Various types of materials were used in preparing this history. At the outset, an extensive computer search of the Department of Energy (DOE) library, including the data base at the Oak Ridge Laboratory, revealed that the type of technical reports there would not be helpful in developing this history. Primarily, three other sources of information were relied upon: materials from DOE Archives, which were identified and assembled by Roger Anders of DOE’s History Division; the data bases of the Library of Congress, which led to a review of newspapers, periodicals, technical journals, and books; and interviews.

Three classes of information were used: technical events and developments, institutional developments, and related events in the milieu. The five categories of materials used are discussed below.

Printed reports and government documents were used to identify particular facts about the RTGs and the program. Some of the materials provided relevant facts covering broad time periods; other sources pinpointed narrow time periods and revealed program status at a time, or presented important decisions or statements relevant to the program. A few of the materials focused on particular aspects of the program.

Books and pamphlets provided a breadth and depth of understanding. Several stand out for an understanding of the technology and the broad and changing issues of the time period covered: the historical documents about the AEC, ERDA, and the DOE, and the energy chronology produced by the history staff of DOE (Buck, Dean, and Holl) were invaluable in succinctly presenting relevant events in the institutional environment. The work on radioisotopic power generation by Corliss and Harvey was a valuable primer in the technology. For background on the times and glimpses of the views of top-level scientists and administrators, the cited books by Seaborg, Webb, Killian, Kistiakowsky, and Levine were profitable. The Newell book also proved helpful in tracing the history of NASA. Detailed information on specific space missions was found in several NASA documents on Apollo, Viking, and
Voyager; the books by Washburn added an emotional dimension. The books
by Rolph and Ford aided in understanding the changing milieu at the time the
AEC was disbanded.

*Articles* from newspapers, periodicals, and technical journals were used to
obtain insights into the changing technical, political, and social milieu during
the period covered by the history. The articles used in the text are presented in
chronological order since the chronology of changing foci and issues was most
significant to the history. All of the newspaper articles came from the DOE
archives: “Other Articles” cited were uncovered in a topical search for specific
facts.

*Unpublished materials* encompass a number of different types of items
uncovered during the research, ranging from documents prepared by program
participants, such as Mike Dix and Tom Kerr, to remarks of key functionaries on
particular occasions. It is possible that some of this may have been published at
a later date.

It should be noted that archives materials were extremely helpful throughout
the research and writing of this history. “Letters”, “memos”, and “news
releases” are not cited in the Bibliography although they are cited with full dates
in the chapter notes; such materials were invaluable in obtaining insight into
day-by-day issues discussed and acted upon by key administrators during
particular time periods. They were most numerous in the archives for the AEC
years but much less so for ERDA and DOE.

*Interviews* were emphasized throughout the research, to preserve an oral
history of the program on tape. All interviewees were cooperative, helpful, and
for the most part eager to share their recollections. Some are now retired but
made themselves available for interviews; others took time from busy work
schedules to be interviewed. The list of those interviewed represents coverage
of differing but important perspectives on and involvements in the program.


U.S. Congress. *Hearings Before Subcommittees of the Joint Committee on Atomic Energy (Development, Growth, and State of the Atomic Energy Industry).* Eighty-Seventh Congress, February 21, 23, 24, 27, 28; March 1, 2,


U.S. Congress. *Hearings Before the Joint Committee on Atomic Energy*


Books and Pamphlets


**Articles**


"Nuclear Flight Programs Cancelled As President Trims FY '65 Budget." Aviation Week & Space Technology, December 30, 1963, p. 22.


“Exuberance Sets Tone of First EVA.” Aviation Week & Space Technology, November 24, 1969, pp. 20ff.


“Pioneer’s Successes Buoy Saturn Hopes.” Aviation Week & Space Technology, December 9, 1974, p. 16.

“Layoffs at Cape Total 2,000.” Aviation Week & Space Technology, July 21, 1975, p. 18.


*Reference Books*


Unpublished Documents/Materials


Holifield, Chet. Remarks By Congressman Chet Holifield, Chairman JCAE, On The Occasion Of Presenting A SNAP 27 Generator To The Smithsonian Institute (sic), December 9, 1970.


Roberts, Dr. Richard W. Statement for The FY 1976 Appropriations Hearings U.S. Congress. No date.


**Interviews**

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FOOTNOTES

Frequently government press releases, Fact Sheets and other documents provide information without naming a person or a title as the source; when such documents are referenced in the text, names of persons and/or titles as sources must, of course, be omitted.

CHAPTER I


CHAPTER II


8. Curies' discoveries and the nuclear battery of Moseley taken from *ibid.*, pp. 604-605, and from Seaborg, op. cit., p. 87.


10. Descriptions taken from *ibid*, p. 8 and from Seaborg, op. cit., p. 87.


13. From Corliss and Harvey, op. cit., p. 3.


15. Chronology of world events and information on AEC expansion is from Buck, op. cit., pp. 1-2.


17. Study *(RAND Report, February 1949)* cited in *ibid*.


21. Letter from Assistant Secretary of Defense to Chairman Atomic Energy Commission, August 15, 1955. (From DOE archives.)


26. “Memorandum For the Chairman, Subject: Chairman’s Request For Information on Pied Piper Change of Name,” from Director Division of Reactor Development AEC, February 24, 1958. (From DOE archives.)


30. Description of SNAP-1 and SNAP-3 concepts and developments taken from SNAP... *Press Kit*, op. cit., (“Attachment 4, History...,” pp. 2-3). (From DOE archives.)


### CHAPTER III


2. *Ibid*.


5. *Ibid*.

7. Letter from Keith Glennan to John McCone, May 12, 1960. (From DOE archives.)

8. Ibid

9. Letter of transmittal (McCone to Glennan) for "Memorandum of Understanding," August 30, 1960. (From DOE archives.)


12. Summary of Attitudes Encountered in Brazil Toward Operational SNAP Devices (by J. G. Morse, Manager Auxiliary Power Systems Department, Nuclear Division, The Martin Company, June 5, 1961). (From DOE archives.)

13. Information about Dr. Lapp's call and the hurried preparation of a safety document obtained in a personal interview with George "Mike" Dix. Mr. Dix also indicated that a comprehensive safety report had already been prepared earlier for the SNAP-1.

14. Personal interview with Mike Dix.


17. Ibid.

19. "Aerospace Nuclear Safety," memorandum for Chairman McCone, September 30, 1960, prepared by Director Division of Reactor Development. (From DOE archives.)

20. Ibid.


23. Personal Interview with Glenn Seaborg.


25. Harold Finger (in a personal interview) stated that in Webb's mind NASA was not only a technical R&D center but a management R&D organization. Webb's own writings clearly bear out this approach and philosophy.


27. Ibid, p. XIII.

28. Personal interview with Dr. Seaborg.

29. Personal interview with James E. Webb.

30. Recollections and expressions of philosophy by James E. Webb obtained in personal interview. Quotation at end is from Levine ("Preface"), op. cit., p. XIII.

31. Personal interview with Glenn Seaborg.

33. Webb’s recollections and point of view are from a personal interview.

34. Personal interview with John Dassoulas.


36. Information from personal interviews with John Dassoulas and Paul Dick.

37. Quoted material on specific initiation of the program for SNAPs at DOD request is taken from a letter to the Vice President of the U.S. (Chairman of the National Aeronautics and Space Council) from John Graham (Acting Chairman of AEC) on May 10, 1961, urging approval by the Council of the use of SNAP-3 on TRANSIT. (From DOE archives.)

38. *Safety Analysis of the Transit Generator* (by D.G. Harvey and T.J. Dobry, The Martin Company), MND-P-2479, March 1961, p. VII. (From DOE archives.)

39. “Impact Test Results for the Transit Generator,” memorandum for Seaborg and the Commissioners from AEC General Manager, April 22, 1961. (From DOE archives.)

