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MONTHLY TECHNICAL ACTIVITIES REPORT  
THROUGH DECEMBER 15, 1957

J. F. Eichelberger and  
D. L. Scott

Date: December 15, 1957  
Issued: JAN 20 1958

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MONSANTO CHEMICAL COMPANY  
Research and Engineering Division  
United States Atomic Energy Commission  
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**PRODUCTION PROGRAM**

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*These projects are concerned with the production of alpha and neutron sources, and with the disposal of radioactive wastes. Work is being done to improve present methods and processes.*

Eight polonium-beryllium neutron sources and four alpha sources were shipped in November, 1957. Five polonium-beryllium sources were for other AEC sites. There were five plutonium-beryllium neutron sources shipped during November, 1957.

Twenty-five tanks of influent water were processed during this period. Two of the tanks required no pre-treatment. Nine of the tanks required one treatment of activated carbon and calcium chloride. Thirteen tanks were given an additional treatment of sodium sulfide and one tank required a second treatment of sodium sulfide to reduce the beta activity level.

Data for the Waste Disposal Operations are given in Table 1.

**Table 1**

**WASTE DISPOSAL DATA**

Discharge Volume	612,000 gallons
Total Alpha Activity	11.7 millicuries
Total Beta Activity	28.9 millicuries
Activity Density	
Alpha	5.6 cts/min/ml
Beta	13.8 cts/min/ml

NUCLEAR RESEARCH AND DEVELOPMENT

GENERAL WEAPONS DEVELOPMENT

*Process development work is being conducted in connection with the fabrication and chemical processes for plastics, high explosives, gases, metals, alloys, and other materials for weapons components and the fabrication and recovery associated therewith.*

**Plastics Project** *The asbestos-filled diallyl phthalate plastic used in molding operations at Mound Laboratory must meet specifications more rigid than are common in industry. Development work has been directed at the determination of the effects of process variables and toward achievement of better control of these variables in order that plastic which meets specifications may be consistently produced. In addition, efforts will be made to find plastics and fillers which would provide improved properties.*

**Formulation** Five sigma-blade mixer runs and three small beaker runs were made during this report period. These were all experimental runs directed toward the development of a formulation which would be less critical in its molding characteristics. Runs B77, B79, B80, and B82 were made to provide material into which various amounts of catalyst, and of lubricant, inhibitor, or both, could be milled. B79, B80, and B82 were formulated without kaolinite and pigment to give translucent heads which would permit visual inspection for internal flaws to supplement the regular X-ray inspection. Runs B76, B79, and B80 were stirred overnight in the sigma-blade mixer and then were transferred to a nine-gallon Pyrex jar for stirring with a ¼-horsepower air motor fitted with multiple impellers. In all three runs, the material was readily picked-up, and excellent high-speed stirring was achieved. They were stirred for approximately seven hours, let stand overnight, stirred again for a short time, and then transferred to the sigma-blade mixer for solvent removal. In run B82 an attempt was made to prewet the Cellulo-200 asbestos directly in the Pyrex jar, after which the concentrated varnish was added with stirring. The mix was stirred at maximum speed for approximately seven hours and at reduced speed overnight. The material was picked-up within a reasonable time the next morning after acetone was added to make up for the solvent lost by evaporation. Although excellent high-speed stirring was finally obtained, this technique is time-consuming with present equipment. It is possible that a higher horsepower motor with larger impellers would reduce the time required to obtain high-speed stirring using this technique.

Once high-speed stirring is achieved, the mechanical work done on the suspension develops sufficient heat to require cooling. Barely adequate cooling has been obtained by placing the Pyrex jar in a water bath made from a cut-down steel drum.

Runs B81 and B83 were made with no added filler to learn more about the diallyl phthalate resin itself. Run B81 had a high monomer-to-prepolymer ratio such as is used in laminating resins; run B83 contained no monomer. Although B81 was milled for over four hours, the final product was too soft and sticky to grind. It gave a very porous cup in the flow tester, but apparently was reasonably well cured in four minutes.

The compositions of Runs B76 through B83 are given in Table 1; the compositions and flow times after milling, and the cures obtained for B77, B78, and B79 are given in Table 2.

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Table 1

**DIALLYL PHTHALATE FORMULATIONS**

Run No.	Parts per 100 parts Dapon-35				Lubricant			Wt. of Charge Minus Solvent lb	Peak Power Input KW	Residual Volatile Content %
	Filler	Acetone	Monomer	Catalyst	Ca <sup>a</sup>	Zn <sup>b</sup>	Aw <sup>c</sup>			
B76	100 <sup>d,i</sup>	225	5.0	2.5	3	1	-	26.8	1.3	11.4
B77	100 <sup>d,i</sup>	225	5.0	2.0	-	-	-	26.3	1.3	12.5
B78	60 <sup>e</sup>	245 <sup>f</sup>	7.0	4.0	5	1	-	-	9	-
B79	40 <sup>h</sup>	168	5.0	1.75	2	-	-	27.5	1.3	13.1
B80	40 <sup>h</sup>	197	5.0	2.0	1	-	-	27.8	1.3	12.5
B81	0	-	30.0	2.5	1	-	-	-	9	-
B82	40 <sup>h</sup>	224	4.0	2.0	1	-	-	27.6	1.3	13.0
B83	0	-	2.0	0.0	1	-	-	-	9	-

a. calcium stearate

b. zinc stearate

c. Acrowax

d. 40 parts Cellulo-200 plus 60 parts Hydrite-PD-121.

e. 30 parts Cellulo-200 plus 30 parts Hydrite-PD-121.

f. methyl ethyl ketone used as solvent.

g. beaker batch; solvent was partially removed in circulating-air oven.

h. 40 parts of Cellulo-200.

i. also contained 2.5 parts Scarlet-25AD and 0.5 part TiO<sub>2</sub>.

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Table 2

**COMPOSITION OF DAP FORMULATIONS AFTER MILLING**

Mill Lot No.	Parts per 100 Parts Dapon-35				Hydro-quinone	Flow Time at 5 Tons sec	CHCl <sub>3</sub> Cure Time min
	Tert-butyl Perbenzoate	Lubricant					
		Ca <sup>a</sup>	Zn <sup>b</sup>	AW <sup>c</sup>			
B77-1	2.0	1	1	1	-	10.69	2.9
B77-2	2.0	2	-	1	-	11.40	4.6
B77-3	2.0	3	-	0.5	-	11.67	3.5
B77-4	2.0	-	-	1	-	10.90	15.7
B77-5	2.0	-	-	0.5	-	11.35	16.5
B77-6	2.0	2	1	-	-	10.33	15.8
B78-1	4.0	5	1	1	-	11.50	10.2
B78-2	4.0	5	1	-	-	8.96	3.1
B79-1	1.75	2	-	-	-	9.02	2.3
B79-2	2.0	3	-	-	0.05	8.96	4.4
B79-3	2.25	3	-	1	0.10	9.02	4.2
B79-4	2.50	3	-	-	0.20	10.37	1.3
B79-5	2.50	3	-	1	0.20	8.56	2.8
B79-6	2.75	4	-	-	0.20	8.66	1.6

a. calcium stearate

b. zinc stearate

c. Acrowax

**Evaluation** It has been felt that Mound Laboratory production batches of DAP might give satisfactory production heads if the molding cycle were made optimum. A preliminary study of the effect of variation in the preheat temperature on the quality of production heads has been made. Batch PB-2 was chosen for test since it appears to be the material most likely to produce rejects for cracks. It was found that preform temperatures above 100°C were definitely better than preform temperatures below 100°C, at least when a short preheat time was used.

