summarizing the results of the study.

III. Fuel Aging Studies (P. E. Teaney)

The final six specimens were removed from the aging furnace after 27 months at 450°C. Two specimens were submitted directly for fines analysis and metallography of the fuel.

Two specimens were thermal ramped prior to submission for fines analysis and metallography. The specimens were heated to 1000°C within five minutes, held at 1000°C for two hours, and cooled to room temperature in a vacuum furnace.

The two remaining specimens were submitted to be impacted prior to fines analysis.

When analyses are completed, the effects of impact and thermal excursions on aged fuel will be determined, in addition to the generation of fines due to aging.

IV. Compatibility (P. E. Teaney and A. R. Kiefer)

Studies on material compatibility are continuing. The materials being evaluated are given in Table I. Metallography of Groups A through N have been completed and Groups 7 through 10 are now being processed. Groups 1 through 6 (platinum and platinum alloys) will be processed last.

V. Encapsulation (C. E. Burgan)

The GTA pulse arc welding machine was received and modified for welding production heat sources. Welding parameters were developed for the liner, strength member, and clad.

As a pre-production check-out of the PP production facility and the pulse arc welder, 22 fueled heat sources (MF-33F through -54F) were fabricated. Twenty-one of the units met all the specification requirements. The only exception was one which had a liner dye penetrant indication after welding. Eleven of these 22 units (MF-33F through -43F) were shipped to GEND for their capability studies.

VI. Impact Studies (C. G. Anderson and W. B. Cartmill)

Ten more units were impacted during the report period, for a total of 17 to date. The first of these were three tungsten-molybdenum simulant capsules, MT-12F, -13F, and -17F, which were impacted at a 90° angle, at 151.1 meters/second, 163.0 meters/second, and 137.0 meters/second, respectively. No release of simulant occurred which led to the 90° impact of three production design fueled units. MF-30F was impacted at

TABLE I
COMPATIBILITY SAMPLE MATRIX

<u>Group</u>	<u>Metal</u>	<u>Fuel</u>	<u>Test Temperature</u> (°C)
A	Ta	SRP	1200
B	T-111	Production ^a	1200
C	Ta-10W/T-111	SRP	1200
D	Ta	PuO _{1.81}	1200
E	Ta-10W	SRP	800
F	Ta-10W	SRP	1200
G	Ta-10W	PuO _{1.81}	1200
H	Ta-10W	SRP + Additive ^b	1200
I	Ta-10W	PuO	1000
J	Ta-10W	Production ^a	1700
K	Ta-10W	Production ^a	1900
L	Mo-50Re	SRP	800
M	Mo-50Re	SRP	1000
N	Mo-50Re	SRP	1200
1	Pt	PuO _{2-x}	1000
2	Pt-20Rh	SRP	1000
3	Pt-40Rh	SRP	800
4	Pt-40Rh	SRP	1000
5	Pt-40Rh	SRP	1200
6	Pt/Pt-40Rh	Production ^a	1200
7	Ti	SRP	800
8	Ti	SRP	1000
9	Hastelloy X	Production ^a	800
10	Haynes 25	Production ^a	800

^aAt Mound

^bYttrium, Tantalum, or Molybdenum

148.4 meters/second, MF-31F at 149.3 meters/second, and MF-44F at 152.1 meters/second. (The latter unit is one of two units funded by Sandia reimbursables, with plutonia analysis to follow.) Results of the fueled units were essentially the same as the recently impacted and previously impacted (MWG Progress Report, Section V, January 16-April 15, 1977) simulant units. Although clad rupture occurred in all cases, and strength member rupture occurred in a few cases, there was no release of simulant or fuel at the test temperature of 450°C, even at 169.7 meters/second. The design therefore meets the safety criteria of no fuel release at a 450°C impact at 150 meters/second.

Also impacted were four units (of the trepan clad cap design) in an effort to determine whether the solution anneal operation could be eliminated in the fabrication of clad bodies. Two of the units had clads that were solution annealed while the other two had clads that were not. All four clads were breached at the approximate impact velocities of 150 meters/second (90° angle, 450°C). These data, in addition to the data on the production design capsules in which clad rupture occurred in all cases at approximately 150 meters/second, led to the conclusion that the clad body solution anneal could be deleted from the process without sacrificing the containment integrity of the unit.

VII. Surveillance Plans (D. R. Schaeffer)

Surveillance procedures have been established to determine the long-term effects of extended storage of T-111. The surveillance requirements, described in SLA Drawing BB309768, include the following Mound responsibilities.

