LA-9672-PR
Progress Report

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Milliwatt-Generator Project

October 1981—March 1982

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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Prepared by Bertha Sandoval, Group MST-11

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MILLIWATT GENERATOR PROJECT
October 1981 - March 1982

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W. J. Maraman

Contributors

W. A. Stark, Jr. (Project Leader), C. E. Frantz, C. C. Land,
T. H. Feiertag, and G. H. Rinehart

ABSTRACT

This formal biannual report covers the effort related to the Milliwatt Generator Project (MWG) carried out for the Department of Energy, Office of Military Applications, by the Los Alamos National Laboratory.

Most of the studies discussed here are of a continuing nature. Results and conclusions may change as the work continues. Published reference to the results cited in this report should not be made without the explicit permission of the person in charge of the work.

I. SCHEDULE

A. General

Los Alamos will fabricate the MC 3599 heat source (4.5 W) for the MC 3500 radioisotopic thermoelectric generator (RTG) in addition to the MC 2893A heat source (4.0 W) for the MC 2730A RTG.

The main tasks to be accomplished before the initiation of WR production at Los Alamos are shown in Figs. I-1 through I-3. This schedule has been agreed to in a series of meetings between Los Alamos personnel and representatives from DOE/ALO, Sandia National Laboratories Albuquerque (SNLA), Mound Facility (MF) of Monsanto Research, and the General Electric Neutron Devices Division (GEND).

DATE: April 1982

Fig. I-1. MWG project schedule, part 1.

DATE: April 1982

Fig. I-2. MWG project schedule, part 2.

Fig. I-3. MWG project schedule, part 3.

DATE: April 1982

During the first half of FY 1982, the primary tasks at Los Alamos were to (1) continue training of personnel, (2) continue surveillance activities, (3) fabricate 32 fueled test units for GEND, (4) complete fabrication of 40 shelf life test units and miscellaneous fueled test units, (5) complete evaluation of the Los Alamos fueled compatibility test units, and (6) complete Tool Made Sample (TMS) activities. Each of these tasks has been accomplished, although some new compatibility testing is not yet complete.

B. TMS Activities

The TMS evaluation consists of an in-depth review and examination by the design agency (SNLA) of the production procedures and operations at Los Alamos. The TMS activities were initiated on July 1, 1981, and by March 1982, all Los Alamos procedures had been reviewed and approved. Final approval of the TMS activities is also dependent on the successful completion of various tests performed with representative Los Alamos heat sources and on resolution of Los Alamos standards and calibration capabilities.

1. Compatibility Tests. Twelve representative heat sources were placed in furnaces for testing at three different temperatures. Fabrication of the heat sources and the test matrix are described in Sec. III. The results are discussed in Sec. V. In addition, four heat sources, fueled with $^{238}\text{PuO}_2$, spiked with specific impurities, were placed in test. These are described in Sec. III, and the results are discussed in Sec. IV.

2. TMS Heat Sources. Fifteen MC 3599 (4.5-W) heat sources were made using the TMS feed lot. Two of these, randomly selected by SNLA personnel, were sectioned and subjected to metallographic and chemical analyses. One of these two was successfully impacted at 150 m/s and 450°C before being sectioned. The remaining heat sources were sent to GEND for testing. The fabrication of the TMS heat source lot is described in Sec. III. The results for the sectioned heat sources are discussed in Sec. V.

II. FUEL PROCESSING AND CHARACTERIZATION

A. Processing

During the first half of FY 1982, eight lots of Savannah River Plant (SRP) feed powder were processed using the MWG fuel-processing glovebox line. The amount of MWG fuel produced totaled 1593 g.

B. Characterization

1. Neutron Emission Data. Neutron emission rate data for the processed fuel lots are listed in Table II-1. The as-received SRP feed powder has an average neutron emission rate of about 16 900 n/s-g ^{238}Pu . After the ^{16}O -exchange reaction and other processing steps, the average neutron emission rate is 4 300 n/s-g ^{238}Pu .

2. Particle Size Data. Particle size data for both as-received SRP feed powder and ball-milled powder are listed in Table II-2. Ball-milling the feed powder for 44 h reduces the mass median diameter of the particles from 3.3 μm a nominal 1.0 μm as preparation for forming the 53- to 500- μm fuel granules.

3. Spectrochemical Data. Spectrochemical data for the 11 lots of as-received SRP feed powder are listed in Table II-3. All of the cation impurity levels are within specification limits except for calcium and occasionally aluminum and silicon. Data for these same lots processed at Los Alamos are listed in Table II-4. These data indicate that processing generally lowers the calcium impurity level but raises the silicon impurity level. Processed fuel lots 75 and 76 will be screened and washed a second time in an attempt to lower the calcium impurity level.

4. Isotopic Data. The plutonium isotopic data for the 11 lots of as-received SRP feed powders are listed in Table II-5. For comparison, the Savannah River values were corrected for decay to the dates of the Los Alamos analyses. In general, very good agreement between the two values is observed.

III. FABRICATION OF TEST UNITS

A. Fueled Test Units

1. Fabrication. During the first half of FY 1982, 15 liners were loaded with PuO_2 fuel and welded. During this same period, 10 fueled liners were encapsulated in strength members and 4 fueled strength members were encapsulated in the outer clad assemblies. Data for liner assemblies that have been fabricated since TMS activities began (in July 1981) are listed in Tables III-1 and III-2. Data for strength member assemblies are listed in Tables III-3 and III-4. Data for the clad assemblies are summarized in Tables III-5 and III-6.

2. Shelf Life and Miscellaneous Test Units. During the first half of FY 1982, seven 4.0-W fuel charges were encapsulated into liners and strength member

TABLE II-1
NEUTRON EMISSION RATE DATA FOR FEED LOTS

ID Numbers			n/s-g ²³⁸ Pu		
Los Alamos	SRP		As		
Lot	Lot	Run	Received	Processed	Loaded ^a
64	498	012207	16 600	4 060	4 210
65	498	012208	17 600	4 160	
66	498	012209	17 200	4 090	3 780
67	477	007124	16 700	4 350	4 380
68	482	009149	16 600	4 580	
70	482	009151	16 600	3 900	
71	482	009152	17 000	5 160	
72	483	009158	16 600	4 490	
73	499	101214	16 600	4 280	
75	499	101216	16 400	4 410	
76	501	101221	17 300	3 930	
77	501	101224	17 500		
			16 900	4 310	4 120
			±400	±360	±310

^aAllowable: <6400 n/s-g ²³⁸Pu.

TABLE II-2
PARTICLE SIZE DATA FOR FEED LOTS

Lot	Mass Median Diameter (μm)	
	As Received	Ball Milled 44 h
64	2.39	0.72
65	2.53	0.92
66	2.86	0.98
67	4.29	1.13
68	3.60	0.86
70	4.07	0.86
71	3.80	0.84
72	3.60	0.98
73	3.25	1.62
75	3.10	0.86
76	3.32	0.73
77	3.02	
		3.32
		0.95
		±0.58
		±0.25

TABLE II-3
SPECTROCHEMICAL DATA FOR FEED LOTS
AS RECEIVED FROM SRP
LOS ALAMOS ANALYSES^a

Species	Specification	Sensitivity Limit	Los Alamos Lot ID											Av
			64	65	66	67	68	70	71	72	73	75	76	
Al	70	5	5 ^b	120	55	50	20	35	55	20	25	10	8	37
B	10	1	<	<	<	<	<	<	<	<	<	<	<	<
Be	25	2	<	<	<	<	<	<	<	<	<	<	<	<
Bi	25	1	<	<	<	<	<	<	<	<	<	<	<	<
Ca	250	3	2000	2000	1000	800	750	250	750	750	500	1000	1000	980
Cd	25	10	<	<	<	<	<	<	<	<	<	<	<	<
Co	50	2	<	<	<	<	<	<	<	<	<	<	<	<
Cr	150	5	15	55	30	80	45	65	15	20	70	50	20	42
Cu	50	1	1	1	3	3	<	<	<	<	<	<	<	1
Fe	500	5	75	160	180	280	120	100	30	90	110	140	80	120
Mn	50	1	1	2	4	10	<	7	3	3	2	5	2	4
Ni	100	5	15	65	30	45	35	50	8	10	30	25	5	29
Pb	50	5	25	20	20	40	5	7	6	6	20	20	20	17
Si	100	5	40	95	90	180	55	8	10	50	65	20	20	58
Sn	50	5	<	<	<	<	<	5	<	<	<	<	<	<
Zn	100	5	5	5	20	8	<	<	<	<	<	<	<	3

^a ppm by weight.