40. “Summary of Hazards Analysis of Transit Generator,” April 26, 1961, by Facilities Licensing, Division of Licensing and Regulation, AEC. (From DOE archives.)

41. “Joint Meeting Concerning Nuclear Safety Responsibilities for Transit,” memorandum to Director Division of Reactor Development from Chief SNAP Branch, May 4, 1961. (From DOE archives.)

42. Letter to Secretary McNamara from John Graham (Acting Chairman, AEC), May 8, 1961. (From DOE archives.)

43. Letter to the President from Glenn Seaborg, May 6, 1961. (From DOE archives.)

44. Letter to Chet Holifield (Chairman, JCAE) from Glenn Seaborg. (From DOE archives; date unclear.)


47. Memorandum, Seaborg to General Manager, June 8, 1961 (in DOE archives), accompanied by note: "This memo not sent. Commission instructed me to convey this message orally to General Manager."

48. Letter to Chairman Seaborg from his Special Assistant, Howard C. Brown, Jr., reporting conversation with Gilpatrick of DOD, June 23, 1961. (From DOE archives.)

49. Personal interviews with Robert Carpenter and John Dassoulas.

50. Account taken from personal interviews with Carpenter and Dassoulas.


52. "World's First 'Atomic Battery' In Space Continues To Operate Successfully," AEC press release, September 8, 1961. (From DOE archives.)


54. Letter from Seaborg to Vice President Lyndon Johnson, November 4, 1961. (From DOE archives.)

55. Letter from Lyndon Johnson to Glenn Seaborg, November 6, 1961. (From DOE archives.)

CHAPTER IV

1. Impressions of organizational atmosphere and relationships at AEC/ERDA from personal interview with Bob Carpenter.

2. Ibid.
3. Letter to John McCone (Chairman, AEC) from T. Keith Glennan (NASA Administrator), August 3, 1960. (From DOE archives.)

4. Information taken from "Opening Statement of Dr. Frank Pittman Before the JCAE Subcommittee on Research and Development and Radiation." (From DOE archives.)

5. Letter to AEC General Manager from Robert C. Seamans, Jr. (NASA Associate Administrator), August 8, 1962. (From DOE archives.)

6. Hearings Before the Subcommittee on Research, Development, & Radiation of the Joint Committee on Atomic Energy Congress of the United States, Eighty-seventh Congress Second Session, on Space Nuclear Power Application, September 13, 14, & 19, 1962 (quotations, pp. 10 and 12-13.)

7. Information on key international events in the period described taken from Seaborg (Kennedy ... and the Test Ban), op. cit.


10. Quoted materials in text of paragraph are from "Kennedy’s Offer Stirs Confusion, Dismay" (by Alfred P. Alibrando), Aviation Week & Space Technology, September 30, 1963, p. 26. Offset quotation is from "Kennedy’s Space Boomerang" (by Robert Hotz) in the same issue of Aviation Week (p. 21).


14. See *Newsweek* issues for September 2 and September 9 (the march on Washington and the test ban treaty), October 21 (poll of whites regarding the Negro revolt), November 5 (Vietnam showdown.)


17. See, for example, “The President’s Policy Statements on Outer Space,” draft from NASA circulated at AEC on June 19, 1962. (From DOE archives.)

18. Letter from NASA Associate Administrator to AEC General Manager, July 8, 1963 — referring to a previous forecast of November 1962. (From DOE archives.)

19. “Nuclear Space Projects — Briefing of the Senate Committee on Aeronautical and Space Sciences,” April 30, 1963. (From DOE archives.)

20. All facts in the preceding summary taken from *SNAP Fact Sheet* (Atomic Energy Commission), September 1, 1963. (From DOE archives.)

21. Information on the strontium-90 device contracts is from “AEC To Negotiate Contracts For Development of Space Nuclear Power Generator,” November 15, 1963, AEC press release. (From DOE archives.)

22. “Summary Notes of Briefing By Representatives of the Martin Company on the SNAP Program,” Tuesday, March 5, 1963 at D.C. office of AEC; published at AEC on March 29, 1963. (From DOE archives.)

24. "Use of SNAP-9A In Navigation Satellites: Report to the General Manager by the Director Division of Reactor Development," transmitted August 1, 1963 by Secretary AEC. (From DOE archives.)

25. "Supplement to AEC 1000/75—Approval To Use SNAP-9A On TRANSIT: Report to the General Manager by the Director of Reactor Development," August 26, 1963. (From DOE archives.)


29. Personal interview with Mike Dix.

30. Procedures for Securing Clearance (by Thomas B. Kerr), no date, National Aeronautics and Space Administration, pp. 1-2. Document provided to interviewer at time of personal interview with Mr. Kerr.

31. Ibid., p. 2.

32. "Safety Review of Aerospace Nuclear Projects," AEC memorandum to the Chairman and Commissioners from the General Manager, January 14, 1963. (From DOE archives.)

33. "Expert Review and Advice on Space Nuclear Safety Problems: Report to the Commission by the General Manager and the Director of Regulation," April 1, 1964. (From DOE archives.)

34. SNAP Fact Sheet, September 1, 1963. (From DOE archives.)
35. Personal interview with Mike Dix.

36. "AEC 1000/75—Approval To Use SNAP-9A On TRANSIT And AEC 1000/76—Supplement to AEC 1000/75," AEC memorandum to Director of Division of Reactor Development from Secretary AEC, September 3, 1963. (From DOE archives.)

37. "Memorandum for Chairman Seaborg, Subject: SNAP-9A," from General Manager, AEC, April 23, 1964. (From DOE archives.)

38. Press release (April 22, 1964) attached to letter from Seaborg to Dr. Welsh (Executive Secretary National Aeronautics and Space Council), April 23, 1964. (From DOE archives.)

39. "Foreign Reaction to SNAP-9A Failure to Orbit," AEC memorandum to Chairman and Commissioners from Director Division of Public Information, June 5, 1964. (From DOE archives.)

40. See, for example, letter to Senator Morse from Seaborg, October 29, 1964. (From DOE archives.)

41. Letter from Dr. Welsh to Glenn Seaborg, November 4, 1964, commending the requested presentation by Dr. Joseph Lieberman and Mr. Robert Carpenter (From DOE archives.)

42. Letter from Seaborg to Senator Pastore (Chairman JCAE) and accompanying press release, January 5, 1965. (From DOE archives.)

43. Personal interview with Bob Carpenter.

44. Personal interview with Mike Dix.

45. Personal interview with Tom Kerr.

46. Ibid.

47. See "Johnson Stress on Military Space Seen," "Johnson Familiar With Aerospace Facilities," and "Continued Space Effort," Aviation Week & Space Technology, December 2, 1963 (pp. 26ff and 28). President Johnson quoted from


50. "South Vietnamese Raiders Extending War" (by Larry Booda) and “Options in Vietnam,” *Aviation Week & Space Technology*, April 6, 1964 (pp. 16-19).


54. "Tentative Schedule—SNAP Program Study Seminars," memorandum for the Commissioners, January 31, 1963. (From DOE archives.)


57. Letter to Seaborg from Welsh (NASC), February 7, 1964. (From DOE archives.)

58. “Agreement Between The Atomic Energy Commission and the National Aeronautics and Space Administration on Space Nuclear Systems” (proposed agreement, attached to memorandum for Chairman and the Commissioners pre-
pared by AEC General Manager, January 22, 1965). (From DOE archives.)


CHAPTER V

1. A good account of this (and other) APOLLO missions appears in Edgar M. Cortright (editor), Apollo Expeditions to the Moon (Washington: National Aeronautics and Space Administration, 1975).


3. Information on changed fuel amounts taken from Nuclear Safety of Space Nuclear Power Systems (by George P. Dix), no date, U.S. Atomic Energy Commission. (Document supplied by Mr. Dix at time of personal interview.)


