Milliwatt Generator Project

April 1988–September 1996

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List of Abbreviations

CERCLA/SARA	Comprehensive Environmental Response, Compensation, and Liability Act/Superfund Amendments and Reauthorization Act
DOE	Department of Energy
GENDD	General Electric Neutron Devices Department
HSWA/RCRA	Hazardous and Solid Waste Amendments of the Resource Conservation and Recovery Act
LANL	Los Alamos National Laboratory
MF	Mound Facility
MWG	milliwatt generator
NEPA	National Environmental Policy Act
PuO ₂	plutonium oxide
RTG	radioisotope thermoelectric generator
SM	strength member
SNL	Sandia National Laboratories
SRP	Savannah River Plant
TA-11	Technical Area 11
VHN	Vickers hardness number

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ABSTRACT

This report covers progress on the Milliwatt Generator (MWG) Project from April 1988 to September 1996. Manufacturing of heat sources for the project ended by September 1990. Beginning in October 1990, the major activities of the project have been surveillance and testing of MWGs, disposal of excess MWGs, and reclamation of the PuO_2 from excess MWG heat sources. Reported activities include fuel processing and characterization, production of heat sources, compatibility studies, impact testing, examination and electrical testing of surveillance units, and recovery of PuO_2 from heat sources.

I. INTRODUCTION

Until October 1990, the major task of the Los Alamos Milliwatt Generator (MWG) Project was to fabricate MC2893A heat sources (4.0 W) for MC2730A radioisotope thermoelectric generators (RTGs) and MC3599 heat sources (4.5 W) for MC3500 RTGs. During this time the MWG Project worked with the following contractors: Sandia National Laboratories (SNL) in Albuquerque (designer); Westinghouse Corporation Savannah River Plant (SRP) (for fuel); EG&G Mound Applied Technologies (metal hardware); and General Electric Company, Neutron Devices Department (GENDD), now Lockheed Martin Specialty Components (RTGs).

In December 1990, Los Alamos National Laboratory accepted the mission assignment from the Department of Energy (DOE) for the relocation of the RTG shelf-life and stockpile evaluation activities from General Electric. Since 1991, Los Alamos has been

involved in (1) transfer of testing equipment from General Electric, (2) installation of surveillance and testing equipment at Los Alamos, (3) revision of procedures related to surveillance and testing of RTGs at Los Alamos, (4) shipment of shelf-life and excess RTGs to Los Alamos, (5) destruction of excess RTGs and heat sources, and (6) reclamation of $^{238}\text{PuO}_2$ from excess heat sources.

II. FUEL PROCESSING AND CHARACTERIZATION

A. Processing

From April 1988 to September 1990, 33 lots (7.72 kg) of SRP feed powder were processed through the MWG fuel-processing line to obtain 7.04 kg of fuel granules. Because impurity contents were above specification for lots 210 (Si), 220 (Si), 221 (Fe and Cr), and 241 (Si and Cr), they were blended with lots 211, 215, 216, 217, 219, 222, and 240 to produce production lots 223M–228M, 232M–235M, and 244M. Each new production lot was created from two original lots.

B. Characterization

1. Neutron Emission. Data on neutron emission rates for the feed lots are presented in Table I. The as-received SRP feed powder had an average neutron emission rate of 23800 n/s · g ^{238}Pu . After ^{16}O exchange and other processing, the average neutron emission rate of the fuel lots was 4970 n/s · g ^{238}Pu .

2. Spectrochemical. Table II compares the average impurity levels determined by spectrochemical analyses for the as-received SRP feed lots with the impurity levels in the fuel after it had been processed at Los Alamos. The data indicate that fuel processing reduced the average calcium level by 70 ppm but increased the average iron and silicon levels by 40 ppm and 60 ppm, respectively.

