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Research Department-Mound Laboratory

February 6, 1963

Trip Report - Washington, D. C., January 21, 1963 - G. R. Grove

MOUND LABORATORY-MONSANTO
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Mr. David L. Scott

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An Isotope Fuels Development and Production Program review meeting was held in Washington, D. C., on January 21, 1963, at the "H" Street AEC Building. This meeting was requested by P. C. Aebersold, Director, Division of Isotopes Development, to serve as a briefing by contractor personnel for the preparation of a summary to be presented to the AEC Commissioners. The presentation of the isotope fuels program to the Commissioners is to be arranged by the Division of Isotopes Development and made by Mr. A. F. Rupp of ORNL. The preliminary outline of the information to be presented is as follows:

PRODUCTION CAPACITY AND RATES

AEC - Present and Projected
Private Nuclear Power - Projected

RESEARCH AND DEVELOPMENT

Production Processes/Including Reactor Irradiation and Chemical Separation
Final Product Form Development

AEC FACILITIES

Present Availability
Future Requirements

MOUND DECLASSIFICATION REVIEW
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AUTHORITY: ☐ AOC ☒ ADC ☐ ADD
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COSTS

Program Costs through FY-1972
Product Costs

PRODUCTION REQUIREMENTS

The agenda for the review meeting on the isotope fuel programs was as follows:

Time	Subject	Presentation By
9:00 a.m.	Fuel Requirements	DID - A. Berman
10:00 a.m.	Plutonium-238	SRP - Charles Wende
10:30 a.m.	Plutonium-238	Mound Lab - G. R. Grove
11:00 a.m.	Polonium-210	Mound Lab - G. R. Grove
11:30 a.m.	Curium-244	SRP - Charles Wende
12:00	Curium-242 and 244	ORNL - A. F. Rupp
12:30	Lunch	
1:30 p.m.	Fission Products Production at Hanford	Hanford - Hugh Warren
2:00 p.m.	Fission Products Production Plant Study at Hanford	Hanford - Hugh Warren
2:30 p.m.	ORNL Fission Products	ORNL - A. F. Rupp
3:00 p.m.	Martin Fission Products	Martin - Justin Bloom
3:30 - 5:00	Discussion	

In attendance at the meeting were the following personnel:

P. C. Aebersold	DID/AEC
Arnold Berman	DID/AEC
W. K. Eister	DID/AEC
W. L. Lennemann	AEC/Production
Captain R. I. Carpenter	DRD/AEC
C. L. Robinson	RLO
W. H. Reas	HAPO
J. H. Warren	HAPO
I. Hobbs	SROO
A. F. Rupp	ORNL
J. W. Nehls	ORO
D. L. Scott	Monsanto Research Corporation
G. R. Grove	Monsanto Research Corporation
E. A. Walker	DAO, AEC/ALOO
Charles Wende	DuPont (SRP)
J. L. Bloom	Martin-Marietta Corporation

The meeting was called to order by Arnold Berman and a brief review of fuel requirements was presented. This followed the basic outline of the recently prepared staff paper (MLM-CF-63-1-149, Forecast of Large Scale Radioisotopes Requirements and Production Planning) which are summarized in the attached Tables I through VII.

Captain R. T. Carpenter, Division of Reactor Development, discussed some of the missions which are planned to use radioisotopic power sources. Among the points which Captain Carpenter emphasized are the following:

1. The Transit Program is a pioneer effort and plutonium-238 is unquestionably the material of first choice for space missions.

2. Design studies have started for the IMP Program using the SNAP IX-A type fuel capsule with SNAP III technology. This program is directed toward the determination of radiation around the earth as a part of the APOLLO Program.

3. The ANNA Program is a geodesic study and is an absolute necessity as a part of the primary NASA space program. It is recommended that plutonium-238 be used as the fuel for these satellites.

4. The RANDOM ACC Program will require between 40 and 100 satellites to be launched with ATLAS AGENA rockets. However, because of the lack of plutonium-238 and curium-244, strontium-90 is planned to be used as the source of nuclear power. Accordingly, complete ground check of launching vehicles prior to beta fueling will have to be made and the launching would have to be over water. Furthermore, complete burn-up upon re-entry is required and remote handling equipment during the fueling operation would have to be developed and used. Strontium-90 is also planned as the fuel for the RELAY B applications which will consist of three units in synchronous orbits in the equatorial plane.

5. Curium-244 is tentatively planned for use in the VOYAGER, APOLLO and MARINER Programs. Curium-242 is being considered for the SURVEYOR, LANDER, ORBITOR, SNAP XIII and APOLLO Programs. A SNAP XIII thermionic demonstration program using curium-242 is in progress with two units which have been in operation for greater than 2000 hours.