The B79 series was consequently molded with a preform temperature of approximately 110°C. The heads had good physical appearance, but the press operator stated that there was more flashing than normal. This indicates that a somewhat lower die temperature might be desirable.

The cure times for heads molded from B77, B78, and B79 are given in Table 2; the results of the first X-ray inspection for heads from PB-2, B77, B78, and B79 are given in Table 3.

Although the B77 series, especially B77-5, looked fairly promising, all heads were found to be cracked on the second X-ray inspection following thermocycling. Both B78-1 and B78-2 gave 100 per cent cracks after thermocycling as did the PB-2 series molded at different preheat temperatures. The data for the second X-ray inspection after thermocycling are given in Table 4. The total per cent of cracks plus voids found on the first X-ray inspection are included for comparison.

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Table 3

**FIRST X-RAY INSPECTION OF MOUND LABORATORY  
DAP FORMULATIONS**

Sample No.	Preheat Temperature °C	Number X-rayed	Cracks %	Voids %	Inclusions %	Cracks plus
						Voids %
PB-2	80 <sup>a</sup>	10	40	40	0	80
PB-2	90	10	40	50	0	90
PB-2	100	10	10	30	10	40
PB-2	110	10	20	10	10	30
PB-2	120	10	10	30	0	40
B77-1	b	25	32	4	0	36
B77-2	b	25	16	12	0	28
B77-3	b	25	8	12	0	20
B77-4	b	25	20	0	0	20
B77-5	b	25	4	0	0	4
B77-6	b	25	4	12	0	16
B78-1	b	25	20	4	72	24
B78-2	b	25	64	4	32	68
B79-1	110 <sup>c</sup>	25	16	4	12	20
B79-2	110	18	0	27	0	27
B79-3	110	25	0	4	12	4
B79-4	110	25	20	20	0	40
B79-5	110	25	4	20	4	24
B79-6	110	25	8	16	4	24

- a. dielectric heater set to give indicated temperature in 30 sec.  
 b. standard production preheat cycle.  
 c. dielectric heater set to give 110°C in one minute.

Table 4

**X-RAY INSPECTION OF MOUND LABORATORY DAP  
FORMULATIONS AFTER THERMOCYCLING**

Sample Numbers	No. in X-ray Sample	Cracks %	Voids %	Inclusions %	Cracks plus Voids	
					2nd X-ray %	1st X-ray %
PB-2 (80°- 120°C) <sup>a</sup>	50	100	-	-	100	30 to 80
B77-1 through B77-6	150	100	-	-	100	4 to 36
B78-1 and B78-2	50	100	-	-	100	24 and 68
B79-1	28	75.0	25.0	-	100	20.0
B79-2	18	16.7	11.1	0	27.8	27.0
B79-3	25	16.0	0.0	4	16.0	4.0
B79-4	23	4.3	8.7	0	13.0	40.0
B79-5	19	26.3	0.0	0	26.3	24.0
B79-6	25	24.0	16.0	0	40.0	24.0

- a. Ten of each having preform temperatures of 80, 90, 100, 110, and 120°C.

Table 5

## CHLOROFORM EXTRACTION CURE TIMES FOR DAP FORMULATIONS

Sample No.	Filler	Monomer	Catalyst		Lubricant			Hydroquinone	Flow Time at five tons, sec	CHCl <sub>3</sub> Cure Time, min
			a	b	Ca <sup>c</sup>	Zn <sup>d</sup>	AW <sup>e</sup>			
B48 <sup>n</sup>	f	5	3	-	2	-	-	-	12.49	6.5
B50	g	5	3	-	-	2	-	-	9.99 (10-ton)	3.4
B52 <sup>n</sup>	f	5	-	3	-	2	-	-	10.78	0.2 <sup>h</sup>
B53 <sup>n</sup>	f	5	2.5	1	-	2	-	-	11.26	3.4
B56	i	5	3.5	-	2	-	-	-	9.28	7.9
PB1-59	f	5	3	-	-	3	-	-	10.27	2.7
PB1-60	f	5	3	-	-	3	-	-	10.33	2.7
PB2-65	f	5	3	-	3	-	-	-	11.42	14.5
B-67	f	5	3.5	-	3	-	-	-	10.12	9.2
B68	f	8	5	-	-	3	-	-	6.40	16.0
PB3-69	f	5	3	-	-	3	-	-	9.02	4.3
B73	f	5	2.5	-	3	-	-	-	11.00	4.3
B74	f	5	2.75	-	2	2	-	-	11.69	1.8
B75	f	5	2.5	-	3	1	-	-	11.23	2.9
B77-1	f	5	2	-	1	1	1	-	10.69	2.9
B77-2	f	5	2	-	2	-	1	-	11.40	4.6
B77-3	f	5	2	-	3	-	0.5	-	11.67	3.5
B77-4	f	5	2	-	-	-	1	-	10.90	15.7
B77-5	f	5	2	-	-	-	0.5	-	11.35	16.5
B77-6	f	5	2	-	3	1	-	-	10.33	15.8
B78-1	j	7	4	-	5	1	1	-	5.86	10.2 <sup>k</sup>
B78-2	j	7	4	-	5	1	-	-	5.70	3.1 <sup>k</sup>
B72-X $\frac{1}{4}$	f	5	3	-	6	-	-	-	12.40	6.6
B72-X5	f	5	3	-	4	-	-	-	11.88	6.6
B72-X6	f	5	3	-	3	3	-	-	10.04	2.6
B75- $\frac{1}{2}$ -2PA	f	5	2.5	-	3	1	2	-	9.99	1.4
B79-1	m	5	1.75	-	2	-	-	-	11.50	2.3
B79-2	m	5	2.0	-	3	-	-	0.05	8.96	4.4
B79-3	m	5	2.25	-	3	-	-	0.10	9.02	4.2
B79-4	m	5	2.5	-	3	-	-	0.20	10.37	1.3
B79-5	m	5	2.5	-	3	-	1	0.20	8.56	2.8
B79-6	m	5	2.75	-	4	-	-	0.20	8.66	1.6

a tert-butyl perbenzoate

b di-tert-butyl peroxide

c calcium stearate

d zinc stearate

e Acrowax

f 40 parts Cellulo-200 plus 60 parts Hydrite-PD-121

g 100 parts Hydrite-PD-121

h CHCl<sub>3</sub> cure for 8 min mold hold-time

i 10 parts Cellulo-200 plus 90 parts Hydrite-PD-121

j 30 parts Cellulo-200 plus 30 parts Hydrite-PD-121

k methyl ethyl ketone used as solvent

m 40 parts of Cellulo-200; no pigment used

n mixed acetone-benzene solvent used.

