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MONTHLY TECHNICAL ACTIVITIES REPORT THROUGH NOVEMBER 15, 1957

J. F. Eichelberger and

D. L. Scott

Date: November 15, 1957

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MOUND LABORATORY

Miamisburg, Ohio

Operated By

MONSANTO CHEMICAL COMPANY

Research and Engineering Division

United States Atomic Energy Commission

Contract Number AT-33-1-GEN-53

MOUND DECLASSIFICATION REVIEW	
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TABLE OF CONTENTS

	Page
PRODUCTION PROGRAM	4
NUCLEAR RESEARCH AND DEVELOPMENT	5
General Weapons Development	5
Plastics Project	5
Formulation	5
Evaluation	9
Service	11
Bridge-Wire Metallurgy	12
Physical Testing	12
Metallographic and X-Ray Studies	14
Helium-3 Recovery Project	18
Tritium Recovery Project	18
Isotope Separation Project	20
Gaseous Thermal Diffusion	20
Liquid Thermal Diffusion	20
Materials of Weapons Interest	23
Ionium Project	23
Protactinium Project	24
REACTOR DEVELOPMENT PROGRAM	26
Civilian Power Reactors	26
Homogeneous Reactor	26
Plutonium Solubility Studies	26
DEPARTMENT OF DEFENSE U. S. ARMY SIGNAL ENGINEERING LABORATORIES	28
Components Branch	28
Nuclear Battery - Thermocouple Type	28

PRODUCTION PROGRAM

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.

Nine polonium-beryllium neutron sources and two alpha sources were shipped in October, 1957. Four of the polonium-beryllium sources were for other AEC sites. There were fifteen plutonium-beryllium neutron sources shipped during October, 1957. Seven of the plutonium-beryllium sources were for other AEC sites.

Twenty-four tanks of influent water were processed during this period. Two of the tanks required no pre-treatment. Seventeen of the tanks required one treatment of activated carbon and calcium chloride. Three tanks were given a second treatment with the same reagents and two tanks required additional treatment with barium chloride and 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	627,800 gallons
Total Alpha Activity	9.6 millicuries
Total Beta Activity	30.1 millicuries
Activity Density	
Alpha	4.5 cts/min/ml
Beta	14.0 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 Ten sigma-blade mixer runs were made during this report period. Six runs were made to produce a fourth production batch; the remainder were experimental runs. With the exception of run B71, all batches contained 40 parts Cellulo-200 asbestos, 60 parts Hydrite-PD-121 kaolinite, 5 parts monomer, 2.5 parts Scarlet 25AD pigment, and 0.5 part TiO_2 pigment per 100 parts of Dapon-35 prepolymer.

Run B71 contained a standard formulation which has been used for high-speed stirring experiments at Chemineer, Inc. A standard mixture of non-fibrous ingredients used by Chemineer for pre-wetting experiments was combined by them with the other experimental material by mistake. The solvent content of the combined material was determined and sufficient prepolymer was added to give a one-to-one ratio of prepolymer to mineral filler. Catalyst and additional monomer were added in calculated quantity and the material was processed in the usual manner.

Runs B73, B74, and B75 contained variations in amount of catalyst and/or stearate. They represent the first of a series of experiments to find a formulation which will be less critical in its molding characteristics and yet will give adequate cures.

Other pertinent data on the sigma-blade mixer runs are given in Table 1. One sigma-blade mixer run of PB4-72 was used for the milling-in of additional amounts of stearates to determine the effect of increasing the internal lubricant concentration. The final stearate compositions of these B72-X runs are given in Table 1.

Table 1

DIALLYL PHTHALATE FORMULATIONS

Monomer, 5 parts; Pigment, 2.5 parts; TiO_2, 0.5 parts; Cellulo-200, 40 parts; Hydrite-PD-121, 60 parts Per 100 Parts of Dapon-35

Run Number	Parts per 100 Parts of Dapon-35				Wt. of Charge Minus Solvent lb	Peak Power Input KW	Residual Volatiles %
	Acetone	Tert-Butyl Perbenzoate	Stearate Zinc	Stearate Calcium			
B71[a]	187	3.0	3.7	-	35.9	1.28	9.9
PB4-72A	225	3.0	-	3.0	26.75	1.32	12.6
PB4-72B	204	3.0	-	3.0	26.75	1.25	13.1
PB4-72C	210	3.0	-	3.0	26.75	1.33	12.9
PB4-72D	225	3.0	-	3.0	26.75	1.35	11.3
PB4-72E	225	3.0	-	3.0	26.75	1.33	13.2
PB4-72F	225	3.0	-	3.0	26.75	1.30	12.2
B73	225	2.5	-	3.0	26.69	1.25	11.6
B74	225	2.75	2.0	2.0	26.84	1.25	12.1
B75	225	2.5	1.0	3.0	26.84	1.25	12.5
B72-X 1/4	Modified PB4		-	6.0			
B72-X5	Modified PB4		-	4.0			
B72-X6	Modified PB4		3.0	3.0			

NOTE: Extra stearate milled in for these three runs to give the totals indicated.

a Material was T-Turbine stirred at Chemineer, Inc. They mistakenly mixed two lots. Prepolymer was added to give a one-to-one ratio of prepolymer to mineral filler. Final composition: Cellulo, 25; Hydrite, 75; Pigment, 1.6; TiO_2, 0.62 parts per 100 parts Dapon.

Fifty lots were milled on the differential rolls during this report period. The data for these lots are given in Table 2. It was again demonstrated that good control of flow time can be obtained by cutting the material off the rolls when a predetermined net input power is reached. Mobility data are given in Table 3. These indicate that changes in formulation and/or processing technique may result in a change in the flow time, even though a batch be milled to the same net input power. There is also evidence that, even with drying, there is some increase in flow time with age. Previous data, however, indicate that this will not be a serious problem in the Production Facility.

Reasonably low and fairly consistent values for residual volatile content have been obtained since the technique of occasional stirring during the first few hours of oven-drying has been used. A summary of residual volatile content determinations is given in Table 4. The higher values for B65C-4 and B65C-5 illustrate the need for this stirring technique. The desirability of a rotary drier for the Production Facility is definitely indicated.

Although Mesa DAP had been running below 0.5 per cent residual volatile content, the material which has been received more recently has been running about one per cent. This is probably undesirably high.

Table 2

MILLING DATA FOR DAP FORMULATIONS

Mill Lot Numbers	Mill Time Range min	Mill Time Avg. min	Max. Plastic Surface Temp. °C	Milled Weight Range Kg	Net Input Power Range KW
B70-1/6	39.0-45.8	43.6	65 - 68	2.00-2.04	1.29-1.30
B71-1	33.5	-	64	2.20	1.31
B71-2/3	35.5-45.0	40.3	65 - 67	2.20-2.22	1.35-1.36
PB4-72A-1/6	20.0-25.0	21.7	62 - 66	1.96-2.00	1.34-1.37
PB4-72B-1/6	24.2-29.0	27.9	63 - 67	2.05-2.15	1.33-1.35
PB4-72C-1/6	19.2-30.2	26.1	63 - 68	2.04-2.09	1.35-1.36
PB4-72D-1/6	18.5-24.0	20.8	63 - 65	2.05-2.10	1.35-1.38
PB4-72E-1/3	19.0-24.0	22.3	63 - 64	2.05-2.10	1.35-1.35
PB4-72E-4[a]	16.25	-	69	2.00	1.40
PB4-72E-5/6	15.2-25.5	20.4	63 - 64	2.00-2.05	1.35-1.35
B72-X-1	19.0	-	68	2.10	1.50
B72-X-2/4	14.2-31.0	23.9	62 - 64	2.12-2.17	1.35-1.36
B72-X-5	18.0	-	64	2.10	1.35
B72-X-6	34.0	-	64	2.15	1.35
B73-1/2	21.0-25.0	23.0	63 - 74	1.95-2.00	1.35-1.35
B74-1[b]	34.0	-	62 - 64	2.06	1.35
B74-2/3	22.5-30.0	26.25	64 - 64	2.00-2.05	1.35-1.35

a Rejected for production batch PB4 master blend.

b Steam was cut off in E-Building during milling operation.