^b Less than sensitivity limit.

TABLE II-4
SPECTROCHEMICAL DATA FOR FEED LOTS
PROCESSED AT LOS ALAMOS^a

Species	Specification	Sensitivity Limit	Los Alamos Lot ID											Av
			64	65	66	67	68	70	71	72	73	75	76	
Al	70	5	35 ^b	9	8	25	110	30	<	30	25	<	40	28
B	10	1	<	<	<	<	<	<	<	<	<	<	<	<
Be	25	1	<	<	<	<	<	<	<	<	<	<	<	<
Bi	25	1	<	<	<	<	<	<	<	<	<	<	<	<
Ca	250	3	50	10	25	100	10	125	50	7	250	750	1500	260
Cd	25	10	<	<	<	<	<	<	<	<	<	<	<	<
Co	50	3	<	<	<	<	<	<	<	<	<	<	<	<
Cr	150	5	<	15	15	80	25	35	<	15	30	20	12	22
Cu	50	1	<	<	1	<	<	3	<	<	<	<	<	<
Fe	500	5	95	160	140	350	130	155	300	100	150	110	65	160
Mn	50	1	<	1	2	5	<	2	<	2	2	1	1	1
Ni	100	5	<	<	<	<	<	5	<	<	<	<	<	<
Pb	50	5	<	<	<	<	<	6	<	<	<	<	<	<
Si	100	5	260	170	210	290	45	60	140	80	140	20	45	130
Sn	50	5	<	<	<	<	<	<	<	<	<	<	<	<
Zn	100	5	<	5	<	10	<	15	<	<	<	<	<	<

^a ppm by weight.

^b Less than sensitivity limit.

TABLE II-5
ISOTOPIC DATA FOR FEED LOTS^a

Feed Lot	Lab	Plutonium Isotope				
		238	239	240	241	242
64	SR ^b	83.23	14.17	2.04	0.41	0.15
	Los Alamos	83.18	14.21	2.05	0.41	0.15
65	SR	83.24	14.16	2.04	0.41	0.15
	Los Alamos	83.19	14.20	2.04	0.41	0.15
66	SR	83.23	14.17	2.04	0.41	0.15
	Los Alamos	83.22	14.19	2.04	0.41	0.15
67	SR	82.96	14.37	2.09	0.43	0.15
	Los Alamos	82.98	14.35	2.08	0.43	0.15
68	SR	82.79	14.57	2.07	0.42	0.14
	Los Alamos	83.18	14.24	2.03	0.40	0.14
70	SR	82.78	14.58	2.08	0.42	0.14
	Los Alamos	83.24	14.18	2.02	0.41	0.15
71	SR	82.77	14.60	2.08	0.42	0.14
	Los Alamos	83.18	14.25	2.02	0.40	0.14
72	SR	83.12	14.29	2.04	0.41	0.14
	Los Alamos	83.14	14.27	2.04	0.40	0.15
73	SR	83.41	14.05	2.00	0.39	0.14
	Los Alamos	83.38	14.08	2.01	0.39	0.14
75	SR	83.41	14.05	2.00	0.39	0.14
	Los Alamos	83.41	14.06	2.00	0.39	0.14
76	SR	83.88	13.70	1.91	0.37	0.13
	Los Alamos	83.83	13.74	1.92	0.37	0.13
Los Alamos Average		83.27	14.16	2.02	0.40	0.14
		±0.22	±0.16	±0.04	±0.02	±0.01

^aWeight percent.

^bSR value corrected for decay to dates of Los Alamos measurements.

TABLE III-1
FUELED LINER WELDS

Liner ID			Type	Lot	Fuel	Y (g)	Weldbox Atmosphere (ppm)			To Strength Member	Purpose	Disposition/Comments
Body ^a	Cap	Shim			PuO ₂ (g)		O ₂	H ₂ O	N ₂			
1925	1920	1641	3599	62	10.854	0.60	<1	<1	35	2046	Shelf Life Test	
1926	1921	1642	3599	62	10.854	0.60	<1	<1	35	2047	Shelf Life Test	
1927	1922	1643	3599	62	10.854	0.60	<1	<1	35	2048	Shelf Life Test	
1928	1924	1644	3599	62	10.854	0.60	<1	<1	35	2049	Shelf Life Test	
1929	1925	1645	3599	62	10.854	0.60	<1	<1	35	2050	Shelf Life Test	
1930	1926	1646	3599	62	10.854	0.60	<1	<1	35	2051	Shelf Life Test	
1931	1927	1647	3599	62	10.854	0.60	<1	<1	35	2052	Calorimeter Std	
1933	1928	1648	3599	62	10.854	0.60	<1	<1	35	2053	Shelf Life Test	
1934	1929	1649	3599	62	10.854	0.60	<1	<1	35	2054	Shelf Life Test	
1936	1936	1651	3599	62	10.854	0.60	<1	<1	38	2056	Shelf Life Test	
1937	1937	1652	3599	62	10.854	0.60	<1	<1	38	2057	Shelf Life Test	
1938	1938	1653	3599	62	10.854	0.60	<1	<1	38	2059	Shelf Life Test	
1954	1945	1685	3599	64	10.830	0.59	<1	2	19	2071	Los Alamos TMS	
1955	1946	1686	3599	64	10.829	0.59	<1	2	19	2072	Los Alamos TMS	
1956	1947	1687	3599	64	10.828	0.59	<1	2	19	2073	Los Alamos TMS	
1957	1948	1688	3599	64	10.828	0.59	<1	2	19	2074	Los Alamos TMS	
1958	1949	1689	3599	64	10.830	0.59	<1	2	19	2075	Los Alamos TMS	
1959	1950	1690	3599	64	10.828	0.59	<1	2	19	2076	Los Alamos TMS	
1960	1951	1691	3599	64	10.829	0.59	<1	2	19	2077	Los Alamos TMS	
1961	1952	1692	3599	64	10.828	0.59	<1	2	19	2078	Los Alamos TMS	
1962	1953	1693	3599	64	10.828	0.59	<1	2	19	2079	Los Alamos TMS	
1964	1954	1694	3599	64	10.831	0.59	<1	2	19	2081	Los Alamos TMS	
1965	1955	1695	3599	64	10.831	0.59	<1	2	19	2082	Los Alamos TMS	
1966	1956	1696	3599	64	10.828	0.59	<1	2	19	2083	Los Alamos TMS	
1967	1957	1697	3599	64	10.829	0.59	<1	2	18	2085	Los Alamos TMS	
1968	1958	1698	3599	64	10.828	0.59	<1	2	18	2088	Los Alamos TMS	
1969	1959	1699	3599	64	10.830	0.59	<1	2	18	2089	Los Alamos TMS	
1971	1961	1700	3599	66	10.876	0.60	<1	3	23	2092	Los Alamos Test	
1972	1962	1701	3599	66	10.877	0.60	<1	3	23	2094	Los Alamos Test	
1973	1963	1702	3599	66	10.876	0.60	<1	3	23	2095	Los Alamos Test	
1974	1964	1703	3599	66	10.877	0.60	<1	3	23	2099	Los Alamos Test	
1975	1965	1704	3599	66	10.879	0.60	<1	3	23	2101	Los Alamos Test	
1978	1966	1705	3599	66	10.877	0.60	<1	3	23	2102	Los Alamos Test	
1982	1967	1706	3599	66	10.877	0.60	<1	3	23	2103	Los Alamos Test	
1984	1968	1707	3599	66	10.877	0.60	<1	3	23	2104	Los Alamos Test	
1986	1969	1708	3599	66	10.878	0.60	<1	3	23	2107	Los Alamos Test	
1990	1970	1709	3599	66	10.878	0.60	<1	3	23	2108	Los Alamos Test	
1996	1973	1710	3599	67	10.920	0.60	<1	3	98	2117	GENE Test	
1999	1974	1760	3599	67	10.919	0.60	<1	3	98	2118	GENE Test	
2003	1975	1761	3599	67	10.919	0.60	<1	3	98	2119	GENE Test	

^aLiner assembly ID number.

