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Chapter 25

Soviet Space Nuclear Reactor Incidents: Perception Versus Reality

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Since the Soviet Union reportedly began flying nuclear power sources in 1965 it has had four publicly known accidents involving space reactors, two publicly known accidents involving radioisotope power sources and one close call with a space reactor (Cosmos 1900). The reactor accidents, particularly Cosmos 954 and Cosmos 1402, indicated that the Soviets had adopted burnup as their reentry philosophy which is consistent with the U.S. philosophy from the 1960s and 1970s. While quantitative risk analyses have shown that the Soviet accidents have not posed a serious risk to the world's population, concerns still remain about Soviet space nuclear safety practices.

Introduction

The reentry over Canada of the Soviet reactor-powered 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, especially its safety philosophy. As a direct consequence of the reentry of Cosmos 954, the United Nations has been actively considering supplementing the norms of international law regarding the use of nuclear power sources (NPS) in outer space (Bennett et al. 1989). The inadvertent reentry of the Cosmos 1402 reactor core over the South Atlantic Ocean on 7 February 1983 only served to increase the concerns in this area. Moreover, the Soviet incidents have been cited in articles which have criticized the U.S. space nuclear power program (see, for example, Deudney 1984, Finn 1984, McGrory 1988, and Roberts 1983).

Given the foregoing situation it is instructive to look at the Soviet space nuclear reactor incidents to determine if perception and reality agree. Particular attention will be focused on Cosmos 954 because that reentry occurred over land, thereby allowing the collection of considerably more data than in the case of Cosmos 1402.

Safety Philosophy

From a safety philosophy viewpoint the 1978 reentry of Cosmos 954 indicated that the Soviet Union had apparently adopted the same reentry safety philosophy as the U.S. had in the 1960s and 1970s, namely, burnup to reduce doses and to eliminate the possibility of recriticality in the event of a reentry accident. In a 1980 working paper distributed to the Working Group on the Use of Nuclear Power Sources in Outer Space (WGNPS) of the Scientific and Technical Subcommittee (STSC) of the U.N. Committee on the Peaceful Uses of Outer Space (COPUOS), the Soviet delegation (USSR 1980) listed three principles ". . . for ensuring population safety in connexion with the use of NPS on board space vehicles:

"1. The use of NPS on board space vehicles is socially justified in the light of the benefits that mankind can gain from progress in the conquest of space.

"2. In order to ensure population safety, it is necessary to preclude any uncontrolled return of an NPS to earth after the reactor has been brought up to criticality. To this end, NPS that are used on board space vehicles with low working orbits must be equipped with a primary radiation safety system which will boost the NPS to a long-duration orbit after completion of the programme or in the event of a disturbance in the normal operating conditions of the NPS or of any malfunctions in the systems of the space vehicle that could result in its uncontrolled return to earth.

"3. If the boost system fails, the NPS must be equipped with a back-up radiation safety system (BRSS) that will disperse the reactor core in such a way that in the case of maximum fall-out the equivalent radiation doses absorbed by the population living in the contaminated area will not exceed 0.5 rem during the first year after the contamination. In this case, the risk associated with radiation over the entire area of the fall-out will not exceed the risk resulting from natural environmental factors."

The Soviets listed two methods for ensuring radiation safety as a result of an accidental reentry of a reactor (USSR

1980):

"–The method of aerodynamic destruction of the reactor and dispersion of the fuel composite into particles whose fall-out to the earth's surface results in radiation that does not exceed the acceptable level;

"–The method of chemical dispersion of the reactor core, with the solution products being ejected and scattered into space."

The Soviets also stated that "The principal method of ensuring the radiation safety of the NPS during the various stages from manufacture to launch is to prevent the reactor from reaching criticality until after the space vehicle has entered its prescribed orbit. The reactor is so designed that the control devices remain fixed in the extreme subcritical positions." (USSR 1980).

In 1981, the Soviet delegation to the WGNPS formally supported the following safety criteria for nuclear reactors: provide for a reboost if reactors are operated in low Earth orbit (LEO) and "In the event of an unsuccessful boost into higher orbit the system should in all credible circumstances be capable of dispersing the radioactive material so that when the material reaches the earth the radiological situation conforms to the recommendations of ICRP (International Commission on Radiological Protection) when relevant." (U.N. 1981).

However, throughout the Cosmos 954 and Cosmos 1402 incidents and the U.N. debates, the Soviet Union did not and still has not provided the detailed safety analyses (such as safety analysis reports) and other technical documentation (such as design reports) that would support that they meet their own criteria.