Table 3

MOBILITY OF DAP FORMULATIONS

Sample Number	Flow Time at 5 Tons Range sec	Flow Time at 5 Tons Ave. sec	Sample Number	Flow Time at 5 Tons Range sec	Flow Time at 5 Tons Ave. sec
B66-1	11.07-11.90	11.57	PB4-72	11.64-11.75	11.76
B66-2	9.35-10.01	9.71	PB4-72E	a	12.94
B66-3	10.35-10.91	10.63	B72-X1/4	12.26-12.52	12.40
B66-4	9.71-10.70	10.09	B73-1	a	10.76
B67-1/6D	10.01-10.28	10.12	B73-2	12.03-12.66	12.43
B68-1/6D	6.28- 6.54	6.40	B74-1	11.55-11.93	11.69
PB3-69	8.92- 9.08	9.02	B74-2/3	11.62-11.92	11.76
B70-1/6D	7.48- 7.90	7.65			
B71-1	6.84- 7.00	6.94	Mesa B-1826	17.01-17.35	17.15[b]
B71-2	6.87- 7.23	7.09			
B71-3	7.10- 7.19	7.15			

a One value only; with the other two samples the press was out of adjustment and did not close at five tons.

b Does not agree with previous value of 14.38 seconds; press was probably out of adjustment.

Table 4

RESIDUAL VOLATILE CONTENT OF DAP MOLDING COMPOUNDS

Sample Number	Residual Volatile[a] %
B50-4/5D	0.33
B65C-4	0.67
B65C-5	0.63
PB1	0.40
PB2-65	0.31
PB3-69	0.43
PB4-72	0.50
B72-X-1/4	0.54
Mesa B-1660	1.09
Mesa B-1773	1.09
Mesa B-1777	0.93
Mesa B-1826	1.35

a Weight loss on drying for 24 hours in a vacuum oven at 70°C.

Evaluation The testing of a large number of test specimens has been completed. In general, the physical properties of our formulations appear to be satisfactory. However, the variations between different specimens of the same material are still too large to permit determination of relatively small differences between formulations.

The Hysco-40 transfer press has been received but is not yet installed. A work order for the conversion of two of our hand molds to semi-automatic molds for use in this press has been submitted for approval.

The results of tensile strength and impact strength determinations are given in Table 5, while the results of heat distortion temperature and arc resistance determinations are given in Table 6. One set of heat distortion specimens was lost because of equipment failure.

Table 5

PHYSICAL PROPERTIES OF DAP FORMULATIONS
TENSILE STRENGTH AND IMPACT STRENGTH

Sample Number	Number of Tensile Breaks		Tensile Strength		Izod Impact Strength ft lb per in. of notch
	Good	Bad	Range psi	Average psi	
B50-4/6D	2	0	6791-6818	6804	0.270
B50-4/6D	2	1	3869-4626	4356	–
B66-2/4	5	1	5625-8049	7366[a]	0.279
B67-1/6D	5	1	6279-8094	7105	0.282
B68-1/6D	6	0	5840-7716	6548	0.279
B70-1/6D	6	1	4841-7213	6885[a]	0.282
B72-X-1/4	6	0	6444-7388	6858	0.281
B73-1CD	4	2	4885-7272	6920[b]	0.287
PB2-65	6	0	5904-7539	6575	0.260
PB3-69	4	2	6048-6543	6276	0.271
PB4-72	5	1	5878-8712	7475[a]	0.282

a One low value excluded from the average

b Two low values excluded from the average

Table 6

HEAT DISTORTION AND ARC RESISTANCE OF DAP FORMULATIONS

Sample Number	Heat Distoration Temperature, °C	Arc Resistance sec
B50-4/6	139	134.3
B66-2/4	–	135.4
B67-1/6D	160	130.7
B68-1/6D	146	132.8
B70-1/6D	159	132.0
B72-X-1/4	–	134.1
B73-1CD	–	135.3
PB2-65	159	131.8
PB3-69	159	131.0
PB4-72	160	135.3

DAP formulations produced at Mound Laboratory have molded satisfactorily, but there have been high rejections for cracks. It is believed that this difficulty could be materially reduced by optimizing the molding conditions; however, a formulation much less critical to the molding conditions should be developed. It is felt that the cracks are caused by irregular filling of the mold cavity and result from poor welds. This is probably caused by the too rapid setting-up of the material during the filling of the mold cavity. A large amount of evidence has accumulated to indicate that most of our formulations lose mobility more rapidly than does Mesa DAP. This may be the fundamental reason for the tendancy of Mound Laboratory DAP to give flow-line cracks.

Production Molding is presently using mold temperatures near the upper recommended limit. Somewhat lower temperatures might be desirable for molding our formulations. Thus, there was a very marked increase in the rejection rate for cracks (3.6 per cent to 74.2 per cent) between the first lot of PB-1 which was molded and subsequent lots which were molded at a mold temperature 10°C higher than that used for the first lot.

The X-ray inspection data on a number of our DAP formulations are summarized in Table 7. It should be noted that three lots, which showed relatively few cracks on the first X-ray inspection, all gave 100 per cent rejection for cracks on X-ray inspection after thermal cycling.

Table 7

X-RAY INSPECTION OF HEADS MOLDED FROM EXPERIMENTAL DAP FORMULATIONS

Batch Number	Number of Heads	Accepted %	Cracks %	Voids %	Inclusions %	Cure min.	Date X-rayed
PB-1[a]	380	94.0	1.3	0.8	3.9	2.7	9-6-57
PB-1[b]	389	89.0	3.6	0.8	6.7	–	9-19-57
PB-1[c]	320	11.6	82.8	3.4	2.2	–	10-9-57
PB-1[c]	479	30.3	62.2	2.7	4.8	–	10-10-57
PB-1[c]	950	25.1	62.7	9.9	2.3	–	10-11-57
PB-1[c]	642	7.0	86.7	3.8	2.5	–	10-14-57
B67-1/6D	23	56.5	39.1	4.4	0.0	9.2	10-18-57
B68-1/6D	24	41.7	50.0	8.3	0.0	16.0	10-18-57
PB2-65	25	72.0	8.0	16.0	4.0	14.5	10-30-57
B72-X-5	25	88.0	8.0	0.0	4.0	6.6	10-30-57
B72-X-1/4	25	92.0	4.0	0.0	4.0	6.6	10-30-57
B70-1/6	25	64.0	24.0	8.0	4.0	2.1	11-1-57
B72-X-6	25	68.0	16.0	4.0	12.0	2.6	11-1-57
B73-1CD	25	20.0	76.0	0.0	4.0	4.3	11-1-57
PB3-69	20	20.0	70.0	10.0	0.0	–	11-7-57
B72-X-5[d]	25	0.0	100.0	–	–	–	11-6-57
B72-X-1/4[d]	25	0.0	100.0	–	–	–	11-6-57
PB2-65	25	0.0	100.0	–	–	–	11-6-57

a Initial X-ray before serial numbering.

b Same heads as (a) X-rayed after serial numbering.

c Molded at 10°C higher mold temperature.

d Second X-ray after thermal cycling.

Service A series of experiments is underway to investigate the feasibility of reducing the magnetite impurity in our DAP formulations by magnetic separation from the ground plastic. Removal of much of the magnetite appears to be possible, but efficient removal appears to present definite problems in design and in the control of material flow. It is probable that it will be necessary to make tests in the manufacturer's laboratory.

A complete flow curve was run on Mesa B-1826 DAP for Production Molding. This material, like the previous Mesa B-1777, was definitely darker in color than previous batches of Mesa Natural DAP. It had a flow time of 14.38 seconds at five tons and a residual volatile content of 1.35 per cent.

[redacted]

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 1E26 detonator heads.*

Physical Testing Physical testing of the gold-solder (Pb-Sn-In) bond, in the manner described in earlier reports, has continued, and additional evaluation tests have been started. The physical testing involved conductivity measurements of completed bridge wire assemblies and tensile strength measurements of two different types of gold-solder bonds. These units have been subjected to various thermal, physical, and chemical treatments before testing.

One group of 48 completed detonator heads has been under test at temperatures of 140°, 130°, 120°, and 110°C for approximately two months. Under 130° and 120°C static heat treatments, six out of twelve heads showed evidence of gold wire deformation and appreciable increases in resistance. With cycling from 130° and 120°C to room temperature a minimum of four times daily, eight out of twelve bridge wire assemblies suffered severe damage. With 110°C static treatment two out of six increased greatly in resistance, while the specimens cycled at 110°C exhibited no resistance change. A damage rate of two in six was observed for samples vibrated at 120°C. No complete breakdowns or ruptures in the gold wire have occurred at these temperatures during the two month test period. The outstanding trend observed during this heat treatment period has been that any bridge wire assemblies that increased greatly in resistance showed severe damage sometime during the first week of treatment. All units whose conductivity have been measured at one week intervals have also been examined under a microscope. After this two month exposure to the above temperatures the mound surface became very crystalline and granular; however, little oxidation has been observed. Each mound has also exhibited appreciable shrinkage.