TABLE III-2
FUELED LINER WELDS

Liner ID			Type	Fuel		Y (g)	Weldbox Atmosphere (ppm)			To Strength Member	Purpose	Disposition/Comments
Body ^a	Cap	Shim		Lot	PuO ₂ (g)		O ₂	H ₂ O	N ₂			
2005	1976	1762	3599	67	10.919	0.60	<1	3	98	2120	GEND Test	
2006	1977	1763	3599	67	10.918	0.60	<1	2	31	2121	GEND Test	
2007	1978	1764	3599	67	10.919	0.60	<1	2	31	2122	GEND Test	
2016	1979	1765	3599	67	10.920	0.60	<1	2	31	2124	GEND Test	
2018	1980	1766	3599	67	10.919	0.60	<1	2	31	2125	GEND Test	
2020	1981	1767	3599	67	10.919	0.60	<1	2	31	2126	GEND Test	
2022	1982	1768	3599	67	10.920	0.60	<1	2	31	2127	GEND Test	
2023	1983	1769	3599	67	10.920	0.60	<1	2	31	2128	GEND Test	
2025	1985	1771	3599	66	10.887	0.60	<1	2	55	2132	Compatibility Test	Doped with Al
2026	1986	1772	3599	66	10.887	0.60	<1	2	55	2133	Compatibility Test	Doped with Ca
2027	1987	1773	3599	66	10.887	0.60	<1	2	55	2134	Compatibility Test	Doped with Si
2028	1988	1774	3599	66	10.887	0.60	<1	2	55	2136	Compatibility Test	Doped with Al, Ca, & Si
2057	1998	1782	2893A	63	9.687	0.53	<1	<1	43	2152	Shelf Life Test	
2058	1999	1783	2893A	63	9.704	0.53	<1	<1	43	2153	Shelf Life Test	
2059	2000	1784	2893A	63	9.690	0.53	<1	<1	43	2154	Shelf Life Test	
2061	2001	1785	2893A	63	9.686	0.53	<1	<1	43	2155	Shelf Life Test	
2062	2002	1786	2893A	63	9.705	0.53	<1	<1	43	2156	Shelf Life Test	
2063	2003	1787	2893A	63	9.696	0.53	<1	<1	43	2157	Shelf Life Test	
2066	2004	2789	2893A	63	9.707	0.53	<1	<1	43	2159	Shelf Life Test	
2068	2006	1790	3599	63	10.906	0.59	<1	<1	45	2148	SNL Test	
2069	2007	1791	3599	63	10.920	0.59	<1	<1	45	2149	SNL Test	
2070	2008	1792	3599	63	10.914	0.59	<1	<1	45			PuO ₂ Contaminated Weld
2038	2009	1793	3599	63	10.915	0.59	<1	<1	45	2150	SNL Test	
2090	2121	1841	2893A	72	9.771	0.54	<1	<1	32		Test	Control
2091	2123	1842	2893A	72	9.772	0.54	<1	<1	63		Test	Doped with Al,Ca, & Si
2092	2124	1843	3599	72	10.992	0.60	<1	<1	63		Test	Control
2093	2125	1844	3599	72	10.992	0.60	<1	<1	63		Test	Doped with Al,Ca, & Si

^aLiner assembly ID number.

TABLE III-3
FUELED STRENGTH MEMBER WELDS

SM ID		Liner Assembly	Type	Weldbox Atmosphere (ppm)			To Clad	Purpose	Disposition/Comments
Cap ^a	Body			O ₂	H ₂ O	N ₂			
2032	2059	1908	2893	<1	<1	20	LASL-104	Shelf Life Test	
2033	2060	1910	2893	<1	<1	20	LASL-105	Shelf Life Test	
2043	2062	1921	3599	<1	<1	31	UAS-038T	Shelf Life Test	
2044	2063	1922	3599	<1	<1	31	UAS-039T	Shelf Life Test	
2045	2064	1924	3599	<1	<1	8	UAS-053T	Shelf Life Test	
2046	2065	1925	3599	<1	<1	31	UAS-041T	Shelf Life Test	
2047	2066	1926	3599	<1	<1	31	UAS-042T	Shelf Life Test	
2048	2067	1927	3599	<1	<1	31	UAS-043T	Shelf Life Test	
2049	2068	1928	3599	<1	<1	31	UAS-044T	Shelf Life Test	
2050	2069	1929	3599	<1	<1	31	UAS-045T	Shelf Life Test	
2051	2070	1930	3599	<1	<1	31	UAS-046T	Shelf Life Test	
2052	2072	1931	3599	<1	<1	31	UAS-047T	Calorimetry Std	
2053	2073	1933	3599	<1	<1	31	UAS-048T	Shelf Life Test	
2054	2074	1934	3599	<1	<1	31	UAS-049T	Shelf Life Test	
2056	2076	1936	3599	<1	<1	8	UAS-054T	Shelf Life Test	
2057	2077	1937	3599	<1	<1	50	UAS-051T	Shelf Life Test	
2059	2078	1938	3599	<1	<1	50	UAS-052T	Shelf Life Test	
2071	2095	1954	3599	<1	3	21	UAS-0001	Los Alamos TMS	
2072	2127	1955	3599	<1	3	21	UAS-0002	Los Alamos TMS	
2073	2128	1956	3599	<1	3	21	UAS-0003	Los Alamos TMS	
2074	2129	1957	3599	<1	3	21	UAS-0004	Los Alamos TMS	
2075	2130	1958	3599	<1	3	21	UAS-0005	Los Alamos TMS	
2076	2131	1959	3599	<1	3	21	UAS-0006	Los Alamos TMS	
2077	2132	1960	3599	<1	3	21	UAS-0007	Los Alamos TMS	
2078	2134	1961	3599	<1	3	21	UAS-0008	Los Alamos TMS	
2079	2135	1962	3599	<1	3	21	UAS-0009	Los Alamos TMS	
2081	2136	1964	3599	<1	3	21	UAS-0010	Los Alamos TMS	
2082	2137	1965	3599	<1	3	21	UAS-0011	Los Alamos TMS	
2083	2138	1966	3599	<1	3	21	UAS-0012	Los Alamos TMS	
2085	2140	1967	3599	<1	3	23	UAS-0013	Los Alamos TMS	
2088	2141	1968	3599	<1	2	10	UAS-0016	Los Alamos TMS	
2089	2142	1969	3599	<1	3	23	UAS-0015	Los Alamos TMS	
2092	2144	1971	3599	<1	2	10	00001	Los Alamos Test	
2094	2145	1972	3599	<1	2	10	00002	Los Alamos Test	
2095	2146	1973	3599	<1	2	10	00003	Los Alamos Test	
2099	2147	1974	3599	<1	2	10	00004	Los Alamos Test	
2101	2148	1975	3599	<1	2	10	00005	Los Alamos Test	
2102	2149	1978	3599	<1	2	10	00006	Los Alamos Test	
2103	2150	1982	3599	<1	2	10	00007	Los Alamos Test	
2104	2151	1984	3599	<1	2	10	00008	Los Alamos Test	

^aStrength member assembly ID number.

