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SC-ARPIC-1011
May 1969

SELECTED THERMOELECTRIC, THERMIONIC,
AND ELECTRON-VOLTAIC ENERGY CONVERSION
DEVICE CHARACTERISTICS

H. J. Gerwin, 9522

AEROSPACE RADIOISOTOPE POWER INFORMATION CENTER

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Printed in the United States of America
Available from
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Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

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SELECTED THERMOELECTRIC, THERMIONIC, AND ELECTRON-VOLTAIC ENERGY CONVERSION DEVICE CHARACTERISTICS

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AEROSPACE RADIOISOTOPE POWER INFORMATION CENTER

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ABSTRACT

This document presents information on thermoelectric, thermionic, and electron-voltaic energy conversion devices that are commercially available or are in the prototype stage of development. Included are certain devices for use in space, terrestrial, and marine environments. The information given includes technical data, applications of devices, and general cost information.

May 1969

The cutoff date for information
in this report is April 1969.

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SELECTED THERMOELECTRIC, THERMIONIC, AND ELECTRON-VOLTAIC ENERGY CONVERSION DEVICE CHARACTERISTICS

Introduction

In the past, when information was required on the status of developments of various long-lived, unattended power supplies for use either in-house or in conjunction with other organizations, a new survey had to be conducted to find the information desired. Each such new effort required an excessive amount of time. As a result, this compilation of pertinent information was developed to provide a concise, ready reference. It is not intended to be absolutely complete in all respects; however, information will be added as availability and time permit.

Types of Energy Conversion Devices Included

This document presents information on U.S. and some foreign thermoelectric, thermionic, and electron-voltaic energy conversion devices that are commercially available or are in the prototype stage of development. Most of the devices listed are for terrestrial or underwater applications, since these areas have employed a significant number of such power supplies. However, many of the basic principles and design techniques are generally applicable for use in space power systems. Therefore, organizations working in space power development are usually interested in developments in nonspace areas as well as in developments in devices for space applications. Because of particular reliability and safety goals, it is recognized that the converter requirements and overall design specifications for space applications of these power devices are generally more stringent than in other applications. This usually necessitates a different class of converters and different design and manufacturing principles.

The data presented are from sources considered to be reliable, although no guarantee is stated regarding their validity. Information contained herein is subject to change without notice, whether or not updated editions of this document are issued on a timely basis, or at all. In particular prices, which are shown only to indicate apparent comparative values, may change. Prices shown are the best available information for single units. Some price advantage may be available for quantity orders, and some units may be subject to price negotiation.

For convenience in locating specific units, the devices are listed in ascending order of the electrical power output rating, beginning with microwatt units.

Changes in Format and Content

As new updated and expanded information becomes available, additional pages or new editions are expected to be issued to keep the document current. Knowledgeable persons or organizations desiring to submit information are urged to do so.

The author and coordinator for information contained in this report is Howard J. Gerwin. Comments and suggested additions or changes to content or format, to make future editions of this document more helpful, are welcome and will be considered carefully. Communications should be addressed directly to the author:

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NAME:	BETACEL	BETACEL	ISOMITE
SUPPLIER:	McDonnell Douglas	McDonnell Douglas	McDonnell Douglas
ELECTRICAL:			
Power Output (watts)	0.00001	0.0001	0.0001
Voltage (volts)	0.3 to 2	0.3 to 5	0.2
Power Conditioning Included	No	No	No
MECHANICAL:			
Size (inches)	0.47D x 0.11H	0.7D x 0.16H	0.5D x 0.5H
Weight (pounds)	0.01	0.04	0.06
GENERATOR:			
Material	Silicon	Silicon	Ta-O-Cs
T _h (°C)	-	-	420
T _c (°C)	-	-	-
Efficiency (%)	0.8	0.8	0.01
FUEL:			
Type	¹⁴⁷ Pm ₂ O ₃	¹⁴⁷ Pm ₂ O ₃	²³⁸ PuO ₂
Consumption Rate (lb/hr)	-	-	-
Shielding Material	Ta	Ta	Ta
DESIGN LIFE (Years):	1	1	10
APPLICATION	Miniature power sources	Miniature power sources	Miniature power sources
UNIT COST (Thousands):	-	-	-
INFORMATION SOURCE*	1	1	1

*See notes at back of report for explanation of numbers.