5. Ibid., pp. 252-253 (offset quotation, p. 253).


7. Description of Sandia taken from memorandum from Har-
old Finger to Assistant General Manager for Reactors, AEC, "Assignment of Space Isotope Power To An AEC Laboratory," October 18, 1965. This memorandum actually describes discussions with, and strengths and weaknesses of, three candidate AEC labs (Brookhaven, Oak Ridge, and Sandia) prior to the selection of Sandia. Information on Sandia, pp. 6-7. (From DOE archives.)

8. Information in this paragraph taken from personal interview with Harold Finger.


11. Ibid.

12. Memorandum, Finger to Director, Office of Congressional Relations, "Suggested Outline for Discussion of Space Nuclear Systems With the Vice President," March 9, 1966. (From DOE archives.)


15. Personal interview with Milton Klein.

16. Personal interview with Bernard Rock.

17. See memorandum for AEC General Manager from Harold B. Finger, March 1, 1966, "Subject: Memorandum of Understanding Between AEC and NASA Concerning The Use of Isotopic SNAP Devices For NASA Space Vehicles." (From DOE archives.)

18. "An Interagency Agreement Between the Atomic Energy Commission and the National Aeronautics and Space Administration Concerning SNAP Devices For NASA Space Vehicles," no date; however, effective date of agreement shown as September 1965. (From DOE archives.)
19. Personal interview with Mike Dix.

20. Ibid.

21. Information in paragraph obtained from personal interviews with Paul Dick and Guy Linkous of Teledyne.


23. See memorandum for Chairman Seaborg (and the Commissioners), "Subject: Use of SNAP-19 Generators on NASA Nimbus-B Spacecraft," by Director of Regulation, November 29, 1967. (From DOE archives.)

24. Memorandum to Milton Klein and Peter A. Morris (Director, Reactor Licensing) from Secretary AEC, "Subject: AEC 1000/120 — Use of SNAP-19 Generators on NASA Nimbus-B Spacecraft," January 16, 1968. (From DOE archives.)

25. Letters from Seaborg to Director DDR&E and to Administrator NASA, May 15, 1968. (From DOE archives.)


27. Personal interview with Harry Press.

28. Information taken from letter from General Manager AEC to Executive Director JCAE, May 20, 1968. (From DOE archives.)

29. Personal interview with Mike Dix.


32. Letter from Acting Administrator NASA to the Vice President, March 13, 1969. (From DOE archives.)

33. Letter from the Vice President to Acting Administrator NASA, March 21, 1969. (From DOE archives.)
34. Personal interview with Harry Press.
35. Information obtained from Mike Dix.
36. These identified elements of ALSEPs are taken from Cortright (editor), op. cit., pp. 240-241.
37. Memorandum for Chairman Seaborg and the Commissioners prepared by Director Division of Reactor Development and Technology, "Subject: Selection of Contractor For Isotopic Orbital Space Power Unit." January 14, 1965. (From DOE archives.)
38. "Report to the General Manager . . . : Approval of SNAP-27 Program And Authority To Execute Modification No. 2 To Contract . . . With The General Electric Company For The Conduct Of SNAP-27 Work," transmitted by Acting Secretary AEC, April 7, 1968. (From DOE archives.)
39. Personal interview with Augustine Pitrolo.
40. Ibid.
41. Ibid.
42. Ibid.
43. In a personal interview Webb stressed this point.
44. Interview with James Webb.
45. Notes of "Telephone Call from George Mueller" (NASA) from Cape Kennedy, 3:00 P.M., October 10, 1968. (From DOE archives.)
46. Letter from George E. Mueller to Glenn T. Seaborg, November 13, 1968. (From DOE archives.)
47. Ibid.
48. Information from personal interview with Augustine Pitrolo and from Cortright (editor), op. cit., p. 225. Astronauts quoted from Cortright.
49. Taken from "Exuberance Sets Tone of First EVA," Aviation Week & Space Technology, November 24, 1969, pp. 19-21, quotation, p. 20.
50. Personal interview with Augustine Pitrolo.

52. Personal interviews with Pitrolo and Dix.

53. Personal interviews with Carpenter, Dix, and Pitrolo.

54. "Response To Queries On SNAP-27 Reentry," by Director AEC Division of Public Information, April 28, 1970. (From DOE archives.)


CHAPTER VI


3. Budget figures from *ibid*.

4. "Report From The Director, Space Nuclear Systems Division To The General Manager (for information meeting item 'AEC/User Agency Funding For Space Nuclear Power Systems')," May 21, 1971, pp. 1-4. Offset quotation, p. 4. (From DOE archives.)

5. Personal interview with Milton Klein.


7. "Correspondence on Sandia Participation In Space Electric Power Program," October 23, 1970. (From DOE archives.)

9. AEC press release, January 5, 1973, “Enclosure 1” to letter from AEC General Manager to Honorable John O. Pastore, Chairman JCAE on the same date. (From DOE archives.)

10. Ibid.

11. Personal interview with John Dassoulas.

12. Description of this RTG taken from “Nuclear Safety Review Procedures For Navy Satellite Mission,” June 1, 1970. (From DOE archives.)

13. Personal interview with John Dassoulas.

14. Personal interviews with Augustine Pitrolo and Tom Kerr.


17. See Remarks [By Congressman Chet Holifield, Chairman JCAE] On The Occasion Of Presenting A SNAP-27 Generator To The Smithsonian Institute (sic), December 9, 1970. (From DOE archives.)


19. Personal interview with Charles Hall.

20. Ibid.

21. Ibid. (Hall was not sure, at first, of the AEC representative’s identity, but finally decided during the interview it was Bob Carpenter.)

22. Ibid.

23. Personal interviews with Charles Hall and Guy Linkous.

25. Personal interview with Charles Hall and Guy Linkous.

26. Information from “Use of Isotopic Nuclear Systems on the NASA PIONEER Spacecraft” (staff paper), December 30, 1971. (From DOE archives.)

27. Personal interviews with Charles Hall and Mike Dix. Hall told of the Bay Area newspaper coverage.


31. Personal interview with Charles Hall.


33. See references to these missions in letter from James Fletcher (NASA Administrator) to William Anders (Commissioner AEC), June 7, 1974, (From DOE archives.)

34. Personal interview with Paul Dick.

35. Letter, Fletcher to Anders, June 7, 1974, op. cit. (From DOE archives.)

36. Letter from Anders to Fletcher, June 28, 1974. (From DOE archives.)

CHAPTER VII


3. View expressed by Mike Dix in a personal interview.


5. *Organization and Functions Fact Sheet*, Department of Energy, Office of Public Affairs, October 1, 1977. (From DOE archives.)


10. Personal interview with Mike Dix.


12. Personal interview with Bernard Rock.


19. Mark Washburn especially has made the point that in spite of terrestrial events that seemed to dull public interest in the Nation’s space program, the Space Age had a dynamic of its own in sensitizing people and piercing their consciousness. See Washburn, op. cit., pp. 7-9.

20. Personal interview with Gerald Soffen.


22. Information from personal interview with Robert Brouns, RTG program representative at Langley for the Viking missions.


24. Interview with Jerry Soffen.


26. Interview with Jerry Soffen.


28. “Information Memorandum: Status of SNAP-19 Radioisotopic Thermoelectric Generators Aboard the NASA VIKING II Lander,” to ERDA Administrator from Director
Division of Nuclear Research and Applications, January 27, 1977. (From DOE archives.)

29. From *Fact Sheet: Lincoln Experimental Satellites LES-8 and 9*, Office of Information, Air Force Systems Command, no date, p. 1. (From DOE archives.)


31. Telephone interview with Philip Waldron.

32. *Information from ERDA: Multi-Hundred Watt Nuclear Generator — Power for LES Satellites 8 & 9*, July 1975, p. 1. (From DOE archives.)


34. "Questions and Answers on LES 8 and 9," p. 4, in *ERDA Public Information Plan LES 8/9*, September 1975. (From DOE archives.)