TABLE III-4
FUELED STRENGTH MEMBER WELDS

SM ID		Liner Assembly	Type	Weldbox Atmosphere (ppm)			To Clad	Purpose	Disposition/Comments
Cap ^a	Body			O ₂	H ₂ O	N ₂			
2107	2152	1986	3599	<1	2	10	00009	Los Alamos Test	
2108	2153	1990	3599	<1	2	10	00010	Los Alamos Test	
2117	2158	1996	3599	<1	<1	6	UAS-0028	GEND Test	
2118	2159	1999	3599	<1	<1	6	UAS-0018	GEND Test	
2119	2161	2003	3599	<1	<1	6	UAS-0019	GEND Test	
2120	2162	2005	3599	<1	<1	6	UAS-0020	GEND Test	
2121	2164	2006	3599	<1	<1	6	UAS-0021	GEND Test	
2122	2165	2007	3599	<1	<1	6	UAS-0022	GEND Test	
2124	2166	2016	3599	<1	<1	6	UAS-0023	GEND Test	
2125	2124	2018	3599	<1	<1	6	UAS-0024	GEND Test	
2126	2125	2020	3599	<1	<1	6	UAS-0025	GEND Test	
2127	2126	2022	3599	<1	<1	6	UAS-0026	GEND Test	
2128	2167	2023	3599	<1	<1	6	UAS-0027	GEND Test	
2132	2169	2025	3599	<1	<1	10	UAS-064T	Compatibility Test	Doped with Al
2133	2170	2026	3599	<1	<1	10	UAS-065T	Compatibility Test	Doped with Ca
2134	2171	2027	3599	<1	<1	10	UAS-066T	Compatibility Test	Doped with Si
2136	2177	2028	3599	<1	<1	10	UAS-067T	Compatibility Test	Doped with Al, Ca, & Si
2148	2187	2068	3599	<1	<1	7		SNL Test	
2149	2188	2069	3599	<1	<1	7		SNL Test	
2150	2189	2038	3599	<1	<1	7		SNL Test	
2152	2121	2057	2893A	<1	<1	8		Shelf Life Test	
2153	2192	2058	2893A	<1	<1	8		Shelf Life Test	
2154	2194	2059	2893A	<1	<1	8		Shelf Life Test	
2155	2195	2061	2893A	<1	<1	8		Shelf Life Test	
2156	2196	2062	2893A	<1	<1	8		Shelf Life Test	
2157	2197	2063	2893A	<1	<1	8		Shelf Life Test	
2159	2198	2066	2893A	<1	<1	8		Shelf Life Test	

^aStrength member assembly ID number.

TABLE III-5
FUELED CLAD WELDS

Clad ID	Subassembly ID		Type	Weldbox Atmosphere (ppm)			Purpose	Disposition/Comments
	SM	Liner		O ₂	H ₂ O	N ₂		
UAS-041T	2046	1925	3599	<1	<1	31	Shelf Life Test	At SNLA
UAS-042T	2047	1926	3599	<1	<1	31	Shelf Life Test	At SNLA
UAS-043T	2048	1927	3599	<1	<1	31	Shelf Life Test	At SNLA
UAS-044T	2049	1928	3599	<1	<1	31	Shelf Life Test	At SNLA
UAS-045T	2050	1929	3599	<1	<1	31	Shelf Life Test	At SNLA
UAS-046T	2051	1930	3599	<1	<1	31	Shelf Life Test	At SNLA
UAS-047T	2052	1931	3599	<1	<1	31	Calorimetry Std	
UAS-048T	2053	1933	3599	<1	<1	31	Shelf Life Test	At SNLA
UAS-049T	2054	1934	3599	<1	<1	31	Shelf Life Test	At SNLA
UAS-051T	2057	1937	3599	<1	<1	50	Shelf Life Test	At SNLA
UAS-052T	2059	1938	3599	<1	<1	50	Shelf Life Test	At SNLA
UAS-053T	2045	1924	3599	<1	<1	8	Shelf Life Test	At SNLA
UAS-054T	2056	1936	3599	<1	<1	8	Shelf Life Test	At SNLA
UAS-063T	1988	1830	3599	<1	<1	6	Shelf Life Test	
UAS0001	2071	1954	3599	<1	3	21	Los Alamos TMS	At GEND
UAS0002	2072	1955	3599	<1	3	21	Los Alamos TMS	At GEND
UAS0003	2073	1956	3599	<1	3	21	Los Alamos TMS	At GEND
UAS0004	2074	1957	3599	<1	3	21	Los Alamos TMS	At GEND
UAS0005	2075	1958	3599	<1	3	21	Los Alamos TMS	At GEND
UAS0006	2076	1959	3599	<1	3	21	Los Alamos TMS	Survived 150 m/s impact at 450°C
UAS0007	2077	1960	3599	<1	3	21	Los Alamos TMS	At GEND
UAS0008	2078	1961	3599	<1	3	21	Los Alamos TMS	At GEND
UAS0009	2079	1962	3599	<1	3	21	Los Alamos TMS	At GEND
UAS0010	2081	1964	3599	<1	3	21	Los Alamos TMS	At GEND
UAS0011	2082	1965	3599	<1	3	21	Los Alamos TMS	At GEND
UAS0012	2083	1966	3599	<1	3	21	Los Alamos TMS	At GEND
UAS0013	2085	1967	3599	<1	3	23	Los Alamos TMS	At GEND
UAS0015	2089	1969	3599	<1	3	23	Los Alamos TMS	Sectioned for metallography
UAS0016	2088	1968	3599	<1	2	10	Los Alamos TMS	
00001	2092	1971	3599	<1	2	10	Los Alamos Test	
00002	2094	1972	3599	<1	2	10	Los Alamos Test	
00003	2095	1973	3599	<1	2	10	Los Alamos Test	
00004	2099	1974	3599	<1	2	10	Los Alamos Test	
00005	2101	1975	3599	<1	2	10	Los Alamos Test	
00006	2102	1978	3599	<1	2	10	Los Alamos Test	
00007	2103	1982	3599	<1	2	10	Los Alamos Test	
00008	2104	1984	3599	<1	2	10	Los Alamos Test	
00009	2107	1986	3599	<1	2	10	Los Alamos Test	Compatibility Test Control
00010	2108	1990	3599	<1	2	10	Los Alamos Test	
UAS0018	2118	1999	3599	<1	<1	6	GEND Test	

TABLE III-6
FUELED CLAD WELDS

Clad ID	Subassembly ID		Type	Weldbox Atmosphere (ppm)			Purpose	Disposition/Comments
	SM	Liner		O ₂	H ₂ O	N ₂		
UAS0019	2119	2003	3599	<1	<1	6	GEND Test	
UAS0020	2120	2005	3599	<1	<1	6	GEND Test	
UAS0021	2121	2006	3599	<1	<1	6	GEND Test	
UAS0022	2122	2007	3599	<1	<1	6	GEND Test	
UAS0023	2123	2016	3599	<1	<1	6	GEND Test	
UAS0024	2125	2018	3599	<1	<1	6	GEND Test	
UAS0025	2126	2020	3599	<1	<1	6	GEND Test	
UAS0026	2127	2022	3599	<1	<1	6	GEND Test	
UAS0027	2128	2023	3599	<1	<1	6	GEND Test	
UAS0028	2117	1996	3599	<1	<1	20	GEND Test	
UAS-064T	2132	2025	3599	<1	<1	12	Compatibility Test	Doped with Al
UAS-065T	2133	2026	3599	<1	<1	12	Compatibility Test	Doped with Ca
UAS-066T	2134	2027	3599	<1	<1	12	Compatibility Test	Doped with Si
UAS-067T	2136	2028	3599	<1	<1	12	Compatibility Test	Doped with Al, Ca, & Si

assemblies for Los Alamos shelf life tests. Four 4.5-W fuel charges were encapsulated into liners and strength member assemblies for tests at SNLA. In addition, two 4.0-W fuel charges and two 4.5-W fuel charges were encapsulated into liner assemblies. One of the 4.0-W fuel charges and one of the 4.5-W fuel charges were doped with aluminum (220 ppm), calcium (550 ppm), and silicon (310 ppm). All four units (Liner Assembly ID 2090-2093) will be encapsulated in strength members, heat treated at 1350°C for one hour, sectioned, and examined metallographically. Results will be compared with those from units that have been aged at 900°C for 60 days. Also the results from the 4.0-W units will be compared with the results from the 4.5-W units.

