1985

The Sky is Falling: Managing Space Objects

William B. Wirin
North American Aerospace Defense Command

Published in:

Proceedings of the Twenty-Seventh Colloquium on the Law of Outer Space, International Institute of Space Law of the International Astronautical Federation, Lausanne, Switzerland, October 7–13, 1984

Published by American Institute of Aeronautics and Astronautics
New York, 1985.

THE SKY IS FALLING

Managing Space Objects

William B. Wirin*

For presentation at the XXXV Congress of the International Astronautical Federation Colloquium on Cooperation in Space to be held by the International Institute of Space Law during the Congress of the International Astronautical Federation, October 8-13, 1984, Lausanne, Switzerland.

The opinions and conclusions expressed in this paper are those of the Author and do not necessarily represent the views of the Department of Defense, the Department of the Air Force, North American Aerospace Defense Command, Space Command, or the United States Government.

Abstract

All countries who launch space vehicles need to focus their attention on steps necessary to prevent damage to mankind by space objects. The 1967 Outer Space Treaty outlines a nation's liability but not the prevention of such damage. Nuclear power sources (NPS), in particular, demand special procedures and precautions. This paper will discuss the reentry into the earth's atmosphere of radioactive materials (such as occurred with COSMOS 954 and COSMOS 1402), the catalogue of space objects maintained by NORAD, and measures which should be taken to avoid damage to or by space objects and debris. The space catalogue presents the opportunity to avoid disaster.

COSMOS 954

0653 Eastern Standard Time January 24, 1978 was a milestone in the evolution of space law--COSMOS 954's orbit reached final decay, marking the first time that nuclear material would reenter the earth's atmosphere from space and strike the earth's surface. Soon after COSMOS 954's reentry, radioactive material was detected by Canada in the sparsely inhabited area southeast of the Great Slave Lake and radioactive debris was scattered over 124,000 square kilometers in the Northwest Territories. This event brought into play the previously untested Convention on International Liability for Damage Caused by Space Objects.[1]

Very suddenly, almost six years after the Liability Convention was signed, its provisions would be put to the test. Article II of the Liability Convention provides that, "A launching state shall be absolutely liable to pay compensation for damage caused by its space objects on the surface of the earth." In the Convention, "damage" is defined in Article I(a) as meaning, "loss of life, personal injury, or other impairment of health; all loss of or damage to property of states or of persons, natural or juridical, or property of international intergovernmental organizations.[2] This particular incident did not pose any definitional problems of "launching state" or whether COSMOS 954 was a "space object." The term "damage" as used in the Convention, however, does not specify injury resulting from nuclear radiation. It is interesting to note that four years earlier A. I. Ioyrysh, a Soviet writer, observed, "The Convention applies to all kinds of damage including nuclear damage.[3]

COSMOS 954 caused some damage by destroying trees and vegetation, but the primary damage was the radioactive residue. It was indeed fortunate that the area was not inhabited and that there was no loss of life or personal injury. Within minutes after COSMOS 954 impacted, the Government of the United States made an offer of assistance to help the Canadian authorities with their emergency operations. This offer was accepted and Operation Morninglight began and did not end until over three months later on April 17, 1978. In order to preclude possible impairment of health, the Canadian Government went to great lengths to remove all radioactive material plus flora and soils that had become radioactively contaminated. The total cost amounted to $13,970,143.66 (CDN).

COSMOS 954 had been launched by the USSR on September 18, 1977. The Soviets described its official objective as the exploration of outer space. Some authors have concluded, however, that it was a satellite whose purpose was to support the Soviet ocean surveillance program.[4] The initial contact by the Canadian Government to the USSR was on January 24, 1978 by the Department of External Affairs which expressed surprise to the Ambassador that the Government of Canada had not previously been notified of the possible reentry of the satellite into the earth's atmosphere over Canada. Additionally, the Ambassador was queried whether there was a nuclear reactor on board and asked for an urgent response.

Later that day the Ambassador of the USSR advised that the satellite had been expected to reenter the earth's atmosphere in the area of the Aleutian Islands. "In case it did not burn out completely in the atmosphere...there should not be any sizable hazard and that in places of impact there could only be insignificant local pollution requiring very limited measures of disactivation." The construction of the nuclear reactor on board the satellite was designed so that it would be destroyed by reentry through the dense layers of the atmosphere.[5] The Ambassador expressed the Soviet Union's readiness to render urgent

*Juris Doctor, Staff Judge Advocate, HQ North American Aerospace Defense Command, HQ Aerospace Defense Command, and HQ Space Command, Colorado Springs, Colorado USA; Member, International Institute of Space Law (IISL), American Institute of Aeronautics and Astronautics (AIAA), American Bar Association committees: Forum Committee on Air and Space Law, and International Law Division.

assistance to ameliorate the possible adverse circumstances and remove any remains of the satellite. The Canadian Government rejected the offer of assistance and again asked for answers as to the nature of the nuclear reactor on board the satellite. In response to Canadian inquiries, the Soviet Union on March 21, 1978 stated that, "The power unit of the COSMOS 954 satellite was an ordinary nuclear reactor working on uranium enriched with an isotope of Uranium-235...The reactor's active zone was a set of heat-emitting elements with a Beryllium reflector." In its further note of May 31, 1978, the Soviets added, "The Beryllium reflector included six moving elements that have already been found (one by Canadian authorities) and several tens of rods of cylindrical form." The United States Department of Energy concluded, "It was thought to be a 100-kilowatt or less reactor estimated to contain in the order of 50 kg of highly enriched U-235."[6]

Operation Morninglight was continued by Canada and United States authorities until they were certain they had located and retrieved all radioactive material that survived reentry into the earth's atmosphere.

