

## A LOOK AT THE SOVIET SPACE NUCLEAR POWER PROGRAM

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### ABSTRACT

The Soviet Union has been flying nuclear power sources in space since about 1965. For the most part these nuclear power sources have been low-power nuclear reactors using a thermoelectric conversion principle. Recently the Soviet Union has flown two satellites using a higher power reactor that employs a thermionic conversion system. Reentry of two of the earlier reactors on board Cosmos 954 and Cosmos 1402 plus the recent potential accident involving Cosmos 1900 have focused world attention on Soviet usage of space nuclear power. Despite these problems the evidence points toward a continued Soviet usage of nuclear power sources in space.

### INTRODUCTION

The reentry over Canada of the Soviet radar ocean reconnaissance satellite (RORSAT) known as Cosmos 954 on 24 January 1978 focused world attention on the Soviet Union's use of nuclear power in space. While Soviet specialists had publicly admitted in the 1960s that they were working on space nuclear reactors, little was known of their actual use. In view of the paucity of Soviet information it is appropriate to assemble what little information is publicly available on the Soviet space nuclear power program.

The Soviet Union has been a steady user of nuclear power in space beginning with their first publicly identified launch in 1965 (four years after the first U. S. launch of a nuclear power source). Whereas the U. S. has tended toward the use of nuclear power on civilian missions, especially on space systems operating on the Moon or beyond Earth orbit, the Soviets have primarily confined their activities to military missions operating in low Earth orbit (LEO). With one exception, the U. S. has used radioisotope thermoelectric generators (RTGs) on its nuclear-powered spacecraft. (The one exception was the SNAP-10A reactor flown in 1965.)[1] It must be emphasized again that very little is publicly known about the Soviet space nuclear power program because, unlike the U. S., they do not publish in the open literature information on the space nuclear power sources they are flying. Thus, what follows on the Soviet program is based largely on speculation.

This paper summarizes the open literature information on the Soviet space nuclear power program, including the "Romashka", "Topaz", the new reactor based on the Topaz program, and the RORSAT reactor experience. A more extensive summary has been prepared for later publication.

### SOVIET SPACE REACTOR PROGRAM

The following sections provide an overview of the Soviet space reactor program, beginning with the known reactor programs (Romashka and Topaz) and then discussing what can be inferred from the RORSATs.

#### Romashka

Figure 1 is a cutaway drawing of Romashka (Camomile), which was unveiled in 1964 at the Third U. N. Conference on the Peaceful Uses of Atomic Energy. Figure 2 depicts one of the  $UC_2$  fuel disks. In many respects Romashka looks like a reactor analog of an RTG in that the heat generated in the core is converted directly to electricity without flowing coolant or rotating machinery. In this respect Romashka resembled the U. S. SNAP 10 reactor which was abandoned in favor of SNAP-10A in order to remove the thermoelectric elements from the vicinity of the core and to provide the ability to deal with planned future temperature increases needed to improve performance.[2,3] Table 1 compares the design features of SNAP-10A and Romashka.

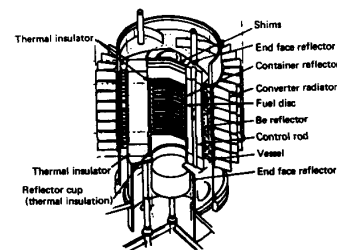


Figure 1. Cutaway view of an early ground-based Romashka reactor showing 11 fuel disks.

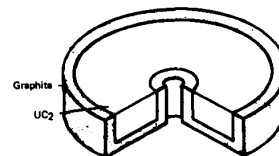
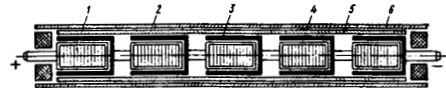


Figure 2. Cutaway view of a Romashka fuel disk.