Microscopic examinations of the bridge wire assemblies which showed a large increase in resistance always show that the wires have undergone severe deformation with a lineal expansion from 4 to 20 mils. This deformation may be described as a kinking or snaking of the wire. The expansion of the gold wire is believed to be the result of an intermetallic compound formed by a reaction taking place in the interphase between the gold wire and the solder. The distorted and expanded wire still retains a circular cross section and has the metallic appearance of the solder. These elongated and deformed sections, which are still under investigation by x-ray diffraction, generally originate at only one of the solder mounds but occasionally are found at both mounds. This distortion can be attributed either to plastic flow or to the formation of a gold-indium-lead-tin quaternary system in the interphase between the gold wire and the solder so that some liquid exists below 110°C. Some samples had a soft, white amorphous substance - possibly residual rosin flux - adhering to the mound and/or gold wire.

A second group of 52 bridge wire assemblies has been under test at temperatures of 110°, 100°, and 90°C for a period of more than two weeks. These tests also include cycling of some of the units to room temperature a minimum of four times daily, static heat treatment, and vibration at 15 cycles per second. No bridge wire assembly has shown any significant change in conductivity to date. Usually the resistance of the bridge wire assemblies decrease an average of 0.00035 ohms during the first week if there is no deformation of the bridge wire. Subsequent treatment will either result in a slight additional decrease in resistance or will very gradually increase the resistance to the resistance observed before thermal treatment.

[redacted]

Microscopically, the gold bridge wires appeared unaltered after two weeks. The mounds retained their smooth, shiny surface, but some puckering or eruptions were observed at or slightly above the interface of the solder mound with the electrode wire. The eruptions of solder became somewhat larger at higher temperatures. No appreciable oxidation has been observed. Since this deformation of the mounds occurs at 90°C, it possibly results from plastic flow of the solder, or from rosin trapped within the solder mound which, upon heating, expands and volatilizes. A slight shrinkage of the mounds has been observed. The same physical appearances described were also found for the first batch of 48 heads after a similar time, but the eruptions were more pronounced because of the higher test temperatures.

The fact that deformation and expansion of the gold bridge wire at 110°C and higher occurred only with a portion of the heads and in most cases at only one mound in spite of the severe test conditions suggests that during the fabrication of the bridge wire assemblies, some mounds or some assemblies received a different treatment than those which had not exhibited a change in resistance upon test treatment. A series of tests has been set up with additional assemblies to explore this idea. To obtain the extremes in soldering temperatures and in speed of soldering the gold wire into the mound, two different batches were prepared, one by a slow-working solderer using an iron of minimum temperature and the second by a fast-working solderer employing an iron of maximum temperature. The mound used to anchor or tack the gold wire during the soldering operation was recorded in order to correlate this factor with the possible failure of the gold wire. Each group was further separated into those assemblies in which the solder mounds have been toughened or worked by the iron a maximum of two times and those which may have been reworked more than two times (as many as ten times in some cases). To test other fabrication variations, several series of bridges are being made from annealed gold wire in which the tensile strength has decreased nearly 50 per cent, and from stretched gold wire to which a dead weight has been attached for several hours. These units will evaluate the effect of prior tension on the gold wire and the effect of the annealing.

Tensile strength test data to date show no evidence of any damage to the gold wire under these various test conditions.

Conductivity measurements of bridge wire assemblies heated in atmospheres of varying relative humidities from zero to 100 per cent and at temperatures of 110°, 100°, and 90°C have been made at regular intervals for two weeks. The severe damage to the mounds found at 100 per cent humidity at 120°C, as described in last month's report, caused this further investigation. At this time, only the observations and conductivity readings for three days and one week are available. As in the dry-heated samples, if no observed damage occurred to the mound or gold wire, the resistances decreased during the first two readings. At 90°C, no appreciable change in resistance was noted except in a 100 per cent relative humidity atmosphere with the major change taking place within the first three days. At 100°C, a linear increase in resistance was noted for the two readings at three days and one week at relative humidities of 60 per cent and 100 per cent. However, at 110°C a very large change was noted in both readings for humidities of 40, 60, and 100 per cent. At this latter temperature, heads under a 20 per cent moisture atmosphere showed a very slight increase after three days, but at one week's exposure they increased in proportion to values obtained at the higher humidities.

Visual observations of each head sealed in a controlled moisture atmosphere indicated that there was no deformation of the gold wire or reaction of solder with the gold wire. At the higher temperatures and relative humidities, the mounds became extremely enlarged and swollen and appeared to be very crystalline and granular. Cracks or splits, often evident in the surface, revealed a dark gray, very crystalline interior. In general, the degree of oxidation and enlargement of the mound agreed closely with the increased resistance observed. There also appeared to be an abundance of soft, amorphous material adhering to the gold wire and particularly to the mounds themselves. This substance, which at the lower humidities and temperatures was generally white and fluffy, was often brownish and glassy appearing at the higher temperatures and might extend outward for a distance of 20 mils on the surface of the plastic surrounding the mound. This substance, also observed occasionally in dry (relative humidity of 5 per cent) temperature tests, is possibly residual rosin flux not removed by the production cleaning process or a substance volatilized from the plastic during thermal treatment. Although this material apparently has no effect upon the conductivity measurements, its source and composition is being investigated further since its presence may have an effect upon the subsequent performance of the completed detonator.

Metallographic and X-ray Studies In the previous progress report a metallographic sample was described which had been obtained after a gold wire (0.032-inch diameter) had reacted with an excess of the indium-lead-tin solder at 130°C. A major layer, approximately 0.003-inch thick and presumed to be an intermetallic compound, had formed between the gold and the solder. A sample of this material was identified as $AuIn_2$ by X-ray diffraction techniques. The very thin, minor layer between the gold and the layer of $AuIn_2$ has not been identified. This second layer is formed after a certain thickness of the $AuIn_2$ compound has been produced. Possibly this inner layer is the result of the gold reacting with the $AuIn_2$ layer to form a compound such as AuIn.

Metallographic examinations of solder mounds with the bridge wires in place are being made. These assemblies are being prepared by production personnel. The gold wire and the solder mound are removed at the faces of the electrodes, mounted in the low temperature clear casting resin, and ground and polished, normal to the gold wire. Because of the great differences in hardness among the gold, solder, and any reaction products, extensive polishing is impractical. Specimens having reasonably good flatness are prepared by using polish which is just sufficient to remove scratches from the solder. Microphotographs of these specimens at 900X reveal a thin ring of $AuIn_2$ around the gold wire in all cases. The layer of $AuIn_2$ is thickest on the portions of the gold wire that had been toward the top of the mounds and thus had been heated to the highest temperature by the soldering iron. The second intermetallic layer found on the 20-gauge gold wire sample has not been found to date on the 1.5-mil gold wires in solder. Reworking of the solder mounds by the solderers during alignment of the gold wire in the mound caused a considerable increase in the amount of $AuIn_2$ formed. A sufficient number of samples has not been examined to give comparative results. Data on the rate of growth of the $AuIn_2$ layer at various temperatures are being compiled.

A number of binary compounds of gold, indium, lead, and tin have been prepared and have been examined by X-ray diffraction techniques.

The X-ray diffraction patterns of gold, indium, lead, and tin appear in the A.S.T.M. tables. The same tabulation also contains the patterns for $AuIn_2$ and for the β-InSn and γ-InSn phase regions of the indium-tin binary system described by Rhines, et al., [Trans. Am. Soc. Metals, 39 694 (1947)]. The compounds, In_3Sn and $InSn_{15}$, reported in "Treatise on Inorganic Chemistry" by H. Remy were found to be β-InSn and β-Sn as reported by Rhines. The compounds, $In_{15}Pb$ and $In_{13}Pb$, reported by H. Remy, were found to be solid solutions of indium in lead, which is in agreement with the indium-lead phase diagram reported by H. M. Davis [Trans. Am. Soc. Metals, 39 712 (1947)].

The powder diffraction data for Au_2Pb and AuSn, indexed according to the data given by Donnay and Nowacki [Geol. Soc. Amer. Mem. No. 60 (1954)] is given in Table 1.

The pattern of AuIn, indexed according to Schubert, et. al [Naturwissenschaften, 40 437 (1953)] appears in Table 1. This phase is triclinic but is indexed as a pseudo-orthorhombic face-centered cell with a = 4.30 Å, b = 10.59 Å, c = 3.56 Å, α = 90.54°, β = 90.00°, γ = 90.17°.