6. Polonium-210 is being considered for the APOLLO Program.

7. Cerium-144 is being considered for the NIMBUS C, OAO, MIDAS and POODLE Programs. Promethium-147 is being considered for the TCC Program (Temperature Controlled Capsules).

In general, for terrestrial and marine applications, strontium-90 seems to be the radioactive material of choice because of its ready availability, inexpensiveness and the fact that massive shielding usually can be used without undue difficulty.

Charles Wende of SRP discussed the availability of plutonium-238 relative to the existing production schedule for several alternatives by which production can be expanded. Assuming the existing production schedule as the base level, the cost of production is estimated to be $390 per gram. Increased production can be achieved by relatively expensive additions and modifications which would result in production increases of 300 and 500 per cent for the two alternatives proposed, and would result in unit costs of plutonium-238 of $540 and $470 per gram, respectively.

An increase over the base level of about 30 per cent could be achieved by the inclusion of the civilian power reactors in the production of plutonium-238.

Mound Laboratory presented a summary of the existing facilities, processes, capacity, unit costs, and technologies of both polonium-210 and plutonium-238. Also, presented were estimates of costs for plutonium-238 power source fabrication projected through FY-1972 based on plutonium-238 availability and estimates of the cost of production of 100 and 1000 grams of polonium-210 per year. Much of this information had previously been supplied to the Division of Isotopes Development (references: MLM-CF-62-12-259 and MLM-CF-63-1-128).

Charles Wende and Arthur Rupp presented information on the planned production and processing of curium-242 and curium-244. No large scale work has been done with curium-242 and they do not have any operating experience with this material on a level which would be required for the APOLLO Program. Neutron radiation from the spontaneous fission of both curium-242 and curium-244 presents a major handling problem. It is planned to concentrate the curium isotopes and form them into cermets of rhodium and gadolinium oxide which should be stable to about 2000°C. The cermets would be about one-half inch in diameter by one-fourth inch high and for curium-242 would have a thermal power output of about 275 watts.

Hugh Warren presented a review of the fission products work at HAPO. A summary of the information he presented is given below.

Fission Products Shipped To-Date

Strontium-90	1150 kilocuries
Cesium-137	830 kilocuries

Inventory on Hand-Presently Available

Strontium-90 (purified)	2270 kilocuries
Strontium-90 (crude)	1000 kilocuries
Cesium-137	60,000 kilocuries

Shipping Capability	**Kilocuries/Year (based on 2-month turn-around per cask)**
Strontium-90	5000 (2 HAPO II, 1 HAPO-1-B)
Cesium-137	1200 (STT)
Cerium-144 + RE Pm-147	3000 (1 HAPO-1-B)

Production Levels and Unit Costs

Phase I (Current Program)	Megacuries	$/Curie
Strontium-90 ($SrCO_3$)	4	0.60
Cesium-137 (crude)	5	0.05
Cerium-144 (crude)	5	0.03
Phase II (FY-1965) $1,500,000 Addition		
Strontium-90 (purified)	5	0.60
Cesium-137 (crude)	5	0.05
Cerium-144 (crude $Ce_2(SO_4)_3$)	10	0.03
Phase III $3,500,000 Addition		
Strontium-90	10	0.25
Cesium-137 (crude)	10	0.05
Cerium-144 CeRE)	100	0.02
Phase IV $1,800,000 Addition		
Strontium-90	10	0.25
Cesium-137	10	0.15
Cerium-144	100	0.03
Promethium-147	30	0.10

Justin Bloom discussed source of the work that has been done at the Martin-Marietta Corporation on fission fragments. Work on the evaluation of high temperature compounds of cesium was described. Compounds studied included $CsWO_3$, $Cs_2U_2O_7$, Cs_4MoO_3, $CsNbO_3$, $CsTaO_3$, $CsTaW_xO_{(3 + 3x)}$, $CsTiO_3$, and Cs_2ZrO_3. A final report on this work is to be issued about March 1, 1963. Operations with strontium-90 at the level of about one million curies per year are expected to be maintained through FY-1965. Their budget for the strontium-90 program for FY-1963 is $861,000 and is proposed to be $1,360,000 for FY-1964.

A rough draft of the information to be presented to the AEC Commissioners is to be prepared by A. F. Rupp and DID personnel and reviewed with the appropriate contractors before it is prepared in its final form.