THE CLAIM

The Canadian Government took the unusual step of making public its claim and cost incurred by it.[7] It argued under the Liability Convention that the Soviet Union, the launching state, was absolutely liable. The Soviet Union was not interested in the return of any of the debris so as to avoid the provisions of the 1968 Rescue Treaty. Under Article 5, paragraph 5, "expenses incurred in fulfilling obligations to recover and return a space object or its component parts under paragraphs 2 and 3 of this article shall be borne by the launching authority." Both paragraphs 2 and 3 provide for the launching state to "request" assistance before an obligation arises to "take such steps as it finds practicable to recover the object or component parts".[8] The essence of the position on this treaty was that by notifying Canada it did not seek return of the debris; the USSR avoided the financial obligations imposed.

The Soviets observed in their note number 37 of May 31, 1978 "that the radiation situation over the entire examined territory judging by the level of external radiation could be recognized as practically safe for population. In similar conditions further search on the Soviet Union's territory would evidently be discontinued."[9] The Soviets maintained that they had a duty to participate in the search and recovery of the debris of the satellite and were disappointed at not being afforded the opportunity. Article XXI of the Liability Convention provides that a launching state shall, upon request, examine the possibility of rendering appropriate and rapid assistance when the damage caused presents a large-scale danger. However, the article specifically provides that nothing in the article shall affect the rights and obligations of the state's parties.[10] Article 5, paragraph 4, of the Agreement on the Rescue of Astronauts, The Return of Astronauts, and the Return of Objects Launched Into Outer Space provides that a State discovering hazardous or deleterious material within its territories "may so notify the launching authority, which shall immediately take effective steps" to eliminate possible danger.[11] Thus while a duty of assistance can arise because of the word "may," it is only after a request has been made by the injured state. In no way does the failure of an injured state to request or permit assistance lessen the liability of the launching country.

Although the total cost amounted to $13,970,143.66 (CDN), Canada decided to seek only incremental expenses. That is, costs that would not have been incurred had the incident not taken place. Thus, the salaries of military and public servants involved in Operation Morninglight were not included although overtime, transportation, and maintenance costs incurred by them as a direct result of the operation were included. The claim brought against the Soviet Union amounted, then, to $6,041,174.70 (CDN).

Canada and the Soviet Union proceeded to settle the claim pursuant to direct negotiations as envisioned by Article IX of the Liability Convention. The provisions of this article require that a claim related to damage caused by space objects should be brought to the launching state through diplomatic channels. If a settlement through diplomatic negotiations is not reached after one year, then a claims commission may be established. Under Article XII, the compensation which the launching state shall be liable to pay for damage under this Convention shall be determined in accordance with international law and the principles of justice and equity, in order to provide such reparation in respect of the damage as will restore the person, natural or juridical, state or international organization on whose behalf the claim is presented to the condition which would have existed if the damage had not occurred. After three rounds of diplomatic negotiations, Canada and the Soviet Union reached a settlement on November 21, 1980 and a formal protocol was signed which provided for payment of 3 million Canadian dollars in full and final settlement of all matters connected with the disintegration of the Soviet satellite COSMOS 954.

Whether or not that was ample and just compensation clearly is debatable. The USSR's position was that the cleanup efforts by Canadians were unreasonable and were not proportional to the radioactive hazard present. Suffice it to say, Article XII relies upon international law and the principles of justice and equity in determining an appropriate compensation--vague terms of reference at best. While useful as guides in most instances they are less helpful when applied against the uncertain effects of radioactivity. What is important is that the two States involved were able to resolve the liability issues amicably and that it was not necessary to resort to a claims commission provided for in Article XV or other international procedures for the resolution of disputes.

COSMOS 1402

Following COSMOS 954, COSMOS 1402, another ocean surveillance satellite, began to malfunction in late 1982. It had been launched on August 30, 1982 to search for and track American and allied ships with its radar.[12] This satellite, as the previous ones in this series, was powered by a nuclear reactor. TASS acknowledged on January 15, 1983 that the fuel elements were made of Uranium-238 enriched with Uranium-235 and encased with a beryllium reflector. In order to preclude reentry, as occurred with COSMOS 954 with a rugged reactor housing, the Soviets developed a way to eject the fuel core from the reactor. This new safety system involved having the satellite split into three pieces after the radar ocean surveillance mission was completed. Two of the pieces remain in low earth orbit while the third, the nuclear reactor, is boosted into a higher orbit. COSMOS 1402, however, failed to kick the radioactive fuel core into a debris storage orbit. The reactor housing reentered the earth's atmosphere over the Indian Ocean on January 23, 1983 with the fuel core, according to the Soviets, coming down some two weeks later on February 7, 1983 in the South Atlantic, off the coast of Argentina. Neither Part 1 or 2 of COSMOS 1402 caused any damage. There were no ships in the immediate impact areas and the depth of the ocean effectively prevented any injury.