36. Personal interview with Augustine Pitrolo.

37. Telephone interview with Phil Waldron.


40. Personal interview with Vincent Truscello.


44. Personal interview with Rod Mills.

46. Ibid., p. 29.

47. Washburn, *Distant Encounters*, op. cit., p. 83.

48. Ibid.


51. *Program Plan: Office of Special Nuclear Projects (Space and Special Radioisotopic Systems Applications, Department of Energy)*, Revised 6/12/84, p. 13. (From DOE archives.)


56. Ibid.


**CHAPTER VIII**

1. Personal interview with Jerry Soffen.

2. Personal interview with Rod Mills.

3. Personal interviews with Vincent Truscello and Gerald Stapfer.

4. Personal interview with Guy Linkous.

5. Personal interview with Bob Carpenter.


8. Personal interview with Bernard Rock.


11. Personal interview with Bernard Rock.


**Time Period**

1896
1913
1945

**July August 1945**
- First A bomb detonated at Alamogordo
- Hiroshima and Nagasaki bombs dropped
- Atomic Age begins

**June July 1946**
- Operation Crossroads conducted at Bikini

**August 1946**
- Operation Crossroads conducted at Bikini

**Jan 1947**
- AEC established by Atomic Energy Act

**Oct 1947**
- AEC appoints Industrial Advisory Group to investigate peaceful uses of atomic energy

**1948 1952**
- U.S. conducts numerous atomic tests in Pacific & Nevada
- Soviets detonate their first A bomb in 1949
- First U.S. test of experimental thermonuclear device at Eniwetok in 1952

**July 1950**
- Eisenhower elected President
- Gordon Dean becomes chairman of AEC

**1951**
- Lewis Strauss becomes head of AEC

**1952**
- AEC lets series of contracts to study 1 kw electrical space power plant using reactors or isotopes
- RAND issues Project Feedback report discussing radioactive power for space
- Several companies recommend using isotopes for space power as result of AEC contracts

**Nov 1952**
- Eisenhower delivers Atoms for Peace speech before UN

**July 1953**
- Eisenhower delivers Atoms for Peace speech before UN
- Lewis Strauss becomes head of AEC

**Dec 1953**
- Atomic Energy Act of 1954 gives added impetus to development of peacetime atomic uses & private development of reactors

**Aug 1954**
- Atomic Energy Act of 1954 gives added impetus to development of peacetime atomic uses & private development of reactors

**1954**

**Defining Events**
- H. Becquerel discovers radioactivity
- H.G.J. Moseley reports construction of first nuclear battery

**Technical Events & Developments**
- Nuclear battery (of Lebanov & Belakov) generates 10 *amps device built by P.H. Miller using PO 210

**Institutional Events**
- AEC begins operations under David E. Lilienthal

**Appendix A. Chronology**

143
July 1955  
Eisenhower proposes "Open Skies" policy for mutual aerial inspection during Geneva Summit

Aug 1955  
Space nuclear auxiliary power program begins in Joint AEC/DOD Aircraft Nuclear Propulsion Office

Feb 1956  
AEC makes available 20,000 kilograms of U-235 for use in power and research reactors abroad and 20,000 kilograms for power reactors in U.S.

Mar 1956  
AEC low-level effort undertaken by Martin Baltimore for isotope-fuel space power unit for military satellite

July 1956  
AF advanced reconnaissance system designated WS-117L

Nov 1956  
AEC proceeds with development of heat source for WS-117L

Nov 1956  
Eisenhower re-elected

Oct 1957  
Soviets launch Sputnik. Name "Pied Piper" (AF code name for 117L) compromised by Aviation Week article

Nov 1957  
President's Science Advisory Committee created

July 1958  
John McCone becomes chairman of AEC, NASA established

Aug 1958  
Eisenhower announces moratorium on weapons testing (to begin Oct 31)

Nov 1958  
T. Keith Glennan appointed first administrator of NASA

Nov 1958 Sept 1961  
U.S., Great Britain, & USSR agree to moratorium on atmospheric nuclear testing

Jan 1959  
Eisenhower reveals existence of plutonium fuel (by product of weapons development) for spacecraft

May 1960  
Summit conference broken up by U-2 incident

Oct 1960  
Joint AEC/NASA Nuclear Propulsion Office created with Harold Finger as head

Nov 1960  
Kennedy elected President

Feb 1961  
James E. Webb becomes head of NASA

Mar 1961  
Glenn Seaborg named AEC chairman, atomic regulatory function placed under AEC Director of Regulations

May 1961  
Kennedy gives special message to Congress committing U.S. to reach the Moon "before decade is out"
June 1961
SNAP 3 A orbits successfully on Navy TRANSIT 4A navigational satellite

Sept 1961
Soviets break nuclear test moratorium. Kennedy orders resumption of underground testing

Nov 1961
Second SNAP 3 A orbits successfully on Navy TRANSIT 4B navigational satellite

Feb 1962
John Glenn becomes first U.S. astronaut to orbit the earth

April 1962
Kennedy authorizes resumption of atmospheric testing

June 1962
Kennedy authorizes resumption of atmospheric testing

Office of Science & Technology created in Executive Office of President

July 1962
Underground tests conducted in Nevada

Oct 1962
Cuban Missile Crisis

Aug 1963
Limited Nuclear Test Ban Treaty signed by U.S., Great Britain & U.S.S.R.

Sept 1963
SNAP 9 A orbits successfully on Navy TRANSIT 5BN 1 navigational satellite

Nov 1963
Kennedy assassinated. Lyndon Johnson becomes President

Dec 1963
Kennedy assassinated. Lyndon Johnson becomes President

April 1964
Gulf of Tonkin resolution begins heavy U.S. involvement in Vietnam. Johnson signs Private Ownership of Special Nuclear Materials Act

Aug 1964
SNAP 9 A orbits successfully on Navy TRANSIT 5BN 2 navigational satellite

Nov 1964
Johnson elected President

Dec 1964
Third SNAP 9 A launched on Navy TRANSIT 5BN 3 mission aborted (SNAP burned up on re-entry)

1965-1970
U.S. involvement in Vietnam increases criticism of government and protests about nuclear safety begins to place stress on space budgets