NAME:	PACEMAKER	BETACEL	SNAP ⁴ 15A
SUPPLIER:	NUMEC ²	McDonnell Douglas	Gulf General Atomic
ELECTRICAL:			
Power Output (watts)	0.00016	0.001	0.001
Voltage (volts)	3.1	0.3 to 28	4.5
Power Conditioning Included	Yes	No	No
MECHANICAL:			
Size (inches)	2.4 x 2.0 x 1.1	0.34D x 1H	2.5D x 5.5H
Weight (pounds)	0.22	0.125	0.85
GENERATOR:			
Material	Cupron Special- Tophel Special	Silicon	Cupron Special- Tophel Special
T _h (°C)	200	-	204
T _c (°C)	43	-	Ambient
Efficiency (%)	0.086	0.8	0.09
FUEL:			
Type	²³⁸ Pu	¹⁴⁷ Pm ₂ O ₃	²³⁸ Pu
Consumption Rate (lb/hr)	-	-	-
Shielding Material	Ta	Ta	-
DESIGN LIFE (Years):	11	1	5
APPLICATION:	Cardiac pacemaker	Miniature power sources	Terrestrial
UNIT COST (Thousands):	-	-	5
INFORMATION SOURCE:	3	1	5

NAME:	ISOMITE	ISOMITE A-4	MILLITRACS-100A
SUPPLIER:	McDonnell Douglas	McDonnell Douglas	NUMEC ²
ELECTRICAL:			
Power Output (watts)	0.01	0.019	0.1
Voltage (volts)	0.28	0.14	7
Power Conditioning Included	No	No	No
MECHANICAL:			
Size (inches)	0.6D x 0.6H	0.9D x 1.1H	7.0D x 14L
Weight (pounds)	0.1	0.20	258
GENERATOR:			
Material	Ta-O-Cs	Ta-O-Cs	Cupron Special- Tophel Special
T _h (°C)	600	600	450
T _c (°C)	-	-	50
Efficiency (%)	0.56	0.55	0.66
FUEL:			
Type	²³⁸ PuO ₂	¹⁴⁷ Pm	SrTiO ₃
Consumption Rate (lb/hr)	-	-	-
Shielding Material	Ta	-	U
DESIGN LIFE (Years):	10	1 to 3	5
APPLICATION:	Miniature power sources	Miniature power sources	Terrestrial
UNIT COST (Thousands):	-	-	5 to 10
INFORMATION SOURCE:	1	1	7, 8

NAME:	MILLITRACS ⁶ -100B	STEP ⁹ I 69-010-1	STEP ⁹ I 38-050-1
SUPPLIER:	NUMEC ²	Sanders	Sanders
ELECTRICAL:			
Power Output (watts)	0.1	0.1	0.5
Voltage (volts)	Variable	0.8	-
Power Conditioning Included	Yes	No	No
MECHANICAL:			
Size (inches)	7.0D x 14L	6.25D x 7.25H	6.7D x 7.5H
Weight (pounds)	258	96	150
GENERATOR:			
Material	Cupron Special- Tophel Special	Bi ₂ Te ₃	Bi ₂ Te ₃
T _h (°C)	450	-	-
T _c (°C)	50	-	-
Efficiency (%)	2	2.7	
FUEL:			
Type	SrTiO ₃	170Tm	SrTiO ₃
Consumption Rate (lb/hr)	-	-	-
Shielding Material	U	U	U
DESIGN LIFE (Years);	5	0.6	5
APPLICATION:	Oceanographic	Terrestrial and undersea	Terrestrial and undersea
UNIT COST (Thousands):	5 to 10	10 to 20 ¹⁰	10 to 20 ¹⁰
INFORMATION SOURCE:	8	11	11