Radiological Aspects of Cosmos 954

The Canadians estimated that " . . . perhaps 20% (4 kg) of the fuel from Cosmos 954 came to earth" and was spread over some 100,000 square kilometers of land and water (Gummer et al. 1980). The Canadian airborne measurements " . . . provided further evidence that the Cosmos-954 reactor had completely disintegrated on entering the earth's atmosphere and that the major area of radioactive contamination was concentrated on Great Slave Lake. However, the most contaminated area on the lake was found to be considerably less radioactive than the natural radioactive background from rocks in the surrounding area". (Grasty 1978).

In terms of assessing how well the Soviets met their own criteria it is instructive to review the conclusions in the Canadian Atomic Energy Control Board report on Cosmos 954 (Gummer et al.1980):

- The total deposition per unit area of ^{90}Sr and ^{137}Cs would have been approximately one-fourteenth of the amount received in the Yellowknife area in 1973 from weapons testing fallout;
- The impact on the environment of the unrecovered particles is likely to be insignificant when compared with the fallout deposition that exists currently;
- The inventory of activation products will be a small fraction of the fission product inventory;
- Residual hazards to people from direct radiation were considered negligible because the core had disintegrated; and
- The effects of the debris on any identified or observed part of the natural environment are considered to be insignificant.

A follow-on health impact study by the Canadian Radiation Protection Bureau included these conclusions (Tracy et al. 1984):

- The particles were found to be largely insoluble in water and in dilute acids that approximate digestive juices;
- Field investigations showed no detectable contamination of air, drinking water, soil, or food supplies; and
- Encountering radioactive debris during or after 1983 would give rise to doses that are insignificant from the viewpoint of public health.

In a recent DOE-sponsored report it was estimated that less than 0.07 excess cancer fatalities might result from the reentry of Cosmos 954 (Bartram and Englehart 1988). Similar low consequences were reported in earlier studies by delegations from Japan and the United Kingdom (Japan 1979 and U.K. 1980). The unfortunate aspect of these studies is that it took an accident for them to be made since apparently the Soviets had no publicly available safety studies. In fact, Soviet information on Cosmos 954 was of little use in the search and recovery operation and what little

Table 1 *Estimated RORSAT Reactor Parameters.*

Parameter	Value
Thermal power	≤100 kWt
Conversion System	Thermoelectric
Electrical Power Output	≤5 kWe (~1.3 kWe to 3 kWe)
Fuel Material	U-Mo (≥3 wt% Mo)
Uranium-235 Enrichment	90%
Uranium-235 Mass	≤31 kg (~20 kg to 25 kg)
Burnup	≤2 × 10^{18} fissions/gram of U
Specific Power	~5 Wt/g of U
Core Arrangement	37 cylindrical elements (probably 20-mm in diameter)
Cladding	Possibly Nb or SS
Coolant	NaK
Coolant Temperature	≥970 K (outlet)
Core Structural Material	Steel
Reflector Material	Be (6 cylindrical rods)
Reflector Thickness	0.1 m
Neutron Spectrum	Fast (~1 MeV)
Shield	LiH (+W & depleted U)
Core Diameter	≤0.24 m
Core Length	≤0.64 m
Control Elements	6 in/out control rods composed of BC_2 with LiH inserts to prevent neutron streaming and Be followers to serve as the radial reflector
Overall Reactor Mass	<390 kg

