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STEPS TAKEN BY SPACE AGENCIES FOR REDUCING THE GROWTH OR DAMAGE POTENTIAL OF SPACE DEBRIS

Report by the Secretariat

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INTRODUCTION

1. At its thirty-fourth session, the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space noted with appreciation the report prepared by the Secretariat on various steps taken by space agencies for reducing the growth or damage potential of space debris (A/AC.105/663), and recommended that it should be updated annually (A/AC.105/672, para. 90).

2. This recommendation was endorsed by the Committee on the Peaceful Uses of Outer Space at its fortieth session.[1]

3. The present report, prepared by the Secretariat in response to the above-mentioned request, contains a summary of the information provided by Member States, as well as by national and international space organizations. The format of the report corresponds to the format of relevant parts of the technical report on space debris that is currently being prepared by the Scientific and Technical Subcommittee.

I. AVOIDANCE OF MISSION-RELATED OBJECTS

4. Launch vehicles and spacecraft can be designed so that they are litter-free; in other words, they dispose of separation devices, payload shrouds and other expendable hardware (other than upper-stage rocket bodies) at a low enough altitude and velocity that they do not become orbital. This is more difficult to do when two spacecraft share a common launch vehicle. In addition, stage-to-stage separation devices and spacecraft protective devices such as lens covers and other potential debris can be kept captive to the stage or spacecraft with lanyards or other provisions to minimize debris. This is being done in some cases using existing or new designs where feasible. These practices should be continued and expanded if possible.

5. When the mission requires delivery of a spacecraft which itself has a manoeuvre capability, two alternatives are possible. One is to leave the upper stage attached for delivery of the spacecraft to orbit to maximize its manoeuvre capability. The second is to separate the spacecraft at suborbital velocity so that the stage decays naturally and the spacecraft uses its on-board propulsion to establish its orbit. From a cost-penalty perspective, the first alternative results in a greater mass in orbit—a potential debris hazard— while the second alternative increases the complexity of the spacecraft. Assessing which alternative is more appropriate requires further study.

6. The National Space Development Agency of Japan (NASDA) requires that the release of mechanical devices at satellite separation and solar panel deployment be avoided except in some particular missions, such as the separation of spent apogee motors for the geostationary meteorological satellite.

7. The principal rule established by the *Centre National d'Études Spatiales* (CNES) (French National Centre for Space Studies) to counter the proliferation of space debris is as follows: at the end of the launching mission, whatever the targeted orbit, there should be no more than one piece of passive debris rendered per satellite placed in orbit. In order to conform to this rule, CNES has incorporated the following debris-reduction techniques in the technical specifications of Ariane launch vehicles:

(a) In the case of a single launch, the orbiter must be rendered passive, which means that residual propellants, including the performance reserve and the propellants used in the attitude-control system, must have been emptied and the tanks depressurized;

(b) In the case of a multiple launch, the adapter structure must also be inert:

(i) The use of solid propulsion in orbit is prohibited (they create clouds of aluminium particles);

(ii) The end-of-life of electrical batteries and cells must not be accompanied by a critical rise in pressure;

(iii) Payload separation systems and multiple launching structures must not generate any debris (sealed pyrotechnic separation and trapping of explosive bolts and of straps);

(iv) The pre-flight mission analysis must make it possible to guarantee, with a probability higher than 1.10^{-4}, that there will be no collision between objects in orbit.

8. With regard to the minimization of new space debris, Surrey Satellite Technology Limited of the United Kingdom of Great Britain and Northern Ireland is applying the following practices in the development of all mini-satellites and microsatellites:

(a) Securing to the structure, whether the launch vehicle or the satellite itself, all the components or parts that might lose their original fastenings during the launching process, including the remains of components subject to breakage;

(b) Use of materials suitable for space in that they do not suffer damage as a result of outgassing or of other environmental conditions that might result in the creation of debris, including the surface treatment of the materials concerned;

(c) Ensuring that all the structural fastenings and all parts of the satellite as a whole are capable of withstanding the mechanical conditions of the launch, placing in orbit and subsequent operation, and of maintaining the integrity of the structure.