NAME:	STEP ⁹ I 69-100-0	ISOMITE	URIPS ¹² -P1
SUPPLIER:	Sanders	McDonnell Douglas	Aerojet ¹³
ELECTRICAL:			
Power Output (watts)	1	1	1
Voltage (volts)	-	0.34	3 to 28
Power Conditioning Included	No	No	Yes
MECHANICAL:			
Size (inches)	9.0D x 7.5H	1.1D x 1.1H	13.7D x 19.7H
Weight (pounds)	250	0.6	800
GENERATOR:			
Material	Bi ₂ Te ₃	Ta-O-Cs	Bi ₂ Te ₃
T _h (°C)	-	740	220
T _c (°C)	-	-	25
Efficiency (%)	-	5.3	2.5
FUEL:			
Type	170Tm	²³⁸ PuO ₂	SrTiO ₃
Consumption Rate (lb/hr)	-	-	-
Shielding Material	U	Ta	Pb
DESIGN LIFE (Years):	0.6	10	5 at 0.98* 10 at 0.95*
APPLICATION:	Terrestrial and undersea	Modular power sources	Undersea
UNIT COST (Thousands):	10 to 20 ¹⁰	-	12
INFORMATION SOURCE:	11	1	11

*Reliability.

NAME:	URIPS ¹² -U1	TRACS ⁶ -2A	Sentinel ¹⁴ -3 (MW-3000)
SUPPLIER:	Aerojet	NUMEC ²	Isotopes ¹⁵
ELECTRICAL:			
Power Output (watts)	1	2	3
Voltage (volts)	3 to 28	17 and 24	4
Power Conditioning Included	Yes	Yes	-
MECHANICAL:			
Size (inches)	9.7D x 15.2H	24D x 14.9L	24D x 26L
Weight (pounds)	490	220	3000
GENERATOR:			
Material	Bi ₂ Te ₃	PbTe	-
T _h (°C)	220	450	525
T _c (°C)	25	96	80
Efficiency (%)	2.5	2.4	-
FUEL:			
Type	SrTiO ₃	SrO	⁹⁰ Sr
Consumption Rate (lb/hr)	-	-	-
Shielding Material	U	W	-
DESIGN LIFE (Years):	5 at 0.98* 10 at 0.95*	5	5
APPLICATION:	Undersea	Terrestrial	Terrestrial and undersea
UNIT COST (Thousands):	15	30	21 ¹⁶
INFORMATION SOURCE:	11	7	11

*Reliability.

NAME:	ITG 109*	STEP ⁹ I 38-500-1
SUPPLIER:	G. V. Planer, Ltd. (UK)	Sanders
ELECTRICAL:		
Power Output (watts)	4 to 5	5
Voltage (volts)	4	-
Power Conditioning Included	-	No
MECHANICAL:		
Size (inches)	14D x 36.5H	7.43D x 8.02H
Weight (pounds)	1100	240
GENERATOR:		
Material	Bi ₂ Te ₃	Bi ₂ Te ₃
T _h (°C)	-	-
T _c (°C)	-	-
Efficiency (%)	-	-
FUEL:		
Type	⁹⁰ Sr	SrTiO ₃
Consumption Rate (lb/hr)	-	-
Shielding Material	-	U
DESIGN LIFE (Years):	5	5
APPLICATION:	-	Terrestrial and undersea
UNIT COST (Thousands):	31	10 to 20 ¹⁰
INFORMATION SOURCE:	17	11

*Evolved from Radio Isotope Powered Prolonged Life Equipment (RIPPLE) project.