- a. Fabrication of 48 pressure burst capsules from FY-78 through FY-82 (eight capsules in FY-78).
- b. Placing these capsules (pressurized at end of life helium pressures) on test, 24 at 210°C and 24 at 410°C at the designated dates and maintaining them at these temperatures through the test duration.
- c. Removing these capsules from test (some as late as FY-2003), pressure burst testing the units, and evaluating the burst units (chemical analysis and metallographically).

The units will be maintained in typical resistance-type furnaces. Protection of T-111 and the Ta pressure burst tubes from air oxidation will be accomplished by encapsulating the units in Hastelloy C-276 (1.25 inch O.D. tubing with 0.148 inch walls and welded end caps). Diffusion of nitrogen through the Hastelloy C-276 walls (which has been a problem with Hastelloy C) will be prevented by a secondary encapsulation, again with Hastelloy C-276 tubing (1.50 inch O.D. with 0.083 inch walls and welded end caps).

Evaluations of the capsules after pressure burst testing include determinations of the oxygen and nitrogen content and microhardness determinations.

Hastelloy C-276 specifications are presently being resolved with the vendor (Stellite Division of Cabot Corporation, Kokomo, Indiana). The testing and evaluation procedures have been finalized and have been formally placed into the documentation system.

VII. Pressure Burst Capsule Evaluations (D. R. Schaeffer and D. A. Pawlak)

Pressure burst data from capsules fabricated from Lot 7 T-111 continue to be collected. Results to date from 10 of the 20 fabricated capsules are shown in Table II. Although only half the Lot 7 capsules have been tested, Sandia has agreed that the data shows Lot 7 T-111 to be acceptable for production.

Future plans include:

- a. Completion of the testing of other Lot 7 capsules.
- b. Fabrication and testing of 10 additional Lot 7 units (SLA reimbursables) at 1050°C, 6500 psia.
- c. Fabrication and testing of approximately 20 Lot 8 capsules (at 1010°C, half at 6500 psia and half at 8000 psia) for qualification of Lot 8 T-111.

VIII. Pressure Burst Capsule Evaluations (E. Stacy)

Six of the pressure burst capsules (MPT-49F through -54F) described in Section VII were evaluated using the scanning electron microscope and associated EDXRA. The results follow.

MPT-49F External fracture or "blow holes" were not present in the weld area or the heat affected zone. There was an accumulation of included material near the weld overlap. The included material was primarily in the capsule body and heat affected zone interface, extending 1-3 mm into the capsule weld. The included material consisted of iron, silicon, molybdenum, and potassium. The included zone and location is clearly visible in Figures 2 and 3.

MPT-50F External fracture occurred near the weld overlap and at the weld heat affected zone and cap. Two circumferential cracks, extended 100 μ along the capsule weld zone, were observed (Figure 4). Included material consisting of iron, silicon, potassium and calcium was evident in the fracture (Figure 5).

MPT-51F External fracture occurred 120° prior to the weld overlap. The fracture or crack was perpendicular to the heat affected zone. The included material was calcium and silicon, with trace elements of titanium, potassium, chlorine, and sodium (Figure 6).

TABLE II
PRESSURE BURST TEST RESULTS
(Lot 7 Capsules, 1000°C)

<u>Capsule Number</u>	<u>Pressure (psia)</u>	<u>Time to Rupture (Hrs)</u>	<u>Failure Location</u>
MPT-44F	8000	4.99	Not determined ¹
MPT-49F	8000	17.47	Cap-body weld
MPT-50F	8001	8.66	Cap-body weld
MPT-51F	8002	4.60	Cap-body weld
MPT-52F	8001	33.39	Cap-body weld
MPT-53F	8001	7.88	Cap-body weld ²
MPT-54F	6501	92.92	Cap-body weld
MPT-55F	6500	96.37	Not yet determined
MPT-56F	6501	65.04	Not yet determined
MPT-57F	6502	71.10	Not yet determined

¹Internal pressure of 9600 psia did not reveal leak

²90% separation of cap from body

Included material in MPT-49F
extending across heat affected zone into the weld area

FIGURE 2

Included material near the weld overlap of MPT-49F

FIGURE 3

Two circumferential cracks near the weld overlap of MPT-50F,
propagating parallel to the weld

FIGURE 4

Included material in MPT-50F,
consisting of iron, silicon, potassium, and calcium

FIGURE 5

Fracture in MPT-51F with included material
consisting of calcium and silicon, with trace elements
of titanium, potassium, chlorine, and sodium

FIGURE 6

MPT-52F External failure occurred 120° prior to the weld overlap. The failure zone was not the typical transgranular separation that occurred in MPT-49F, -50F, and -51F. The failure was of the "blow hole" type with debris adjacent to the point of failure (Figure 7). The debris consisted of iron, silicon, calcium, and potassium, with the darker area containing sodium, chlorine, potassium, and silicon.