**TABLE 1**  
**COMPARATIVE DESIGN FEATURES**  
**OF SNAP-10A AND ROMASHKA<sup>[2,7,15]</sup>**

<b>FEATURES</b>	<b>SNAP-10A</b>	<b>ROMASHKA</b>
Thermal Power	34 - 45.5 kWt	40 kWt
Thermal Energy Produced	44,000 kWt-h (SNAPSHOT) 382,944 kWt-h (FS-3)	~600 kWt-h
Electrical Power	0.54-0.65 kWe	0.5-0.8 kWe
Fuel Material	U-ZrHx	UC <sub>2</sub>
Core Loading of <sup>235</sup> U	4.3 kg	49 kg
Mass	435 kg (shielded)	455 kg (unshielded)
Enrichment of Fuel	>90% <sup>235</sup> U	90% <sup>235</sup> U
Reflector Material	Be	Be
Coolant	NaK	(Conduction)
Temperatures		
Core, maximum	858 K	2173 K
Hot Junction	774 K	1253 K
Base of Radiator, average	588 K	823 K
Differential across converter	152 K	~315 K
Neutron Spectrum	Thermal	Fast
Average Flux	$1.7 \times 10^{11}$ n/cm <sup>2</sup> -s	$\sim 9 \times 10^{12}$ n/cm <sup>2</sup> -s
Converter Characteristics		
Material	SiGe	SiGe
Figure of Merit	$0.58 \times 10^{-3}/K$	N/A
Material Efficiency	9.4%	N/A
Overall Efficiency	~1.3%	~1.5%
Working Voltage	~30V	1.6V/section



**Figure 3. Basic arrangement of the TOPAZ thermionic fuel element (TFE): 1) fuel pellet; 2) emitter; 3) collector; 4) interelectrode gap; 5) collector insulation; 6) sheath.**

### Topaz

In several papers and press releases dating from 1971, Soviet authorities cited the existence of a thermionic reactor program known as "Topaz" (signifying thermionic, experimental, conversion in the active zone). At least three versions of Topaz were tested. The first reactor tests on a single thermionic converter were reportedly carried out even earlier in April 1961.[4,5,6]

Like Romashka, Topaz was a direct conversion nuclear power source with no moving parts. The thermionic converter was combined with the fuel element as shown in Figure 3 to produce a single power-generating channel ("power channel"). The power channels included uranium fuel, cathodes made from a tungsten alloy or the molybdenum alloy VM-1, anodes made from the niobium alloy VN-2, beryllia insulators, stainless steel outer casings and cesium vapor in the interelectrode gap. Figure 4 shows a cutaway of the Topaz reactor showing the principal subsystems and design features.[4,7]

Referring to Figure 4, Soviet specialists have described Topaz as comprising "... a set of channel converters (8) arranged in a moderator (3) and defining the reactor core. The reactor control is effected by means of rotatable cylinders (7) of

boron carbide arranged in a beryllium reflector (4). The profiling of fuel and moderator helps attain a high radial uniformity of energy generation. The plant is provided with caesium delivery (1) and removal (5) devices, coolant (2), commutation chamber (11) and current leadouts (10). All this is housed in a single body (9) and results in an adequately compact arrangement ... "[7]

Table 2 lists the publicly known design features of the Topaz thermionic reactor system.

The Soviets have recently announced that they have flown two 5-Mg Cosmos satellites powered by 10-kWe reactors based on the Topaz design albeit with a reported two-fold improvement over Topaz.[6,8,9,10] Reportedly one of the reactors "... successfully functioned in orbit for six months and the second one for a year".[8] It is widely believed that these satellites were Cosmos 1818 and Cosmos 1867, which were launched on 1 February 1987 and 10 July 1987 respectively and are rumored to be a new generation of ocean surveillance satellite.[9,10,11,12] Additional information reported by the Soviets may be found in Table 3.[6,10]

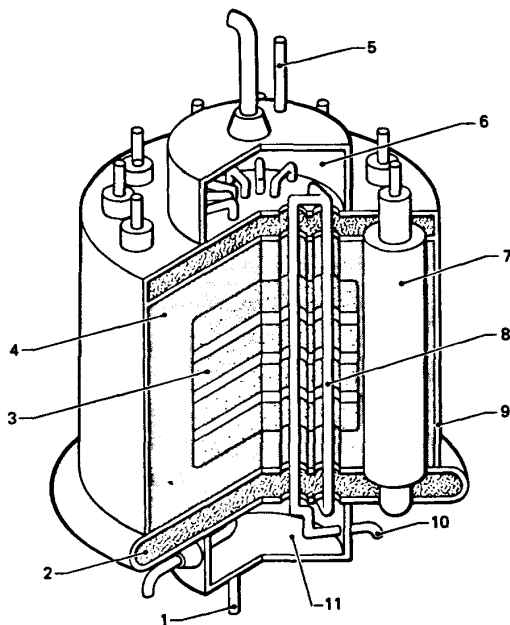


Figure 4. Configuration of the TOPAZ reactor.