3. Isotopic. The plutonium isotopic contents for the fuel lots are listed in Table III. The SRP isotopic contents in the table have been corrected (decayed) to the same dates as those of the Los Alamos analyses. Excellent agreement exists between the SRP and Los Alamos results. The ^{238}Pu enrichment averaged 83.09% compared with 84.40% for fuel processed from April 1986 through March 1988¹ and 83.96% for fuel processed from April 1984 through March 1986.²

Table I. Neutron Emission Rate Data for Feed Lots

Lot Numbers			Neutron Emission Rate	
LANL	SRP		(n/s · g ²³⁸ Pu)	
Lot	Lot	Run	As Received	As Processed
201	29	8704-126	35600	4000
202	30	8705-127	25700	3900
203	30	8704-128	24900	4170
204	30	8705-130	20400	4060
205	30	8705-129	23400	3850
206	37	8708-153	22000	5160
207	31	8704-132	19300	4750
208	32	8706-133	27100	5030
209	31	8704-131	22800	4480
210	33	8708-136	22400	4670
211	33	8704-139	28000	5750
212	34	8708-140	25000	5170
213	34	8708-141	29600	5190
214	41	8708-172	19700	4400
215	40	8707-166	18500	5480
216	41A	8708-173	22700	5070
217	40	8708-168	24400	5900
218	25	8702-107	21800	4560
219	35	8705-144	23500	5040
220	37	8706-152	20100	5570
221	35	8705-145	21500	5230
222	28	8703-120	20400	4450
229	35	8705-146	25300	5320
230	28	8705-121	20000	4650
231	27	8702-116	24200	6060
236	49	8712-200	23600	5260
237	49	8712-198	24500	5470
238	18	8611-075	28600	5910
239	49	8712-199	21500	5440
240	36	8706-149	19600	5800
241	25	8702-105	22300	4580
242	18	8611-076	32800	5260
243	41	8706-170	<u>24500</u>	<u>4470</u>
Average			23800	4970
			±3800	±620

Table II. Average Impurity Levels Determined by Spectrochemical Analyses for Feed Lots

Element	Specification (ppm)	As Received (ppm)	As Processed (ppm)
Ag	25	5	8
Al	175	45	40
B	10	<5	<5
Ba	25	<6	<6
Bi	25	<6	<6
Ca	315	175	105
Cd	25	<10	<10
Co	50	<13	<13
Cr	150	75	75
Cu	50	<13	<13
Fe	500	140	180
Mg	50	<20	<20
Mn	50	<20	<20
Ni	100	60	20
Pb	50	45	<13
Si	250	75	135
Sn	50	<13	<13
Zn	100	<25	<25

Table III. Plutonium Isotopic Contents of Feed Lots

Lot	Analyst	Plutonium Isotope (wt %)				
		238	239	240	241	242
201	SRP	83.13	14.39	2.04	0.31	0.13
	LANL	83.11	14.41	2.04	0.31	0.13
202	SRP	83.20	14.34	2.03	0.30	0.13
	LANL	83.08	14.42	2.05	0.31	0.14
203	SRP	83.20	14.35	2.03	0.30	0.13
	LANL	83.10	14.41	2.04	0.31	0.14
204	SRP	83.20	14.35	2.03	0.30	0.13
	LANL	83.09	14.42	2.05	0.30	0.14
205	SRP	83.19	14.35	2.03	0.30	0.13
	LANL	83.28	14.28	2.02	0.30	0.13
206	SRP	83.07	14.47	2.04	0.29	0.12
	LANL	83.03	14.49	2.05	0.30	0.13