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The interpretation of the data in Tables 3 and 4 is difficult, particularly in the case of heads molded from the B79 series. Apparently some defects read as voids in the first X-ray inspection were read as cracks in the second X-ray inspection. The smaller number of rejects for B79-4 after thermocycling than before thermocycling may be partially explained by the fact that, with the exception of B79-1, the first and second X-ray films were read by different operators. The 40 per cent reject rate for B79-4 on the first X-ray inspection seems to be abnormally high.

The following conclusions can be tentatively made from these and past results. Tertiary-butyl perbenzoate is sufficiently active at relatively low temperatures that concentrations above 2.5 parts are probably undesirable. Low concentrations of inhibitors are probably desirable, but the optimum concentration is apparently quite critical. Both the nature and the concentration of the internal lubricant is important. Cracks can be produced by a too rapid setting-up of the material, by exotherms (localized hot-spots), or by both.

To get a formulation which will be relatively insensitive to molding conditions and which will still give an adequate cure in a four-minute molding cycle will probably require accurate control of the concentrations of a number of components. The cure data which have been obtained to date on Mound Laboratory formulations of DAP are summarized in Table 5.

The data in Table 5 are not too consistent, but several conclusions can be tentatively drawn. Zinc stearate appears to be an excellent internal lubricant but also appears to inhibit polymerization, especially at higher temperatures. Calcium stearate is a good internal lubricant, and although it may have some inhibiting action, this action is markedly less than that of zinc stearate. Acrowax is a poor internal lubricant in low concentrations, but it is an excellent one in higher concentrations, particularly in the presence of stearates. Data on its inhibiting action are rather contradictory. It is felt that it has little or no inhibiting action and that low cure values may be caused by a combination of high solubility in hot chloroform and poor dispersion of the Acrowax.

Additional tensile strength and impact strength determinations have been made. These are summarized in Table 6.

**Table 6**  
**TENSILE STRENGTH AND IMPACT STRENGTH OF**  
**DAP FORMULATIONS**

Sample No.	Tensile Strength lb./in <sup>2</sup>	Izod Impact Strength ft-lb per in. of notch
B66-2/4	7366	0.279
B71-2	7113	0.282
B72-X-1/4	6858	0.281
PB4-72	7475	0.282
B73-1CD	6920	0.287
B74-2/3	7042	0.268
B75-1/2PA	6958	0.269
B75-3	6686	0.265
B76-1	7966	0.261
B78-1	7834	0.259
B78-2	6661	0.257
B79-1	9425	0.239

The data for B79-1 should be noted. The tensile strength was unusually high and the impact strength was unusually low.

For some time it has been felt that the cup flow test did not give adequate information concerning the flow characteristics of DAP formulations. An attempt is being made to develop a more informative test using presently available equipment. After a preliminary investigation, the following technique was found to have some promise.

A 1 $\frac{3}{8}$ -inch diameter preform having the weight required to make a standard A.S.T.M. tensile strength dog-bone specimen is used. The dog-bone die is held at a constant temperature, the preform is inserted, and the die is closed using air pressure on the oil reservoir of the Wabash press. The closing of the die is measured with a dial micrometer. The time for the closing rate to drop below 0.001-inch per five seconds and the dial reading at this time are recorded. The pressure is kept on the die for an additional six minutes, and the additional distance that the punch has closed is recorded.

A summary of the data obtained by this method is given in Table 7.

Table 7

## MOUND LABORATORY FLOW TEST OF DAP FORMULATIONS

Full Air Pressure on Wabash Press; Die at 148°C

Sample No.	Time to close <sup>a</sup>		Amount not closed <sup>b</sup>		Creep <sup>c</sup>		Flow Time at 5 Tons, sec
	No preheat <sup>d</sup> sec.	preheat <sup>e</sup> sec.	No preheat <sup>d</sup> in.	preheat <sup>e</sup> in.	No preheat in.	preheat in.	
Mesa B1860	113	86	0.229	0.201	0.004	0.004	11.51
PB-1	96	70	0.224	0.231	-	0.005	10.30
PB-2	116	68	0.259	0.221	0.005	0.0025	11.42
B79-1	111	45 <sup>f</sup>	0.054	0.0175	0.0025	0.0025	11.50
B79-2	96	62 <sup>f</sup>	0.161	0.031	0.004+	0.0022	8.96
B79-3	101	47 <sup>f</sup>	0.120	0.021	0.005+	0.0028	9.03
B79-4	117	40 <sup>f</sup>	0.075	0.015	0.004	0.0029	10.37
B79-5	109	45 <sup>f</sup>	0.088	0.0175	0.004-	0.003	8.56
B79-6	105	42 <sup>f</sup>	0.118	0.020	0.004+	0.0024	8.66
B21	58 <sup>f</sup>	-	0.066	-	0.0034	-	4.73

- a Time from application of pressure on preform until mold closure rate was less than 0.001 in. during 5 sec.  
 b Additional distance punch would have to travel to completely close mold; reading is taken at end of timing period of Note "a".  
 c Additional closure of mold during 6 min holding time.  
 d 1 $\frac{3}{8}$ -in. dia. preform having weight required to make standard A.S.T.M. tensile strength dog-bone.  
 e Preform heated 6 min in oven at 90°C.  
 f Flow restricted at the end of this time as plastic had reached the end of the cavity.

Although PB-2 and Mesa B1860 had essentially the same cup flow time, there is a distinct difference in the data obtained for these two materials. The belief that both PB-1 and PB-2 set up more rapidly than Mesa DAP is definitely confirmed. The data also indicate that short dielectric preheating cycles would probably be definitely superior to long cycles and especially to oven preheating.

The differences between B79-1 and Mesa B1860 is very marked although these two materials had identical cup flow times at five tons. The variation in flow between the various B79 samples does not correlate with the variations in cup flow time.

Since the B79 samples all filled the mold to the end (although not necessarily to the corners) when preheat was used, the use of somewhat lower pressures is indicated, and considerably more work will be required before one or more standard conditions can be chosen. However, the results to date justify a further investigation along the present lines.

**Services** A preliminary study has been made of the feasibility of removing magnetite from Mound Laboratory DAP by means of a table-type magnetic separator. The results indicate that tests at the manufacturer's laboratory will be required. However, it does appear that separation of the magnetite would be feasible with equipment of proper design.

The following tentative conclusions can be drawn from our study:

1. Vibration of the table will be required.
2. The angle of inclination of the table may be critical.
3. A uniform, controlled feed will be required.
4. An electroconducting table surface will be necessary to minimize electrostatic effects.
5. Mechanical hold-up must be held to a practical minimum.