The powder diffraction pattern of $AuSn_2$ indexed by the cell of Schubert, et. al., (a = 6.859Å, b = 7.004Å, c = 11.784Å) is given in Table 1.

Two groups of eight each 1E26 bridge wire assemblies were made using two different experimental solders, the first containing 10 atom per cent gold, 55 atom per cent bismuth, and 35 atom per cent lead, and the second containing 10 atom per cent gold, 50 atom per cent bismuth, and 40 atom per cent lead. The first experimental solder had a melting range of 137-142°C. Bridge-wire assemblies made from this solder had a mean resistance of 0.03583 ohms. The second experimental solder had a melting range of 127-132°C. Bridge wire assemblies made from this second experimental solder had a mean resistance of 0.03485 ohms. Deviations from the mean in both groups occurred in the fourth place.

[redacted]

Table 1

INTERPLANAR SPACINGS FOR BINARY ALLOYS OF Au, In, Sn, AND Pb

Compound	Intensity, I	Spacing, d Å	Indices (hkil)
$AuSn_2$	M	4.57	11.1
	M	3.79	11.2
	W	3.49	02.0
	W	3.39	10.3
	M	3.12	12.0
	W	3.01	12.0, 02.2
	M+	2.94	00.4
	S-	2.75	12.2
	F	2.71	10.4, 01.4
	M	2.61	02.3
	W	2.40	22.1
	W	2.23	20.4, 01.5
	W	2.12	21.4, 11.5
	S	2.08	22.3
	W	2.04	31.2
	W	1.90	31.3
	W	1.82	11.6, 32.2
	F	1.75	31.4, 04.0
	W	1.71	40.0, 02.6
	F	1.59	11.7, 31.5
	F	1.55	24.1
	F	1.51	20.7
	F	1.46	41.4, 24.3
	F	1.43	42.3
	F	1.37	43.1, 50.0, 15.0
	F	1.34	33.5, 43.2, 51.0
	F	1.30	25.0, 15.3
	F	1.26	22.8, 32.7
	F	1.21	12.9, 04.7, 52.3
	F	1.13	13.9, 04.8, 61.1
	F	1.07	35.5, 60.4, 26.3
			15.7, 42.8
	F	1.03	25.7, 63.0
AuSn	S	2.65	11.1
	M	2.15	20.0
	W	1.79	00.2
	W	1.74	06.0
	F	1.66	24.0
	VF	1.37	26.0

[redacted]

Table 1 - Continued

INTERPLANAR SPACINGS FOR BINARY ALLOYS OF Au, In, Sn, AND Pb

Compound	Intensity, I	Spacing, d Å	Indices (hkil)
	F	1.32	22.2
	F	1.26	04.2
	F	1.24	33.1
	F	1.21	20.2
	F	1.17	31.1
Au_2Pb	W	2.82	22.0
	S	2.40	31.1
	M	2.29	22.2
	W	1.62	42.2
	M	1.53	51.1, 33.3
	M	1.40	44.0
	F	1.26	62.0
	F	1.21	53.3
	F	1.20	62.2
	VF	1.06	64.2
	M	1.03	55.3
	W	0.917	55.5, 75.1
	F	0.833	93.1
AuSn	M	3.78	10.0
	M	3.11	10.1
	S	2.23	10.2
	M	2.17	11.0
	W	1.88	20.0
	W	1.77	20.1
	W	1.65	10.3
	M	1.55	20.2
	W	1.37	00.4
	F	1.30	20.3, 10.4
	M	1.26	12.2
	W	1.16	11.4
	W	0.926	40.0
	W	0.894	40.2

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.*

The third uranium pump was completed and delivered to the processing line in room R-106.

Facilities for recovery of tritium from various gas residues from Los Alamos Scientific Laboratory are being readied.

Uranium bed No. 1 was outgassed to a pressure of 25 microns in three hours by simultaneously heating to 425°C and evacuating. Following this outgassing, the bed was tested for reproducibility of hydrogen take-up. Using hydrogen from which condensibles had been removed by passage through a liquid nitrogen cold-trap, the following results were obtained.

	Calculated Take-up	Observed Take-up	Per Cent Take-up
First Take-up	308 liters	299 liters	97.2
Second Take-up	308 liters	301 liters	97.8

A double-flow thermal conductivity cell unit is being tested for reliability as a monitoring and controlling instrument for helium-3 separation.

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 was assembled and vacuum tested. Several leaks were found and repaired. Vacuum testing and heat leak testing have been continued both at room temperature and at liquid nitrogen temperature. The necessary instruments have been repaired and calibrated.

Work is progressing on the mounting of the gas-sampling manifold and manometer tubes, and the system is expected to be complete in the very near future.

A library search is continuing for vapor pressure data on the isotopes of oxygen which are to be used in the initial evaluation of the performance of the reassembled still.

The installation of the calorimeter in room R-108 is nearly complete. A ⅓ h.p. direct-drive circulator, mounted in the center and above the bath, will be used for water circulation. Due to the extreme size of the bath, impellers of various designs will be tested to find an appropriate one for efficient stirring. Immersion heaters are still to be acquired.

Plans are being made to control the calorimeter from a panel in the adjacent room, R-109.

The design of an all-metal drybox and of processing facilities to be used in the salt recovery program has been completed.

Several approaches to the method for the purification and drying of circulated argon gas are being investigated. Several industrial concerns have been asked to submit bids for consideration.

Since the hydride salts to be stored in the drybox are hygroscopic, a specification of -70°F, or less, for the dew point of the argon atmosphere has been set.

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

Gaseous Thermal Diffusion Work was continued in removing neon-21 and neon-22 from approximately 100 liters of neop-20 by-product obtained from the separation and purification of neon-22. To date, approximately 30 liters having an isotopic purity over 99.8 per cent in neon-20 have been collected. The starting material is approximately 98 per cent neon-20. Separation is achieved by means of the four, twelve-foot thermal diffusion columns operated in series-cascade. Draw-off rates of approximately 200 milliliters per hour at the top and 25 milliliters per hour at the bottom were maintained during the working hours, and the columns were allowed to recover equilibrium overnight. Periodic mass spectrometer samples were taken at four points in the cascade juring the day to show whether any correction was necessary in either draw-off rate.

An automatic pressure regulator and pilot control were installed in the one hood and have been leak tested. This installation will provide well-regulated column pressures for future continuous-flow work in this hood independent of continuous-flow work in the other hood.

In order to collect the enriched neon-20 gas in a reasonable volume, two peristaltic pumps in series are being used to transfer the gas from the standard volume collection tank to a pre-evacuated propane tank. Pressures as low as ten millimeters of mercury have been obtained against a head pressure of 325 millimeters using these pumps.

A total of 120 neon samples have been analyzed by the mass spectrometer group in connection with this work.

Liquid Thermal Diffusion The results of a 48-hour run employing a 50:50 volume per cent D_2O:H_2O mixture as feed are reported in Table 1.

Table 1

SEPARATION OF D_2O FROM H_2O. RUN 62

Time = 48 hours, ΔT = 17°C, Charge = 50% D_2O

Solution	Density g/ml	Mole Fraction D_2O	Mole Ratio D_2O/H_2O	q
Feed	1.0503	0.4955	0.9820	
Top Fraction	1.0499	0.4843	0.9391	1.036
Bottom Fraction	1.0508	0.5006	1.0023	

A second run, made under the same conditions, but utilizing a feed containing only 25 per cent by volume D_2O, showed no separation in the end fractions.

The column was operated at full power. In order to reduce the disturbing influence of vertical gradients, tap water at the rate of 7.2 liters per minute was employed as coolant. The separation factor was defined as the mole ratio (D_2O to H_2O) for the bottom fraction divided by the same ratio for the top fraction. Mole ratios were calculated from densities, assuming ideal solutions.

The results of a 24-hour run, employing a TBP feed whose nominal concentrations in cerous nitrate and yttrium nitrate were both 0.1-molar, are given in Table 2.

Table 2

SEPARATION OF $Ce(NO_3)_3$ FROM $Y(NO_3)_3$ IN TBP

Temperature Difference = 41°C Time = 24 hours

Fraction	Cerium Molarity	Yttrium Molarity
Feed	0.1021	0.0862
1 Bottom	0.220	0.189
2	0.183	0.162
3	0.141	0.136
4	0.121	0.109
5	0.0944	0.0902
6	0.0673	0.0552
7	0.0402	0.0362
8	0.0196	0.0106
9 Top	0.0144	0.0031

The cerium concentration was determined by titration of an aliquot of the strip with standard ferrous iron. A new volumetric procedure was used to obtain the total metal concentration. The metals were precipitated from an aliquot of the strip as oxalates, washed free of excess oxalic acid, and redissolved. The resulting oxalic acid was titrated with standard permanganate. The yttrium concentration was calculated as a difference.