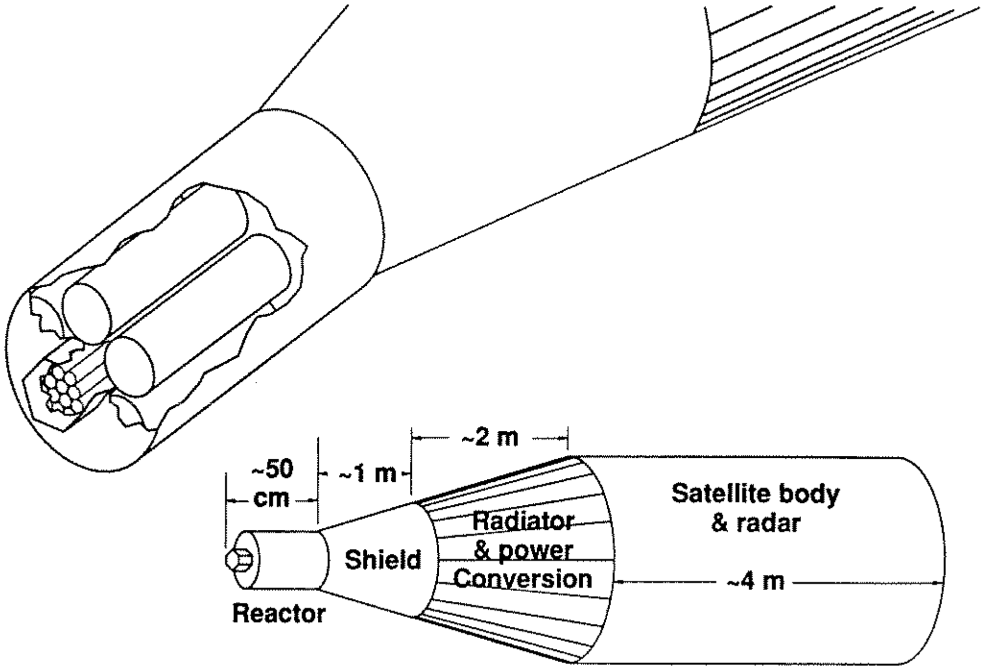

Figure 1 Artist's Concept of Cosmos 954 showing the Reactor.

information was provided would be considered extremely inadequate for typical Western emergency planning.

RORSAT Reactor

Based on an analysis of the Cosmos 954 data and other information, Table 1 was constructed to illustrate the estimated RORSAT reactor parameters. Figure 1 is an artist's concept of Cosmos 954 and Figure 2 is an engineering sketch of the general features of the Cosmos 954 reactor (Bennett 1989).

Cosmos 1402 and Cosmos 1900

According to various sources, the Soviets apparently made changes in both the design and operation of their RORSATs following the Cosmos 954 reentry (Johnson 1984, Johnson 1986, and Anselmo and Trumpy 1986). At the time of the Cosmos 1402 incident in 1983, the Soviets reported that, upon completion of its work, Cosmos 1402, " . . . on command from earth, ended its active existence on 28 December 1982. The safety system with which the satellite was equipped then split it into three fragments, one of which burnt up on entry into the dense layers of the atmosphere on 30 December 1982. The two remaining fragments consist of the main part of the satellite structure and the reactor core, which has been separated from it. Before the satellite was split into fragments, the reactor was shut off on command from earth . . . The extraction of the core from the reactor ensures that the core will burn up in the dense layers of the atmosphere and be dispersed into fine

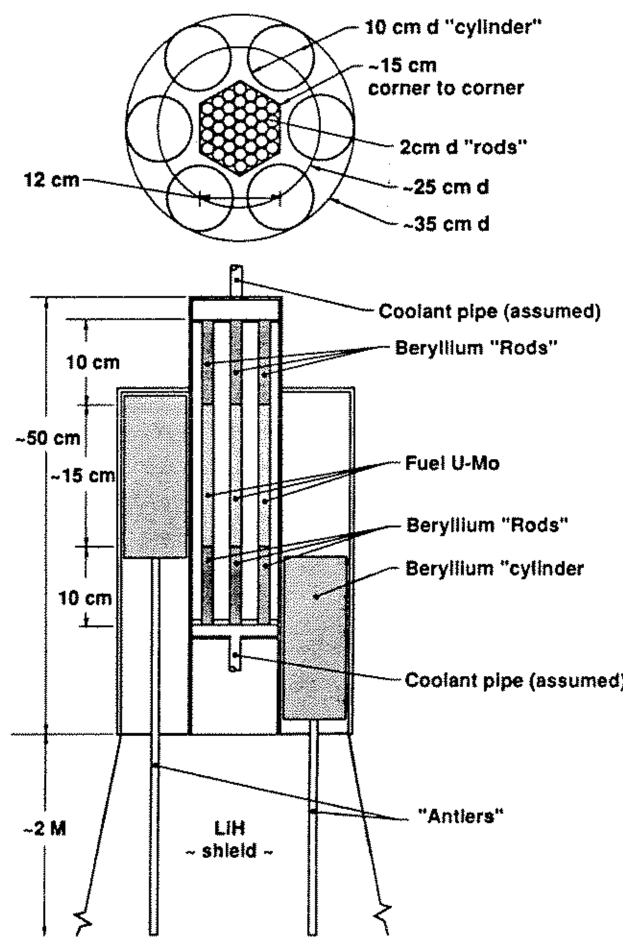

Figure 2 Engineer's Sketch of the Cosmos 954 Reactor.