3. Compatibility Test Units. The data listed in Table II-3 indicate that many of the feed lots received from SRP contain aluminum, calcium, and silicon in amounts exceeding the specification limits. Thus, during the first half of FY 1982, four MC 3599 heat sources were made with fuel doped with aluminum, calcium, and silicon to check possible compatibility effects between the fuel and the T-111 capsule. The dopant levels for these units are summarized in Table III-7. The heat sources were encapsulated in Hastelloy X containers and placed in furnaces for compatibility testing for 60 days at 900°C. The units were then removed from the furnaces, sectioned, and examined metallographically. The results from these units are discussed in Sec. IV.

B. End-of-Life Test Units.

As noted in the last report, during the second half of FY 1981, eight liner assemblies were fueled with a 50/50 mixture (by weight) of molybdenum and tungsten powders and the caps were welded. Each assembly had a 0.10-mm-diam hole drilled through the liner cap. Each liner assembly was then encapsulated in a strength member assembly having a 0.10-mm-diam hole drilled through the cap. These assemblies were pressurized to 1 250 psi with helium while the holes in the strength member caps were sealed with a laser weld. The pressurized assemblies were then encapsulated in outer clad assemblies and shipped to SNLA for testing under conditions simulating end-of-life helium pressures.

Three of these units, UAS-055T, UAS-056T, and UAS-057T, have been received from SNLA for posttest analysis. The three units have been radiographed, and measurements to determine the approximate amount of helium contained in the units are in progress.

TABLE III-7
SPECTROCHEMICAL DATA FOR DOPED COMPATIBILITY UNITS^a

Clad ID	Subassembly ID		Impurity Content (ppm by weight)			Comments
	SM	Liner	Al	Ca	Si	
00009	2107	1986	30	400	220	Control capsule
UAS-064T	2132	2025	220	500	310	Doped with Al
UAS-065T	2133	2026	20	1000	280	Doped with Ca
UAS-066T	2134	2027	20	250	1000	Doped with Si
UAS-067T	2136	2028	100	2000	780	Doped with Al, Ca, & Si

^a60-day, 900°C test.

IV. DESTRUCTIVE TESTING

A. Impact Tests

During the first half of FY 1982, one heat source, MAD-0108, an MF-fabricated surveillance unit was impacted at the "standard" conditions: 150 m/s impact velocity, side-on impact attitude, and 450°C temperature. The unit survived impact, with the results shown in Figs. IV-1 and IV-2. Postmortem of this unit is not yet complete.

Because of concerns raised during TMS activities, the temperature difference between the impact facility sample furnace and a typical heat source (UAS-047T) was measured under simulated pre-impact conditions. Thermocouples were spot-welded midway on the side of the heat source, which was then assembled for impact per procedure HS-CMB5-PP-1. During heat-up of the furnace, the temperatures of both the furnace and the heat source were monitored, with the results shown in Fig. IV-3. These results indicate that the heat source temperature during pre-impact test preparation may be as much as 140°C above indicated furnace temperature because of the isotopic heating. Impact procedures have since been modified to incorporate direct temperature measurement of the heat source during pretest heating.

B. Compatibility Testing.

Twelve Los Alamos manufactured MWG heat sources (LASL-51 through 56, and LASL-63 through 68), which are to be used for compatibility studies, were placed on test at 600, 900, or 1100°C on January 26, 1981. The test periods were 60 days, 240 days, and 2 years.

1. 60 Day Test Results. The 60-day results were reported in the last Milliwatt Semi-Annual Report.¹ The oxygen, nitrogen, and hardness data for this test series are shown in Table IV-1 and are included in this report to allow comparison of the 60-day test results with the 240-day test results, which will be discussed later.

Metallographic evaluations of the 600, 900, and 1100°C 60-day tests revealed that (1) at 600°C neither the liner nor the strength member was affected; (2) at 900°C the strength member was unaffected, but the liner was hardened, with oxygen level as high as 3800 ppm; and (3) at 1100°C the strength member was unaffected by oxygen from the fuel but suffered some hardening as a result of the inward diffusion of nitrogen through the Hastelloy C clad. The liner was

Fig. IV-1. MAD-0108-K77 after impact, 90° to impact face. Simulant capsule WYMT-02 is on right.

Fig. IV-2. Impact face of MAD-0108-K77 after impact. Simulant-loaded capsule WYMT-02 is on the right.

Fig. IV-3. Measured temperatures of impact furnace and prototype 4.5-W heat source (UAS-047T) in the furnace. Steady-state temperature difference is approximately 140°C.

hardened considerably and the oxygen level was high after the 1100°C tests, as can be seen in Table IV-1.

2. 240-Day Test Results. The oxygen, nitrogen, and hardness data for the 240-day test series are listed in Table IV-2. Hardness profiles for the respective liners and strength members are shown in Figs. IV-4 through IV-9.

Metallographic evaluations of the 240-day test capsules revealed that (1) neither the liner nor the strength member was affected by the 600°C test; (2) at 900°C the strength member was unaffected, but the liner was strongly affected in terms of increased oxygen content and hardness (see crack in Fig. IV-10); and (3) at 1100°C the strength member was unaffected by oxygen from the fuel but was hardened considerably by the nitrogen picked up from the air as a result of the nitrogen diffusing the Hastelloy C clad. In this test the liner was hardened considerably and the oxygen level was high as can be seen in Table IV-2.

Metallic components from the clad transferred to the outer surface of the strength member (see Fig. IV-11). This effect, and the hardening of the strength member resulting from inward diffusion of nitrogen, raised serious concern regarding the safety of the 2-year, 1100°C tests because the tests are being conducted in a nonradioactive area. Saturation of the strength member with nitrogen was also making the data accumulated at 1100°C less valuable. Permission was received to terminate these tests on December 23, 1982.

The oxygen levels achieved in the 240-day tests at both 900 and 1100°C were about the same as those achieved in the 60-day tests. This fact suggests a saturation limit for the T-111 at a given temperature. Liu and coworkers at Oak Ridge National Laboratory (ORNL)² have suggested that the primary mechanism of oxidation for the T-111 alloy is initial oxidation of the hafnium in the alloy to HfO_2 , after which the tantalum becomes saturated interstitially with oxygen. The ORNL workers observed saturation levels of 3500 ppm O_2 at 1000°C, whereas after 240 days we measured levels of 3400 ppm at 900°C and 4100 ppm at 1100°C. In spite of this apparent saturation, the oxygen does not appear to diffuse into the strength member.

The oxygen levels achieved in this compatibility study at 900 and 1100°C in both the 60- and the 240-day test periods are higher (by factors of 2-10) than the oxygen levels achieved at MF in a similar study.^{3,4} The MF 240 day 1100°C oxygen levels appear to be approaching the oxygen levels obtained when the Los Alamos units approached saturation at the 900°C test temperature. This result originally suggested that the Los Alamos tests might have been running at

TABLE IV-1

OXYGEN, NITROGEN, AND AVERAGE VICKERS
HARDNESS VALUES FOR 60-DAY COMPATIBILITY TESTS

Heat Source	Location	O ₂ (ppm)	N ₂ (ppm)	Av VHN
LASL-56 (600°C Test)	Liner			
	Cap	-	-	251
	Dome	240	12	287
	Body	90	11	266
	Weld	95	20	252
	Strength Member			
	Cap	-	-	257
	Dome	65	13	248
	Body	45	13	254
	Weld	45	20	260
LASL-64 (900°C Test)	Liner			
	Cap	-	-	230
	Dome	2000	11	701-950
	Body	770	10	426-891
	Weld	100	18	262
	Strength Member			
	Cap	-	-	247
	Dome	60	45	253
	Body	60	30	248
	Weld	50	32	264
LASL-67 (1100°C Test)	Liner			
	Cap	-	-	233
	Dome	3800	34	375
	Body	3800	35	350
	Weld	1100	24	249
	Strength Member			
	Cap	-	-	265
	Dome	60	990-1180	300
	Body	50	880-1165	334
	Weld	110	475-595	288

TABLE IV-2

OXYGEN, NITROGEN, AND AVERAGE VICKERS
HARDNESS VALUES FOR 240-DAY COMPATIBILITY TESTS

<u>Heat Source</u>	<u>Location</u>	<u>O₂</u> <u>(ppm)</u>	<u>N₂</u> <u>(ppm)</u>	<u>Av</u> <u>VHN</u>
LASL-54 (600°C Test)	Liner			
	Cap	-	-	257
	Dome	150	40	256
	Body	150	50	264
	Weld	75	60	258
	Strength Member			
	Cap	-	-	249
	Dome	60	65	251
	Body	85	45	253
	Weld	50	50	258
LASL-55 (900°C Test)	Liner			
	Cap	-	-	253
	Dome	2600	45	432
	Body	3400	55	797
	Weld	50	45	263
	Strength Member			
	Cap	-	-	250
	Dome	120	290	301
	Body	100	105	268
	Weld	30	55	243
LASL-68 (1100°C Test)	Liner			
	Cap	-	-	366
	Dome	4000	150	433
	Body	4100	165	418
	Weld	2700	95	366
	Strength Member			
	Cap	-	-	295
	Dome	70	2500	547
	Body	110	2500	435
	Weld	40	2200	417

Fig. IV-4. Hardness profile for LASL-54 liner after 240-day, 900°C soak.