NPS ISSUES

Clearly it was beneficial for the various states to have concluded the Liability Convention. Now, as the number of objects in space increases, it is necessary for the respective states to come together again and devise means of reducing the likelihood of damage from space objects falling back to earth--particularly those possessing radioactive materials.[13]

What then of the risks that nuclear power sources pose? Is it then safe to conclude that these concerns are now behind us and therefore we should turn our attention to more viable space law issues? I don't believe so. Past spacecraft have fulfilled their missions by and large with one or two kilowatts of power; however, the next generations will call for up to hundreds of kilowatts of continuous power plus an effort to reduce volume, mass, and cost. Designers will be comparing photovoltaic, electrochemical battery systems, and nuclear reactors.[14]

While the exact context of this issue remains to be seen, Dr. George E. Mueller's words are true: "What I can predict with absolute certainty, however, is that there will be a great diversity of operations in space by the end of the century. And we currently lack an accepted set of laws and international agreements to effectively deal with this new environment. It took centuries to develop a comprehensive body of law to govern here on Earth. We have perhaps a decade to develop a comprehensive <u>and</u> <u>acceptable</u> body of law for space."[15]

The approaches to the use of nuclear power sources lie in the safer use rather than the elusive goal of a no-risk regime.[16]

Nuclear power sources offer the advantage of high-power capacity, long life, compact size, and the ability to function independently of solar radiation. They, however, as we've seen, pose significant risk in the event the nuclear fuel lands on the earth or other celestial bodies. Therefore, their use must take into consideration the risks as well as the benefits and achieve a balance. In this balancing, three factors must be carefully evaluated. First, the essential nature of the space mission; second, the existence of alternate power sources to accomplish a particular purpose; and third, the maximization of safety precautions. These are, in turn, compared to the potential detriment to mankind through injuries and political costs.

Whether or not a given space mission is essential is, however, a political question and as such is beyond the scope of this paper. Nonetheless, it is appropriate to observe that if a nation determines that a particular space mission is truly essential for its political, military, or economic survival, then it will turn to nuclear power sources--regardless of the other constraints.

NPS USES

Turning now to a brief review of power systems, nuclear power sources do have their advantages: continuous and predictable output of heat, very reliable power output in useful wattage ranges, long service lifetime, low weight per power output, compact structure, adaptability to any spacecraft, resistance to radiation and meteorite damage, and complete independence from the sun. There are also two types of nuclear systems. One is a nuclear reactor and the other, which has been more widely used by the United States, employs radioisotopes. Radioisotopes are unstable and thus undergo a decay process which emits energy as heat. Heat is converted into energy in various ways, but in the US space program dissimilar metals are joined in a closed ciruit and the two functions are kept at different temperatures producing electric voltage. Plutonium-238 with a half life of 87.7 years is used as the heat source in US space missions. These radioisotope thermoelectric generators (RTG) have been used by the US on 23 space systems.[17] Only on one occasion, the SNAP 10A (Systems for Nuclear Auxiliary Power), was a nuclear reactor used. The Soviet Union is believed to have launched at least 19 reconnaissance satellites, including COSMOS 954 and COSMOS 1402, powered by nuclear reactors.[18]

Solar arrays, fuel cells, and chemical batteries each have limitations. Solar arrays work well for orbital missions and those moving toward the sun. However, as a satellite moves away from the sun, the energy developed drops off dramatically making solar energy impractical. Fuel cells and chemical batteries have a limited life and cannot produce great amounts of energy. RTGs are also limited because of the direct relationship of weight to power output. Bennett and Buden suggest the following missions for which nuclear reactors may prove to be the optimum power sources:

<u>Orbital Applications</u>

Communications system requiring only small, low power, earth-based transmitters/receivers

Remote sensing of the earth

Electrical power supply for a manned space-based space exploration

<u>Space Exploration</u>

Nuclear electrical propulsion

Electrical power supply for manned or unmanned deep space probes

Electrical power supply for bases established on planetary bodies in the distant future

NPS RISK MANAGEMENT

Experience teaches us that technology marches on and that new methods will replace the old ones. But in the mean time, it does not behoove us to abandon a means of accomplishing space exploration because there are risks involved. The sensible approach is to manage the risks.

The Working Group on the Use of Nuclear Power Sources in Outer Space, a subcommittee of COPUOS, was established in accordance with General Assembly Resolution 33/16 of November 10, 1978. The February 6, 1981 report of the Working Group reaffirmed that nuclear power sources can be used safely in outer space provided that all necessary safety requirements are met.[19] The report went on to recommend that the question of the use of nuclear power sources in outer space be retained as a priority item and that member States continue to carry out studies.