The total yttrium recovered in the fractions was calculated as 100.6 per cent of the charge; the cerium recovery was 96.1 per cent of the charge. No consistent separation was observed; however, as previously shown, equilibrium is not established in 24 hours.

The material balance obtained is an indication only of the reliability of the relative concentrations of the same metal so long as the same method of analysis is used for the feed as for the products. Several trial analyses of solutions containing yttrium only have indicated that the volumetric method for yttrium may give lower results than the gravimetric procedure. The latter procedure gives correct results under these conditions.

Several additional runs have been made with the carbon tetracholride-benzene system, all employing a 50-50 volume per cent mixture as feed. The study of the effect of time on separation was extended with runs of 1, 11, 16, and 30 hours, while holding the hot-to-cold wall temperature difference at 33°C. Also, two six-hour runs were made, employing temperature differences of 23.5°C and 39.7°C respectively.

The data from each run provide four values of the separation factor corresponding to the four pairs of fractions collected in addition to the middle or feed fraction. These four pairs correspond, in turn, to four values of the average column length. Table 3 shows how the separation factor is influenced by variations in column length and temperature difference for a constant time of six hours. The separation factors reported are not equilibrium values.

Table 3

VALUES OF THE SEPARATION FACTOR (q) FOR THE C_6H_6-CCl_4 SYSTEM FOR DIFFERENT VALUES OF TEMPERATURE DIFFERENCE, ΔT AND COLUMN LENGTH, L

ΔT °C	L, cm			
	54.8	91.3	127.8	164.3
14.6	1.16	1.31	1.52	3.73
23.5	1.53	2.14	5.08	27.57
33.0	4.10	13.80	55.0	240.0
39.7	16.10	77.90	272.5	1,086.3
46.5	512.2	1,504.5	6,288.1	∞

[redacted]

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.*

Solutions containing about 40 grams of ionium were contacted with small portions of TBP-Amsco to remove a heavy contamination of uranium. Based on X-ray diffraction assay, approximately 1400 grams of the original two kilograms of uranium was removed. However, this method of uranium extraction (by hand) was very slow, and with progressive contactings the ionium losses were too high.

From past experiences, crud formations could be broken by treatment with concentrated HNO_3, but this practice usually resulted in the formation of an organic phase rich in thorium, which, when stripped, gave new cruds. Since the presence of sodium sulfate results in a greater extractability of uranium as compared to thorium, and since emulsions (which the cruds are assumed to be) are best broken by strong acids, it was decided to use concentrated sulfuric acid to satisfy both conditions - provide sulfate ion and give a strong acid solution. All the organic solutions and cruds on hand were treated with concentrated sulfuric acid, and the resulting aqueous solutions were found to contain practically all the thorium. The stripped organic was added to sawdust-filled drums for disposal.

On the assumption that sulfuric acid would precipitate the thorium, while the uranium would stay in solution as a soluble sulfate, all the solutions containing ionium (approximately 55 grams) were combined and made up to 12 normal in sulfuric acid. This solution was centrifuged and the resultant supernate was found to contain 1.85 grams of ionium and approximately 800 grams of uranium. The supernate was neutralized and precipitated with 50 per cent caustic. Although the precipitate undoubtedly contains a considerable amount of iron (from the action of sulfuric acid on pilot plant equipment), it will be dissolved in nitric acid and added to the previous uranium reclamations for return to Mallinckrodt Chemical Works.

It would appear that a good separation of the thorium from the uranium was effected by the sulfate precipitation, and the subsequent thorium sulfate precipitate should be fairly free of both uranium and rare earths (whose solubility, in general, is much greater than that of thorium).

It is hoped that the thorium sulfate precipitate can be dissolved in water and nitric acid, and that, after multiple precipitations with ammonium hydroxide, a product solution that will satisfy specifications for shipment will be obtained.

[redacted]

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

Processing of the FY 1956 protactinium to bring it into homogeneous solution is continuing and should be completed within the next two weeks. An estimated 625 milligrams of protactinium is now in di-isobutyl carbinol solution, and 130 milligrams remain to be homogenized. There has been a small amount of hydrolytic precipitation in several of the storage bottles, principally those in which the aqueous phase was not completely separated before the organic phase was transferred to storage.

Some difficulty has been experienced because of the growth of decay products which have gamma energies near the 300 Kev level. It has been necessary to run gamma spectra on the raffinates from the di-isobutyl carbinol extractions in order to determine how much, if any, of the 300 Kev gamma count was due to protactinium. The protactinium, if present, is readily identified by the presence of a distinct photopeak at 27 Kev. If protactinium is found in the raffinate, the extraction is repeated.

The protactinium is being homogenized to a concentration of at least one milligram per milliliter of di-isobutyl carbinol. In cases where the extraction results in lower concentrations, the protactinium is stripped into hydrogen peroxide, and the resulting precipitate is redissolved in sulfuric acid and re-extracted.

Although the primary objective at this point is the preparation of a homogeneous solution, it is evident that a considerable amount of purification is being carried on simultaneously. The raffinates, which are being retained for later scavenging, develop large, flocculent precipitates on standing. These precipitates are, to a considerable extent, soluble in alkaline solution, and probably consist principally of niobium and titanium phosphates. They contain small amounts of protactinium which may be worthwhile recovering at a later time.

No difficulty is anticipated in preparing a pure aqueous protactinium solution. A spectrographic analysis of the sample sent to Los Alamos Scientific Laboratory last May is now available (Table 1).

Table 1

SPECTROGRAPHIC ANALYSIS OF PROTACTINIUM SULFATE

Element	Per Cent*
Si	0.13
Pt	0.039
Mg	0.014
Fe	0.25
Al	0.056
Nb	0.083
Cu	0.008
Ag	0.003
Ca	0.014

* All values are ± 50%

The spectrographic sample was prepared by evaporating to dryness a sulfuric acid solution of protactinium, and igniting the residue at 400°C The protactinium content of the ignited residue, as determined by alpha counting, was 49.0 per cent, corresponding to the formula: $Pa_2(SO_4)_5$.

REACTOR DEVELOPMENT PROGRAM

CIVILIAN POWER REACTORS

Homogeneous Reactor *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 solution up to 300°C will be measured.*

Further studies have been made on the system water, lithium bicarbonate, plutonium (VI) carbonate, and carbon dioxide. The solutions have been prepared by dissolving solid plutonium (IV) sulfate in dilute sulfuric acid and oxidizing it with ammonium persulfate, using silver nitrate as a catalyst. The excess oxidizing agent is destroyed by boiling the solution. Solid lithium hydroxide is then added to the hot solution to give, on cooling, a high yield of lithium plutonate. This precipitate is washed twice with water and then slurried in water while carbon dioxide is slowly bubbled through. The dark brown precipitate slowly converts to a light buff-colored precipitate in the presence of the carbon dioxide.

The results of the solubility versus temperature determinations on these solutions are summarized in Table 1. The first result noted was that the solutions which contained no excess carbon dioxide gave a fine, white precipitate near 90°C which appeared to be lithium carbonate. This white precipitate persisted on further heating until heated above 200°C where the solution became colorless and the precipitate increased in volume and became yellow. This yellow precipitate did not redissolve on cooling and yielded only a small amount of carbon dioxide gas when treated with dilute hydrochloric acid. Since an excess of carbon dioxide increases the solubility of lithium carbonate, carbon dioxide was added to decrease the apparent precipitation of lithium carbonate in the plutonium solutions. However, increased carbon dioxide pressure decreased the apparent solubility in the 0 5- and 0.25-molar lithium bicarbonate solutions. The 0.5-molar lithium bicarbonate solution formed a precipitate under 1000 pounds per square inch of carbon dioxide at room temperature. Only in the case of the 0.94-molar lithium bicarbonate solutions did an excess of carbon dioxide increase the solubility. The precipitates formed in the presence of carbon dioxide were light pink in color, did not redissolve on cooling, and evolved a large amount of carbon dioxide when treated with dilute hydrochloric acid. Apparently, there are several mixed lithium plutonyl carbonate compounds formed. Further examination of the higher concentrations of lithium bicarbonate under carbon dioxide pressure will be made since some higher temperature stability was shown.