Complete flow curves were run for three new lots of Mesa DAP. The flow times at five tons and the volatile content are listed in Table 8.

**Table 8**

**FLOW AND VOLATILE CONTENT OF MESA DAP**

Mesa DAP Batch No.	Flow Time at 5 Tons sec	Residual Volatile Content %
B-1860	11.51	0.98
B-1925	11.66	1.11
B-1938	11.47	1.10

It should be noted that the volatile content is rather high. It is suggested that the reject rate of production heads for voids could be reduced by drying the DAP before preforming.

A considerable amount of time has been spent in connection with the design of the Plastics Production Facility and the procurement of equipment.

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**Bridge Wire Metallurgy** *An investigation of interalloy effects between gold and solder has been begun in order to obtain information which may be of benefit in minimizing wire failures in IE26 detonator heads.*

**Physical Testing** Conductivity measurements are being continued on completed bridge wire assemblies which have been maintained at temperatures from 90°C to 130°C. These units, as well as specimens for tensile strength testing, have been subjected to various physical treatments including static heat, vibration at 15 cycles per second, cycling to room temperature a minimum of four times daily, and subjection to various relative humidities ranging from 5 per cent to 100 per cent. In this report some of the significant observations of the effects of these treatments upon the completed bridge wire assemblies will be given.

Each specimen in a group of 48 bridge wire assemblies treated at temperatures of 110°, 120°, 130°, and 140°C for eleven weeks showed initial deformation of the gold bridge wire during the first week of treatment. The term deformation is used to define a distinct change in length, shape, or appearance of the assembly. These deformities, presently manifested by a 4 to 20 mil elongation or growth of the bridge wire, have the appearance of a solder alloy on the wire adjacent to the solder mounds. These elongated sections are believed to be the result of intermetallic compound formation by indium and gold. X-ray diffraction studies of random samples of these sections indicated the major constituent to be AuIn<sub>2</sub>. The large volume ratio of resultant AuIn<sub>2</sub> to gold, which is approximately 6 to 1, may explain why there is an extreme growth in the length of the wire when the solder attacks the gold at the interface of the mound and wire to form this intermetallic compound. These deformations in the bridge wire are always accompanied by a very significant decrease in conductivity. There appears to be no noticeable difference between the static, vibrated, and cycled samples, except that the mound surface of the cycled samples is considerably more granular and rough. This latter condition is probably caused by the frequent expansion and contraction of the mound surfaces. A severe shrinkage of the mounds during thermal treatment, which is common to all assemblies, has not caused any appreciable effect on the conductivities. For those assemblies not exhibiting any deformation of the bridge wire, and appreciable "necking out" or attack of the solder upon the gold wire at the interface between the wire and mound has occurred during this period of treatment. This 4 to 8 mil "necking out", which had not altered the bridge wire, has been accompanied by an appreciable enlargement in the diameter of this section of the bridge. The material at this interface appears visually to be the alloy AuIn<sub>2</sub> obtained in the expanded sections of highly deformed bridge wires. Conductivity apparently has been unaffected by this limited attack, which may be the forerunner of deformation of the bridge wire.

One lot of 52 bridge wire assemblies subjected to similar treatment at temperatures of 90°, 100°, and 110°C has been under test for six weeks. All heads in these temperature groups continue to show the very slight increased conductivity exhibited after the first week of treatment. No deformation of the bridge wire has been observed. Some small eruptions or protuberances have appeared around the edge of the mound at the interface of the mound and electrode. These eruptions, which do not appear to be serious, are common to all heads examined and always appear during the first week of treatment. There is, as yet, very little shrinkage of the mounds. As with heads under test at higher temperatures and for longer periods, there is a noticeable "necking out" and attack of the solder upon the gold wire. In these groups the "necking out" has not exceeded one mil, but it is evident because of an apparent increase in the diameter of this section of bridge wire at the interface with the solder mound. This "necking out" is due to slow interaction of the solder with the gold and appears to be the early stage of the deformation process in which AuIn<sub>2</sub> is formed.

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Gold-solder bond samples which have been under treatment for 44 days at 90°, 100°, and 110°C for tensile strength testing show, by visual observation, that there is "necking out" upon the gold wire at the interface of the mound and wire and intermetallic compound formations which are considered to be the result of a solid state reaction. The tensile strength tests indicated that the solder bonds were as strong as the wire if deformation of the gold wire at the interface had not occurred. However, if deformation had occurred the tensile strength was zero. Tensile strength specimens, both those made by production solderers and those prepared by beading the solder upon the wire in a controlled temperature oven, appeared to be more susceptible to deformation of the wire, "necking out", or both, than bridge wire assemblies under similar thermal treatment.

Possibly the rate of the alloying of solder with gold to form  $AuIn_2$  may be determined by impurities or imperfections on the surface of the gold wire. In some samples the reaction may be fast enough to cause expansion chiefly in the length of the bridge wire as the compound  $AuIn_2$  is formed. If the reaction is inhibited by some means, the alloying with the gold will progress very slowly and in a lateral direction perpendicular to the bridge wire, thus causing a swelling in the diameter of the "necked out" portion.

From the past data, neither the occurrence of deformation in the bridge wire assemblies, nor failure of tensile strength specimens, have shown any consistent pattern. An investigation has been made to determine why deformation appears to have a random occurrence. A possible answer may lie in the differences among operators in the soldering process during the bridge wire construction. Ten groups of completed bridge wire assemblies, totaling 154 units, have been under test at 110°C for two weeks to investigate various variables of construction. Seven variables, chosen as possible factors for the random failures, are listed below. Two groups, one in which the solder in the assemblies was reworked up to ten times, and a second in which the solder was worked only two times each were made by a slow working solderer employing a relatively cool iron (230°C). Another two groups of reworked and non-reworked mounds were made by a fast working solderer employing a hot iron (260°C). Other groups were constructed from gold wire, annealed at 400°C, which possessed one-half the tensile strength of the wire normally employed, and from gold wire which has been stretched by suspending the wire with an attached weight for eight hours. The latter two groups were further subdivided evenly into groups of reworked and non-reworked heads. Smaller groups which were constructed by a fast working operator, were employed to determine the effect of a trace of rosin flux added, after construction to the interface of the wire and solder mound. During solder assembly, all heads were oriented in the same manner so that the anchor mound in each case was known.

Conductivities and visual observations after the first week of treatment showed a total of 39 deformed bridge wire assemblies in the 154 units constructed in the manner described above. In each case of deformity, conductance had decreased markedly. Only one additional failure occurred during the second week of treatment. Early conclusions from these tests indicate that the deformation of the bridge wire is somewhat random. Only two variables showed a significant trend. The bridge-wire assemblies fabricated by slow working solderers employing a cool iron are more likely to suffer deformation; nearly a third of such units were so affected. Those heads in which the mounds have been greatly reworked are also more susceptible to failure.