TABLE 2

**DESIGN FEATURES OF THE TOPAZ  
THERMIONIC REACTOR SYSTEM<sup>[4,5,6]</sup>**

Parameter	Value
Thermal Power	130 - 150 kWt
Electrical Power (maximum)	5 - 10 kWe
Fuel Material	UO <sub>2</sub>
Fuel Loading ( <sup>235</sup> U)	12 kg
Enrichment of Fuel	~90% <sup>235</sup> U
Moderator	ZrH
Neutron Spectrum	Thermal
Reflector	Be
Reactor Mass	320 kg
Core Diameter	0.3 m
Core Length	0.4 m
Reflector Thickness	0.08 m
Control Drums	12 Rotary, Be with B <sub>4</sub> C backing
Coolant	NaK
Converter Characteristics	
Efficiency	4 - 7 %
Number of Converters	5 (of variable length) per TFE, totaling 395
Emitters	Mo or W (may be W-coated Mo)
Collectors	Nb
Emitter Temperature	~1725 K
Collector Temperature	~ 925 K

**TABLE 3  
SUMMARY OF CHARACTERISTICS OF  
TOPAZ-TYPE  
REACTORS FLOWN ON COSMOS 1818 AND  
COSMOS 1867<sup>[6,8,10]</sup>**

Electrical Power	~10 kWe
Conversion System	~80 in-core thermionic fuel elements (TFEs)
Emitter Temperature	~1875 K
Collector Temperature	~800-875 K
Efficiency	5 - 10%
Fuel Material	Urania (hollow geometry)
Uranium-235 Enrichment	90%
Uranium-235 Loading	~12 kg
Moderator	Zirconium Hydride
Cooling System	Pumped loop radiator (EM pump) with fins (all stainless steel loop)
Outlet Temperature	875 K
Inlet Temperature	790 K
Core Arrangement	0.3-m D x 0.3-m L single stainless steel calandria can
Reflector Material	Beryllium
Reflector Thickness	~8 cm
Neutron Spectrum	Thermal
Shield	Gamma: borated stainless steel Neutron: lithium hydride
Control Elements	Rotating drums (no central control rod)
Overall Reactor Mass	~1000 kg

**RORSATs**

The Soviet Union has been launching RORSAT-related spacecraft since 1967. Table 4, which is based on the extensive studies of N. L. Johnson and others, provides a listing of publicly identified launches.<sup>[13]</sup> The Soviets have recently confirmed Western speculation that the RORSATs are fast reactors using a thermoelectric conversion system and that they are of a different design from Romashka.<sup>[10]</sup>

Based on an analysis of the RORSATs flown through Cosmos 954, G. E. Perry concluded that "The Russian ocean surveillance satellite probably consists of three parts -- the final stage of the rocket which carries the slot antenna for the SLR [side-looking radar] along its length, an attitude stabilisation platform, and a nuclear power source with its own rocket engine. Normally, at the end of the mission, the three parts separate. The nuclear power plant is raised to a higher circular orbit where it will remain for up to 500 years or more and the other two parts decay rapidly from the lower orbit. It seems probable that it proved impossible to separate the components of Cosmos 954 during November and that it remained in one piece until the end."<sup>[14]</sup> Following the reentry of Cosmos 954, the RORSATs reportedly displayed a new sequence of operations and events. Upon completion of its operational life the RORSAT was split into three parts:

**TABLE 4**  
**SOVIET ORBITAL REACTOR PROGRAM HISTORY\***

<u>Number</u>	<u>Name</u>	<u>Launch Date</u>	<u>Termination Date</u>	<u>Lifetime</u>
1	Cosmos 198	27 Dec 67	28 Dec 67	1 da
2	Cosmos 209	22 Mar 68	23 Mar 68	1 da
3	Cosmos 367	3 Oct 70	3 Oct 70	< 3 h
4	Cosmos 402	1 Apr 71	1 Apr 71	< 3 h
5	Cosmos 469	25 Dec 71	3 Jan 72	9 da
6	Cosmos 516	21 Aug 72	22 Sep 72	32 da
7	Cosmos 626	27 Dec 73	9 Feb 74	45 da
8	Cosmos 651	15 May 74	25 Jul 74	71 da
9	Cosmos 654	17 May 74	30 Jul 74	74 da
10	Cosmos 723	2 Apr 75	15 May 75	43 da
11	Cosmos 724	7 Apr 75	11 Jun 75	65 da
12	Cosmos 785	12 Dec 75	12 Dec 75	< 3 h
13	Cosmos 860	17 Oct 76	10 Nov 76	24 da
14	Cosmos 861	21 Oct 76	20 Dec 76	60 da
15	Cosmos 952	16 Sep 77	7 Oct 77	21 da
16	Cosmos 954	18 Sep 77	~31 Oct 77	~43 da
17	Cosmos 1176	29 Apr 80	10 Sep 80	134 da
18	Cosmos 1249	5 Mar 81	18 Jun 81	105 da
19	Cosmos 1266	21 Apr 81	28 Apr 81	8 da
20	Cosmos 1299	24 Aug 81	5 Sep 81	12 da
21	Cosmos 1365	14 May 82	26 Sep 82	135 da
22	Cosmos 1372	1 Jun 82	10 Aug 82	70 da
23	Cosmos 1402	30 Aug 82	28 Dec 82	120 da
24	Cosmos 1412	2 Oct 82	10 Nov 82	39 da
25	Cosmos 1579	29 Jun 84	26 Sep 84	90 da
26	Cosmos 1607	31 Oct 84	1 Feb 85	93 da
27	Cosmos 1670	1 Aug 85	22 Oct 85	83 da
28	Cosmos 1677	23 Aug 85	23 Oct 85	60 da
29	Cosmos 1736	21 Mar 86	21 Jun 86	92 da
30	Cosmos 1771	20 Aug 86	15 Oct 86	56 da
31	Cosmos 1818	1 Feb 87	~ Jul 87	~6 mo
32	Cosmos 1860	18 Jun 87	28 Jul 87	40 da
33	Cosmos 1867	10 Jul 87	~ Jul 88	~1 yr
34	Cosmos 1900	12 Dec 87	~14 Apr 87	~124 da**
35	Cosmos 1932	14 Mar 88	19 May 88	66 da

\* Sources include references 10, 11, 12, 13, and 14.

\*\*Note: The Cosmos 1900 reactor continued to operate past the 124-day mission lifetime.

- Object A - reactor plus small kick stage;
- Object B - expended Scarp-11 second stage of the launch vehicle plus instrument section; and
- Object C - radar antenna.

The reactor was boosted into a higher orbit and the reactor core was then ejected (Object D) to prevent reentry for some 500 years.[17,18,19]

In the non-technical summary of the U. S. participation in "Operation Morning Light" (as the U.S. participation in the Cosmos 954 reentry was named), the Cosmos series of satellites were pictured as shown in Figure 5 and described as being cylindrical with a mass of approximately 4000 kg. The reactor was described as producing 100 kWt or less and containing "... on the order of 50 kg of highly enriched uranium-235".[15] The Soviets have recently reported the satellite to be 1.3-m in diameter and 10-m long.[16]

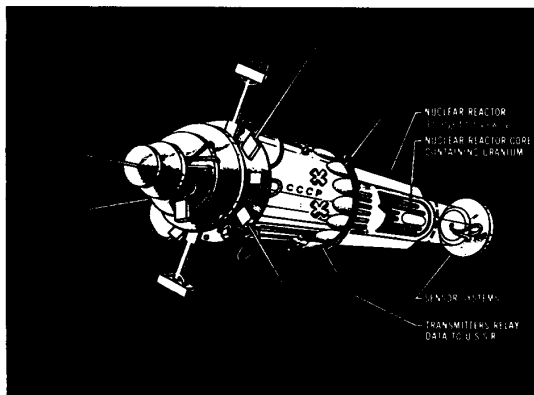


Figure 5. Artist's early conception of one of the RORSATs (courtesy DOE).

Given that the RORSAT reactors use a thermoelectric conversion system allows some estimates to be made of the electric power output. For example, Romashka was about 1.5% efficient (although values from 1.25% to 2% have also been cited) and the SNAP-10A flight reactor was about 1.3% efficient. While current U. S. RTGs are 6.8% efficient, the SP-100 reactor is estimated to be only about 4% efficient. These efficiencies when coupled to a 100-kWt reactor would yield electrical power outputs in the range of 1.3 kWe to 4 kWe.