And the Special Political Committee in its 18th meeting held in New York in November 1983 continued the lively debate on the use of nuclear power sources in outer space. Viri Pavlovsky of Czechoslovakia observed that to forego the use of nuclear power sources in space would be tantamount to establishing a barrier to scientific progress and would delay the exploration of space for peaceful purposes.[20] Sweden proposed that there be a moratorium until use is regulated.[21] Canada reaffirmed its concern on the issues of responsibility of states engaged in using NPS, adequate safety measures, and assistance to states affected.[22] Iraq felt there should be a minimum number and they should be in a prescribed orbit.[23] Austria welcomed the format on notification of malfunctions and hoped there would soon be agreement on safety standards and assistance in case of accidents.[24]

The essence of the 1981 Working Group thoughts on safety procedures was that design should assure a high probability of successful launch, start of the operations in orbit, and, where use was intended for low earth orbit, successful boosting of the NPS to a higher decay orbit. If boosters were not successful, the system should be capable of dispersing the radioactive material so that if it reaches the earth, radiation does not exceed the recommendations of the International Commission on Radiological Protection (ICRP) in Document Number 26. Additionally, prior to launch, an assessment of the collective and individual dose equivalents must be carried out for all phases of the proposed space mission. The Working Group noted the ICRP recommends an annual dose equivalent for workers of 50mSu (5 rem) whole body dose and an annual dose equivalent limit for the most highly-exposed members of the public of 5mSu from all man-made sources.[25]

The United States safety regime includes an Interagency Nuclear Safety Review Panel composed of three coordinators appointed by the Secretary of Defense (DOD), the Administrator of the National Aeronautics and Space Administration (NASA), and the Secretary of Energy (DOE). The Nuclear Regulatory Agency, the Environmental Protection Agency, and the National Oceanic and Atmospheric Administration also participate in these reviews. The safety review ascertains whether the risks associated with the use of NPS are commensurate with the benefits. The policy of the United States in using RTGs following SNAP 9A[26] was to design the container so that all nuclear material would survive intact regardless of the nature of an accident. Reentry and impact on earth were specifically envisioned and this occurred on the May 18, 1968 launch of NIMBUS-B1. The range officer aborted the launch at an altitude of 30 kilometers over the Santa Barbara channel and the RTG capsules were recovered without incident. The US policy is to reduce the risks when using nuclear reactors. When SNAP 10A was launched in 1965 with a nuclear reactor, the following steps were taken: the reactor was launched in a subcritical mode, the reactor was designed to remain subcritical at or after impact should it reenter the atmosphere before startup, and reactor startup was delayed until it had reached orbit. The almost circular polar orbit should last some 4000 years before decay in the earth's atmosphere. Additionally, the nuclear reactor package was designed to disassemble on reentry.[27] It, therefore, should pose no risk to earth.

Design for safety, however, must include not only system design but also mission design. The methods to reduce risks include confinement and containment (used with RTGs), dilution and dispersion (nuclear reactors), delay and decay (boosting into a decay orbit), and possibly retrieval and reboost (using a vehicle like the shuttle).[28]

The United States is now developing the Space Power Advanced Reactor (SPAR) power plant. It is being designed to have a power range of 10 to 100 kilowatts with growth potential up to 400 kilowatts. It is hoped that it will have a conversion efficiency of nine percent. The significance is that a 100-kilowatt SPAR may be able to deliver three times more payload to geosynchronous orbit than the three-stage chemical Inertial Upper Stage (IUS).[29] Multimegawatt space reactors will most likely require a different set of technologies which are now being explored. A design concept shold be selected by 1991.[30]

SPACE CATALOGUE

One of the missions of the North American Aerospace Defense Command (NORAD) is to maintain the catalogue of space objects. This requires over 20,000 daily observations. The NORAD Space Surveillance Center (NSSC) maintains accurate positional data on all man-made objects in earth orbit. The primary function of this catalogue is to alert the NORAD commander to a decaying space object so that it will not be mistaken for a reentering intercontinental ballistic missile (ICBM). The Tracking Impact Prediction (TIP) program focuses attention on all space objects which are due to decay within 20 days--if there is greater than five percent possibility that the space object will survive reentry and strike the earth. This program considers debris which has a radar cross-section greater than one square meter and all payloads, rocket bodies, and platforms--regardless of size. From the time that a decaying object comes under scrutiny, it is tracked carefully because its rate of decay is not exactly predictable--the more observations, the more accurate a prediction. A difficulty with predictions, however, is that space objects starting to decay may tumble and spin, causing their orbits to change more quickly than more stable orbiting bodies. Additionally, the earth's atmosphere has similar properties to a body of water which can cause some reentering space objects to "skip along the surface."

The predominant factor which affects predictions, however, is the earth's weather and its effects on low earth orbit as space debris typically has no well-defined aerodynamic properties. An additional consideration is that the earth is not round; therefore, the gravitational pull of the earth varies as a satellite orbits. And the density of the atmosphere varies above the earth's surface so a satellite encounters different amounts of drag during its orbit.[31] While there may come a point in time that technological breakthroughs will make reentering predictions more reliable, at the present time there is a degree of error. The error factor in computations of the TIP program is plus or minus 20 percent from the time of the last observation to the time of the predicted decay.

Therefore, as time passes, and the time for reentry comes closer, the window gets smaller. NORAD very carefully tracked COSMOS 954 and 1402 parts 1 and 2. I was in the NORAD Command Post in Cheyenne Mountain during the final hours of the COSMOS 1402 decay and it was not until the two-hour point prior to impact that there was any degree of confidence that the landing would be benign. One minute is equal to roughly 300 miles. However, because of the possibility that the reentering space object might "skip," no official statements could be made as they could result in either a false sense of security or panic, depending upon the circumstances.