AEC issues permit to construct Oyster Creek power plant—first civilian reactor built on competitive basis without government assistance
<table>
<thead>
<tr>
<th>Month</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 65</td>
<td>SNAP 10 (reactor) successfully achieves orbit</td>
</tr>
<tr>
<td>June 65</td>
<td>Harold Finger heads new Space Nuclear Systems Division of AEC</td>
</tr>
<tr>
<td>Nov 65</td>
<td>Finger decentralizes many space nuclear functions to laboratories</td>
</tr>
<tr>
<td>Jan 67</td>
<td>Fire on APOLLO at Cape Kennedy delays lunar program</td>
</tr>
<tr>
<td>Mar 67</td>
<td>Harold Finger receives new permanent assignment at NASA</td>
</tr>
<tr>
<td></td>
<td>replaced in AEC and RTG program roles by Milton Klein</td>
</tr>
<tr>
<td>Feb 68</td>
<td>Tet offensive in Vietnam</td>
</tr>
<tr>
<td>Apr 68</td>
<td>M.L. King Jr assassinated</td>
</tr>
<tr>
<td>May 68</td>
<td>SNAP 19B2 launched on NIMBUS B 1 weather satellite mission aborted</td>
</tr>
<tr>
<td></td>
<td>heat source retrieved</td>
</tr>
<tr>
<td>Jun 68</td>
<td>Robert F. Kennedy assassinated</td>
</tr>
<tr>
<td>July 68</td>
<td>Treaty for Non Proliferation of Nuclear Weapons signed</td>
</tr>
<tr>
<td>Oct 68</td>
<td>James Webb retires as administrator of NASA</td>
</tr>
<tr>
<td>Nov 68</td>
<td>Nixon elected President</td>
</tr>
<tr>
<td>Dec 68</td>
<td>Official decision made not to use SNAP device on first APOLLO lunar</td>
</tr>
<tr>
<td></td>
<td>landing</td>
</tr>
<tr>
<td>Jan 69</td>
<td>APOLLO 8 orbits Moon</td>
</tr>
<tr>
<td>Mar 69</td>
<td>Council on Environmental Quality established</td>
</tr>
<tr>
<td>Apr 69</td>
<td>Thomas O. Paine becomes NASA administrator</td>
</tr>
<tr>
<td>Apr 69</td>
<td>SNAP 19B3 launched on NIMBUS III successfully achieves orbit</td>
</tr>
<tr>
<td>July 69</td>
<td>APOLLO 11 lands on Moon</td>
</tr>
<tr>
<td>Nov 69</td>
<td>SNAP 27 device successfully placed on lunar surface on APOLLO 12 mission</td>
</tr>
<tr>
<td>Jan 70</td>
<td>Russell Train appointed chairman of Council on Environmental Quality</td>
</tr>
<tr>
<td></td>
<td>submitted to Congress in August 1970</td>
</tr>
<tr>
<td>Month</td>
<td>Event</td>
</tr>
<tr>
<td>--------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Mar 1970</td>
<td>Treaty for Non Proliferation of Nuclear Weapons ratified by U S Great Britain U S S R &amp; 45 other nations</td>
</tr>
<tr>
<td>Apr 1970</td>
<td>Millions participate in first Earth Day anti pollution demonstrations APOLO 13 mission aborted on way to Moon</td>
</tr>
<tr>
<td>May 1970</td>
<td>Campus unrest and Kent State killings follow president’s announcement of Cambodian incursion</td>
</tr>
<tr>
<td>Jul 1970</td>
<td>Environmental Protection Agency and National Oceanic &amp; Atmospheric Administration created</td>
</tr>
<tr>
<td>Jan 1971</td>
<td>President proposes new Department of Natural Resources</td>
</tr>
<tr>
<td>June 1971</td>
<td></td>
</tr>
<tr>
<td>July 1971</td>
<td></td>
</tr>
<tr>
<td>Aug 1971</td>
<td>James R Schlesinger becomes chairman of AEC replacing Seaborg</td>
</tr>
<tr>
<td>Nov 1971</td>
<td>David Gabriel replaces Milton Klein as director of Space Nuclear Systems Division</td>
</tr>
<tr>
<td>Feb 1972</td>
<td>President Nixon visits China pledges normalization of relations</td>
</tr>
<tr>
<td>Mar 1972</td>
<td></td>
</tr>
<tr>
<td>Apr 1972</td>
<td></td>
</tr>
<tr>
<td>May 1972</td>
<td>President Nixon visits U S S R holds summit talks and signs SALT 1</td>
</tr>
<tr>
<td>Sept 1972</td>
<td></td>
</tr>
<tr>
<td>Nov 1972</td>
<td>Nixon re-elected President</td>
</tr>
<tr>
<td>Dec 1972</td>
<td></td>
</tr>
</tbody>
</table>
Feb 1973  Joint AEC NASA Space Nuclear Systems Office dissolved
Mar 1973  Doxy Lee Ray designated AEC chairman
April 1973  Last GIs leave Vietnam
June 1973  National Energy Office established in Executive Office of the President
Summer 1973  President proposes to Congress a Department of Energy & Natural Resources & an independent Energy Research & Development Administration (ERDA)
Oct 1973  Watergate hearings held in Washington
Nov 1973  Yom Kippur War Arab OPEC countries embargo oil sales to U.S.
Dec 1973  Gerald Ford sworn in as vice president following resignation of Spiro Agnew
May 1974  President establishes Energy Research and Development Advisory Council
Aug 1974  President Nixon resigns; Vice President Ford becomes President
Dec 1974  SNAP 19 powers PIONEER 10 in its fly by of Jupiter
Jan 1975  ERDA activated; Robert Seamans Jr. named administrator
April 1975  South Vietnam falls to North Vietnamese
Aug 1975  SNAP 19 device successfully launched on VIKING 1 mission to Mars
Sept 1975  SNAP 19 device successfully launched on VIKING 2 mission to Mars
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar 1976</td>
<td>MHW devices successfully orbit on LES 8/9 DOD communication satellites</td>
</tr>
<tr>
<td>May 1976</td>
<td>ERDA assumes responsibility for managing Clinch River Breeder Reactor</td>
</tr>
<tr>
<td>July-Aug 1976</td>
<td>SNAP 19 devices successfully power VIKINGs 1 and 2 in</td>
</tr>
<tr>
<td>Nov 1976</td>
<td>Carter elected President</td>
</tr>
<tr>
<td>Apr 1977</td>
<td>President announces U.S. will defer reprocessing of spent reactor fuel indefinitely, delays Clinch River development</td>
</tr>
<tr>
<td>Aug 1977</td>
<td>President proposes a Cabinet level Department of Energy (DOE)</td>
</tr>
<tr>
<td>Sept 1977</td>
<td>Energy Reorganization Act creates DOE, abolishing ERDA</td>
</tr>
<tr>
<td>Oct 1977</td>
<td>DOE activated, James Schlesinger nominated as first Secretary of Energy</td>
</tr>
<tr>
<td>Jan 1978</td>
<td>Soviet spy satellite containing nuclear reactor breaks up over northwest Canada</td>
</tr>
<tr>
<td>Mar 1978</td>
<td>Nuclear Non-Proliferation Act authorizes President to pursue international studies on proliferation of nuclear materials</td>
</tr>
<tr>
<td>Jan 1979</td>
<td>Revolution forces Shah of Iran to flee</td>
</tr>
<tr>
<td>Mar 1979</td>
<td>Three Mile Island accident</td>
</tr>
<tr>
<td>July 1979</td>
<td>MHW successfully powers VOYAGER 1 fly through of Jupiter system</td>
</tr>
<tr>
<td>Aug 1979</td>
<td>Charles Duncan Jr. named Secretary of Department of Energy</td>
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<tr>
<td>Sept 1979</td>
<td>MHW successfully powers VOYAGER 2 fly through of Jupiter system</td>
</tr>
<tr>
<td>Nov 1979</td>
<td>SNAP 19 successfully powers PIONEER 10 in Saturn fly by</td>
</tr>
<tr>
<td>Nov 1980</td>
<td>Ronald Reagan elected President</td>
</tr>
</tbody>
</table>
Jan 1981

Feb 1981
Reagan presents "America's New Beginning: A Program for Economic Recovery" to Congress
Edward announces major reorganization of DOE creates Energy Policy Task Force

Aug 1981
Reagan announces nuclear energy policy proposes accelerated deployment of methods for storing high-level radioactive waste lifts ban on commercial reprocessing of nuclear fuel