Studies were made on $Pu(HPO_4)_2 \cdot xH_2O$ (a white, gelatinous phosphate having a pinkish cast) and water. This phosphate was prepared in the quartz microtubes by placing plutonium (IV) sulfate solution in the tube and adding five microliters of one per cent phosphoric acid solution. The tube was centrifuged and the aqueous portion removed. The precipitate was washed twice with water,

50 microliters of water were added, and the tube was sealed. On heating, the dispersed floc clumped, with a maximum agglomeration at 175-200°C. At no temperature was the solubility greater than 0.195 gram of plutonium per liter, the lowest concentration studied. Measurement of the radioactivity of the aqueous portion from the tubes at room temperature showed no appreciable concentration of plutonium present.

Table 1

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

$LiHCO_3$ concentration moles/liter	Pu concentration g/liter	CO_2 Pressure approx. p.s.i. at 24°C	Temperature of Phase Change (°C)		
			Li_2CO_3 ppt.	Pu ppt. (yellow)	Pu ppt. (pink)
0.25	–	–	120	–	–
0.25	5.3	0	88–93	255	–
0.25	5.3	150	–	–	100
0.25	5.3	1000	–	–	70
0.5	–	–	98–100	–	–
0.5	–	400	208	–	–
0.5	14.6*	0	95	214	–
0.5	14.6	570	–	–	90–96
0.5	14.6	1000**	–	–	24
0.5	7.3	0	90	236	–
0.5	7.3	630	–	–	100–120
0.5	7.3	1000**	–	–	24
0.94	–	–	40	–	–
0.94	9.04	–	85	273	–
0.94	9.04	600	–	–	135
0.94	9.04	1000**	–	–	<100 no ppt
0.94	4.5	0	86	270	–

* Saturated solution

** Liquid CO_2 present at 24°C

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 circuit of the thermoelectric generator is shown in Figure 1. Figures 2 through 4 show specific circuit values calculated for Generator No. 2, which was described in MLM-CF-57-10-33, at various power inputs and with two different insulating materials. Power is expressed in watts, thermal resistances are expressed as degrees Centigrade per watt, and temperatures are expressed as degrees centigrade.

To show experimentally the effect of a matching load on the operation of the generator, a plot, shown in Figure 5, was made of the ratio, $W_0/W_{52.5}$, of the power output at various loads and various heater inputs to the power output at a fixed load of 52.5 ohms, versus the load resistance, R_L. A curve was drawn through these points indicating a peak matched load at 54.5 ohms. This curve has only a small change of slope indicating slight dependence of output on exact matching of the load.

A series of calculations was made to determine the characteristics of a battery using a thermoelectric generator similar to that reported last month with a 701-curie polonium-210 heat source having an initial output of 22.44 watts. Experimental values obtained from measurements made with an electrical heater simulating the radioactive heat source were used in calculating values for the open circuit voltage and power output as a function of elapsed time. Curves representing these calculations are shown in Figures 6 and 7. Output voltage and power were also calculated as if they were a function of the decay of the polonium-210 only, and these curves are also shown for comparison. If this battery were considered useful until the voltage fell to one-half of its initial value (170 days), the work available from the battery over this period of time would be:

$$\int_0^{170} W_0 \, dt = 338 \text{ watt-hours}$$

If the battery characteristics followed the decay of the polonium-210 only, its work, over 170 days, would be:

$$149.4 \int_0^{170} e^{-0.01002t} \, dt = 293 \text{ watt-hours}$$

If we consider this only for the half life of polonium (138.4 days), the work obtainable would be:

$$149.4 \int_0^{138.4} e^{-0.01002t} \, dt = 179 \text{ watt-hours}$$

This indicates that the battery would have a longer and more useful life than that indicated by considering only the half life of the isotope used.

Two new thermoelectric generators have been designed and are being constructed. The first is a modification of Generator No. 2; the size of the thermocouple wire was reduced to 0.005-inch diameter and the construction of the cold junction retainers was changed. The number of cold junctions can be nearly doubled in the new design; yet, the leads will have the same thermoconductivity and there will be the same number of rings as in Generator No. 2. The second design consists of mica cards, each mounting 20 to 50 thermocouples with one type of junction aligned along one edge, vertically mounted and radially spaced around the heat source container.

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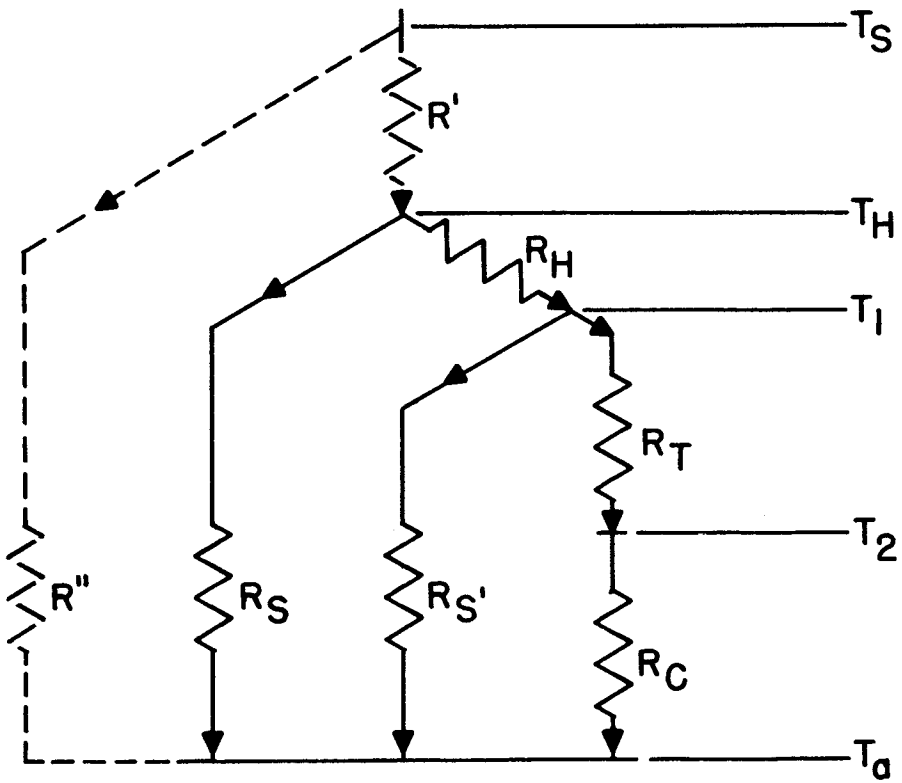

LEGEND

T_s = Temperature of heater

T_H = Temperature of source container

T_1 = Temperature of hot junction

T_2 = Temperature of cold junction

T_a = Ambient temperature

R_H = Thermal resistance, heater to hot junction

R_s = Thermal resistance, insulation

$R_{s'}$ = Lateral thermal resistance, thermocouple leads through insulation

R_c = Thermal resistance, cold junction to ambient

R_T = Thermal resistance, hot to cold junction

R' = Thermal resistance, heater to container

R'' = Thermal resistance, heater to ambient

NOTE: (1) Dash line represents heater circuit; it would not be present with a radioactive heat source.

(2) All thermal resistances are in °C-watt^{-1}; temperatures are in °C.

Figure 1. Thermal Circuit for Thermoelectric Generator

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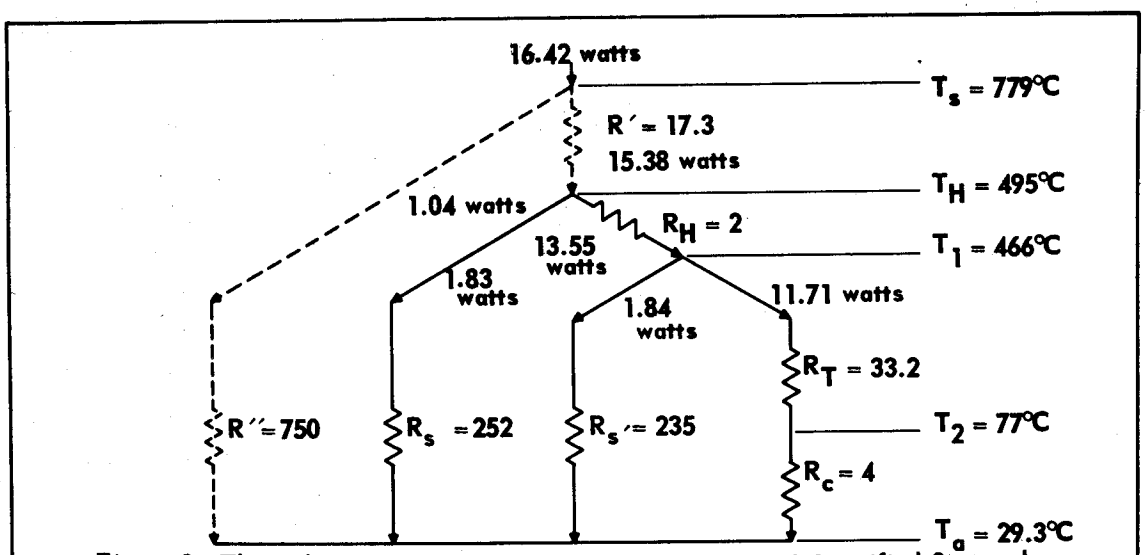