NAME:	TELAN-T1P	SNAP ⁴ 21B	STEP ⁹ II
SUPPLIER:	GI ¹⁸	3M	Sanders
ELECTRICAL:			
Power Output (watts)	9	10	10
Voltage (volts)	0.90	24	3
Power Conditioning Included	No	Yes	No
MECHANICAL:			
Size (inches)	17H x 11W x 18L	16D x 25H	6.75D x 6.25H
Weight (pounds)	28	640	4.86
GENERATOR:			
Material	Bi ₂ Te ₃	PbTe/Bi ₂ Te ₃	SiGe
T _h (°C)	300	-	-
T _c (°C)	50	-	-
Efficiency (%)	2.3	7.5*	4.1
FUEL:			
Type	Gas	SrTiO ₃	²³⁸ PuO ₂
Consumption Rate (lb/hr)	0.07	-	-
Shielding Material	-	U	-
DESIGN LIFE (Years):	1 to 5	5	5
APPLICATION:	Terrestrial	Undersea	Space ²⁰
UNIT COST (Thousands):	0.5	-	-
INFORMATION SOURCE:	11	19	11

*Before power conditioning.

NAME:	510	TELAN-T2P	SNAP ⁴ 21
SUPPLIER:	3M	GI ¹⁸	3M
ELECTRICAL:			
Power Output (watts)	14 to 18 ²¹	18	20
Voltage (volts)	12 and 24	1.8	24
Power Conditioning Included	Yes	No	Yes
MECHANICAL:			
Size (inches)	14 x 21 x 18	17H x 23W x 13L	18D x 32L
Weight (pounds)	35	42	900
GENERATOR:			
Material	PbTe	Bi ₂ Te ₃	PbTe/Bi ₂ Te ₃
T _h (°C)	-	300	-
T _c (°C)	-	50	-
Efficiency (%)	-	2.3	7.5*
FUEL:			
Type	Propane, natural gas	Gas	SrTiO ₃
Consumption Rate (lb/hr)	0.1	0.13	-
Shielding Material	-	-	U
DESIGN LIFE (Years):	1 to 3	1 to 5	5
APPLICATION:	Terrestrial	Terrestrial	Undersea
UNIT COST (Thousands):	0.9 ¹⁹	0.8	-
INFORMATION SOURCE:	11	11	19

*Before power conditioning.

NAME:	STEP ⁹ III	TRACS ⁶ -25A TRACS-25B*	Sentinel ¹⁴ -25 Models A,B,C,D
SUPPLIER:	Sanders	NUMEC ²	Isoopes ¹⁵
ELECTRICAL:			
Power Output (watts)	25	25	25
Voltage (volts)	3	24	As desired
Power Conditioning Included	No	Yes	Yes
MECHANICAL:			
Size (inches)	13.2D x 18.5H	24D x 40L	25.6D x 35.1H
Weight (pounds)	<1000	1400	1700 or 3300
GENERATOR:			
Material	Segmented	PbTe	-
T _h (°C)	-	485	524
T _c (°C)	-	88	80
Efficiency (%)	8	3.1	>5
FUEL:			
Type	SrTiO ₃	SrTiO ₃	⁹⁰ Sr
Consumption Rate (lb/hr)	-	-	-
Shielding Material	U	W	-
DESIGN LIFE (Years):	5	5	8
APPLICATION:	Terrestrial and undersea	Terrestrial *Oceanographic	Terrestrial
UNIT COST (Thousands):	-	85	66.0 to 77.4 ¹⁶
INFORMATION SOURCE:	11	7, 8	11