Table III, continued. Plutonium Isotopic Contents of Feed Lots

Lot	Analyst	Plutonium Isotope (wt %)				
		238	239	240	241	242
207	SRP	83.13	14.42	2.04	0.29	0.12
	LANL	83.07	14.44	2.05	0.30	0.13
208	SRP	83.09	14.43	2.05	0.30	0.13
	LANL	83.07	14.46	2.05	0.30	0.13
209	SRP	83.13	14.42	2.04	0.29	0.12
	LANL	83.07	14.44	2.05	0.30	0.14
210	SRP	83.04	14.48	2.06	0.30	0.13
	LANL	83.00	14.49	2.06	0.31	0.14
211	SRP	83.00	14.52	2.06	0.29	0.13
	LANL	82.95	14.51	2.07	0.31	0.15
212	SRP	83.02	14.51	2.05	0.29	0.13
	LANL	83.00	14.51	2.06	0.30	0.13
213	SRP	83.02	14.51	2.05	0.29	0.13
	LANL	83.00	14.52	2.06	0.29	0.13
214	SRP	83.13	14.43	2.04	0.29	0.12
	LANL	83.11	14.42	2.04	0.30	0.13
215	SRP	83.08	14.46	2.04	0.29	0.13
	LANL	83.00	14.49	2.06	0.30	0.15
216	SRP	83.13	14.42	2.03	0.29	0.12
	LANL	83.06	14.45	2.04	0.30	0.14
217	SRP	83.08	14.46	2.04	0.29	0.13
	LANL	83.03	14.49	2.05	0.29	0.14
218	SRP	83.35	14.25	1.98	0.30	0.11
	LANL	83.41	14.19	1.97	0.31	0.12
219	SRP	82.99	14.53	2.06	0.29	0.13
	LANL	82.95	14.54	2.07	0.31	0.14
220	SRP	83.01	14.53	2.05	0.29	0.12
	LANL	82.98	14.54	2.05	0.30	0.13
221	SRP	82.99	14.54	2.06	0.29	0.13
	LANL	82.93	14.57	2.06	0.30	0.14
222	SRP	83.14	14.41	2.03	0.30	0.12
	LANL	83.10	14.43	2.04	0.30	0.13
229	SRP	82.97	14.56	2.06	0.29	0.13
	LANL	82.91	14.60	2.07	0.30	0.13

Table III, continued. Plutonium Isotopic Contents of Feed Lots

Lot	Analyst	Plutonium Isotope (wt %)				
		238	239	240	241	242
230	SRP	83.08	14.46	2.04	0.29	0.12
	LANL	83.03	14.48	2.06	0.30	0.14
231	SRP	83.16	14.44	2.01	0.28	0.11
	LANL	83.23	14.34	2.01	0.30	0.12
236	SRP	83.25	14.43	1.94	0.28	0.09
	LANL	83.22	14.44	1.95	0.29	0.10
237	SRP	83.25	14.43	1.94	0.28	0.09
	LANL	83.24	14.42	1.96	0.29	0.10
238	SRP	83.43	14.19	1.97	0.30	0.11
	LANL	83.40	14.21	1.98	0.30	0.11
239	SRP	83.24	14.44	1.94	0.28	0.09
	LANL	83.16	14.46	1.96	0.30	0.12
240	SRP	82.96	14.59	2.06	0.28	0.12
	LANL	82.81	14.64	2.09	0.30	0.15
241	SRP	83.25	14.35	1.99	0.29	0.11
	LANL	83.35	14.27	1.98	0.29	0.11
242	SRP	83.40	14.22	1.98	0.30	0.11
	LANL	83.35	14.24	1.99	0.30	0.12
243	SRP	82.98	14.57	2.06	0.27	0.13
	LANL	82.88	14.61	2.08	0.29	0.14
SRP Average		83.13	14.43	2.03	0.29	0.12
		± 0.12	± 0.10	± 0.04	± 0.01	± 0.01
LANL Average		83.09	14.44	2.04	0.30	0.13
		± 0.15	± 0.11	± 0.04	± 0.01	± 0.01

III. PRODUCTION OF HEAT SOURCES

From April 1988 through September 1990, a total of 861 MC2893A heat sources (4.0 W) were accepted by DOE. The average thermal power of the MC2893A heat sources was 4.008 ± 0.009 W.

Acceptance rates for liner, strength number, and clad assemblies were 96.5%, 98.9%, and 96.7%, respectively. Fabrication summaries for the three types of assemblies showing the various causes for rejection are given in Table IV.