#### RORSAT Reactor

From References 10, 15, 16, 20, 21, 22, and 23, it is possible to construct the following table of estimated RORSAT reactor parameters:

Thermal Power	≤100 kWt
Conversion System	Thermoelectric
Electrical Power Output	≤5kWe (~1.3-2 kWe)
Fuel Material	U-Mo(≥3wt% Mo)
Uranium-235 Enrichment	90%
Uranium-235 Mass	≤ 31 kg (~20-25 kg)
Burnup	≤2x10 <sup>18</sup> fissions/g of U
Specific Power	~ 5 Wt/g of U
Core Arrangement	37 cylindrical elements (probably 2-cm dia) Possibly Nb or SS
Cladding	NaK
Coolant	≥ 970 K (outlet)
Coolant Temperature	Steel
Core Structural Material	Be (6 cylindrical rods)
Reflector Material	0.1 m
Reflector Thickness	Fast (~ 1 MeV)
Neutron Spectrum	LiH (+ W & depleted U)
Shield	≤ 0.24 m
Core Diameter	≤ 0.64 m
Core Length	6 in/out control rods composed of BC <sub>2</sub> with LiH inserts to prevent neutron streaming and Be followers to serve as the radial reflector
Control Elements	< 390 kg
Overall Reactor Mass	

Figure 6 is an artist's concept of Cosmos 954. Figure 7 is an engineering sketch of the general features of the Cosmos 954 reactor. While public attention has focused on Cosmos 954, Cosmos 1402, and Cosmos 1900, the DOE and other observers have noted that the Soviets have had other accidents involving space nuclear power sources (see Table 5).

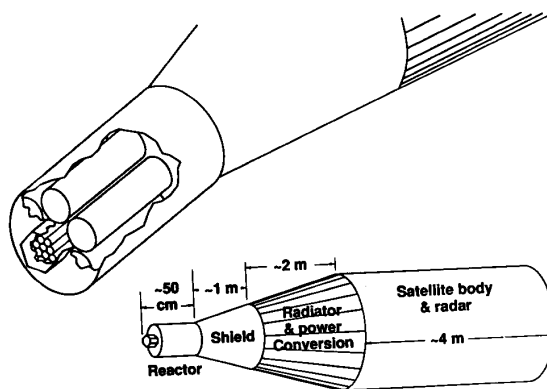


Figure 6. Artist's concept of Cosmos 954 showing the reactor (courtesy LLNL).

**TABLE 5**  
**REENTRIES OF SOVIET SPACE NUCLEAR POWER SOURCES<sup>[13]</sup>**

<u>Name</u>	<u>Launch Date</u>	<u>Reentry Date</u>	<u>Type of Power Source</u>	<u>Comments</u>
	25 Jan 1969	25 Jan 1969	Reactor	Possible launch failure of RORSAT.
Cosmos 300	23 Sep 1969	27 Sep 1969	Radioisotope	One or both of these payloads may have been a Lunokhod and carrying a <sup>210</sup> Po heat source. Upper stage malfunction prevented payloads from leaving Earth orbit.
Cosmos 305	22 Oct 1969	24 Oct 1969		
	25 Apr 1973	25 Apr 1973	Reactor	Probable launch failure of RORSAT.
Cosmos 954	18 Sep 1977	24 Jan 1978	Reactor	Payload malfunction caused reentry near Great Slave Lake in Canada.
Cosmos 1402	30 Aug 1982	23 Jan 1983 (spacecraft) 7 Feb 1983 (reactor core)	Reactor	Payload failed to boost to storage orbit on 28 Dec 1982. Spacecraft structure reentered at 25°S, 84°E. Fuel core reentered at 19°S, 22°W.

**TABLE 6**  
**SUMMARY OF RADIOISOTOPE POWER SOURCES**  
**REPORTED TO HAVE BEEN LAUNCHED BY THE U.S.S.R.<sup>[13]</sup>**

<u>Power Source</u>	<u>Spacecraft</u>	<u>Mission Type</u>	<u>Launch Date</u>	<u>Status</u>
RTG (?)	Cosmos 84	Navigation (?)	3 Sep 65	In orbit
RTG (?)	Cosmos 90	Navigation (?)	18 Sep 65	In orbit
RHU	Luna 17 (Lunokhod-I)	Lunar rover	10 Nov 70	Shutdown
RHU	Luna 21 (Lunokhod-II)	Lunar rover	8 Jan 73	Shutdown