On the basis of these early results it appears that random deformation of the bridge wire assemblies may be due only in part to the manner of construction. The randomness of failure may be ascribed to possible damage to the surface of the gold wire, impurities or lack of impurities on the surface of the wire, or human factors. This approach to the bridge wire problem is being investigated.

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**Metallographic and X-ray Studies** Eight 1E26 bridge wire assemblies were made with a solder containing 18 atom per cent gold, 48 atom per cent bismuth, and 34 atom per cent lead, which had a melting range of 131-163°C. The electrical conductivities of these assemblies were 0.003 to 0.004 ohms greater than the average conductivities of bridge wire assemblies made with the indium-tin-lead solder. The solderer had some difficulty in readily adapting the soldering technique to give acceptable mounds. These bridge wire assemblies have been held at 120°C for one month. A "necking out" of the solder of about one mil on the gold wire occurred during the heat treatment. The mounds had a mottled appearance from air oxidation, and fissures up to five mils deep appeared in the surface.

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**Helium-3 Recovery Project** *Mound Laboratory has been given the responsibility of recovering helium-3 from Savannah River Plant gaseous wastes. A process involving both chemical and isotopic purification is being developed.*

A cold run is being started on the gas purification system. A mixture of helium and hydrogen gas has been charged into one of the gas storage tanks (a three cubic foot propane tank), and a sample has been analyzed with the mass spectrometer. The feed sample tested 90.7 per cent helium and 9.3 per cent hydrogen. Contamination by oxygen and nitrogen was negligible (only about twice the background reading for these elements on the mass spectrometer).

A series of resistance checks was run on two ion-chambers of different sizes which were designed and built for use in the Hot Gas Facility and are to be used temporarily in the gas purification system. The resistance between the center collection electrode and the grounded outer shell was about  $2 \times 10^{10}$  ohms in the 100 milliliter chamber and  $2 \times 10^{11}$  ohms in the 1000 milliliter chamber.

The thermal diffusion cascade system currently being used to separate neon isotopes will be modified to separate helium-3 from helium-4 in the north hood, and to separate krypton from xenon in the south hood.

The Consolidated Model 21-620 Mass Spectrometer to be used in conjunction with heavy gas analysis has been received and has been partially assembled. Complete assembly and final adjustments of the instrument await the arrival of a field engineer from Consolidated Electrodynamics Corporation.

**Tritium Recovery Project** *A process is to be developed for the unloading of tritium reservoirs, the chemical and isotopic purification of the tritium, and the reloading of the reservoirs. The process is to include the capability of loading and unloading at special high pressures. The initial process development will include the recovery of tritium from Los Alamos Scientific Laboratory's decayed salt, and from aqueous and gaseous materials.*

The low temperature still has been installed, and the first successful run has been completed. The feed for the run consisted of 200 (S.T.P.) liters of cylinder oxygen. This produced a charge of 250 milliliters of liquid oxygen in the still pot. The charge was distilled with total reflux and a vapor velocity of about one inch per second for 2½ hours. Liquid nitrogen was used as a coolant and produced an operating pressure of about 20 centimeters of mercury absolute in the still column. The samples are being analyzed for isotopic separation.

An Arthur D. Little, Inc. Helium Cryostat has been ordered and is scheduled for delivery on December 31, 1957. The cryostat and the low temperature still are to be installed in Area SW-1B which is adjacent to the Hot Gas Facility. The cryostat is being modified to produce 10 liquid liters of hydrogen per hour. Following the installation of the low temperature equipment in the SW Building, fractionation studies of the hydrogen isotopes will be started. This facility will provide a reserve capacity for the recovery of the tritium from the material which is to be transferred from Los Alamos Scientific Laboratory to Mound Laboratory, and will provide a suitable means of evaluating the relative merits of thermal diffusion and low temperature distillation in the separation of the hydrogen isotopes under a wide range of expected variables.

The calorimeter bath has been installed in the analysis area to be used in conjunction with the Hot Gas Facility. The bath has been filled with distilled water, and the stirrer has been found to be quite adequate for thorough circulation of the water. Two immersion heaters are in place, one of which will be used for constant temperature control and the other for variable control. Work on instrumentation for control of the bath from the calorimetry laboratory is in progress.

The final drawings and plans for the construction of a steel dry-box are being completed. The equipment accessories for the dry-box, including a gas blower and Lectrodryer (with heat exchangers), are being procured. Delivery time on these items has been tentatively set at six to eight weeks.

Purchase requisitions for all of the equipment needed for the process line are being prepared. Most of this equipment should be delivered by March 1, 1958.

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**Isotope Separation Project** *Mound Laboratory is responsible for the production of several isotopes needed in research projects at several Division of Military Application sites. Particular emphasis is placed on the investigation and use of the thermal diffusion process for separating gaseous isotopes. Processes and facilities to handle both inert and radioactive gases are being developed.*

**Gaseous Thermal Diffusion** Work has continued on the removal of small amounts of neon-21 and neon-22 from approximately 75 liters of neon-20 by-product from the previous enrichment of neon-22. Approximately 45 liters of neon-20 with an isotopic purity of greater than 99.8 per cent has been collected to date. Separation is achieved by means of the four, twelve-foot long thermal diffusion columns in series-cascade operated under continuous flow conditions. Draw-off rates of approximately 200 milliliters per hour at the top of the cascade and 24 milliliters per hour at the bottom are maintained during working hours, and the cascade is permitted to recover equilibrium over nights and week-ends. Periodic gas samples are taken from four points in the cascade each day. The results from mass spectrometer analyses of these samples are used to regulate the draw-off rates.

**Liquid Thermal Diffusion** Two additional runs with a 50-50 volume per cent H<sub>2</sub>O-D<sub>2</sub>O feed were made. Both runs had an approximate average temperature difference between walls of 17°C. Running times were 96 hours and 239 hours, respectively. Compositions were calculated from densities, assuming ideal solutions and allowing for 16 parts per million of D<sub>2</sub>O in ordinary water. The separation factors obtained with the two runs and with an earlier 48-hour run with the same feed and temperature differences are compared in Table 1. The separation factor is defined as the mole ratio of D<sub>2</sub>O to H<sub>2</sub>O in the lower fraction divided by the same ratio for the corresponding upper fraction. The values of column length given in the table are the mean distances between pairs of corresponding fractions on either side of the feed fraction.

Table 1

**THE H<sub>2</sub>O-D<sub>2</sub>O SYSTEM: EFFECT OF TIME AND COLUMN LENGTH  
ON SEPARATION FACTOR**

(Feed: Approx. 50-50 Vol. % Average Temp. Diff. 17°C)

Column Length cm	Time		
	48 hr.	96 hr.	239 hr.
54.8	-	1.000	1.000
91.3	1.000	1.019	1.023
127.8	1.019	1.038	1.026
164.3	1.034	1.050	1.156

The table reveals a consistent increase in separation factor with column length, and, except for one reversal, with time. The improved consistency of these results, compared with the results obtained with an average temperature difference of 33°C, may be attributed to reduced vertical temperature gradients, and possibly to reduced corrosive action.