Table IV. MC2893A Heat Source Fabrication Summary

Liner Assembly	Fabricated	938
	Rejected	33 ^a
	Yield	96.5%
Strength Member Assembly	Fabricated	888
	Rejected	10 ^b
	Yield	98.9%
Clad Assembly	Fabricated	890
	Rejected	29 ^c
	Yield	96.7%

^a16—Insufficient weld penetration.

12—High direct alpha count in weld area.

5—Visual appearance.

^b4—Incorrect heat treatment.

4—Visual appearance.

2—Insufficient weld penetration.

^c12—Visual appearance.

9—Insufficient weld penetration.

3—Failed dye penetrant inspection.

2—Oversize diameter.

1—Failed flatness inspection.

1—Low thermal power.

1—Used incorrect hardware.

IV. COMPATIBILITY STUDIES

Both 4.0- and 4.5-W heat sources were being treated at 600°C for times ranging from 2 to 15 years³ to characterize the effects on alloy T-111 from long-term exposure to PuO_{2-x}. With the concurrence of SNL (Albuquerque), these 600°C tests were terminated in 1990. The last two 600°C test units were removed from the aging furnaces in December 1987 and August 1988.

A 4.0-W compatibility test unit (LASL-127) that had been heat treated at 600°C for five years, five months was impacted (side on) at 150 m/s and 450°C. The impact face of the unit is shown in Fig. 1. As in LASL-53 and LASL-142 that were impacted after 600°C heat treatments for two and four years, respectively, the clad partially bonded to the strength member along the impact face, and the liner and strength member appeared to have failed as a result of shear and bending stresses at impact (Fig. 2).

Figure 1. Impact face of LASL-127, showing extent of failure.

Figure 2. Longitudinal section of liner and strength member of LASL-127 after impact at 150 m/s and 450°C. Clad is bonded to strength member along impact face. As polished. 4.5×

Chemical analyses and hardness values of the liner and strength member of LASL-127 are shown in Table V. Although LASL-53, LASL-142, and LASL-127 (Table VI) failed as a result of 150 m/s impacts, there has been little indication from average oxygen content (58-82 ppm) of the strength members of the three impacted units heat treated at 600°C that the mechanical properties of the strength members were degraded by diffusion of oxygen from the fuel. Some changes on the mechanical properties of the strength member could have occurred as a result of the prolonged heat treatments, however. The average hardness of the strength members after 24, 48, and 65 months were 235, 263, and 284 Vickers hardness number (VHN), respectively (Table VI).

A 4.5-W compatibility test unit (LASL-143) that had been heat treated at 600°C for six years was destructively examined. Metallography of LASL-143 revealed that the liner breached as a result of intergranular cracking (Fig. 3). Because a significant amount of alpha contamination was detected on the exterior of the strength member, the strength member was assumed to have also breached, although the crack was not found after repeated sectioning. Chemical analyses and hardness values of the liner and strength member of LASL-143 are shown in Table V.

Although the average oxygen content of the LASL-143 liner showed an increase from 117 ppm in the as-fabricated T-111 liners to 285 ppm after 72 months at 600°C, this was only slightly higher than the average oxygen content of the liners in the four compatibility units that were heat treated at 600°C for 24–65 months (Table VI). The T-111 liner and the yttrium addition to the fuel appear to be quite effective in preventing oxygen diffusion into the T-111 strength member at 600°C. Comparison of the three compatibility units heat treated for 48–72 months in Table VI to the four units heat treated for 2–24 months shows an average oxygen increase from 64 to 82 ppm and an average hardness increase from 248 to 262 VHN.

Figure 3. Intergranular cracking in the liner of LASL-143. Etched. 50×

Table V. Compatibility Test Results

Unit No.	Assembly	Oxygen (ppm)			Hardness (VHN)		
		Dome	Body	Weld + Cap	Dome	Body	Weld
127	Liner	195	160	70	350	300	292
	SM	65	75	60	295	272	258
143	Liner	430	140	110	245	273	283
	SM	100	80	75	236	242	291

Table VI. Effect of Time on Oxygen Content and Hardness of Liners and Strength Members at 600°C