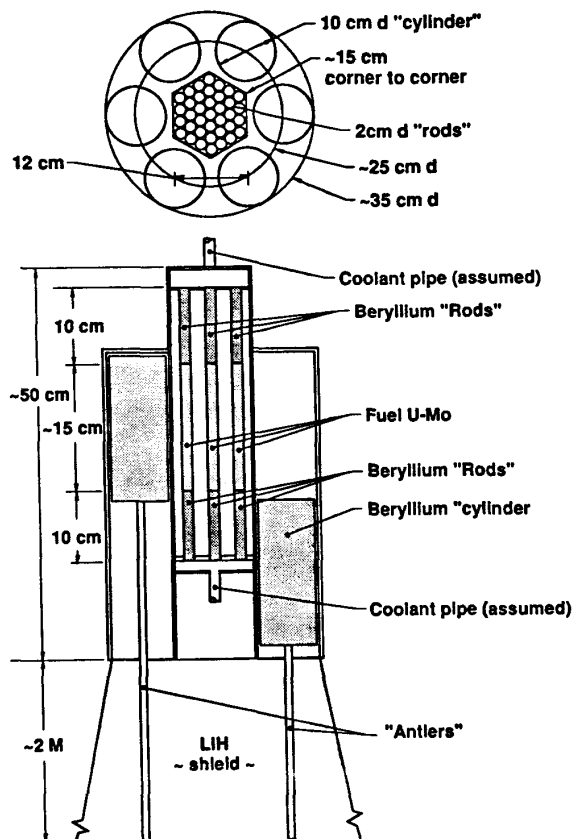


Figure 7. Engineer's sketch of Cosmos 954 reactor (courtesy LLNL).

#### SOVIET SPACE RADIOISOTOPE PROGRAM

The Soviets have reported using only a few radioisotope power sources -- including their first radioisotope generator, Orion 1, on Cosmos 84 and Cosmos 90.[24] For Lunokhod-I ("Moonwalker I") and Lunokhod-II, the Soviets used an isotopic heat source to maintain the desired temperatures in the Lunokhod compartment during the lunar night.[25] Table 6 summarizes what has been publicly reported on the successful flights of Soviet radioisotope power sources.[13]

#### FUTURE USES OF SPACE NUCLEAR POWER

The Soviets have consistently stated that they intend to continue using nuclear power in space. Less than a month after the reentry of Cosmos 954, Soviet Academician Yevgeni Federov "... made it clear that the Soviets will continue launching satellites with nuclear power plants aboard. In fact, Federov suggested that at least two new types of atomic powered satellites are under development". Federov was

indirectly quoted as saying one of the satellites would be a television relay and the other would be a meteorology satellite with a radar to map storms.[26]

Following the Cosmos 1900 incident, *Izvestia* reported that "The operation of nuclear power plants in radiation-safe orbits opens up broad scope for the introduction of nuclear power on spacecraft with a national economic purpose". The article went on to note that "Nuclear power plants can play an important role on interplanetary flights. According to the assessments of Soviet specialists, a multimegawatt nuclear plant can create the necessary jet thrust for a spacecraft on a flight to Mars".[27]

There have been several recent quotes from the Soviets that they plan to use nuclear reactors for power on a manned mission to Mars, including the possible use of nuclear electric propulsion (NEP or NEJ in Soviet parlance).[28,29,30] One concept calls for a hybrid system -- a direct nuclear thermal rocket that would eventually be used as a closed Brayton cycle power converter for a NEP system.[30]

The Soviets have also shown illustrations of a Mars rover with an RTG and they have spoken of planning unmanned missions to the outer planets, which would clearly require RTGs.

Looking to the future, it is clear that the Soviets intend to continue using nuclear power in space.

#### CONCLUSION

By Western practices, the Soviet Union has a vigorous, ongoing program to develop and employ space nuclear power sources, especially reactors. The two types of reactors that have been flown appear to have been used or are planned to be used for ocean reconnaissance satellites. The Soviets have made it clear that the continued use of space nuclear power is important to their national goals.