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An additional 48-hour run with a 25-75 volume per cent  $D_2O - H_2O$  feed was made, again using a temperature difference of  $17^\circ C$ . No separation was observed.

The results of a 48-hour run, employing a feed approximately 0.1 molar in each salt and a mean temperature difference of  $41^\circ C$  are given in Table 2. An important innovation in this run was the use of yttrium-91 tracer for the yttrium analysis. Fractions were collected in sufficiently small vials to permit direct introduction into the well of the gamma pulse height analyser. To reduce the influence of possible protactinium contamination, the fractions and the feed were first counted with the integral switch set to register all gamma activity above 349 Kev. This procedure gave only a 71 per cent activity balance. However, when the samples were recounted at 34 Kev, where a slight peak was observed, a 97 per cent balance was obtained. The cerium balance, obtained by the usual titration procedure, showed only a 92 per cent recovery. Separation factors computed from the molarities of the end fractions, the fractions once removed from the ends, and the fractions twice removed from the ends, were 1.274, 1.098, and 1.131, respectively. The separation factor is defined as the mole ratio of cerium to yttrium for the lower fraction divided by the mole ratio for the corresponding upper fraction.

Table 2

**SEPARATION OF  $Ce(NO_3)_3$  FROM  $Y(NO_3)_3$  IN T.B.P. BY  
LIQUID THERMAL DIFFUSION (RUN-69)  
(Average Temperature difference =  $41^\circ C$ , Time = 48 hrs)**

Fraction	Yttrium Molarity	Cerium Molarity	Mole Ratio Ce/Y
Feed	0.0961	0.0941	0.979
9 (Top)	0.0038	0.0031	0.818
8	0.0036	0.0034	0.942
7	0.0049	0.0044	0.904
6	0.0067	0.0068	1.007
5	0.0524	0.0378	0.722
4	0.1545	0.0945	0.611
3	0.2093	0.2140	1.022
2	0.2277	0.2356	1.034
1 (Bottom)	0.2215	0.2285	1.042

A troublesome feature of this system has been the appearance of a small amount of a heavier liquid phase, presumably water from the hydrated nitrates, in the bottom fractions. To alleviate this phase separation, feed concentrations were reduced to approximately 0.05 molar for each salt, and samples were collected and counted in graduated centrifuge tubes, thus permitting direct measurement of volumes. The yttrium analysis, based on the gamma count at 34 Kev, gave excellent results with an activity balance of 99.7 per cent. However, the run is being repeated since the cerium analyses were unsatisfactory.

**Plutonium Urinalysis** *Present methods for determining the amount of plutonium in human urine give unsatisfactory results. A study directed toward adaptation of the present successful procedure for actinium-thorium urinalysis to the recovery and determination of plutonium is being made.*

(Ed. Note: Consult MLM-CF-57-3-32, "Monthly Technical Activities Report Through March 15, 1957", and preceding reports for previous work on this project.)

Work has been resumed on development of the plutonium urinalysis procedure. The technique for precipitating and separating the cerium carrier has been modified, and good plutonium yields have been obtained using urine obtained from 20 different donors.

The procedure now in use calls for the precipitation of calcium phosphate from the urine, decantation of the supernate, and boiling of the precipitate with nitric acid, as described in MLM-1003. In the present modification, however, the filtrate and wash from the barium nitrate precipitation (when this is used to recover radium isotopes) are transferred to a 50-milliliter centrifuge cone instead of to a 250-milliliter beaker. The solution in the centrifuge cone is neutralized with concentrated ammonium hydroxide to incipient turbidity, then with 3-normal and 1-normal ammonium hydroxide until the methyl orange endpoint is reached. The precipitate is centrifuged, and the supernate discarded. The precipitate is redissolved in dilute hydrochloric acid and reprecipitated with ammonium hydroxide at the methyl orange endpoint. The acidity is adjusted to pH 4.4-4.6 with narrow-range pH paper. The precipitate is centrifuged, and the supernate is discarded. The precipitate is washed with a one per cent solution of ammonium dihydrogen phosphate, centrifuged, and transferred to a stainless steel disk in the usual manner for counting.

The results obtained (Table 1) by this modification have been very satisfactory, and indicate that, contrary to the previous assumption that losses were due to inadequate carrying by the calcium phosphate precipitate, the filtration of the cerium phosphate precipitate was at fault.

The data in Table 1 have been arranged according to the volume of calcium precipitate obtained and tend to confirm the tentative conclusion (page 15, MLM-1003) that a certain minimum quantity of calcium phosphate, magnesium phosphate, or both is necessary for quantitative yields. A series of experiments is under way to establish the validity of this conclusion.

The amount of plutonium being used as a spike in the present work is 243 alpha counts per hour per 24-hour sample, which is close to the maximum permissible concentration (MPC) of 210 alpha counts per hour. Another series of experiments will be carried out to determine the efficiency of recovery at one-tenth of MPC.

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Table 1

**RECOVERY OF PLUTONIUM FROM HUMAN URINE**

Donor	Urine Volume ml	Calcium Ppt. Volume ml	Background <sup>a</sup> cts/hr	Plutonium Recovery <sup>b</sup> %
7	2060	380	c	97.5
3	1900	280	6	97.5
9	1850	270	c	95.9
1	1550	260	5	95.8
2	1600	250	9	94.7
4	1460	230	9	99.2
3	1720	230	6	93.2
15	1080	210	c	92.2
4	1120	200	9	93.4
20	1480	180	7	91.8
16	1380	170	9	108.2
19	1660	170	9	102.5
2	980 <sup>d</sup>	160	9	95.5
10	1120	160	-	92.6
17	1400	150	3	93.0
2	980 <sup>d</sup>	140	9	95.5
12	630	130	c	88.1
13	3000	130	11	100.8
8	1240	120	c	91.8
14	1560	90	9	98.1
18	1800	90	10	90.9
11	1640	80	12	89.5
5	1280	80	c	80.7
6	2000	70	4	68.7

a Background counts per hour per 24-hour sample of the donor were obtained from records which are not necessarily current.

b Plutonium recovery was not corrected for donor's background. The total amount of spike was 243 alpha counts per hour.

c No record available.

d One-half of a 48-hour sample.

Materials of Weapons Interest *Process development for the production of small amounts of unusual materials is occasionally required to meet the needs of the weapons program.*

Ionium Project *The extraction of ionium from partially-processed raffinates from the Mallinckrodt Uranium Refinery is being completed to fulfill previous commitments.*

The thorium sulfate precipitate, obtained as reported last month, was dissolved in a large volume of dilute nitric acid. The sulfate ion was removed by repeated precipitations with ammonium hydroxide and dissolution of the hydroxide precipitate in nitric acid. The final nitric acid solution was boiled down to effect the desired ionium concentration.

Although the product contained considerable impurities, 2384 milliliters of solution containing 34.6 grams of ionium, 359 grams of total thorium, and 40.5 grams of uranium was shipped to University of California Radiation Laboratory, Livermore, California.