No.	Test Time (Months)	Liner		Strength Member	
		Oxygen Content (ppm)	Hardness (VHN)	Oxygen Content (ppm)	Hardness (VHN)
LASL-56	2	165	277	55	251
LASL-54	8	150	260	70	252
LASL-52	24	400	267	70	253
LASL-53 ^b	24	240	233	60	235
LASL-142 ^{a,b}	48	245	272	85	263
LASL-127 ^b	65	180	325	70	284
LASL-143 ^a	72	285	259	90	239

^a4.5 W

^b Impacted

V. SURVEILLANCE UNITS

Fifteen MC2893 units manufactured at the Mound Facility (MF) during 1978–79, four MC2893A units manufactured at LANL during 1982–84, and two MC3599 units manufactured at LANL during 1983–85 were destructively examined. Eleven of the units were impact tested. Identification of these 21 units, along with the tests and analyses performed, are shown in Table VII. Although the condition of the strength member is of primary importance in the evaluation of surveillance units, the liners, which show the greatest effects because of contact with the fuel, are also evaluated.

A. Impact Tests

Some of the surveillance units returned for destructive examination are impacted against hardened steel at nominal conditions of 150 m/s and 450°C. These testing conditions are sufficient to rupture the liner and clad and are nearly sufficient to rupture the strength member on as-fabricated MC2893 or MC3599 heat sources. Therefore, this impact test is not for qualification purposes; it serves only to show whether the strength member has remained ductile.

Seven MC2893 units, three MC2893A units, and one MC3599 unit were impact tested at 149 to 151 m/s and 450°C. Photographs of one MC2893 unit and one MC2893A unit are shown in Figs. 4 and 5. All the clads failed in the weld region on impact. The strength member of MAD-1175 was breached as indicated by an external alpha count after testing; the other strength members were unbreached.

Diametral deformations of the impacted units were characterized by the relative decreases in the original diameters parallel to the impact direction and the increases in width of the impact faces relative to the original diameters. Table VIII shows the diametral deformations of the impacted units. A total of 30 surveillance units were impact

Table VII. Surveillance Units Tested and Examined

Fabrication				Impact Test	Metallography	Liner Oxygen and Hardness	Fines Analysis
Unit	Date	Type	Origin				
MAD-0217	1/78	2893	MF	—	X	X	—
MAD-0255	1/78	2893	MF	X	X	X	X
MAD-0284	1/78	2893	MF	X	X	X	—
MAD-0319	2/78	2893	MF	—	X	X	X
MAD-0435	4/78	2893	MF	—	X	X	—
MAD-0450	4/78	2893	MF	—	X	X	—
MAD-0458	4/78	2893	MF	X	X	X	—
MAD-0479	4/78	2893	MF	—	X	X	—
MAD-0510	5/78	2893	MF	X	X	X	—
MAD-0711	8/78	2893	MF	—	X	X	—
MAD-0733	8/78	2893	MF	X	X	X	X
MAD-0734	8/78	2893	MF	—	X	X	—
MAD-1011	12/78	2893	MF	X	X	X	—
MAD-1159	2/79	2893	MF	—	X	X	—
MAD-1175	2/79	2893	MF	X	X	X	—
UAS-0064	5/82	2893A	LANL	X	X	X	X
UAS-0073	5/82	2893A	LANL	—	X	X	—
UAS-0190	8/82	2893A	LANL	X	X	X	—
UAS-0888	7/84	2893A	LANL	X	X	X	—
UAS-0320	2/83	3599	LANL	X	X	X	X
UAS-1406	3/85	3599	LANL	—	X	X	X

Figure 4. MAD-0458 after side-on impact at 151 m/s and 450°C. A, impact face; B, side view.

Figure 5. UAS-0064 after side-on impact at 151 m/s and 450°C. A, impact face; B, side view.