#### REFERENCES

1. G. L. Bennett, J. J. Lombardo, and B. J. Rock, "Development and Use of Nuclear Power Sources for Space Applications," *The Journal of the Astronautical Sciences*, Vol. XXIX, No. 4 (October-December 1981).
2. S. D. Strauss, "Romashka in Perspective," *Nucleonics* (December 1964).
3. G. L. Bennett, "On the Application of Nuclear Fission to Space Power," in *Proceedings of the ANS Conference on 50 Years With Nuclear Fission*, held in Washington, D. C. and Gaithersburg, MD, 26-28 April 1989.
4. V. A. Kuznetsov et al. "Development and Construction of the Thermionic Nuclear Power Installation 'Topaz'," *Atomnaya Energiya*, Vol. 36, No. 6 (June 1974).
5. V. A. Kuznetsov et al. "Construction of the TOPAZ Thermionic Reactor-Converter and Its Power Trials," *Sixth International Conference on the Peaceful Uses of Atomic Energy*, Geneva, September 1971.

6. G. M. Grijaznov et al. "Thermionic Reactors for Space Nuclear Power," presentation made at the Sixth Symposium on Space Nuclear Power Systems held in Albuquerque, New Mexico, 9-12 January 1989.
7. A. S. Pushkarsky and A. S. Okhotin, "Methods of Thermal-to-Electric Energy Conversion in On-Board Nuclear Power Plants for Space Applications," Atomic Energy, Vol. 13, No. 2, International Atomic Energy Agency, Vienna (June 1975).
8. N. Zheleznov, "Nuclear Power Plants for Space Vehicles Developed," TASS, Moscow, 5 January 1989.
9. T. M. Foley, "Soviets Reveal Testing in Space of Thermionic Nuclear Reactor," Aviation Week & Space Technology, 16 January 1989.
10. N. N. Ponomarev-Stepnoi, "Nuclear Energy in Space," presentation to the Sixth Symposium on Space Nuclear Power Systems held in Albuquerque, New Mexico, 9-12 January 1989.
11. TRW Space Log 1957-1987, Vol. 23, TRW Space & Technology Group, Redondo Beach, California (undated).
12. N. L. Johnson, The Soviet Year in Space 1987, Teledyne Brown Engineering, Colorado Springs, Colorado, 1988.
13. N. L. Johnson, "Nuclear Power Supplies in Orbit," Space Policy (August 1986). Supplementary information provided in a letter from Mr. Johnson to the author on 25 June 1988.
14. G. E. Perry, "Russian Ocean Surveillance Satellites," The Royal Air Forces Quarterly, Vol. 18, No. 1 (Spring 1978).
15. U. S. Department of Energy, Operation Morning Light, DOE Nevada Operations Office report NV-198 (September 1978).
16. G. M. Grijaznov, "The Concepts of Radiation Safety in Nuclear Power Systems and Its Implementation on Satellite 'Cosmos 1900'," presentation to the Sixth Symposium on Space Nuclear Power Systems held in Albuquerque, New Mexico, 9-12 January 1989.
17. L. Anselmo and S. Trumpy, "Short-Term Predictions of COSMOS 1402 Reentry," The Journal of the Astronautical Sciences, Vol. 34, No. 3 (July-September 1986).
18. P. S. Clark, "The Soviet Space Year of 1983," Journal of the British Interplanetary Society, Vol. 38, No. 1 (January 1985).
19. N. L. Johnson, The Soviet Year in Space: 1983, Teledyne Brown Engineering, Colorado Springs, Colorado, 1984.
20. W. K. Gummer, et al., COSMOS 954. The Occurrence and Nature of Recovered Debris, Canadian Atomic Energy Control Board report INFO-0006 (May 1980).
21. USSR, "Information Furnished in Conformity with the Convention on Registration of Objects Launched into Outer Space," U. N. Document ST/SG/SER.E/72 (29 December 1982) with addenda Add.1 (20 January 1983), Add.2 (21 January 1983), Add.3 (27 January 1983) and Add.4 (9 February 1983).
22. USSR, "Additional Information Furnished in Conformity with the Convention on Registration of Objects Launched into Outer Space," U. N. Document ST/SG/SER.E/176/Add.1 (18 May 1988), Add.2 (15 June 1988), and Add.3 (27 September 1988).
23. USSR, "Communication of the USSR State Committee on the Utilization of Atomic Energy," (undated statement given to the IAEA in 1988).
24. V. Vershchetin, E. Vasilevskaya, and E. Kamenetskaya, Outer Space: Politics and Law, Progress Publishers, Moscow.
25. A. P. Vinogradov, ed., Lunokhod-1 -- Mobile Lunar Laboratory, Joint Publications Research Service publication JPRS 54525, available from National Technical Information Service, Springfield, Virginia (22 November 1971) (Translation of the Russian-language monograph Perdvizhnaya Laboratoriya na Lune Lunokhod-1, signed to press 4 June 1971).
26. T. O'Toole, "Soviets Will Continue Use of A-Powered Satellites," The Washington Post (20 February 1978).
27. N. Zheleznov, "Reactors in Space, Scientists on a New Direction in 21st Century Power Engineering," Moscow Izvestia (16 October 1988).
28. M. Sieff, "Cosmonaut gives insight to Soviets' plans for Mars," The Washington Times (15 February 1988).
29. "Soviets Consider Varied Concepts for 1994 Mars Exploration Flight," Aviation Week & Space Technology (18 July 1988).
30. A. A. Ivanov et al., "Nuclear Power Propulsion System Concept for a Manned Mars Mission," presentation made at the Sixth Symposium on Space Nuclear Power Systems held in Albuquerque, New Mexico, 9-12 January 1989.