Fig. IV-5. Hardness profile for LASL-54 strength member after 240-day, 900°C soak.

Fig. IV-6. Hardness profile for LASL-55 liner after 240-day, 900°C soak.

Fig. IV-7. Hardness profile for LASL-55 strength member after 240-day, 900°C soak.

Fig. IV-8. Hardness profile for LASL-68 strength member after 240-day, 900°C soak.

Fig. IV-9. Hardness profile for LASL-68 liner after 240-day, 900°C soak.

Fig. IV-10. LASL-55, 900°C, 240-day compatibility test unit; liner dome, 100X, AP.

Fig. IV-11. LASL-68, 1100°C, 240-day compatibility test unit; strength member, 100X, AP.

a higher temperature than the MF test. To check this possibility, we installed a test capsule with a thermocouple welded directly to the Hastelloy C clad in the furnace where the 900°C test was being run. Results verified that the capsule surface temperature was within $\pm 15^\circ\text{C}$ of the indicated furnace temperature. Since the MF temperatures cannot be verified, the above test only validates the Los Alamos test temperature and reveals nothing about the apparent discrepancy in the test temperatures.

The Los Alamos test data in the 60- and in the 240-day tests at 900°C agree quite well (1900 vs 2000 ppm O_2 after 60 days at 900°C) with the test data obtained by MF on test units in which yttrium chips were added to the fuel but were not given the 1 hour at 1350°C pretreatment. An apparent ineffectiveness of the yttrium chips in reducing the fuel is also a possible explanation for the difference between the Los Alamos and the MF test results. The yttrium chips might not be effective if the pretreatment temperature were too low, if a protective oxide layer had formed on the surface of the chips, or if the spatial distribution were poor.

3. 60-Day, 900°C Dopant Compatibility Tests. Concern about a possible raising of the impurity limits for the $^{238}\text{PuO}_2$ feed stock from SRP and the lack of agreement between Los Alamos and MRC 60 day compatibility studies resulted in a further compatibility test matrix. Five 4.5- W_T heat sources, consisting of a control heat source (UAS-0009), a heat source (UAS-064T) doped with aluminum (220 ppm), a heat source (UAS-065T) doped with calcium (1000 ppm), a heat source (UAS-066T) doped with silicon (1000 ppm), and a heat source (UAS-067T) doped with all three (100 ppm Al, 2000 ppm Ca, 780 ppm Si), were placed on test at 900°C for 60 days. These impurity levels are summarized in Table III-7.

All five of these units have been metallographically evaluated and generally confirmed the results obtained on the initial Los Alamos 60-day, 900°C test series. The liners picked up oxygen (~ 2500 ppm) and were hardened, whereas the strength members remained unaffected. The oxygen, nitrogen, and hardness data for these units are listed in Table IV-3. Hardness profiles for the respective liners and strength members are shown in Figs. IV-12 through IV-21.

There were no obvious reactions that could be directly linked to the dopants nor was there any indication in the spectrographic analysis of the metal hardware that aluminum, calcium, or silicon levels had increased. It is interesting to note that about 20% of the yttrium chips were consumed in the heat source containing silicon; about 80% of the chips were consumed in the heat

TABLE IV-3
OXYGEN, NITROGEN, AND AVERAGE VICKERS
HARDNESS VALUES FOR 60-DAY COMPATIBILITY TESTS

<u>Heat Source</u>	<u>Location</u>	<u>O₂ (ppm)</u>	<u>N₂ (ppm)</u>	<u>Av VHN</u>
UAS-00009 (900°C Test)	Liner			
	Cap	-	-	245
	Dome	830	43	262-336
	Body	1200	57	258-390
	Weld	640	45	259-399
	Strength Member			
	Cap	-	-	252
	Dome	85	56	252
	Body	60	57	247
	Weld	55	47	253
UAS-064T (900°C Test)	Liner			
	Cap	-	-	245
	Dome	1200	35	251-405
	Body	2200	53	258-387
	Weld	90	14	262
	Strength Member			
	Cap	-	-	268
	Dome	70	35	257
	Body	70	22	264
	Weld	65	30	258
UAS-065T (900°C Test)	Liner			
	Cap	-	-	242
	Dome	2700	22	263-468
	Body	790	15	284-471
	Weld	280	7	248
	Strength Member			
	Cap	-	-	272
	Dome	60	34	268
	Body	60	33	268
	Weld	30	44	266
UAS-066T (900°C Test)	Liner			
	Cap	-	-	237
	Dome	1300	17	271-553
	Body	4400	17	362-469
	Weld	110	11	243
	Strength Member			
	Cap	-	-	257
	Dome	75	41	262
	Body	75	37	269
	Weld	75	35	232
UAS-067T (900°C Test)	Liner			
	Cap	-	-	214-445
	Dome	1800	32	252-442
	Body	1800	33	331-705
	Weld	2000	9	223-433
	Strength Member			
	Cap	-	-	256
	Dome	100	47	252
	Body	60	42	249
	Weld	60	40	257

Fig. IV-12. Hardness profile for 00009 liner after 60-day, 900°C soak. This unit, having nominal Al, Ca, and Si impurity levels of 30, 400, and 220 ppm, respectively, served as control.

Fig. IV-13. Hardness profile for 00009 strength member after 60-day, 900°C soak. This unit, having nominal Al, Ca, and Si impurity levels of 30, 400, and 220 ppm, respectively, served as control.

Fig. IV-14. Hardness profile for UAS-064T liner after 60-day, 900°C soak. This unit had nominal Al, Ca, and Si impurity levels of 220, 500, and 300 ppm, respectively.

Fig. IV-15. Hardness profile for UAS-064T strength member after 60-day, 900°C soak. This unit had nominal Al, Ca, and Si impurity levels of 220, 500, and 310 ppm, respectively.

Fig. IV-16. Hardness profile for UAS-065T liner after 60-day, 900°C soak. This unit had nominal Al, Ca, and Si impurity levels of 20, 1000, and 280 ppm, respectively.

Fig. IV-17. Hardness profile for UAS-065T strength member after 60-day, 900°C soak. This unit had nominal Al, Ca, and Si impurity levels of 20, 1000, and 280 ppm, respectively.

Fig. IV-18. Hardness profile for UAS-066T liner after 60-day, 900°C soak. This unit had nominal Al, Ca, and Si impurity levels of 20, 250, and 1000 ppm, respectively.

Fig. IV-19. Hardness profile for UAS-066T strength member after 60-day, 900°C soak. This unit had nominal Al, Ca, and Si impurity levels of 20, 250, and 1000 ppm, respectively.

Fig. IV-20. Hardness profiles for UAS-067T liner after 60-day, 900°C soak. This unit had nominal Al, Ca, and Si impurity levels of 100, 2000, and 780 ppm, respectively.

Fig. IV-21. Hardness profiles for UAS-067T strength member after 60-day, 900°C soak. This unit had nominal Al, Ca, and Si impurity levels of 100, 2000, and 780 ppm, respectively.

source containing all three dopants; essentially none of the chips were consumed in the other three heat sources.