SENSORS

Information on COSMOS 954, COSMOS 1402, and other satellites comes from dedicated sensors, contributing sensors, and collateral sensors. Dedicated sensors are those under the operational control of NORAD with a primary mission of space track support. These include NAVSPASUR, GEODSS, Baker-Nunn, and San Miguel. NAVSPASUR, or the United States Naval Space Surveillance System, is an electronic fence stretching 3000 miles across the southern United States. It is located at approximately 33 degrees north latitude and detects all space objects which break the plane of the screens. GEODSS is the Ground Based Electro-Optical Deep Space Surveillance System which has, as its name implies, the mission of supplying information on space objects a great distance from the earth. Sites are currently located in Soccoro, New Mexico; Taegu, Korea, and Maui, Hawaii. Two more are planned--one in Diego Garcia in the Indian Ocean and another in Portugal. The system is sophisticated--coupling an optical telescope, a low-light level television camera, and a computer. It does a highly complex operation very quickly; however, it must rely upon a clear, night sky. Thus poor weather impairs the quality and timeliness of GEODSS information necessary to update the catalogue. It is, however, capable of detecting and collecting data from 5000 to 35,000 kilometers or more. Each site has three telescopes capable of performing search and track functions as well as space object identification.

Baker-Nunn cameras are the predecessors of GEODSS and are being phased out. This system relied upon photographs which had to be developed and then analyzed before the information could be passed to NORAD. However, without this approximate hour and a half delay, GEODSS can see an object 1000 times dimmer. In addition to GEODSS, the tracking radar at San Miguel, Philippines, is also dedicated to space track support and the equipment there consists of a GPS-10 mechanical tracker.

The contributing sensors are non-NORAD sensors which are under contract to the United States Air Force to provide space track support upon request. These mechanical trackers are located at Ascension Island; Antigua Island, Kwajalein Island; and Maui, Hawaii.

The collateral sensors are under the operational control of NORAD, but their primary mission is other than space track. For example, the detection fans and mechanical trackers at the three Ballistic Missile Early Warning Sites (BMEWS) have as a primary mission missile warning and perform their space track function as a lesser priority. They are located at Clear, Alaska; Thule, Greenland; and Fylingdales, England.

Other collateral sensors include phased array radars at Otis Air Force Base, Massachusetts; Beale Air Force Base, California; Eglin Air Force Base, Florida; PARCS (Perimeter Acquisition Radar Characterization System) at Cavalier Air Force Station, North Dakota; and COBRA DANE on Shemya Island at the end of the Aleutian chain in Alaska.

LAUNCH NOTICE

Initial notice of a domestic launch comes from a report 15 days prior to launch. The "R-15 message" is prepared by the launch controlling agency and includes nominal orbital elements, launch window, characteristics of each piece to achieve orbit, launch vehicles, launch site, space track requirements, sequence of events, cataloging instructions, and communications frequencies. From this information a nominal element set is provided each sensor which is tasked to track and verify a successful launch with proper orbit. When requested by the launch agency this information is given in an Early Orbit Determination (EODET) report which requires additional support from the sensors.

The first notification of many foreign launches comes from the Satellite Early Warning System (SEWS) which provides infrared information to the Space Defense Operations Center (SPADOC) at NORAD. Only after a satellite begins to orbit is it clear that it was not an ICBM that was being launched. The SPADOC passes the launch information to the NSSC which then processes the information and includes it in the catalogue of space objects. Additionally, through Space Object Identification (SOI), the size, shape, motion, and orientation of satellites is determined. Because of the limited number of sensors, however, and the great number of space objects, priorities are established to ensure the most effective use of available assets. The highest priority is given to new foreign launches and satellites in the final stages of decay. These two categories are of immense interest to NORAD because both may be identified incorrectly as an

ICBM posing a threat to the North American continent.

U. S. international treaty obligations also demand close monitoring of decaying objects. NORAD carefully tracks a decaying space object which has a predicted point of impact plus or minus 15 minutes or 100 nautical miles of the border of the USSR. Under the 1971 Agreement on Measures to Reduce the Risk of Outbreak of Nuclear War Between The United States of America and the Union of Soviet Socialist Republics, such notification is provided to ease tensions and serves to reassure the Soviet Union that there is no hostile intent.[32] An additional reason to place a high priority on decaying objects which may strike the earth's surface is potential liability which may be incurred by the launching State.[33]

States who are parties to the Convention on Registration of Objects Launched into Outer Space[34] "including in particular States possessing space monitoring and tracking facilities," must respond "to the greatest extent feasible" to a request of a Party State unable to identify a space object that has caused damage to it or its nationals, for assistance in identification of the space object.

The next level of priority is given to special events such as maneuvers, deorbits, domestic launches, and special tests and projects. Routine satellites in orbit have third priority, ahead of the growing amount of debris.

CALCULATIONS

There are two kinds of computer calculations that the NSSC can do on a given space object. Both batch and sequential corrections are used to update the orbital element sets. Sequential corrections use the current element set plus new observation which results in a time weighing toward the new data. Batch corrections, on the other hand, use a greater number of observations, thereby eliminating a time weighing. However, weighing is permitted based upon sensor accuracy. Sequential corrections take less time to accomplish because less data is used, but they may be flawed if used on other than stable orbits because one or more bad observations can distort the conclusion.