Oct 1981
James B. Edwards named Secretary of Department of Energy

MHW successfully powers VOYAGER 2 in rendezvous with Saturnian system
<table>
<thead>
<tr>
<th>Power Source</th>
<th>Sponsoring Agency and Spacecraft</th>
<th>Mission Type</th>
<th>Launch Date</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNAP-3A</td>
<td>Navy-Transit 4A</td>
<td>Navigational</td>
<td>June 29, 1961</td>
<td>Successfully achieved orbit</td>
</tr>
<tr>
<td>SNAP-3A</td>
<td>Navy-Transit 4B</td>
<td>Navigational</td>
<td>Nov. 15, 1961</td>
<td>Successfully achieved orbit</td>
</tr>
<tr>
<td>SNAP-9A</td>
<td>Navy-Transit-5BN-1</td>
<td>Navigational</td>
<td>Sept. 28, 1963</td>
<td>Successfully achieved orbit</td>
</tr>
<tr>
<td>SNAP-9A</td>
<td>Navy-Transit-5BN-3</td>
<td>Navigational</td>
<td>April 21, 1964</td>
<td>Mission aborted; burned up on re-entry</td>
</tr>
<tr>
<td>SNAP-19B3</td>
<td>NASA-Nimbus-III</td>
<td>Meteorological</td>
<td>April 14, 1969</td>
<td>Successfully achieved orbit</td>
</tr>
<tr>
<td>SNAP-27</td>
<td>NASA-Apollo 12</td>
<td>Lunar</td>
<td>Nov. 14, 1969</td>
<td>Successfully placed on lunar surface</td>
</tr>
<tr>
<td>SNAP-27</td>
<td>NASA-Apollo 13</td>
<td>Lunar</td>
<td>April 11, 1970</td>
<td>Mission aborted on way to Moon; heat source returned to South Pacific Ocean</td>
</tr>
<tr>
<td>SNAP-27</td>
<td>NASA-Apollo 15</td>
<td>Lunar</td>
<td>July 26, 1971</td>
<td>Successfully placed on lunar surface</td>
</tr>
<tr>
<td>SNAP-27</td>
<td>NASA-Apollo 16</td>
<td>Lunar</td>
<td>April 16, 1972</td>
<td>Successfully placed on lunar surface</td>
</tr>
<tr>
<td>Transit-</td>
<td>Navy-&quot;Transit&quot;</td>
<td>Navigational</td>
<td>Sept. 2, 1972</td>
<td>Successfully achieved orbit</td>
</tr>
<tr>
<td>RTG</td>
<td>(TRIAD-01-1X)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>SNAP-27</td>
<td>NASA-Apollo 17</td>
<td>Lunar</td>
<td>Dec. 7, 1972</td>
<td>Successfully placed on lunar surface</td>
</tr>
<tr>
<td>SNAP-19</td>
<td>NASA-Pioneer 11</td>
<td>Planetary</td>
<td>April 5, 1973</td>
<td>Successfully operated to Jupiter, Saturn, and beyond</td>
</tr>
<tr>
<td>SNAP-19</td>
<td>NASA-Viking 1</td>
<td>Mars</td>
<td>Aug. 20, 1975</td>
<td>Successfully landed on Mars</td>
</tr>
<tr>
<td>SNAP-19</td>
<td>NASA-Viking 2</td>
<td>Mars</td>
<td>Sept. 9, 1975</td>
<td>Successfully landed on Mars</td>
</tr>
<tr>
<td>MHW</td>
<td>AF-LES 8</td>
<td>Communications</td>
<td>Mar. 14, 1976</td>
<td>Successfully achieved orbit</td>
</tr>
<tr>
<td>MHW</td>
<td>Project</td>
<td>Type</td>
<td>Date</td>
<td>Outcome</td>
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<tr>
<td>MHW</td>
<td>AF-LES 9</td>
<td>Communications</td>
<td>Mar. 14, 1976</td>
<td>Successfully achieved orbit</td>
</tr>
<tr>
<td>MHW</td>
<td>NASA-Voyager 2</td>
<td>Planetary</td>
<td>Aug. 20, 1977</td>
<td>Successfully operated to Jupiter, Saturn, and beyond</td>
</tr>
<tr>
<td>MHW</td>
<td>NASA-Voyager 1</td>
<td>Planetary</td>
<td>Sept. 5, 1977</td>
<td>Successfully operated to Jupiter, Saturn, and beyond</td>
</tr>
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</table>
### APPENDIX C. BUDGETS FOR THE RTG PROGRAM

**TABLE C: BUDGETS FOR THE RTG PROGRAM***

(Figures in thousands of dollars)

<table>
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<tr>
<td></td>
<td>46</td>
<td>486</td>
<td>1,890</td>
<td>3,526</td>
<td>2,386</td>
<td>1,170</td>
<td>4,189</td>
<td>11,279</td>
<td>27,260</td>
<td>28,643</td>
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<td>37,158</td>
<td>48,154</td>
<td>35,516</td>
<td>29,703</td>
<td>20,645</td>
<td>18,294</td>
<td>16,372</td>
<td>29,030</td>
<td>27,900</td>
<td>27,272</td>
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<td></td>
<td>25,085</td>
<td>29,137</td>
<td>24,100</td>
<td>34,000</td>
<td>33,700</td>
<td>36,000</td>
<td>34,246</td>
<td>37,962</td>
<td>27,735</td>
<td>27,950</td>
</tr>
</tbody>
</table>

**Explanation of Budget Figure Aggregations**

The space RTG program existed under many organizational names and within many organizational configurations. Therefore, it is not readily identifiable as a single, separate entity through the years since 1956. In preparing the budget figures and plottings for APPENDIX C, the following procedures were followed to identify dollar amounts that could be said to represent allocations to the “Space RTG Program”:

- for the years 1956-1972, subtotals were obtained from budgets for “Space Electric Power Development” at the AEC. The specific line items included to arrive at the program totals were: “Radioisotopes,” “Power Conversion Technology,” “Space Nuclear Safety,” and “Isotope Fuel Development.” “Isotope Fuel Development” did not appear as a budget item until 1962.

- for the years 1973-1974, two items were taken from the “Space Electric Power Program” budgets: “Total Isotope Systems Operating” funds and “Total Radioisotope Systems Equipment” funds.

- for 1975, two items were taken from the “Space Nuclear Systems Program” budget: “Total Space Electric Power Operating” funds and “Total Space Electric Power Equipment” funds.

- for 1976 and 1977, three items were taken from the “Nuclear Research and Applications Program” budgets: “Total Space Applications Operating,” “Space Applications Capital Equipment,” and “Advanced Isotope Separation Technology Capital Equipment” funds.
for 1978 and 1979, totals for "Space and Terrestrial Applications Operating Expenses" "Space and Terrestrial Applications Capital Equipment" were used, but from each of these totals, sub-items for "Terrestrial Isotope Applications" were subtracted. In 1978, the latter amount was substantial for "Operating," $4,400 thousand; but in 1979, the figure on this item was $4,300 thousand.

for 1980-1982, subtotals under "Advanced Nuclear Systems" were taken for "Space and Terrestrial Applications Operating Expenses" and "... Capital Equipment," and the sub-item "Terrestrial Isotope Applications" was subtracted, amounting to $2,000 to $2,700 thousand in each of those years.

for 1983-1985, subtotals under "Advanced Nuclear Systems" were taken for "Space and Special Applications Operating Expenses" and "... Capital Equipment," and the sub-item "Special Applications" (described as heavily terrestrially-oriented) was subtracted. This item amounted to -0- in 1983 and $1,000 thousand in 1984 and 1985.

Dollars
(1000)

Figure C-1 RTG budget fluctuations
APPENDIX D. CHANGES IN ORGANIZATIONAL LOCATIONS OF THE RTG PROGRAM

During the years 1955-1982, the location of the RTG program within government agencies changed from time to time. (See organization charts in Figs. D-1 to D-7.

1955-1960

Figure D-1

*Aircraft Nuclear Propulsion Office (Joint AEC/AF).
1961-1965
(As of August 1960)

AEC
Division of Reactor Development

SNAP Branch

RTC Office

Reactor Power Office

NASA
Launch Vehicle Programs

SNPO

Project Rover

Figure D-2
*Space Nuclear Propulsion Office (Joint AEC/NASA).