Table 2 *Reentries of Soviet Space Nuclear Power Sources.*

Name	Launch Date	Reentry Date	Type of Power Source	Comments
—	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 ^{210}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 3 *Soviet Orbital Reactor Program History.*[a]

Number	Name	Launch Date	Termination Date	Lifetime
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

[a]Sources include references Bennett 1989, Griaznov 1989, Gummer et al. 1980, and Johnson 1986. Note: The Cosmos 1900 reactor continued to operate past the 124 mission lifetime.

particles . . . Radiation after the fragments of Cosmos 1402 enter the dense layers of the atmosphere will be within the limits recommended by the International Commission on Radiological Protection''. (USSR 1982). In essence, the boost operation had failed to occur and the core was ejected to facilitate burnup.

On 7 February 1983, the Soviets notified the U.N. that " . . . on 7 February 1983, at 1356 hours Moscow time, a fragment consisting of the reactor core of the nuclear energy unit entered the dense layers of the atmosphere over the southern part of the Atlantic Ocean and was completely burnt up.

"From that time Cosmos-1402, launched in the Soviet Union on 30 August 1982, completely ceased to exist." (USSR 1982).

A DOE-sponsored study estimated the health effects from the assumed complete reentry burnup of Cosmos 1402 as less than 0.03 excess cancer fatalities (Bartram and Englehart 1988). Soviet representatives informed the author that Cosmos 1402 (and Cosmos 1900) were of a new design that would completely burn up on reentry so that no activated components would reach the ground as happened with Cosmos 954 (Bennett 1988). Again, unfortunately, the Soviet Union has provided no technical documentation to support their assertions of complete burnup.

At the time of the Cosmos 1900 incident, in which the Soviets could not command the reactor's safety systems and the reactor was still operating, the Soviets reported that the RORSATs had two autonomous safety systems. The first safety system was designed to separate the reactor part of the spacecraft and boost it to a higner orbit if any anomalies were detected. If there was a failure to boost the reactor, the second safety system would operate along the same lines as on Cosmos 1402 and eject the core (Bennett 1988). The Soviets have said the combined probability of having a failure to boost and a failure to separate and disperse is 10^{-4} (Griaznov 1989). Again, the Soviets have failed to provide the kind of supporting documentation that the U.S. regularly provides on its space nuclear power systems.

Triggering events for the boost of Cosmos 1900 were reported to include (Griaznov 1989 and Bennett 1988):

- Failure of the stabilization system,
- Failure of the thermoelectric conversion system (power failure),
- Temperature increase in the reactor,
- Failure to establish a time sequence,
- Increase or decrease in voltage, and
- Loss of integrity of the main instrumentation section of the satellite.

While the Soviets have described in general terms which triggering events could have occurred at specific altitudes, they have not specified exactly which one caused Cosmos 1900 to boost (Griaznov 1989). In any case on 30 September 1988, the reactor was placed in an orbit 693 × 761 km with an inclination of 66.1 degrees (*Aerospace Daily* 1988). A DOE-sponsored study estimated the "pre-boost" risk of Cosmos 1900 as ranging from less than 0.05 to less than 0.2 excess cancer fatalities for a reentry depending on whether or not the core was ejected before reentry. Given that Cosmos 1900 successfully reached its storage orbit, the long-term risk associated with a reentry of the Cosmos 1900 core in about 500 years was estimated to be less than 0.005 excess cancer fatalities (Bartram and Englehart 1988).

Table 2 summarizes what is publicly known about Soviet reentries involving nuclear power sources. Table 3 provides a listing of publicly identified Soviet space reactor launches (Johnson 1986). More information on what is publicly known about the design features of the Soviet reactors may be found in Bennett 1989.

The one remaining open question concerns the new generation of space reactors which the Soviets launched in 1987 (Cosmos 1818 and Cosmos 1867) (Bennett 1989). These spacecraft with their TOPAZ thermionic reactors were placed in 786-km by 800-km orbits which presumably will enable them to remain in orbit for over 300 years. The ultimate reentry mode (intact or burnup) has not yet been specified.

Conclusion

In terms of the original question of perception versus reality, the publicly available evidence suggests that the Soviets have apparently addressed the various safety issues associated with their use of nuclear reactors. The evidence also suggests that the Soviet reentry philosophy is consistent with WGNPS safety criteria. Canadian, Japanese, U.K., and U.S. studies have shown that the actual risk from an accidental RORSAT reentry is much less than the perceived risk. However, perceptions cannot be ignored. The facts remain that the Soviets continued to operate reactors in LEO despite public concerns and the Soviets have not provided the kind of design information or safety analysis reports that would demonstrate that they are operating their reactors in a safe mode. It is hoped that the advent of *glasnost* will provide an opportunity for more openness in the Soviet space nuclear power program.

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