Lower priority space objects in stable orbits lend themselves to automatic processing. The computer runs a series of programs to save the orbital analysts' time. Essentially, if the object remains within acceptable perameters, the computer automatically updates the catalogue. If not, the particular object is flagged for an orbital analyst's evaluation.

The catalogue of space objects started in 1957 and includes a total of 15,094 space objects. Of these 9795 have decayed but 5299 are still in orbit. The United States has launched 524 payloads, the USSR 1161 payloads, and other nations 48.[35] Large objects monitored by the TIP program come down at a rate of approximately 140 per year while smaller pieces come down at a rate of approximately 550 per year. As of 30 June 1984, the satellite catalogue looked like this: 458 US earth orbiting satellites and 30 space probes; 785 Soviet satellites and 27 space probes; 127 satellites from other nations and 2 space probes.[36] The remaining 3870 objects are debris which range from rocket bodies to a camera from an Apollo launch. The catalogue now tracks space objects as small as a soccer ball at 22,300 miles (geosynchronous).[37]

DEBRIS

The problem of debris has received some interest but little worldwide concern. The report of UNISPACE 82 held in Vienna, August 1982, noted, "While the probability of accidental collision with a 'live' space object is yet statistically small, it does exist and the continuation of present practices ensures that this probability will increase to unacceptable levels".[38] V. A. Chobotov, in an excellent article, noted that debris flux and the probability of collision is greatest in the 600-1200 km altitude range for polar and retrograde orbits in general. For geosynchronous satellites, the orbital concentration is a significant issue. The worst case probability of collision was $6X10^{-5}$yr (six in a million per year) or two orders of magnitude greater than that for a typical geosynchronous satellite. He concluded that the probability of collision for a spacecraft in orbit is a function of altitude and orbit plane inclination, as well as longitudinal position for geostationing satellites.[39]

Simply stated, must we wait for this problem to come to worldwide public attention through a catastrophe before the technical and legal scholars come together to seek workable solutions? The problem of nuclear power sources would likely have remained just an intellectual concern were it not for COSMOS 954. As Moore and Leaphart note, media coverage has brought worldwide attention to satellite events and "these falling 'stars' have captured the public's interest on a magnitude far beyond the significance of the harm caused."[40]

Collision avoidance is, however, a prime way of solving the problem. NORAD performs a COMBO (Computation of Miss Between Orbits) especially for the shuttle orbiter missions. The purpose is to assure that during launch and on orbit there is a safe separation of the shuttle orbiter from other space objects. Through the catalogue for space objects and the computer, a comparison is made between the flight path of the shuttle and other space objects. A point of closest approach (PCA) is determined and if a risk is presented, maneuvering could be accomplished. Collision avoidance is also affected by proper preplanning of orbital locations. It is only through careful management of critical orbital paths and locations that safety can be enhanced.

Debris can also be held to a minimum by proper design of launch systems and the limiting of loosely attached mechanisms. For example, use of the shuttle orbiter rather than expendable launch vehicles (ELV) reduces the debris produced by multiple launches and eliminates rocket bodies with unspent fuel thereby reducing explosions which creat an instantaneous increase in debris. Better design of satellites so they are more cohesive will also reduce debris. The use of disposal orbits, however, needs further study. As noted earlier, the USSR has used this technique for their satellites with nuclear reactors. This program calls for boosting the reactor up to 900 to 1000 km altitude so that the radioactivity will be significantly lessened prior to decay and reentry through the earth's atmosphere some 1000 years from now.[41]

The ultimate solution for eliminating satellites that have completed their missions and debris is removal.[42] At the present time technology and costs make such efforts impractical. However, in the nature of things, such developments seldom take place until there is a viable need. Dean Olmstead at the International Astronautical Federation meeting in October 1983 presented a most interesting dilemma.[43] In order to effectively control debris, including "dead" satellites, there must either be an economic benefit that accrues to the launching agency or enforceable laws must be agreed to by the launching states.[44] He points out that extremely useful orbits such as geosynchronous do not "belong" to a using State because Articles I and II of the Outer Space Treaty provide that space shall be the province of all mankind and states may not establish claims of sovereignty over outer space or the moon and other celestial bodies.[45] The other alternative, to create a system of enforceable laws to clean up debris, seems both politically difficult and almost impossible with current technology. Olmstead's conclusion, with which I agree, is to create some sort of limited property rights which would induce the using State to clean up its own house or, better yet, not litter it in the first place.[46]

The world must decide what the solution to the problem is now, before debris gets to a point that it jepardizes productive use of space. Authoritative enforcement to control the actions of people has usually been less than totally satisfactory and the application of similar efforts towards sovereign states has been less successful. There is an invitation to "cheat" when there is no sure method to verify the creation of all debris coupled with an absence of a meaningful regime to enforce compliance. Economic regimes on the other hand which reward efficient use of a resource are usually successful because they are self rewarding and, therefore, self policing. One invariably serves one's own self interests.

An economic solution would lead a satellite owner to use the last of the fuel available to remove it from a usable orbit rather than leave it as debris. In a similar vein, cleaner launches would occur even if procured at a greater cost because the launching state would have an economic interest in the avoidance of debris.