1965-1972*

AEC
Assistant General Manager for Reactors

Space Nuclear Systems Division

Space Electric Power Office

Safety Branch

Isotope Power Branch

Reactor Power Branch

NASA
Associate Administrator for Advanced Research & Technology

SNPO

Nuclear Systems & Space Power Division

Figure D-3
*After creation of Space Nuclear Systems Division at AEC. There were 23 divisions at the Commission at this time.
1973-1974*
AEC

Figure D-4
*After dissolution of Joint AEC/NASA Space Nuclear Propulsion Office.
**Earlier divided into Reactor Power Systems Branch & Power Conversion Branch.
1975-1977
ERDA

Assistant Administrator
Nuclear Energy*

Division of
Nuclear Research & Applications

Assistant for
Requirements & Applications

Assistant for Safety

Assistant for Army Reactors

Office of Assistant Director
Administration, Planning & Budget

Office of Isotope Separation

Office of Space Applications

Office of Reactor Programs

Office of Technology Development & Special Projects

Office of Nuclear Assessment

Figure D-5

*Other "Assistant Administrators" at ERDA were for: Administration, Conservation; Environment and Safety, Field Operations, Fossil Energy; International Affairs, National Security; Planning & Analysis, Geothermal & Advanced Energy Systems.
1978-1981
DOE

Assistant Secretary for Nuclear Energy*

Office of Uranium Enrichment & Assessment
Deputy Assistant Secretary for Naval Reactors
Deputy Assistant Secretary for Nuclear Reactor Programs
Deputy Assistant Secretary for Nuclear Waste Management & Fuel Cycle Programs

Office of Reactor Research & Technology
Office of Coordination & Special Projects
Office of Nuclear Power Systems

Space Systems Team
(Other Teams)
(Other Teams)

Figure D 6

*At first the term at this level was Energy Technology, later it became Nuclear Energy. Other Assistant Secretaries at DOE were for Conservation & Solar Applications, Defense, Environment, Intergovernmental & Institutional Affairs, International Affairs, Policy & Evaluation Resource Application
*Although configurations varied somewhat under DOE/Nuclear Energy, just two are shown before and after a reorganization which "flattened" the organization.

**Later this was designated Space & Terrestrial Applications Programs, and then Space & Special Applications Programs.
### TABLE E. DEVELOPMENTS IN RTG TECHNOLOGY

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>SNAP-3B</th>
<th>SNAP-9A</th>
<th>SNAP-19</th>
<th>SNAP-27</th>
<th>TRANSIT-RTG</th>
<th>MHW-RTG</th>
<th>GPHS-RTG</th>
</tr>
</thead>
<tbody>
<tr>
<td>MISSION</td>
<td>TRANSIT 4</td>
<td>TRANSIT 5BN</td>
<td>PIONEER</td>
<td>APOLLO</td>
<td>TRIAD</td>
<td>VOYAGER</td>
<td>GALILEO</td>
</tr>
<tr>
<td>BOM POWER* PER RTG, W(E)</td>
<td>2.7</td>
<td>26.8</td>
<td>40.3</td>
<td>73.4</td>
<td>35.6</td>
<td>158.0</td>
<td>292.0</td>
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<tr>
<td>THERMOELECTRIC MATERIAL</td>
<td>PBTE 2N/2P</td>
<td>PBTE 2N/2P</td>
<td>PBTE 2N/ TAGS-8</td>
<td>PBTE 3N/3P</td>
<td>PBTE 2N/3P</td>
<td>SIE</td>
<td>SIE</td>
</tr>
<tr>
<td>PU-238 FUEL FORM</td>
<td>METAL</td>
<td>METAL</td>
<td>PMC*</td>
<td>OXIDE MICROSPHERES</td>
<td>PMC*</td>
<td>PRESSED OXIDE</td>
<td>PRESSED OXIDE</td>
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<tr>
<td>CONVERSION EFFICIENCY, %</td>
<td>5.1</td>
<td>5.1</td>
<td>6.2</td>
<td>5.0</td>
<td>4.2</td>
<td>6.6</td>
<td>6.6</td>
</tr>
<tr>
<td>SPECIFIC POWER W(E)/KG</td>
<td>1.29</td>
<td>2.2</td>
<td>3.0</td>
<td>2.3*</td>
<td>2.6</td>
<td>4.2</td>
<td>5.2</td>
</tr>
</tbody>
</table>


*Beginning-of-Mission.

*Cermet: a heat-resistant alloy formed by compacting and sintering a metal and a ceramic substance.*

*The SNAP-27 Specific Power is calculated with the mass of the fuel cask included.*

The table above indicates changes and improvements in the RTG technology from early SNAP-3 devices to the GPHS = RTG to be used on the GALILEO mission.
Significance of Developments in RTG Technology*

Essentials of the Technology. An RTG basically consists of a radioisotopic heat source and a thermoelectric converter that transforms thermal energy into electrical energy through two conductors, made of different metals, which are at different temperatures at their point of juncture. The heat results from the radioactive decay of plutonium-238, a radioisotope which has a half-life of 87.8 years. Plutonium-238 fueled all RTGs that flew on U.S. space missions. The principal decay process of this radioisotope is by emission of alpha particles, which are easily absorbed in the heat source to produce heat and require no special shielding.

Design Type and Trends. The RTG's flown since 1961 can be grouped into six basic design concepts—SNAP-3, SNAP-9A, SNAP-19, SNAP-27, TRANSIT-RTG, MHW-RTG. The general trend was to improve generator performance, efficiency, and specific power (electric power per kg of weight).

Basic Improvements. Power requirements for missions rose from a few watts electric to the 292 W(e) required in the forthcoming Galileo mission. Conversion efficiency rose slightly but specific power improved greatly as lighter weight converter materials (Beryllium or aluminum) reduced mass, even as fuel loadings increased and high-temperature thermoelectric power-conversion materials were introduced.

Snap-3(B). Each generator in the SNAP-3(B) RTG, which was the first to fly, was designed to provide an initial power output of 2.7 W(e). Heat source was approximately 52.5 W(t) of encapsulated plutonium-238 metal. Design life was five years. The power-conversion subsystem consisted of 27 spring-loaded, series-connected pairs of PbTe 2N/2P thermoelectric elements operating at a hot-juncture temperature of about 783 K and a cold-juncture temperature of about 366 K. This subsystem had a power-conversion efficiency of 5 to 6 percent and specific power of 1.29.

SNAP 9A. RTGs were adopted for the DOD Transit 5BN-1 and 5BN-2 satellites because RTGs are inherently radiation-resistant, while solar cells on earlier Transits were adversely affected by the 1962 high-altitude nuclear explosion. Each SNAP-9A was designed to provide 25 W(e) at a nominal 6V for five years in space after one year of storage on Earth. Thermal inventory of approximately 525 W(t) was supplied by Pu-238 metal encapsulated in a heat

*Abstracted from Bennett et al, 1983 paper (op. cit.) and Enhancing Technology Leadership: Space . . . (op. cit.), by the same authors.

W(e) = Watts electric
W(t) = Watts thermal
K = Kelvin
source of six fuel capsules maintained in a segmented graphite heat-accumulator block. The main body of the sealed generator was a cylindrical magnesium-thorium shell containing six heat-dissipating magnesium fins and 36 threaded holes; 70 pairs of series-connected PbTe 2N/2P thermoelectric couples were assembled in 35 modules of two couples each. Hot-junction temperature was calculated at about 790 K at beginning of life. Some waste heat from the RTG was used to maintain electronic instruments in the satellite at a temperature near 293 K.

SNAP-19. This technology-improvement program built on the SNAP-9A developments. The SNAP-19B power system was designed specifically for NASA's Nimbus weather satellites—a first demonstration of RTG technology aboard NASA spacecraft. Modifications to SNAP-19B were required to power the Pioneer and Viking missions.

Nimbus/SNAP-19. Specifications required 50 W(e) deliverable after one year in orbit. Two SNAP-19B's, with higher fuel loadings than those of SNAP-9A, were used on Nimbus III. To meet safety requirements, the Pu-238 fuel was changed from a metal form to oxide microspheres. Thermoelectric elements were made of cold-pressed and sintered PbTe. Each RTG thermopile consisted of 90 PbTe 3P/2N couples distributed in six modules of three parallel rows of five couples each. Modules were connected in series and enclosed in a magnesium-thorium housing. Hot-junction temperature was 800K. The two RTG's produced 56 W(e) — 49.4 W(e) usable — at launch and 47 W(e) one year later. Unlike the sealed capsules used in SNAP-3B and SNAP-9A's, the SNAP-19B fuel capsule was vented into the generator. Possible sources of power degradation were identified as: rate of argon leakage; replacement of argon with helium in fuel decay; oxygen released from the PuO fuel attacking the thermoelectric elements and bonds. Design of subsequent RTGs was changed to reduce these sources of degradation.