Approximately 24 grams of ionium remain at Mound and will be separated from uranium, rare earths, and common elements by small-scale solvent extraction. The purified product will be used for cross-section studies, and will be irradiated to produce protactinium-231.

Organic waste solutions and uranyl nitrate solutions have been drummed for disposal, and processing hoods and adjacent high-risk areas have been made ready for decontamination.

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Protactinium Project *The production for Albuquerque Operations of a gram of protactinium-231 from unprocessed Sperry-Filter-Press residues from Mallinckrodt is being completed.*

All of the protactinium recovered during FY 1956 operations has now been homogenized in 600 to 650 milliliters of di-isobutyl carbinol solution. The homogenized protactinium solution is a composite of 13 different batches processed at various times, so that the individual batches range in age from seven months to two weeks. Because of dilution during transfer, it is not possible to estimate the composite age of the protactinium. Since the alpha pulse height analyzer is presently inoperative, radiochemical techniques are being applied to determine the actual protactinium concentration.

The composite solution has a concentration, based on direct alpha counting of 1.43 milligrams of protactinium per milliliter. If the total volume is conservatively estimated to be 600 milliliters, this would indicate that the total protactinium in the composite solution is 860 milligrams. Assuming, however, that the average age of the protactinium in solution is 100 days, the actinium content would be approximately 0.86 per cent, and the alpha activity of the decay products would be about three per cent of that of the protactinium. The total protactinium is therefore estimated to be 830 milligrams. A more precise value should be available for next month's report.

Raffinates from the homogenizing operations have been transferred to a 10-gallon carboy. This composite waste contains solids, aqueous solutions, and organic solutions. It is likely that it contains approximately as much actinium and other decay products as protactinium. However, no analysis of this waste material has been made, and it is unlikely that any analysis of it will be made until such time as processing of 1957 protactinium is resumed.

REACTOR DEVELOPMENT PROGRAM

CIVILIAN POWER REACTORS

**Homogeneous Reactors** *The Civilian Power Reactor Program is concerned with the development of reactors suitable for the production of power or heat for civilian use. Homogeneous reactors are one of the types being investigated. In a homogeneous reactor, the fuel is, by definition, evenly dispersed in the moderator, so that solutions of uranium-233, uranium-235, or plutonium-239 are acceptable fuels if their chemical and physical properties permit low capital and operating costs.*

**Plutonium Solubility Studies** *A project has been initiated to investigate aqueous systems containing plutonium as a fuel for a homogeneous reactor. Initially, the solubility of various plutonium salts in aqueous solutions up to 300°C will be measured.*

The solubility of white, gelatinous plutonium (IV) phosphate in the presence of several different concentrations of phosphoric acid was studied with the following results. (1) No plutonium phosphate appeared to dissolve in a 0.0847-normal phosphoric acid solution at any temperature up to 270°C. The composition of the sample was equivalent to 0.195 gram plutonium as the insoluble phosphate in contact with one liter of the phosphoric acid solution. (2) No plutonium phosphate appeared to dissolve in a 0.847-normal phosphoric acid solution at any temperature up to 297°C. The sample composition was equivalent to 0.390 gram plutonium as the insoluble phosphate in contact with one liter of the phosphoric acid solution. It was noted that the gelatinous precipitate became crystalline at an elevated temperature. An analysis of the aqueous solution following the high temperature treatment showed that no plutonium was in solution at 24°C. (3) Nearly all the precipitate dissolved at 24°C, when a sample equivalent to 0.390 gram of plutonium as the insoluble phosphate was added to one liter of a 8.47-normal phosphoric acid solution. On heating, all the phosphate dissolved, but it reappeared at 90°C, and the gelatinous precipitate became crystalline at 172°C. On cooling and with agitation, the crystals did not appear to redissolve. An analysis of the aqueous solution in contact with these crystals showed it to contain 0.174 gram plutonium per liter at 24°C.

Additional quantities of lithium plutonium (VI) carbonate were prepared as previously described. Portions of the material were dissolved in various concentrations of lithium bicarbonate solutions to produce saturated solutions. The concentrations of plutonium in these saturated solutions and the high-temperature stability of these solutions are recorded in Table 1. In contrast to previous measurements, the precipitations of lithium carbonate in the more dilute solutions (0.25, 0.10, and 0.05-molar lithium bicarbonate) did not occur near 100°C; instead, the precipitation, which removed all the plutonium from solution, containing 1.12 grams of plutonium per liter, was stable to 243°C. For these same dilute solutions the addition of the carbon dioxide over-pressure caused a precipitate to form at room temperature.

Table 1

**SOLUBILITY MEASUREMENTS FOR THE SYSTEM WATER-LITHIUM  
BICARBONATE-PLUTONIUM (VI) CARBONATE - CARBON DIOXIDE**

Plutonium g/liter	Concentration LiHCO <sub>3</sub> moles/liter	CO <sub>2</sub> Pressure p.s.i. at 24°C	Temperature of Phase Change, °C	
			Li <sub>2</sub> CO <sub>3</sub> ppt.	Pu ppt.
24.2	0.94	0	112	222
24.2	0.94	370		100
11.4	0.25	0		200
11.4	0.25	400		24
3.01	0.10	0		215
3.01	0.10	~ 500		24
1.12	0.05	0		243
1.12	0.05	~ 500		24

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**Plutonium Fast Breeder Reactor** *Fast breeder reactors are of interest to the Civilian Power Reactor Program. Plutonium, which has a high neutron efficiency, is being considered for use in reactors of this type. Mound Laboratory has been given the responsibility for acquiring data on some of the proposed fuel systems, and for maintaining technical cognizance of fuel cycle problems associated with the Fast Breeder Reactor Program.*

**Plutonium Alloy Research** *A project has been initiated for the determination of the density, viscosity, heat capacity, thermal conductivity, and phase equilibria of plutonium alloys proposed as fuels for fast breeder reactors.*

The initial planning has been completed for the physical facilities for the plutonium laboratory area. The layout of necessary hood space in R-159 designates 46 linear feet of gloved alpha-hoods, with a major portion to be serviced with air at -40°C dew point or an inert atmosphere, 13 linear feet of fume hoods, and 5 linear feet of vacuum glove boxes.

There are 22 linear feet of gloved alpha-hoods available at Mound which will be modified by Mound personnel to make them suitable for plutonium handling. The remainder of the required gloved alpha-hoods will be constructed similar to hoods developed by Argonne National Laboratory for the plutonium fabrication facility at that site. This additional hood space is in a preliminary procurement status.

Necessary apparatus to measure the density and viscosity of molten plutonium and its alloys is being designed to permit these measurements to be made in a vacuum.

It is planned initially to obtain phase information in the ternary system of plutonium, cobalt, and cerium in an area which has less than 50 atom per cent plutonium and which includes the ternary eutectic valley originating at 17.6 atom per cent cobalt on the cerium-cobalt binary and extending across the ternary to 12 atom per cent cobalt on the plutonium-cobalt binary. Several different types of capsules for this study are being fabricated of tantalum.