CONCLUSION

We must learn from COSMOS 954 that, where risks exist, the world community must focus attention on viable solutions. We can not wait for a calamity or hope for new scientific insight before coming to grips with the problem.

Nuclear power sources must be used judiciously and safe launches are a must. Criteria for a launch should emulate the safety procedures and techniques used for manned launches rather than expendable launched vehicles. If an NPS launch fails to reach orbit, the abort procedures should ensure minimal radioactive risk. It is essential that nuclear reactors employ "cold launches" with the reactor not being activated until an altitude is reached that assures minimal risk in the event of an unplanned return.

The 1981 United Nations Working Group on NPS outlined effective procedures for notification of errant vehicles so that affected states will be advised. There is no reason to believe that launching states will not provide such information should the returning space vehicle pose a radiological hazard.[47]

A problem as critical as the use of nuclear power sources and the radiological hazard which they pose is the growing amount of space debris and uncleared launches. While the odds of an incident are extremely small now, the result of a collision may still be catastrophic. Should a manned vehicle be struck by a sizable space object, loss of life is almost certain. Thus, we need to turn our legal and scientific attention to the objects which are presently in space and the potential threat posed by a new launch striking a manned vehicle or working satellite. To avoid this latter possibility, a clearinghouse should be made available to all nations.

States bear international responsibility under Article VI of the Outer Space Treaty for authorizing and supervising both their acts and the acts of non-governmental entities launching from their territory.[48] Cooperation by all launching nations to ensure safe insertion of payloads into orbit will not only reduce the potential for liability but significantly reduce the possibility of a more threatening international incident.

The problems of debris can be ameliorated by cleaner launches and particularly the use of vehicles like the space shuttle which avoid multiple expendable launch vehicles. In the future, it may even be possible for laser technology to burn up debris in low earth orbit.

At geosynchronous altitude, worn out satellites are growing in profusion. These "junk cars" strewn all over the road must be cleared up. The presence of "dead" satellites may present a small risk but the potential economic loss should damage occur could be staggering. A regimen for avoiding this must be internationally devised. I recommend a solution involving limited property rights to orbital positions rather than a law enforcement approach. Whatever is to be done, it must be done now--before the "junk yard" is so filled that society loses this unique space resource. The use of space is clearly at the point where each state must be concerned with the launches and the debris created by others. It is no longer safe to act unilaterally.

FOOTNOTES

1. 24 U.S.T. 2389, T.I.A.S 7762 (effective October 9, 1973).

2. See Carl Q. Christol, International Liabilibility for Damage Caused by Space Objects, The American Journal of International Law, Vol. 74, p. 346 (1980).

3. International Space Law, edited, Professor A. S. Piradov, Mezhdunarodnye Ojnosheniya, Publishing House, 1974 p. 160.

4. The Soviet Year in Space 1983, Teledyne & Brown Engineering, p. 32.

5. Statement of Claim, "Annex A," Note Number FLA 268, January 23, 1979, 18 International Legal Material, p. 899 and 903, July 1979.

6. Department of Energy, Operation Morninglight.

7. See L. H. Legault and A. Farand, "Canada's Claim for Damage Caused by the Soviet COSMOS 954 Satellite," presented in January 1984 at the ABA Forum Committee on Air and Space Law.

8. 19 U.S.T. 7570, T.I.A.S. 6599, 672 U.N.T.S. 119 (effective December 3, 1968).

9. Supra, Note 5, p. 927.

10. Supra, Note 1.

11. Supra, Note 8.

12. The Soviet Year in Space 1983, p. 31.

13. For an excellent review of the work done on COPUOUS and its subcommittees, see Carl Q. Christol, The Modern International Law of Outer Space, Pergamon Press (1982)).

14. Charles C. Badcock, High Power for Space Systems, Aerospace America, June 1984.

15. Dr George E. Mueller, "The Next 25 Years: A View From 1984," presented to United Nations COPUOS legal subcommittee.

16. See Jason Reiskind, Toward a Responsible Use of Nuclear Power in Outer Space - The Canadian Initiative in the United Nations, Annals of Air and Space Law 1981, p. 461.

17. See Appendix A.

18. Gary L. Bennett and David Buden, "Use of Nuclear Reactors in Space," The Nuclear Engineer, p. 108, Vol. 24, Number 4, July/August 1983.

19. United Nations Document A/AC.105/278, 13 Feb 1981.

20. United Nations Document GA/SPC/1723, p. 1359.

21. Id, p. 1365.

22. Id, p. 1367.

23. United Nations GA/SPC 1722, p. 3.

24. Id, p. 4.

25. A/AC.105/287 Annex II, paragraph 14.

26. See Appendix A.

27. Refer to Bennett and Buden, "Use of Nuclear Reactors in Space," p. 115.

28. David Buden and Gary L. Bennett, "On the Use of Nuclear Reactors in Space," Physics Bulletin, Vol. 33, Number 12, December 1982.

29. Gary L. Bennett, James L. Lombardo and Bernard J. Rock, "Development and Use of Nuclear Power Sources for Space Application," The Journal of the Astronautical Sciences, Vol. XXIX, Number 4, Oct-Dec 1981.

30. Jonathan B. Tucker, "U. S. Revives Space Nuclear Power", High Technology, August 1984, p.15.

31. At geosynchronous orbit, satellites are further affected by solar wind and the gravitational pull of the sun and moon.