There were defects in two liners and one strength member, but it is believed that these defects are not directly linked to the compatibility tests. A series of cracks was present in the strength member of the silicon-doped heat source (see Figs. IV-22 and IV-23) in the body just below the weld area. While possibly a sectioning phenomenon, these cracks appear to have originated at the exterior surface. Defects of this nature are not uncommon after the deep-drawing operation. Because there was no apparent increase in oxygen, nitrogen, or hardness, it is assumed that these defects were not caused by the dopant impurities.

The liner of the aluminum doped heat source had a crack in the lid near the weld (see Figs. IV-24 and IV-25) and what appeared to be a piece of fuel adhering to the body just below the weld (see Fig. IV-26) in an area where the weld shim was probably located during welding. Microprobe examination of the adherent material and the surrounding area revealed that the adherent particle contained plutonium and oxygen (probably PuO_2) and that the oxygen had diffused into the surrounding area. Microprobe examination of the crack in the cap revealed the presence of plutonium in the grain boundaries. These data indicate that the fuel can be incorporated into the liner near the welds during the welding process.

The liner of the heat source doped with Al, Ca, and Si had a grain boundary separation at the weld/heat affected-zone-interface on one side (see Fig. IV-27) and a series of cracks (see Figs. IV-28 and IV-29) in the liner body just below the weld, in an area near where the weld shim would be during welding. The location and nature of the cracks suggest that this problem may have resulted from a combination of overheating during the welding operation and resultant interaction with the fuel.

4. New Compatibility Test Matrix. Because of the high oxygen levels and high hardness numbers observed in the liners of the Los Alamos manufactured MWG heat sources after the 900°C compatibility tests, the SNLA TMS team has given only conditional permission for Los Alamos manufacture of the MWG heat sources. Tests of additional compatibility units were requested to assure that Los Alamos manufactured heat sources will safely survive 25 years of service at a ~400°C operating temperature. The newest test matrix is shown in Tables IV-4 and IV-5. The 900°C, 60-day tests will directly compare Los Alamos and MF-manufactured

Fig. IV-22. UAS-066T, 900°C, 60-day (Si-doped) compatibility test; strength member, 10X, AE.

Fig. IV-23. UAS-066T, 900°C, 60-day (Si-doped) compatibility test; strength member, 50X, AE.

Fig. IV-24. UAS-064T, 900°C, 60-day (Al-doped) compatibility test; crack in liner cap, 10X, AE.

Fig. IV-25. UAS-064T, 900°C, 60-day (Al-doped) compatibility test; PuO_2 adhering to liner body, 10X, AE.

Fig. IV-26. UAS-064T, 900°C, 60-day (Al-doped) compatibility test; PuO₂ adhering to liner body, 100X, AE.

Fig. IV-27. UAS-067T, 900°C, 60-day (Al-, Si-, Ca-doped) compatibility test; grain boundary separation in weld, 100X, AE.

Fig. IV-28. UAS-067T, 900°C, 60-day (Al-, Si-, Ca-doped) compatibility test; cracks in liner body, 10X, AE.

Fig. IV-29. UAS-067T, 900°C, 60-day (Al-, Si-, Ca-doped) compatibility test; cracks in liner body, 50X, AE.

TABLE IV-4

900°C, 60-DAY COMPATIBILITY TEST MATRIX

<u>Unit^a</u>	<u>Purpose</u>
4.0-W _T UAS Unit	4.0-W _T Control Unit
4.0-W _T -MAD Unit	Los Alamos vs MF comparison
4.0-W _T UAS Unit No pretreatment	Effect of pretreatments; compare with MF data on un- treated MF unit
4.5-W _T UAS Unit	Compare 4.0-W _T and 4.5-W _T units
4.5-W _T UAS Unit No pretreatment	Effect of pretreatment on 4.5-W _T units
4.5-W _T UAS Unit No Y. No pretreatment	Compare with 4.5-W _T units containing Y
4.5-W _T UAS Unit No Y, but undergo pre- treatment cycle	Compare with above

^aMAD = Mound manufacture
UAS = Los Alamos manufacture

TABLE IV-5

MILLIWATT KINETIC COMPATIBILITY STUDIES^a

	<u>60 days</u>	<u>240 days</u>	<u>2 yr</u>	<u>4 yr</u>	<u>8 yr</u>
600°C			(xx)	x	x
700°C	x	x	x	x	
800°C	x,z	x	x		
900°C		x			

^ax = Los Alamos 4.0-W_T Milliwatt heat source.
z = Los Alamos 4.0-W_T Milliwatt heat source with no 1350°C,
1 hour pretreatment.
(xx) = On test already for ~15 months.

units, and Los Alamos manufactured 4.0- and 4.5-W_T units. Additionally, the matrix will study the effectiveness of the Los Alamos pretreatment (1350°C for 1 h) as well as the effect of the yttrium chips with no pretreatment.

A crude extrapolation of the MF data at 800°C (240 days to reach ~1100 ppm O₂) and 900°C (60 days to reach ~1100 ppm O₂) obtained on MF manufactured 4.0-W_T units, which were not given the 1 h, 1350°C yttrium pretreatment, suggests that it would take ~171 year at 400°C for the oxygen level to reach ~1100 ppm O₂. The 600, 700, and 800°C test matrix is intended to be a kinetic study designed to shed light on the rate and mechanism of oxidation. The mechanisms involved at 900 and 1100°C, where the original tests were made, may not accurately reflect the mechanisms occurring at the operating temperature (~400°C).

V. QUALITY ASSURANCE

A. Standards and Calibrations

On February 3-4, 1982, representatives of the ALO Primary Standards Laboratory audited the MWG program activities for conformance to the ALO Standards and Calibration Program, as required by DOE Manual, Chapter 72XF.⁵ Major deficiencies in the Los Alamos standards laboratory (at MEC-4) were noted in the audit, such that DOE QA refused acceptance of the heat sources.

Subsequent to these audit findings, MWG operations and QA personnel worked with MEC-4 personnel to implement corrective actions as necessary. On April 7, 1982, a request for a status review was made by Los Alamos to DOE. This review was performed April 20, 1982, by SNLA representatives. On May 7, 1982, actions to withhold acceptance of the MWG heat sources were formally rescinded by DOE.

With the loss of MEC-4 as a calibration facility (except for mass and length), steps were taken to assure that the MWG program will have the capability to provide necessary calibration and certifications. These steps include the following:

1. Experienced staff have been hired to set up and operate a calibration facility.
2. Space for a small facility has been obtained.
3. Use of outside facilities such as NBS and the SNLA PSL has been strengthened.

B. Documents and Procedures

Documents, procedures, and data forms currently used for MWG production and inspection are listed below.

<u>ID</u>	<u>Revision</u>	<u>Title</u>
HS-QA-PD-1	3	Quality Assurance Program Plan
HS-QA-PD-2	2	Procurement Procedure
HS-QA-PD-3	0	Personnel Qualification and Certification Procedure
HS-QA-PD-4	0	Specification Exception Release Procedure
HS-QA-PD-5	1	Submission of Material to DOE
HS-CMB11-PD-1	1	Change Control Procedure
HS-CMB11-PD-2	2	Document Control Procedure
HS-QA-DF-1	0	Personnel Certification Form
HS-QA-DF-2	0	Specification Exception Release Data Form
HS-CMB11-PP-1	0	Isothermal Calorimeter Operation
HS-CMB11-PP-2	0	Decay Calculation Procedure
HS-CMB11-PP-3	0	Introduction of Feed to Line
HS-CMB11-PP-4	0	Oxygen-16 Exchange Procedure
HS-CMB11-PP-5	1	Ball-Milling Procedure
HS-CMB11-PP-6	0	Furnace Operating Procedure
HS-CMB11-PP-9	0	Hardware Cleaning
HS-CMB11-PP-11	2	Gamma III Balance Operation
HS-CMB11-PP-12	1	Recorder Operation Procedure
HS-CMB11-PP-13	3	Sampling PuO ₂ Procedure
HS-CMB11-PP-17	1	Procedure for Particle Size Analysis of PuO ₂ Fines
HS-CMB11-PP-18	0	Neutron Emission Rate Measurement Procedure
HS-CMB11-PP-21	1	Calibration of Sedigraph 5000 GB Procedure
HS-CMB11-PP-22	2	Operation of Oxygen Analyzers Procedure
HS-CMB11-PP-23	0	Dri-Train/Ni-Train Operation
HS-CMB11-PP-24	2	Operation of Moisture Monitors
HS-CMB11-PP-25	2	Operation of Nitrogen Analyzers
HS-CMB11-PP-27	0	Operation of Ionization Gauges
HS-CMB11-PP-30	2	Decontamination of Welded Capsules
MWG-CMB11-PP-1	1	Slugging and Screening
MWG-CMB11-PP-2	1	Granule Seasoning Procedure
MWG-CMB11-PP-3	0	Weight and Calorimeter Charges
MWG-CMB11-PP-4	0	Heat Source Cleaning Procedure
MWG-CMB11-PP-5	1	Helium Pressurization Leak Check
MWG-CMB11-PP-6	2	Welding Procedure for Milliwatt Heat Source Components
MWG-CMB11-PP-7	0	Leak Check - Accumulated
MWG-CMB11-PP-8	2	Reduction Reaction Procedure
MWG-CMB11-PP-9	2	Final Granule Screening
MWG-CMB11-PP-10	1	Hardware Control Procedure
MWG-CMB11-PP-11	1	Helium Leak Check Procedure (Liner Assemblies)