Pioneer/SNAP-19. Improvements for powering the Jupiter fly-by were made in the 19B converter, heat source, and structural configuration. A TAGS-SnTe/2N* thermocouple was designed with modified electrical circuitry to limit the magnetic field from the RTG to very low levels. Fill gas was a 75:25 helium-argon mixture, with a zirconium getter added to eliminate oxygen in the RTG. End covers were bolted and seam-welded to the cylindrical housing to further reduce gas leakage. Mission requirement called for four RTGs to produce 120 W(e) total at the Jupiter fly-by. Power output at Jupiter encounter was 144 W(e) for Pioneer 10 and 142.6 W(e) for Pioneer 11. Estimated minimum power requirements for a Saturn fly-by were 90 W(e) and the RTG's on Pioneer 11 actually provided 119.3 W(e) at Saturn.

*TAGS: a solid solution of silver antimony telluride in germanium telluride.
Viking SNAP-19. Distinctive mission requirements for Viking included high-temperature (400 K) sterilization, storage during the long cruise to Mars, and ability to withstand the rapid, extreme temperature changes of the Martian day-night thermal cycle. Each Viking Lander used two Snap-19 RTG's modified to meet those requirements. Each RTG was to produce a minimum of 35 W(e) during a 90-day Mars surface mission following an 11 to 12-month cruise after launch. The two series-connected RTGs were the primary power sources on each Viking Lander, supplying the energy for scientific instruments and for recharging four nickel-cadmium batteries. The RTGs also supplied the Landers with thermal energy. All four RTGs more than met the 90-day requirement.

A modification from Pioneer SNAP-19 was the addition of a dome reservoir. Initial fill gas for the converter was a 90:10 helium-argon mixture; the reservoir was filled with a 95:5 argon-helium mixture. This configuration permitted a controlled interchange of gases in the two volumes to minimize heat-source operating temperatures up to launch while maximizing electrical output at the end of the mission. Although data-relay capability ended, the RTGs on the Viking Landers were still operating when last transmissions were received and those on Viking Lander-1 were capable of providing power through 1994.

In the development of the SNAP-19s, the principal contribution to power degradation was judged to come from gas effects. Changes made in SNAP-9A and Nimbus SNAP-19 designs significantly minimized the degradation effects in the SNAP-19s.

SNAP-27. The SNAP-27 RTG was developed to power the experiments of NASA's Apollo Lunar Surface Experiments Package (ALSEP). The RTG design requirement was to provide at least 63.5 W(e) at 16 V DC one year after lunar emplacement. The use of RTGs was a natural choice because of their light weight, reliability, and ability to produce full electrical power during the long lunar night-day cycle. Since the ALSEPs were to be positioned manually by the astronauts, the designers took advantage of this assembly capability: the converter and sealed-fuel-capsule were kept separate in the Lunar Module and assembled on the Moon.

SNAP-27 used 442 thermoelectric couples made of PbTe 3N/3P elements arranged in two series strings of 221 couples connected in parallel. Heat from the fuel capsule, which was loaded with Pu-238 oxide microspheres and had a nominal rating of 1,480 W(t), was transmitted to the hot frame of the RTG by radiation coupling. Design analysis and ground tests indicated that the hot-junction temperature was about 866 K and the cold-side thermoelectric temperature was maintained at about 547 K in the lunar environment. Both the cold frame and the outer case were made of beryllium. Eight cross-rolled beryllium fins were attached integrally to the outer case by brazing. The converter had a mass of 12.7 kg. The mass of the fuel-capsule assembly,
without the graphite Lunar Module cask, was about 7 kg.

Five SNAP-27 powered ALSEPs were placed on the lunar surface. In each case, all of the RTGs exceeded their mission requirements in both power and life-cycle. All five ALSEPs, powered by RTGs, were operating when NASA shut down the stations on 30 September 1977.

**Transit-RTG.** The Transit-RTG was developed specifically as the primary power source for the DOD TRIAD navigational satellite. Auxiliary power was provided by four solar-cell panels and one 6 Ah nickel-cadmium battery. The objective of the Transit-RTG program was to produce an RTG capable of providing a minimum end-of-mission power of 30 W(e) after five years, at a minimum of 3 V. To do this, the 12-sided converter used light-weight PbTe thermoelectric panels (Isotec) that operated at a low hot-side temperature of 673 K in a vacuum, eliminating the need for hermetic sealing and a cover gas to inhibit the sublimation of thermoelectric material. The Transit-RTG was designed to be modular; each of the 12 Isotec panels contained 36 PbTe 2N/3P couples arranged in a series-parallel matrix with four couples in a row in parallel and nine rows in series. The panels were supported structurally by 12 webbed, magnesium-thorium corner posts with teflon insulators. The masses of the converter and heat source were 5.98 and 4.2 kg respectively. Including a titanium heat-source cage and support structure, the Transit-RTG had a mass of about 13.6 kg. The short-term objectives of the TRIAD satellite were demonstrated, including a checkout of RTG performance; however, a telemetry-converter failure caused a loss of further telemetry data. The TRIAD satellite continues to operate normally and to provide magnetometer data using power from the RTG.

**MHW-RTG.** The MHW-RTG was designed to provide a major increase in the power output of a space RTG. The DOD Lincoln Experimental Satellites 8 and 9 required 125 W(e) per RTG, with an output voltage of 30 (± 0.5) V at the end of mission — an operational life of at least five years after launch. The NASA VOYAGER mission required 128 W(e) per RTG, with an end-of-mission output of 30 (± 0.5) V or an operational life of at least four years after launch. To achieve these requirements, the MHW-RTG was equipped with a new heat source of 24 pressed plutonium oxide fuel spheres, each producing about 100 W(t). Electrical conversion was achieved through 312 silicon-germanium (SiGe) thermoelectric couples — high temperature alloys. The converter consisted of a beryllium outer case; end-closure structures that physically held the heat source; thermoelectric elements; a multifoil (molybdenum-Astroquartz) insulation packet and a molybdenum internal frame; and a gas-management system. The gas-management system maintained an argon or xenon gas environment to allow partial power operation on the launch pad; full-power operation in space was effected by venting the gas
through a pressure-relief device. The average RTG flight masses were 39.69 kg for LES 8/9 and 37.69 kg for Voyager 1/2. The 312 thermoelectric couples were arranged in 24 circumferential rows, each row containing 13 couples individually bolted to the outer case. The design hot-junction temperature was 1,273 K with a cold-junction temperature of 573 K. Design voltage was 30 V. The peak initial power was 159.6 W(e) for RTG Number 3 on Voyager 2. The MHW-RTGs allowed the LES 8/9 satellites to operate beyond the five-year operational life; enabled NASA to complete flights to Jupiter and Saturn; and will enable Voyager 2 to conduct an extended mission to Uranus in 1986.

GPHS-RTG. The successful performance of the MHW-RTG led to the use of SiGe technology for the high-power — 285 W(e) — General Purpose Heat Source RTG, which is to be launched in 1986 on the NASA Galileo Mission to Jupiter and the International Solar-Polar Mission around the sun.

Transition to High-Temperature Materials. The use of high-temperature SiGe alloys as thermoelectric power-conversion materials was a direct outgrowth of spacecraft requirements for higher RTG power levels and lower RTG masses. In general, higher hot-side operating temperature means a high efficiency, although the optimum temperature is dictated by the mission life, i.e., minimizing sublimation. The cold-side temperature is optimized to obtain the desired power-to-mass ratio. To a first approximation, PbTe can be used from room temperature to about 900 K before materials properties and the figure of merit become concerns. The SiGe alloy can be used from room temperature to about 1,300 K and offers the potential of higher power with improved efficiency.
Figure E. RTG performance demonstrated predicted

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