MPT-53F A 90% fracture of the weld during pressure burst testing is shown in Figure 8. Complete fracture occurred at the capsule body heat affected zone with partial fracture also occurring at the capsule cap heat affected zone.

MPT-54F External fracture occurred near the weld overlap. The fracture or crack (Figure 9) was not as well defined as those observed in MPT-50F and -51F. The material in and adjacent to the fracture consisted of iron, calcium, potassium, and silicon.

All of the evaluated capsules fractured at the body heat affected zone interface. There was no observable element foreign to the capsule material composition, with one exception. MPT-50F and -51F had an area located at the weld termination that produced an iron signal when subjected to the EDXRA. Although there were no individual particles observable on the surface, the iron could be in the matrix, especially since the grain had a strange appearance (Figure 10).

IX. Documentation (W. C. Wyder and D. E. Friedline)

All the drawings of the hardware forming tooling, machining fixtures, and gages have been updated, finalized and submitted to Drawing Control. Also finalized and submitted to Drawing Control were all the production operation sheets (including surveillance procedures), flow sheets, and associated manuals (Material Control and MC2893 Reference Manual). The Product Index has been established and is being routinely distributed to involved operating supervisors.

Input to the computer was provided by dummy data on the rough draft versions of the flow sheets. The computer output (variables data and GEISHA transmission to SLA) permitted all necessary changes to be made prior to finalizing the forms. Examples of some of the production flow sheets are shown in Figure 11 (Liner Shim Manufacturing), Figure 12 (Liner Assembly Process), Figure 13 (Strength Member Assembling Process), and Figure 14 (Clad Assembling Process).

X. TMS and Production Plans

Tool Made Sample activities will take place from July 11, 1977, through September 9, 1977. Hardware fabrication and fuel processing will be initiated in a parallel manner at the beginning of TMS, with encapsulation to be initiated August 2, 1977. Nondestructive testing of the sources will follow, along with fabrication and testing of pressure burst capsules.

"Blow hole" type failure in MPT-52F,
with included material consisting of iron, silicon, potassium, and calcium

FIGURE 7

FIGURE 8

Weld separation occurring along 90% of the weld
heat affected zone of MPT-53F

Poorly defined crack in MPT-54F, with included material
consisting of iron, calcium, potassium, and silicon

FIGURE 9

Area at weld termination that produced an iron signal
when subjected to the EDXRA

FIGURE 10

01		DATE 6		DRAWING NO 8 10		PROD. SPEC 16 17		75 TABLE 78		79 80		FORM NO.		ISSUE 3		EFFECTIVITY		Cut here USE BLACK INK	
		1		291669		314643		0 1 3 1 7 1 1		0 1 1		ML-6021		01-A		07.01.77			
		LOT 1 2		79 80															
		NO.		4 1 1															

**MD 70166: MILLIWATT GENERATOR COMPONENT FABRICATION
OPERATION SHEET 01 MC2893 LINER SHIM MANUFACTURING**

SERIAL NUMBER	IDENTIFY A01 A02	VISUAL INSPECT 3 4 1	DIAMETER 4.3		THICKNESS 4.3		SCLC	REVIEW 5	SPARE		DEVIATION CODE		CLEAN HEAT TREAT STORE 6 7 8	REMARKS:	TRANS. For Material Control Use Only																																																																																																																																																																																																																																																																																																																																													
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FIGURE 12 - MC2893 LINER ASSEMBLING PROCESS

☒ MEANS CONFORMANCE TO SPECIFICATIONS

MBC ML 6917 (7-77)

A change in production plans has been directed by ALO, with heat source production start-up now planned on October 3, 1977. An accelerated schedule will follow, with fabrication of heat sources for the first two users to be completed in two years (by October 1, 1979) rather than the previously planned four years. (Production of units with the four-year schedule was paced by the 26-1/2 year design life, and the associated pre-production restrictions of seven months. The design life is now shortened with the accelerated schedule.)

To allow sufficient hardware and fuel to be produced, qualified, and available for heat source fabrication, WR production for these operations is scheduled immediately after TMS. The revised schedule for plutonium-238 fuel feed requirements has been submitted to DMA and ALO (Weapons Programming and Scheduling Division and Nuclear Materials Waste Management Division). Preliminary indications are that Savannah River Plant can provide fuel to meet the accelerated schedule needs.