Table VIII. Diametral Deformations of Surveillance Units Impacted at ~150 m/s and 450°C

Unit	Type	Impact Velocity (m/s)	ΔH (%)	ΔW (%)	Clad Condition	SM Condition
MAD-0255	2893	151	-24.7	+14.8	Breach	Intact
MAD-0284	2893	149	-25.8	+10.5	Breach	Intact
MAD-0458	2893	151	-24.9	+9.7	Breach	Intact
MAD-0510	2893	151	-22.0	+12.3	Breach	Intact
MAD-0733	2893	150	-24.4	+10.7	Breach	Intact
MAD-1011	2893	151	-24.2	+14.2	Breach	Intact
MAD-1175	2893	150	-22.9	+15.0	Breach	Breach
MC 2893 Average			-24.1	+12.5		
UAS-0064	2893A	151	-26.8	+14.0	Breach	Intact
UAS-0190	2893A	150	-22.1	+10.9	Breach	Intact
UAS-0888	2893A	151	-13.4	+12.1	Breach	Intact
MC 2893A Average			-20.8	+12.3		
UAS-0320	3599	151	-24.4	+11.4	Breach	Intact

tested from 1980 to 1990; a summary of the diametral deformations of these units is shown in Table IX. Except for UAS-888, the average deformation of the MC2893A units appeared to be the same as the MC2893 units. Part of the greater deformation shown by the MC3599 units relative to that of the MC2893 units may be attributed to the greater amounts ($\approx 1.2\text{g}$) of PuO_2 fuel in the MC3599 units.

B. Metallography

No significant differences were observed in the longitudinal sections of the 11 impacted units and those of previously impacted surveillance units.¹⁻⁴ All units deformed similarly and all demonstrated the ductile nature of the strength member. The greater strength at the top of the units, attributable to the thickness of the strength member cap, results in considerable bending in the bottom of the unit in side-on impact testing and extreme thinning of the strength member in this area (Fig. 6).

Table IX. Summary of Diametral Deformations of Impacted Surveillance Units (1980–1990)

Type	Number of Units	$\Delta H\%$	$\Delta W\%$
2893	21	-23.9 ± 1.6	+13.5 ± 2.0
2893A	3	-20.8 ± 6.8	+12.3 ± 1.6
3599	6	-25.3 ± 1.1	+15.2 ± 2.1

Figure 6. Deformation of liner and strength member at bottom of impact surface in MAD-0458. Etched. 50×

C. Oxygen Analyses and Microhardness Measurements of Liners

The oxygen contents and the microhardness (VHN) values of the liners of the 21 surveillance units in the dome, body, and weld-plus-cap regions are shown in Table X. As in the previously examined surveillance units,¹⁻⁴ the standard deviations in the oxygen averages for the MC2893, MC2893A, and MC3500 units were relatively large. A

Table X. Oxygen Contents and Microhardness of the T-111 Liners of Surveillance Units

Unit	Oxygen Content (ppm)			Hardness of Liner (VHN)		
	Dome	Body	Weld and Cap	Dome	Body	Weld
MAD-0217	145	115	120	222	216	219
MAD-0255	265	140	80	273	287	247
MAD-0284	250	150	85	230	223	277
MAD-0319	85	125	90	243	242	232
MAD-0435	215	205	100	261	283	251
MAD-0450	110	80	60	208	219	222
MAD-0458	230	215	70	239	224	273
MAD-0479	255	150	85	295	286	234
MAD-0510	115	150	90	286	267	282
MAD-0711	415	275	75	252	256	240
MAD-0733	220	140	95	304	323	329
MAD-0734	270	330	70	317	295	289
MAD-1011	140	145	80	323	311	276
MAD-1159	285	305	70	236	228	231
MAD-1175	125	25	80	329	279	272
MC2893	210	170	85	268	263	258
Average ^a						
UAS-0064	190	90	185	250	255	270
UAS-0073	135	210	90	216	224	168
UAS-0190	120	155	125	250	259	216
UAS-0888	240	110	105	213	212	229
MC2893A	170	140	125	232	238	221
Average ^a						
UAS-0320	115	145	85	272	272	282
UAS-1406	205	125	80	248	264	240
MC3599	160	135	85	260	268	261
Average ^a						

^aTo nearest 5 ppm

summary of the oxygen contents and microhardness values for all the three types of units examined at Los Alamos from 1980 to 1990 is shown in Table XI.