MWG-CMB11-PP-12	1	Primary Shipping Container Welding
MWG-CMB11-PP-13	2	Liner Assembly Procedure
MWG-CMB11-PP-14	3	Strength Member Assembly Procedure
MWG-CMB11-PP-15	2	Clad Assembly Procedure
MWG-CMB11-PP-16	0	Final Lapping
MWG-CMB11-PP-17	0	Storage and Shipment
MWG-CMB11-PP-18	1	Neutron Emission Rate Measurement Procedure
MWG-CMB11-PP-19	0	Final Acceptance Gaging
MWG-CMB11-PP-20	1	Dose Rate Measurements
MWG-CMB5-PP-1	1	Metallographic Evaluation of Milliwatt Heat Sources
MWG-CMB5-PP-2	0	Fuel Removal and Fines Separation for Milliwatt Heat Sources
MWG-CMB5-PP-4	0	Milliwatt Heat Source Compatibility Studies
HS-CMB5-PP-1	0	Impact Tests for Heat Sources
WX-3-MWG-FP-1	2	Fluorescent Penetrant Procedure for Liners, Strength Members, and Clads
M-5-MWG-R-1	1	Radiographic Procedure for Strength Member and Clad Cap Welds
M-5-MWG-R-2	0	Radiographic Procedure for Pressure Burst Capsules
M-5-MWG-US-1	1	Ultrasonic Inspection Procedure for Strength Member and Clad Cap Welds
HS-CMB11-DF-1	0	Isothermal Calorimeter Data Form
HS-CMB11-DF-2	0	Decay Calculation and Assignment Data Form
HS-CMB11-DF-3	0	Introduction of Feed Data Form
HS-CMB11-DF-4	0	Oxygen-16 Exchange Form
HS-CMB11-DF-5	1	Ball-Milling Data Form
HS-CMB11-DF-6	1	Change Control Data Form
HS-CMB11-DF-7	0	Granule Seasoning Data Form
HS-CMB11-DF-8	0	Granule Storage Data Form
HS-CMB11-DF-12	1	Recorder Calibration Certificate Data Form
HS-CMB11-DF-17	1	Particle Size Analysis of PuO ₂ Fines
HS-CMB11-DF-18	1	Neutron Emission Rate Measurement Data Form
HS-CMB11-DF-19	1	Distillation of H ₂ ¹⁶ O Data Form
HS-CMB11-DF-21	1	Calibration of Sedigraph 5000 GB Data Form
HS-CMB11-DF-22	1	Oxygen Analyzer Calibration Certificate
HS-CMB11-DF-24	2	Moisture Monitor Calibration Certification
HS-CMB11-DF-25	0	Nitrogen Analyzer Calibration Certification Data Form
HS-CMB11-DF-26	0	Calorimetry of Residue Material Data Form
HS-CMB11-DF-27	0	PuO ₂ Fuel Lot Traveler
HS-CMB11-RB-1	1	Acceptance Review and Release
MWG-CMB11-DF-1	1	Slugging and Screening Data Form
MWG-CMB11-DF-5	0	Helium Pressurization/Accumulation Leak Check

MWG-CMB11-DF-6	0	Recorder Zero Set Data Form
MWG-CMB11-DF-7	0	Flatness Measurement Data Form
MWG-CMB11-DF-9	1	Final Granule Screening Form
MWG-CMB11-DF-10	1	As-Received Material Inventory Form
MWG-CMB11-DF-12	0	Nonconforming Material Inventory Form
MWG-CMB11-DF-13	1	MWG Liner Assembly Traveler
MWG-CMB11-DF-14	1	MWG Strength Member Assembly Traveler
MWG-CMB11-DF-15	1	MWG Clad Assembly Traveler
MWG-CMB11-DF-16	*	Summary Data Form
MWG-CMB11-DF-17	0	Helium Leak Check Data Form (Liner Assemblies)
MWG-CMB11-DF-18	1	Neutron Emission Rate Measurement Data Form
MWG-CMB11-DF-19	1	Welding Primary Shipping Container Data Form
MWG-CMB11-DF-20	0	Dose Rate Measurement Data Form
MWG-CMB5-DF-1	1	Data Form for the Metallographic Evaluation of Milliwatt Heat Sources
MWG-CMB5-DF-2	0	Fuel Removal and Fines Separation for Milliwatt Heat Sources Data Form
HS-CMB5-DF-1	0	Impact Tests for Heat Sources

*Not yet approved

VI. MEETINGS

On October 28, 1981, W. A. Stark, Jr. and J. A. Pattillo visited SNLA/QA representatives to discuss MWG drawings and aperture card distribution.

On November 12, 1981, R. Harnar and R. T. Jankowski (SNLA) visited Los Alamos to observe TMS activities.

On December 22, 1981, J. Calek, R. Harnar, R. T. Jankowski, W. Kass, H. Saxton, and T. Young (SNLA), and C. Richardson (DOE/ALO) attended a MWG TMS final data review meeting at Los Alamos. A conditional release for MWG production was allowed at that time.

On February 3-4, 1982, D. Braudaway, E. Franzak, and A. Reger (SNLA) conducted a measurement and test equipment calibrations survey of the MWG production line at Los Alamos. C. Richardson (DOE/ALO) was also in attendance.

On February 9, 1982, E. Franzak and A. W. Reger (SNLA), G. Polallis and C. Richardson (DOE/ALO), and G. Granere (DOE/LAAO) attended the Calibration Survey Wrapup meeting at Los Alamos.

On February 18, 1982, R. Harnar, R. T. Jankowski, T. Young (SNLA), and C. Richardson (DOE/ALO) visited Los Alamos to discuss status of calibrations program.

On March 17, 1982, W. Stark attended the RTG Program Review meeting at GEND.

On March 30, 1982, R. Harnar, R. T. Jankowski, W. Kass, and T. Young (SNLA) visited Los Alamos for discussions on MWG compatibility testing.

REFERENCES

1. "Milliwatt Generator Project, October 1980-March 1981," Los Alamos National Laboratory report LA-8881-PR (June 1981).
2. "Mechanical Properties and Structure of Oxygen-Doped Tantalum-Base Alloy," Oak Ridge National Laboratory report ORNL-4839 (December 1972).
3. "Plutonium-238 Dioxide/T-111 Compatibility Studies," Monsanto Research Corporation, Mound Facility report MLM-2209 (September 1975).
4. P. E. Teaney and R. L. Wise, "Studies of Yttrium Gettering Efficiency in Radioisotopic Heat Sources," *Microst. Sci.* 5, 425 (1977).
5. U. S. Energy Research & Development Administration, ERDA Manual Vol. 7000, Part 7200, Chapter 72XF, "ALO Standardization Program," (1976).

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