## CSTI HIGH CAPACITY POWER

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## ABSTRACT

The SP-100 program was established in 1983 by DOD, DOE, and NASA as a joint program to develop the technology necessary for space nuclear power systems for military and civil application.

During FY86 and 87, the NASA SP-100 Advanced Technology Program was devised to maintain the momentum of promising technology advancement efforts started during Phase I of SP-100 and to strengthen, in key areas, the chances for successful development and growth capability of space nuclear reactor power systems for future space applications.

In FY88, the Advanced Technology Program was incorporated into NASA's new Civil Space Technology Initiative (CSTI). The CSTI Program was established to provide the foundation for technology development in automation and robotics, information, propulsion, and power. The CSTI High Capacity Power Program builds on the technology efforts of the SP-100 program, incorporates the previous NASA SP-100 Advanced Technology project, and provides a bridge to NASA Project Pathfinder.

The elements of CSTI High Capacity Power development include Conversion Systems, Thermal Management, Power Management, System Diagnostics, and Environmental Interactions. Technology advancement in all areas, including materials, is required to assure the high reliability and 7 to 10 year lifetime demanded for future space nuclear power systems. The overall program will develop and demonstrate the technology base required to provide a wide range of modular power systems as well as allowing mission independence from solar and orbital attitude requirements.

Several recent advancements in CSTI High Capacity power development will be discussed.

## INTRODUCTION

As part of the NASA, DOE and DOD SP-100 nuclear space power program, the NASA Advanced Technology Program was devised to maintain the momentum of promising aerospace technology development and to enhance the chances for successful development and growth capability of future space nuclear reactor power systems. In 1988, the

Advanced Technology Program was incorporated into NASA's new Civil Space Technology Initiative (CSTI). CSTI is a \$900 million, 7 year program intended to start the revitalization of NASA's space technology by means of a focused effort in the areas of transportation, operations, and science. SP-100 advanced technology is now a \$65 million, 7 year effort under CSTI Operations called High Capacity Power. The overall goal of this element is to develop the technology base needed to meet the long duration, high capacity power requirements for future NASA Pathfinder space applications such as lunar and planetary bases, high-power-demand electric propulsion systems, and large space platforms.

The funding planned for the remaining 6 years of the program is included in Table 1, which summarizes the funding of each element and lists the totals by element and by year. The FY88 expenditures totalled \$12.8 million, of which \$10 million was for GES support. SDIO has contributed approximately \$500,000/year to the advanced technology work from FY86 through 89. Present plans show \$1 million/year from SDIO for SP-100 advanced technology in FY90, 91 and 92.

## CSTI HIGH CAPACITY POWER

The High Capacity Power program will focus on the development of key aerospace technology in the areas of Energy Conversion, Advanced Materials, Thermal Management, Power Management, System Diagnostics and Environmental Interactions. Program Management is located in the Office of Aeronautics and Space Technology (OAST) at NASA Headquarters. Project Management is located at NASA Lewis Research Center in the Power Technology Division of the Aerospace Technology Directorate. The advanced thermoelectric energy conversion element is carried out at Jet Propulsion Laboratory in Pasadena, California.

A Systems Analysis and Missions Support element is used to assess the benefits from technology advancements in all areas, and to show how new technology impacts future NASA missions. Figure 1 illustrates the goal of the High Capacity Power project in terms of increased power as well as higher specific power available from the GES reactor when all technology goals are met.

The overall project roadmap is shown on Fig. 2. The timing was originally intended to