NAME:	515	TELAN-T3P	SNAP ⁴ 19
SUPPLIER:	3M	GI ¹⁸	Isotopes ¹⁵
ELECTRICAL:			
Power Output (watts)	26 to 32 ²¹	27	30
Voltage (volts)	12 and 24	2.7	2.7
Power Conditioning Included	Yes	No	No
MECHANICAL:			
Size (inches)	14 x 21 x 18 (+13)	17H x 23W x 21L	21.3D x 11H
Weight (pounds)	60	58	30.5
GENERATOR:			
Material	PbTe	Bi ₂ Te ₃	PbTe
T _h (°C)	-	300	493
T _c (°C)	-	50	204
Efficiency (%)	-	2.3	5
FUEL:			
Type	Propane, natural gas	Gas	²³⁸ PuO ₂
Consumption Rate (lb/hr)	0.18	0.20	..
Shielding Material	-	-	-
DESIGN LIFE (Years):	1 to 3	1 to 5	1
APPLICATION:	Terrestrial	Terrestrial	Space
UNIT COST (Thousands):	1.1 ¹⁹	1.0	-
INFORMATION SOURCE:	11	11	22

NAME:	TELAN-T4P	TELAN-T5P	520
SUPPLIER:	GI ¹⁸	GI ¹⁸	3M
ELECTRICAL:			
Power Output (watts)	36	45	46 to 60 ²¹
Voltage (volts)	3.6	4.5	6, 12 and 24
Power Conditioning Included	No	No	Yes
MECHANICAL:			
Size (inches)	17H x 23W x 21L	17H x 23W x 29L	14 x 21 x 18 (+20)
Weight (pounds)	73	87	130
GENERATOR:			
Material	Bi ₂ Te ₃	Bi ₂ Te ₃	PbTe
T _h (°C)	300	300	-
T _c (°C)	50	50	-
Efficiency (%)	2.3	2.3	-
FUEL:			
Type	Gas	Gas	Propane, natural gas
Consumption Rate (lb/hr)	0.27	0.33	0.3
Shielding Material	-	-	-
DESIGN LIFE (Years):	1 to 5	1 to 5	1 to 3
APPLICATION:	Terrestrial	Terrestrial	Terrestrial
UNIT COST (Thousands):	1.3	1.5	1.7 ¹⁹
INFORMATION SOURCE:	11	11	11

NAME:	Sentinel ¹⁴ 50 Models A,B,C	TRACS ⁶ -50A TRACS-50B*	TELAN-T6P
SUPPLIER:	Isotopes ¹⁵	NUMEC ²	GI ¹⁸
ELECTRICAL:			
Power Output (watts)	50	50	54
Voltage (volts)	As desired	24	5.4
Power Conditioning Included	Yes	Yes	No
MECHANICAL:			
Size (inches)	49L x 26D	32D x 28L	17H x 23W x 29L
Weight (pounds)	2800 to 5300	1400	100
GENERATOR:			
Material	-	PbTe	Bi ₂ Te ₃
T _h (°C)	-	485	300
T _c (°C)	-	85	50
Efficiency (%)	>5	3.5	2.3
FUEL:			
Type	⁹⁰ Sr	SrTiO ₃	Gas
Consumption Rate (lb/hr)	-	-	0.40
Shielding Material	W	W	-
DESIGN LIFE (Years):	5	5	1 to 5
APPLICATION:	Prototype on Test	Terrestrial *Oceanographic	Terrestrial
UNIT COST (Thousands):	120	130	1.7
INFORMATION SOURCE:	11	8	11

NAME:	SNAP ⁴ 23A	3M40	TELAN-T7P
SUPPLIER:	3M/Westinghouse	3M	GI ¹⁸
ELECTRICAL:			
Power Output (watts)	60	60	63
Voltage (volts)	24	28	6.3
Power Conditioning Included	Yes	Yes	No
MECHANICAL:			
Size (inches)	24D x 27H	12.2 x 5.5 x 9.1	17H x 23W x 37L
Weight (pounds)	1056	8	114
GENERATOR:			
Material	PbTe	PbTe	Bi ₂ Te ₃
T _h (°C)	1085	-	300
T _c (°C)	191	-	50
Efficiency (%)	6.98	-	2.3
FUEL:			
Type	SrTiO ₃	Liquid ²⁴	Gas
Consumption Rate (lb/hr)	-	-	0.47
Shielding Material	U	-	-
DESIGN LIFE (Years):	10	3000 hrs	1 to 5
APPLICATION:	Terrestrial	Army field use	Terrestrial
UNIT COST (Thousands)	-	5 ¹⁹	2.0
INFORMATION SOURCE:	23	19	11