As soon as suitable containers become available, thermal conductivity and heat capacity measurements will be begun on plutonium metal.

DEPARTMENT OF DEFENSE

U. S. ARMY SIGNAL ENGINEERING LABORATORIES (Components Branch)

(Contract No. R-50-799965-SC-01-91)

NUCLEAR BATTERY - THERMOCOUPLE TYPE

*The development of a system for the direct conversion of the energy of radioactive decay as heat into electrical energy is under investigation for the U. S. Army Signal Engineering Laboratories by Mound Laboratory. Radioactive materials are being evaluated as heat sources with consideration given to availability, cost, half-life, shielding, health hazard, and efficiency. Thermocouples and optimum shape and configuration for maximum efficiency output are being considered, and prototype thermoelectric generators are being constructed.*

The thermal resistances ( $R_s$ ), between a source container with three square centimeters of surface area and an outer right cylinder two inches by two inches with the space between filled first with Santocel and then with diatomaceous earth, were measured at various temperature differences up to 800°C. The physical set-up was equivalent to Generator No. 2 with only one thermocouple. The results are given in Figure 1. At room temperature and with a small temperature difference, Santocel has about twice the thermal resistance of diatomaceous earth. At a 630°C temperature difference, both have the same thermal resistance. This would indicate that the conductivities of Santocel and diatomaceous earth are equal at about 350°C. A composite of both insulations would be beneficial in generators operating at 350°C or higher. In the present application, Santocel, with a negligible density and a greater compensation to the decay of a nuclear power source, is more advantageous.

The new generator design, consisting of 12 mica cards 0.003-inch thick, each supporting 40 thermocouples, appears to have sufficient advantages to supersede the Generator No. 2 design. New techniques, jigs, and fixtures were required for construction. The mica cards were squared and notched, forty at a time, with a surface grinder. A sandwich of alternate mica cards and 0.005-inch shim stock was mounted between two 0.25-inch steel plates, and the assembly was pressed together with two screws. The grooves, 80 per inch for the hot junctions and 30 per inch for the cold junctions, were ground with a 220-grit wheel with a 60° cutting edge. The hot junctions were spot welded; the cold junctions were twisted and silver soldered. The cold junctions are clamped between anodized aluminum bars which serve to dissipate the heat and to press the hot junctions against the heat source.

Advantages of this design over that of Generator No. 2 are (1) the cards are interchangeable so that only the card with a failure need be removed for repair, (2) the source diameter is essentially independent of the card dimensions, and (3) more junctions per unit of source surface area are possible.

Equations expressing the theory of the thermoelectric generator have been revised to take more rigorously into account the effect of loading on the efficiency, and the effect of thermal resistances between the cold junctions and the outer container. The heat loss from the surface of the thermocouples was included in the thermal circuit rather than being treated separately as had been done previously.

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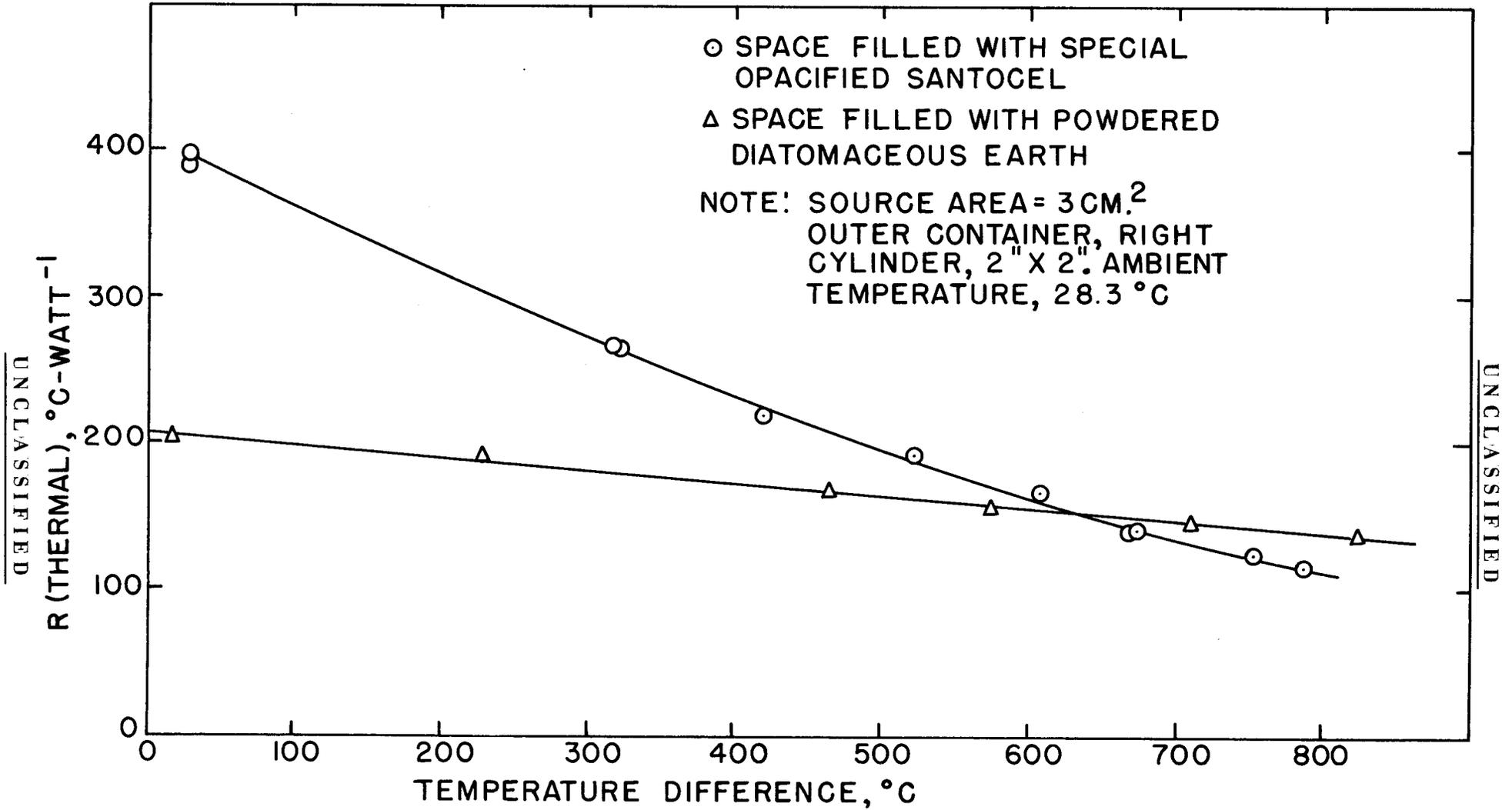


Figure 1. Thermal Resistance From Source Container To Outer Container Versus Temperature Difference