Figure 2. Thermal Circuit, Gen. No. 2: Insulation - Special Opacified Santocel

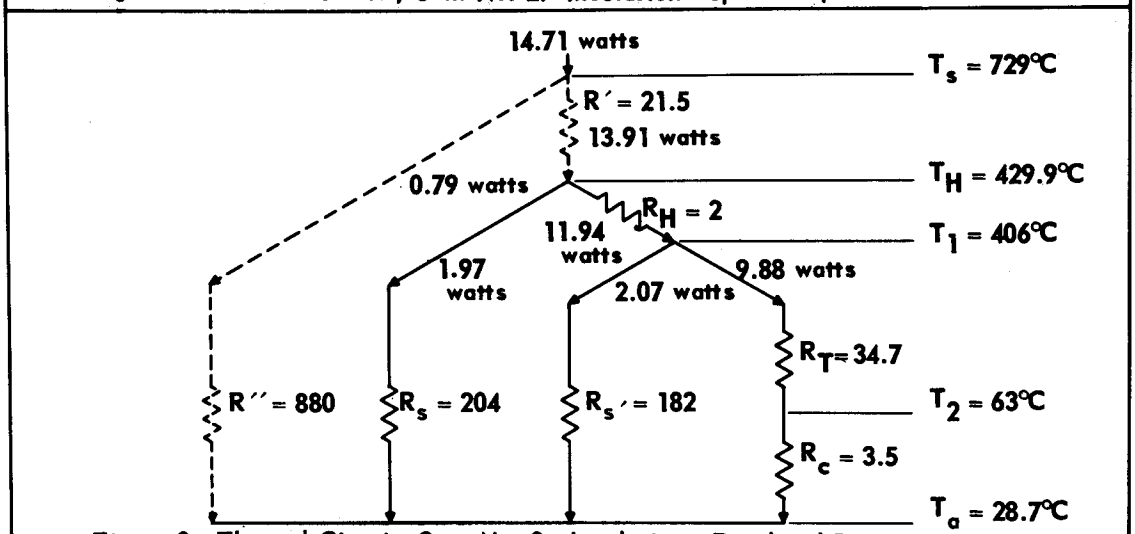

Figure 3. Thermal Circuit, Gen. No. 2: Insulation - Powdered Diatomaceous Earth

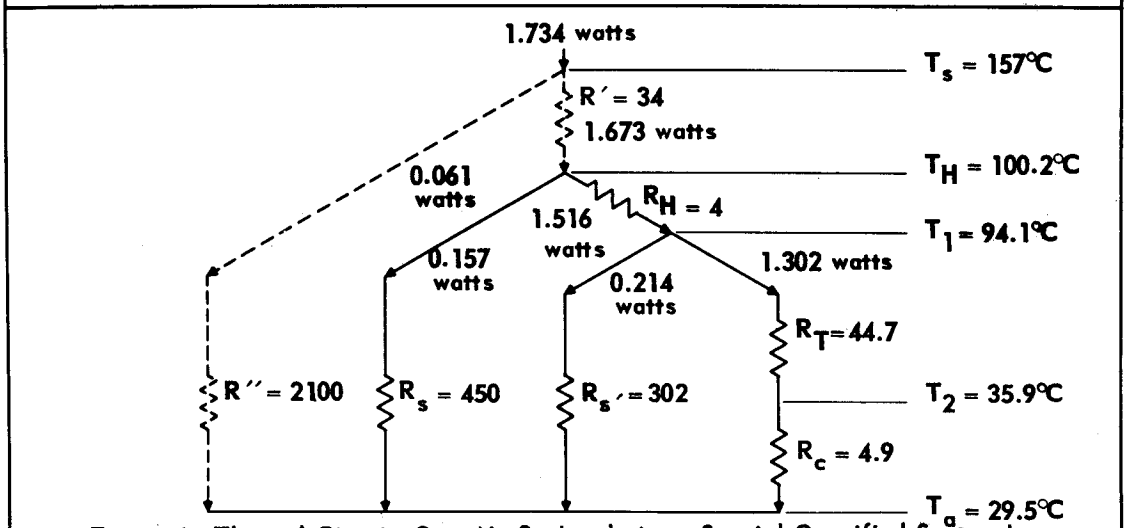

Figure 4. Thermal Circuit, Gen. No 2: Insulation - Special Opacified Santocel

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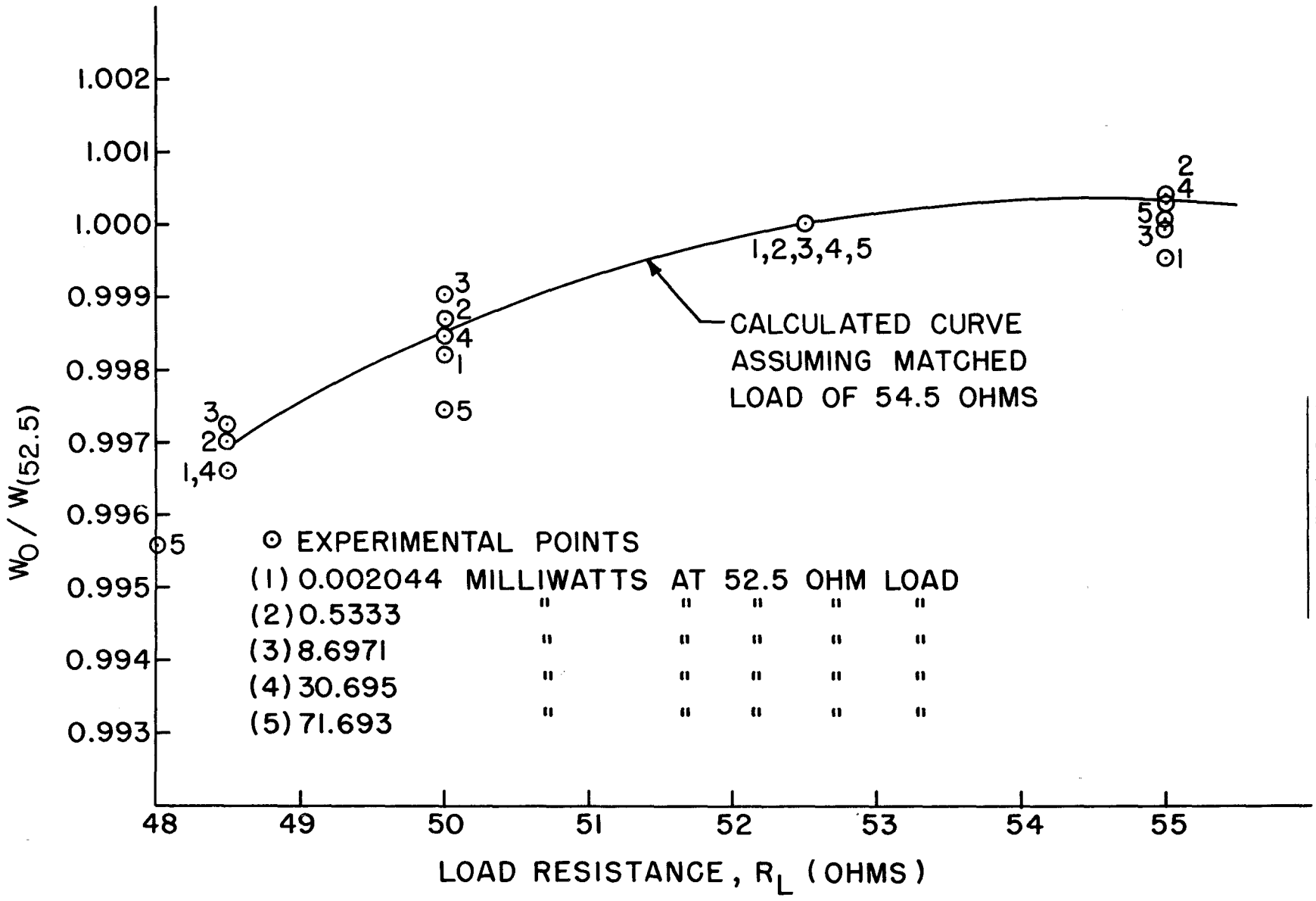