NAME:	SNAP ⁴ 27	TELAN-T8P	TELAN-T9P
SUPPLIER:	GE	GI ¹⁸	GI ¹⁸
ELECTRICAL:			
Power Output (watts)	65	72	81
Voltage (volts)	-	7.2	8.1
Power Conditioning Included	No	No	No
MECHANICAL:			
Size (inches)	15.8D x 18.1H	17H x 23W x 37L	17H x 23W x 45L
Weight (pounds)	42.7*	130	144
GENERATOR:			
Material	PbTe	Bi ₂ Te ₃	Bi ₂ Te ₃
T _h (°C)	1100	300	300
T _c (°C)	525	50	50
Efficiency (%)	4.7	2.3	2.3
FUEL:			
Type	²³⁸ PuO ₂	Gas	Gas
Consumption Rate (lb/hr)	-	0.53	0.60
Shielding Material	-	-	-
DESIGN LIFE (Years):	1	1 to 5	1 to 5
APPLICATION:	Lunar surface	Terrestrial	Terrestrial
UNIT COST (Thousands):	-	2.2	2.4
INFORMATION SOURCE:	25	11	11

*Without 25-pound shipping cask for heat source safety.

NAME:	535	-	-
SUPPLIER:	3M	RCA	Aerojet ¹³
ELECTRICAL:			
Power Output (watts)	92 to 120 ²¹	100	100 to 300
Voltage (volts)	6, 12, and 24	12	24
Power Conditioning Included	Yes	Yes	Yes
MECHANICAL:			
Size (inches)	32 x 25 x 23 (+13)	12 x 13 x 18	30D x 30H
Weight (pounds)	300	30	1200 to 1600
GENERATOR:			
Material	PbTe	SiGe	SiGe, or SiGe/Bi ₂ Te ₃ , or PbTe/Bi ₂ Te ₃
T _h (°C)	-	892	1000
T _c (°C)	-	182	30
Efficiency (%)	-	2.75	4.4 to 5.7
FUEL:			
Type	Propane, natural gas	Gasoline	⁶⁰ Co
Consumption Rate (lb/hr)	0.6	0.67	-
Shielding Material	-	-	W
DESIGN LIFE (Years):	1 to 3	1000 hrs	5
APPLICATION:	Terrestrial	Terrestrial	Terrestrial or sea
UNIT COST (Thousands):	3.46 ¹⁹	-	-
INFORMATION SOURCE:	11	26	27

NAME:	-	Cylindrical	TUBULAR MODULE
SUPPLIER:	Aerojet	3M	Westinghouse
ELECTRICAL:			
Power Output (watts)	100 to 300	225	273
Voltage (volts)	24	14.5	14.3
Power Conditioning Included	Yes	No	No
MECHANICAL:			
Size (inches)	30D x 30H	3D x 18L	1.48D x 18L
Weight (pounds)	600 to 1000	15	7.8
GENERATOR:			
Material	SiGe, or SiGe/Bi ₂ Te ₃ , or PbTe/Bi ₂ Te ₃	PbTe	PbTe
T _h (°C)	1000	532	607
T _c (°C)	30	221	299
Efficiency (%)	4.4 to 5.7	5.9	4.8
FUEL:			
Type	⁹⁰ Sr	Reactor loop	Reactor loop
Consumption Rate (lb/hr)	-	-	-
Shielding Material	W	-	-
DESIGN LIFE: (Years):	10	10	5
APPLICATION:	Terrestrial or sea	Terrestrial	Space
UNIT COST (Thousands):	-	-	-
INFORMATION SOURCE:	27	19	28