Original Signed By
G. Richard Grove

G. Richard Grove

GRG:la

TABLE I

ISOTOPE FUEL REQUIREMENTS FOR SPACE
AS PRESENTED BY DOD
(FY-1964 Through FY-1970)

Plutonium-238 (kilograms)		1964	1965	1966	1967	1968	1969	1970	Total
Supply		6	13	18	24	32	36	42	171
TRANSIT	25W	6	6	2	2	2	2	2	22
IMP	25W	(4)	4	4	4	4	4	4	(28)
ANNA	25W	(4)	4	4	4	4	4	4	(28)
RANDOM ACC	35W	-	(3)	(3)	-	-	-	-	(6)
RELAY B	160W	-	(6.7)	(6.7)	-	-	-	-	(13.4)
SYNCOM B	160W	-	-	(6.7)	6.7	-	-	-	(13.4)
SYNCHRONOUS	250W	-	-	-	11	-	-	-	11
MARINER*	250W	-	-	11*	11*	-	11*	-	33*
Total		(20)	(36.7)	(55.4)	62.7	42	57	52	(325.8)

Strontium-90 (megacuries)									
Supply		3	5	5	10	10	10	10	53
RANDOM ACC	35W	-	1.4	2.8	2.8	1.4	1.4	1.4	11.2
RELAY B	160W	-	1.3	1.3	2.6	-	-	-	5.2
SYNCOM B	160W	-	-	1.3	1.3	2.6	-	-	5.2
SYNCHRONOUS	250W	-	-	-	1.0	2.0	2.0	2.0	7.0
Total		3	7.7	10.4	17.7	16.0	13.4	13.4	81.6

Curium-244 (kilograms)									
Supply		0.1	0.4	6	18	40	56	56	176.5
VOYAGER	1000W	-	-	-	13	-	13	-	26
APOLLO*	1500W	-	-	6*	6*	-	-	-	12
MARINER	250W	-	-	3.3*	-	3.3*	-	3.3*	9.9
Total		0.1	0.4	15.3	37	43.3	69	59.3	224.4

() Means capacity can be made available.
* More than one isotope being considered.

TABLE I (CONTINUED)

ISOTOPE FUEL REQUIREMENTS FOR SPACE
AS PRESENTED BY DID
(FY-1964 Through FY-1970)

Curium-242 (grams)		1964	1965	1966	1967	1968	1969	1970	Total
Supply		12	80	80	80	80	80	80	492
SURVEYOR		-	-	-	-	-	-	-	-
LANDER	25W	8	16	16	16	16	-	-	72
ORBITOR	25W	-	16	16	16	16	-	-	64
SNAP XIII	12W	4	-	-	-	-	-	-	4
APOLLO	1500W	-	40*	-	-	-	-	-	40
Total		24	152	112	112	112	80	80	672
Polonium-210 (grams)									
Supply		20	50	100	100	100	100	100	570
APOLLO	1500W	-	50*	(400)*	(400)*	(400)*	-	-	1250
Total		20	100	(500)	(500)	(500)	100	100	(1820)
Cerium-144 (megacuries)									
Supply		3.5	3.5	3.5	100	100	100	100	410.5
NIMBUS C	210W	-	3.0	3.0	3.0	3.0	3.0	3.0	18.0
OAO	400W	-	-	(3.0)	3.0	3.0	-	-	(9.0)
MIDAS	300W	-	(2)	(20)	40	40	40	40	(182)
POODLE		-	-	-	-	-	-	-	-
Total		3.5	(8.5)	(29.5)	146	146	143	143	(619.5)
Promethium-147 (megacuries)									
Supply		0.02	0.5	0.5	30	30	30	30	121.02

() Means capacity can be made available.
* More than one isotope being considered.

TABLE II

RADIOISOTOPE PRODUCTION CAPABILITY FOR ISOTOPIC POWER APPLICATIONS

Isotope	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Sr^{90} (Mc)	3	5	5	5	10	10	10	10	10	10
Cs^{137} (Mc)	1	3.5	3.5	3.5	10	10	10	10	10	10
Ce^{144} (Mc)	3.5	3.5	3.5	3.5	100	100	100	100	100	100
Pm^{147} (Mc)	0.02	0.5	0.5	0.5	30	30	30	30	30	30
Pu^{238} (Kg)	3	6	13	18	24	32	36	42	47	51
Cm^{244} (Kg)	-	0.05	0.1	6	18	40	56	56	58	58
Cm^{242} (Gm)	-	12	80	1000	1000	1000	1000	1000	1000	1000
Po^{210} (Gm)	20	50	100	100	1000	1000	1000	1000	1000	1000

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TABLE III

PROPERTIES OF RADIOISOTOPES FOR ISOTOPIC POWER APPLICATION

Isotope	Type of Decay	Half-life	Chemical Form	Specific Thermal Power Watts/kc	Watts/gm	Watts/cc	Material Requirement for Mission: Mission Life (yrs)	Curies/Electrical Watt
Sr^{90}	Beta	28 yrs	Titanate	6.5	0.2	0.7	10	4,000
Cs^{137}	Beta Gamma	27 yrs	Glass	4.8	0.072	0.22	10	5,500
Ce^{144}	Beta Gamma	285 days	Oxide	7.9	2.3	13.8	1	7,000
Pm^{147}	Beta	2.6 yrs	Oxide	0.37	0.18	1.0	2.6	108,000
Pu^{238}	Alpha	89.6 yrs	Metal	34.5	0.48	9.3	10	625
Cm^{244}	Alpha	18.4 yrs	Oxide	35.0	2.3	22.4	10	840
Cm^{242}	Alpha	163 days	Oxide	36.2	120	1170	0.5	1,190
Po^{210}	Alpha	138 days	Metal	31.7	140	1320	0.5	1,550