32. 22 U.S.T. 1590, T.I.A.S. 7186, 807 U.N.T.S. 57 (effective September 30, 1971).

33. Convention on International Liability for Damage Caused by Space Objects, Article IV, 24 U.S.T. 2389, T.I.A.S. 7762 (effective September 15, 1976).

34. 28 U.S.T. 695, T.I.A.S. 8480.

35. Discrepancy between payloads "on-orbit" vs payloads "launched"-US/USSR launch payloads for other countries for a fee as a routine practice. Other nations own 127 satellites but launched only 48.

36. Not all of these are active. Some have stopped functioning and some may be activated at a later time.)

37. Note Martin Menter's article, "Space Objects: Identification, Regulation, and Control," October 20, 1978. As of October 15, 1978, there were 4621 objects in space of which 3574 were debris.

38. Paragraph 289, United Nations Paper, August 1982, A/CONF.101/10).

39. V. A. Chobotov, Classification of Orbits with Regard to Collision Hazard in Space, Astronautics and Aeronautics (Now Aerospace America), Vol. 20, Number 5, Sep-Oct 1983.

40. Dr. Armanda L. Moore and Jerry V. Leaphart, Catch That Falling Star! State Responsibility and The Media in the Demise of Space Objects, IISL 83-36.

41. Lubos Perek, Safety of Space Activities, IAA 83-255.

42. R. Cargill Hall, "Comments on Salvage and Removal of Man-Made Objects from Outer Space," Journal of Air Law and Commerce, Vol. 33, p. 288, 1967.

43. Dean Olmstead, "Orbital Debris Management: International Cooperation for the Control of a Growing Safety Hazard," IAA 83-254.

44. Another alternative would be to have a system similar to the one that exists in many places in the United States: one returns soft drink bottles, and receives the prepaid deposit regardless of who bought them.

45. 18 U.S.T. 2410, T.I.A.S. 6347, 610 U.N.T.S. 205 (effective October 10, 1967).

46. While I agree with his ultimate conclusion, I do not agree with his statement that identification of an object's origin at GEO is virtually impossible. Supra, Note 42, p. 3.

47. General Assembly Resolution 33/16.

48. Supra, Note 45.

SUMMARY OF SPACE NUCLEAR POWER SYSTEMS LAUNCHED BY THE U. S. A. (1961-1980)

Power Source[1]	Spacecraft	Mission Type	Launch Date	Status
SNAP-3A	TRANSIT 4A	Navigational	June 29, 1961	Successfully achieved orbit
SNAP-3A	TRANSIT 4B	Navigational	November 15, 1961	Successfully achieved orbit
SNAP-9A	TRANSIT-5BN-1	Navigational	September 28, 1963	Successfully achieved orbit
SNAP-9A	TRANSIT-5BN-2	Navigational	December 5, 1963	Successfully achieved orbit
SNAP-9A	TRANSIT-5BN-3	Navigational	April 21, 1964	Mission aborted; burned up on reentry
SNAP-10A (Reactor)	SNAPSHOT	Experimental	April 3, 1965	Successfully achieved orbit
SNAP-19B2	NIMBUS-B-1	Meterological	May 18, 1968	Mission aborted; heat source retrieved
SNAP-19B3	NUMBUS III	Meterological	April 14, 1969	Successfully achieved orbit
SNAP-27	APOLLO 12	Lunar	November 14, 1969	Successfully placed on lunar surface
SNAP-27	APOLLO 13	Lunar	April 11, 1970	Mission aborted on way to moon. Heat source returned to south Pacific Ocean.
SNAP-27	APOLLO 14	Lunar	January 31, 1971	Successfully placed on lunar surface
SNAP-27	APOLLO 15	Lunar	July 26, 1971	Successfully placed on lunar surface
SNAP-19	PIONEER 10	Planetary	March 2, 1972	Successfully operated to Jupiter and beyond
SNAP-27	APOLLO 16	Lunar	April 16, 1972	Successfully placed on lunar surface
TRANSIT-RTG	"TRANSIT" (TRIAD-01-1X)	Navigational	September 2, 1972	Successfully achieved orbit
SNAP-27	APOLLO 17	Lunar	December 7, 1972	Successfully placed on lunar surface
SNAP-19	PIONEER 11	Planetary	April 5, 1973	Successfully operated to Jupiter and Saturn and beyond
SNAP-19	VIKING 1	Mars	August 20, 1975	Successfully landed on Mars
SNAP-19	VIKING 2	Mars	September 9, 1975	Successfully landed on Mars
MHW	LES 8	Communications	March 14, 1976	Successfully achieved orbit
MHW	LES 9	Communications	March 14, 1976	Successfully achieved orbit
MHW	VOYAGER 2	Planetary	August 20, 1977	Successfully operated to Jupiter and Saturn and beyond
MHW	VOYAGER 1	Planetary	September 5, 1977	Successfully operated to Jupiter and Saturn and beyond

---

[1]SNAP stands for Systems for Nuclear Auxiliary Power. All odd-numbered SNAP power plants use radioisotope fuel. Even-numbered SNAP power plants have nuclear fission reactors as a source of heat. MHW stands for the Miltihundred Watt RTG.