Figure 5. Ratio of Power Output of Generator No. 2 with R_L Ohm Load to to Output with 52.5 Ohm Load vs Load Resistance, R_L

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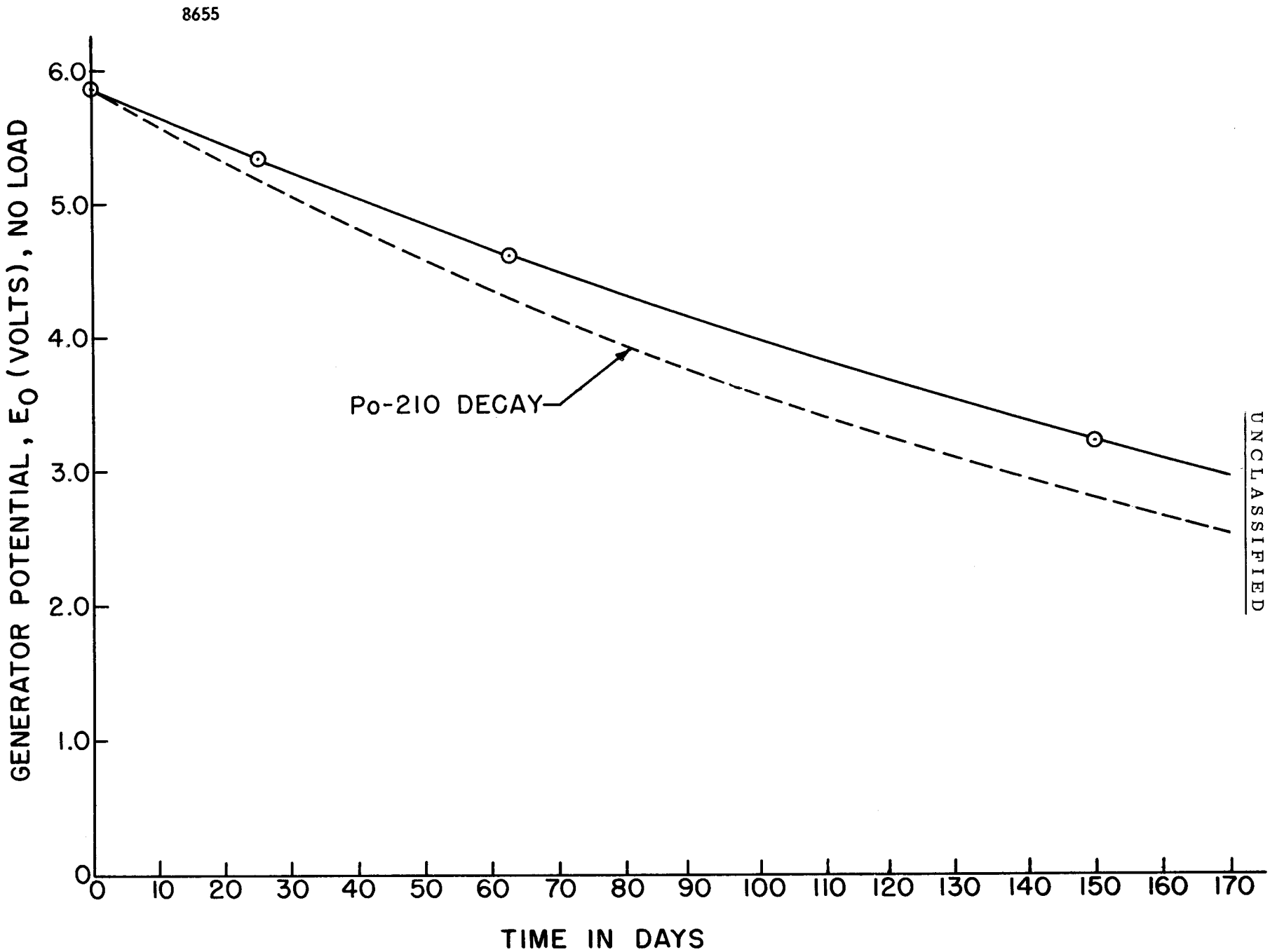

Figure 6. Calculated Generator No. 2 Potential vs Elapse time after Loading a 701-Curie Polonium-210 Heat Source

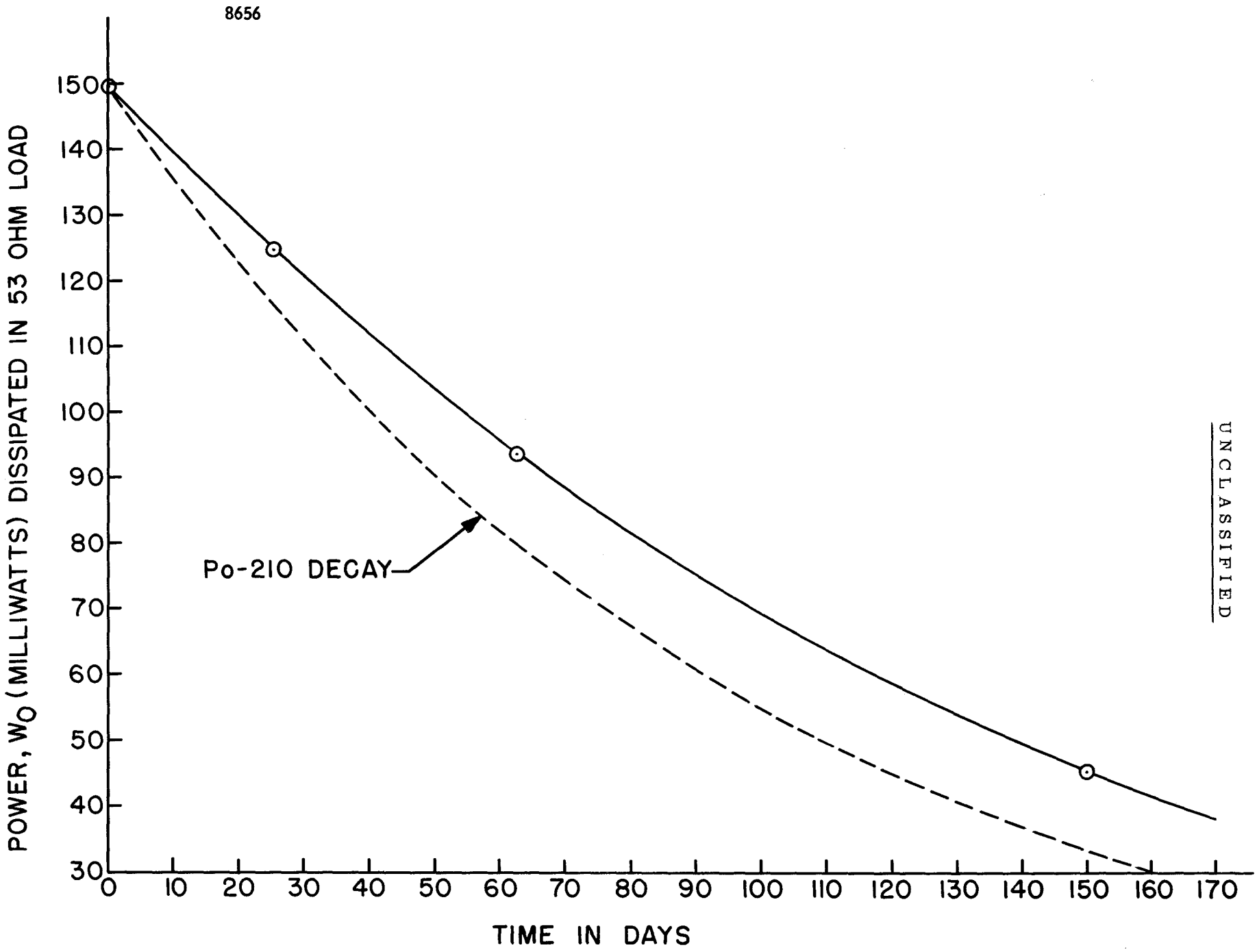

Figure 7. Calculated Power Output of Generator No. 2 vs Elapse Time After Loading a 701-Curie Polonium-210 Heat Source