NAME:	3M26	3M28	3M48
SUPPLIER:	3M	3M	3M
ELECTRICAL			
Power Output (watts)	300	560	1000
Voltage (volts)	28	28	28
Power Conditioning Included	Yes	Yes	Yes
MECHANICAL:			
Size (inches)	13D x 21H	14.6D x 23H	17.8D x 23H
Weight (pounds)	25	35	55
GENERATOR:			
Material	PbTe	PbTe	PbTe
T _h (°C)	-	-	-
T _c (°C)	-	-	-
Efficiency (%)	3.7	3.7	3.7
FUEL:			
Type	Liquid ²⁴	Liquid ²⁴	Liquid ²⁴
Consumption Rate (lb/hr)	1.5	2.8	5
Shielding Material	-	-	-
DESIGN LIFE (Years):	3000 hrs	3000 hrs	3000 hrs
APPLICATION:	Army field use	Army field use	Army field use
UNIT COST (Thousands):	8	10	12
INFORMATION SOURCE:	19	19	19

NOTES

1. Letter from G. D. Morse, McDonnell Douglas Astronautics Company, Richland, Washington, dated February 6, 1969.
2. NUMEC stands for Nuclear Materials and Equipment Corporation.
3. T. F. Hursen, "Radioisotope Powered Cardiac Pacemaker - An Implantable Thermoelectric System," Intersociety Energy Conversion Engineering Conference, Boulder, Colorado (1968).
4. SNAP stands for Systems for Nuclear Auxilliary Power, an AEC designation.
5. Private communication from J. T. Ream, Gulf General Atomics Incorporated, San Diego, California, dated February 13, 1969.
6. TRACS stands for Thermoelectric Radioisotope Conversion System.
7. J. F. Williams, "TRACS Underground and Undersea RTG Review," IECEC, Boulder, Colorado (1968).
8. Letter from G. Hagey, NUMEC, Apollo, Pennsylvania, dated February 3, 1969.
9. STEP stands for Sanders Thermoelectric Power Supply.
10. Private communication from K. Mayo, Sanders Nuclear Corporation, Nashua, New Hampshire, dated December 4, 1968.
11. Company specification sheet.
12. URIPS stands for Undersea Radioisotope Power Supply.
13. Aerojet stands for Aerojet-General Corporation, Nuclear Division, San Ramon, California.
14. Sentinel was formerly called LCG.
15. Isotopes Nuclear Systems Division of Teledyne Company was formerly Martin-Marietta Corporation, Nuclear Division.
16. Letter from N. F. Campbell, Isotopes Nuclear Systems Division, Middle River, Maryland, dated December 9, 1968.
17. J. E. Rice, "Practical Aspects and Potentialities of Isotopic Generators," Newsletter of the Isotopic Generator Information Centre, No. 6 (May 1968).
18. GI stands for General Instrument Corporation, Thermoelectric Division, Newark, New Jersey.
19. Private communication from R. L. Sisler, Minnesota Mining and Manufacturing Company, Space and Defense Products Department, Roseville, Minnesota, dated February 10, 1969.
20. Adaptable to terrestrial and undersea.

21. Power shown at -32°C (-25°F) and at $+52^{\circ}\text{C}$ ($+125^{\circ}\text{F}$) extremes.
22. SNAP 19 Final Report.
23. S. Cerni, SNAP 23A Quarterly Progress Report, dated June 9, 1967.
24. Liquid includes kerosene, JP-4, JP-5, CITE, leaded or combat gasoline and diesel fuel.
25. SNAP 27 Report.
26. O. H. Schade, Jr., and H. P. Van Heyst, "100 Watt Thermoelectric Generator," Final Report, dated July 31, 1965.
27. Letter from R. L. Newacheck, Aerojet-General Corporation, Nuclear Division, San Ramon, California, dated January 27, 1969.
28. SNAP Reactor Programs Progress Report, August-October 1968, AI-AEC 12750.

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