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TABLE IV

THERMAL POWER AVAILABILITY FROM RADIOISOTOPES
(Kilowatts/Year at Fuel Fabrication Time)

Isotope	Fiscal Years 1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Sr^{90}	19	32	32	32	63	63	63	63	63	63
Cs^{137}	5	17	17	17	48	48	48	48	48	48
Ce^{144}	25	25	25	25	700	700	700	700	700	700
Pm^{147}	0.01	0.2	0.2	0.2	14	14	14	14	14	14
Pu^{238}	1.5	3.0	6.0	8.5	11.5	15	17	20	23	25
Cm^{244}	-	0.1	0.2	14	41	92	129	129	134	134
Cm^{242}	-	1.5	9.5	120	120	120	120	120	120	120
Po^{210}	3.0	7.0	14	14	140	140	140	140	140	140

TABLE V

ELECTRICAL POWER AVAILABILITY FROM RADIOISOTOPES
(Kilowatts/Year Based on Indicated Mission Time and Per Cent Conversion Efficiency)

Isotope	Mission Time(yr)	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Sr^{90}	10	0.75	1.2	1.2	1.2	2.5	2.5	2.5	2.5	2.5	2.5
Cs^{137}	10	0.2	6.3	6.3	6.3	1.8	1.8	1.8	1.8	1.8	1.8
Ce^{144}	1	0.5	0.5	0.5	0.5	14	14	14	14	14	14
Pm^{147}	2.6	-	0.005	0.005	0.005	0.27	0.27	0.27	0.27	0.27	0.27
Pu^{238}	10	0.07	0.13	0.29	0.4	0.53	0.7	0.79	0.92	1.03	1.12
Cm^{244}	10	-	-	-	0.47	1.4	3.1	4.4	4.4	4.5	4.5
Cm^{242}	0.5	-	0.03	0.22	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Po^{210}	0.5	0.05	0.14	0.28	0.28	2.8	2.8	2.8	2.8	2.8	2.8

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TABLE VI

ISOTOPIC POWER COSTS*

Isotope	Material Cost ($) Present	Material Cost ($) Projected	Yearly Production Rate	Thermal Power ($/watt)	Electric Power Mission Time (years)	Electric Power $/watt	Electric Power $/watt-hour
Sr^{90}	1.00	0.50/curie	10 Mc	77	10	2,000	0.023
Cs^{137}	0.75	0.50/curie	10 Mc	104	10	2,750	0.031
Ce^{144}	0.50	0.04/curie	100 Mc	5	1	280	0.032
Pm^{147}	1.00	0.18/curie	10 Mc	485	2.6	19,500	0.86
Pu^{238}	1000	500/gram	50 Kg	1,040	10	22,500	0.26
Cm^{244}	-	1000/gram	50 Kg	435	10	12,700	0.15
Cm^{242}	-	19,800/gram	80 g	165	0.5	7,160	1.64
Po^{210}	88,000	26,500/gram	100 g	190	0.5	9,300	2.12

* These are estimated costs based on the indicated production rates and studies are in progress to provide improved cost data.

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TABLE VII

PRIVATE POWER REACTOR PRODUCTION
CAPACITY FOR ISOTOPIC FUELS

Isotopic Fuel	Unit	Potential Capacity* 1965 Unit/yr	1965 Kwt/yr	1970 Unit/yr	1970 Kwt/yr	1980 Unit/yr	1980 Kwt/yr
Fission Products							
Sr^{90}	Mc	4.4	2.7	15	94	100	630
Cs^{137}	Mc	3.8	1.7	13	62	86	410
Ce^{144}	Mc	26.0	182	90	630	600	4200
Pm^{147}	Mc	11	4	40	14	270	100
Neutron Transmutation Products							
Pu^{238}	Kg	3	1.4	12.4	5.8	100	48
Cm^{244}	Kg	-	-	-	-	-	-
Cm^{242}	Gm	-	-	-	-	-	-
Po^{210}	Gm	-	-	-	-	-	-

* Based on thermal megawatt operation rates of private nuclear power reactors as predicted in the AEC report Civilian Nuclear Power - A Report to the President - 1962 as

3,500 Mwt in 1965
12,000 Mwt in 1970
80,000 Mwt in 1980