D. Fines Analyses

Four impacted units and two nonimpacted units were cut open to characterize the amount of PuO_2 fines ($<20\ \mu\text{m}$) in these surveillance units. Respirable fines, which in the case of PuO_2 would be about $3\ \mu\text{m}$ in diameter, were categorized as those particles that were less than $5\ \mu\text{m}$ in diameter. The results are shown in Table XII.

A summary of the fines analyses for all MC2893, MC2893A, and MC3599 surveillance units examined from 1982 to 1990 is shown in Table XIII. Comparison of the nonimpacted units indicated equal amounts of respirable fines in the three types of units. However, the average amount of fines smaller than $20\ \mu\text{m}$ was somewhat greater (0.09 g) in the MC2893 units than in the MC2893A and MC3599 units, which were manufactured three to seven years later. The impacted units showed an average decrease of 0.18 g in the amount of respirable fines and an average decrease of 0.27 g in the amount of fines smaller than $20\ \mu\text{m}$ in the MC2893A and MC3599 units compared with the older MC2893 units.

Table XI. Summary of Oxygen Contents and Microhardness of Liners and Surveillance Units (1980–1990)

Type	Number of Units	Oxygen Content (ppm) ^a			Hardness (VHN)		
		Dome	Body	Weld and Cap	Dome	Body	Weld
2893	50	205 ± 100	235 ± 190	90 ± 40	267 ^b ± 42	265 ± 25	255 ^b ± 27
2893A	7	220 ± 70	145 ± 95	120 ± 30	252 ± 29	254 ± 27	240 ± 38
3599	14	225 ± 115	150 ± 60	90 ± 15	288 ^c ± 20	288 ± 18	274 ^c ± 13

^aTo nearest 5 ppm

^bFor 30 units

^cFor 12 units

Table XII. PuO_2 Fines from Surveillance Units

Unit	Type	Impacted	Amount (g)			
			$<5\ \mu\text{m}$	5–10 μm	10–20 μm	$<20\ \mu\text{m}$
MAD-0319	2893	No	0.02	0.04	0.11	0.17
MAD-0255	2893	Yes	1.33	0.46	1.68	3.47
MAD-0733	2893	Yes	0.67	2.87	0.41	3.95
Average			1.00	1.66	1.05	3.71
UAS-0064	2893A	Yes	0.74	0.99	1.76	3.49
UAS-1406	3599	No	0.01	0.01	0.04	0.06
UAS-0320	3599	Yes	0.50	1.29	2.09	3.88

Table XIII. Summary of PuO₂ Fines Analyses (1982–1990)

Type	Impacted	Number of Units	Amount (g)			
			<5 μm	5–10 μm	10–20 μm	<20 μm
2893	No	15	0.06 $\pm$ 0.05	0.10 $\pm$ 0.06	0.12 $\pm$ 0.08	0.28 $\pm$ 0.17
2893A	No	1	0.07	0.05	0.06	0.18
3599	No	5	0.05 $\pm$ 0.03	0.08 $\pm$ 0.06	0.07 $\pm$ 0.04	0.19 $\pm$ 0.13
2893	Yes	7	1.06 $\pm$ 0.32	1.67 $\pm$ 0.84	1.12 $\pm$ 0.56	3.84 $\pm$ 0.22
2893A	Yes	1	0.74	0.99	1.76	3.49
3599	Yes	3	0.93 $\pm$ 0.39	1.60 $\pm$ 0.31	1.07 $\pm$ 0.89	3.59 $\pm$ 0.29

VI. SURVEILLANCE RTG UNITS

A. Shelf-Life Surveillance

The original sixty-two MC2730, MC2730A, and MC3500 RTGs from the Shelf-Life Surveillance project were transferred to Los Alamos from GENDD in 1991. These RTGs are maintained at either 358 K (85°C) or 219 K (–54°C). Subsequently, 34 additional RTGs were added to the project by SNL and are maintained at ambient temperature. The number of each model type and corresponding maintenance temperature are as follows:

Temperature	MC2730	MC2730A	MC3500
85°C	12	10	10
–54°C	13	9	8
<u>Ambient</u>	<u>9</u>	<u>25</u>	<u>–</u>
Total	34	44	18

The Shelf-Life Surveillance project includes RTGs representing all years of production from 1977 to 1990. The number of each model type and year of production are as follows:

Year	MC2730	MC2730A	MC3500
1977	4	—	—
1978	5	—	—
1979	8	—	—
1980	6	—	—
1981	11	—	—
1982	—	4	—
1983	—	3	—
1984	—	5	6
1985	—	9	11
1986	—	4	1
1987	—	5	—
1988	—	4	—
1989	—	5	—
1990	—	5	—
Total	34	44	18

B. RTG Shelf-Life Data Base

The tape containing the RTG shelf-life data base was received at Los Alamos in January 1992. In a subsequent meeting of the RTG Transition Team, the decision was made to keep all data pertaining to MWGs at SNL in Albuquerque, NM. The tape was sent to Sandia in April 1992.

All data from electrical testing of shelf-life RTG surveillance units and from excess RTGs since April 1992 have been transmitted to SNL.

C. RTG Electrical Tester

The PT3580 RTG electrical tester was received at Los Alamos in February 1992. After an unsuccessful qualification attempt in March 1992, design changes were made to the testing chamber cables, the chamber controller, and the tester software. The tester was qualified and released to Los Alamos for RTG testing in August 1992. The calibration and operating procedures and the software documentation from Martin Marietta Specialty Components were incorporated into Los Alamos procedures between January and June 1993. The Los Alamos safety review for the tester was completed in April 1993.

D. Vibration and Mechanical Shock Testing

The vibration and mechanical shock testing equipment used at GENDD was received at Los Alamos in March 1991. Because similar equipment was available at Technical Area 11 (TA-11) and approved for use in testing MWGs by SNL in November 1991, the General Electric equipment was placed on an excess property list and transferred from Los Alamos in 1992. A preamplifier from the vibration test console was returned to Martin Marietta Specialty Components (formerly GENDD).

Reviews of the vibration and mechanical shock testing at TA-11 under the Comprehensive Environmental Response, Compensation, and Liability Act/ Superfund Amendments and Reauthorization Act (CERCLA/SARA) and the Hazardous and Solid Waste

Amendments of the Resource Conservation and Recovery Act (HSWA/RCRA) were approved in September 1991. Another review under the 40 CFR Part 61, Subparts A and H, National Emission Standards for Hazardous Air Pollutants was approved in November 1991. Another review under the National Environmental Policy Act (NEPA) determined in July 1992 that these activities were categorically excluded from the requirement to prepare NEPA documentation. All procedures required for the vibration and mechanical shock testing of MWGs at Los Alamos were approved in January 1993.

VII. DISPOSITION OF EXCESS RTGS

A. RTG Opening System

An existing glovebox at Los Alamos was redesigned to replace the RTG opening system used by GENDD. Modifications to the glovebox to provide for either an air- or an inert-gas-atmosphere and the addition of oxygen and water vapor analyzers were completed in September 1992. A replacement lathe was installed in January 1993.

B. Transfer of MWG Heat Sources

During 1992-1995, 53 MWG heat sources (MC2893A and MC3599) were approved by DOE-Albuquerque for use as calorimetry or neutron standards. The following heat source transfers were made:

Battelle Pacific Northwest Laboratory	3
EG&G Mound Applied Technologies	6
Los Alamos National Laboratory	44

C. Destruction of RTGs and Heat Sources

From October 1990 until September 1996, a total of 487 RTGs and 790 heat sources were destroyed. A summary of these activities is as follows:

Fiscal Year	RTG	Heat Source
1991	24	177
1992	116	311
1993	64	10
1994	115	145
1995	138	99
<u>1996</u>	<u>30</u>	<u>48</u>
Total	487	790

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