9. In order to minimize the creation of space debris, the Canadian Radarsat programme established a system-level requirement that any solid debris resulting from the operation of a restraint/release mechanism be contained. That is, all contractors were required to design a system such that no debris would be released by the spacecraft during its deployment in orbit.

10. Recently, the modernization of operative, and the development of new, space and rocket technology led space-related enterprises in the Russian Federation to undertake a number of preventive measures for reducing the level of space debris. For example, a new DM upper stage of the Proton launcher is under development, incorporating provisions to eliminate the separation of the engine starting system (SOZ motor) from the stage during its powered ascent into orbit, so that no additional debris are created.

11. The task of litter-free operations could combine design and operational practices to achieve the goal of limiting further orbital debris created by any space operations. As a result of these efforts, the growth rate of orbital debris will decline, although the overall debris population will still increase.

II. IMPROVED STRUCTURAL INTEGRITY OF SPACE OBJECTS

12. The debris produced by upper stage fragmentations now accounts for more than 30 per cent of the catalogued Earth-orbiting object population. As many as 82 per cent of all upper-stage break-ups could have been prevented by executing proper passivation techniques. During the period 1990-1996, a total of 28 upper stages—an average of four per year—associated with 10 different vehicle types broke up in Earth orbit. Although some of these events originated with old upper stages already in orbit for a long time, the vast majority of the vehicles were launched in 1988 or later, after widespread attention had been given to the issue of upper-stage passivation.

13. Perhaps the first significant debris-reduction policy has been the requirement of the National Aeronautics and Space Administration (NASA) of the United States of America for the venting of unspent propellants and gases from Delta upper stages to prevent explosions caused by the mixing of fuel residues. In August 1981, the company

providing the Delta second stage implemented a new procedure calling for a restart of the stage engine to burn the remaining propellants to depletion. No Delta second stage that has performed this depletion burn has experienced a subsequent break-up. In 1985, NASA notified NASDA of the Delta second stage problem because the Japanese N-II launch vehicle employed a second stage based upon this Delta stage. Consequently, NASDA also adopted a passivation policy and no N-II second stages have broken up in orbit.

14. In August 1995, the NASA Office of Safety and Mission Assurance issued NASA safety standard 170.14, “Guidelines and assessment procedures for limiting orbital debris”. Guideline 4-2 of this document addresses the issue of spacecraft and upper-stage passivation. It specifically states the following: “All on-board sources of stored energy will be depleted when they are no longer required for mission operations or post-mission disposal. Depletion will occur as soon as such an operation does not pose an unacceptable risk to the payload.”

15. On-board energy sources cited in the standard include chemical energy in the form of fuels and explosives associated with range safety systems, energy in the form of pressurized volumes (as in sealed batteries, thermal control, attitude control and propulsion systems) and kinetic energy (as with control moment gyroscopes). The NASDA Debris Mitigation Standard and the draft *Space Debris Mitigation Handbook* of the European Space Agency (ESA) also strongly recommend upper-stage passivation measures.

16. Propellant elimination actions should also be designed to relieve high-pressure gases employed in pressure-fed propulsion systems. This can normally be accomplished by keeping propellant lines and vents open for longer periods. Alternatively, pressurants can be removed with the use of special venting lines and pyrotechnical valves. For vehicles where fuel and oxidizer is to reside in a common propellant tank, separated only by a membrane or wall, venting procedures should be designed to prevent the development of excessive differential pressures. Finally, stage passivation measures should include the disarming of the range safety system (that is, detonation charges) and the isolation and discharge of the electrical power system.

17. The principal energy source of upper-stage break-ups clearly appears to be residual propellants, whether in the form of hypergolics, cryogenics, monopropellants or simple oxidizers. More importantly, the removal of these energy sources has been 100 per cent successful in preventing future fragmentations. Residual propellant elimination is normally accomplished by initiating depletion burns or simply venting propellant tanks. The first option can require full propulsion restart, as practised by the Delta, Delta 2, Pegasus, and Japanese N-II programmes, or idle-motor burns, as demonstrated by the H-I and H-II upper stages. The United States Centaur hydrazine altitude control system also burns residual propellants to depletion after payload separation. To gain greatest environmental benefit from these burns, they should be performed in a manner that will reduce the orbital lifetime of the vehicle. Using this technique, the Delta second stage (1996-024B) reduced a projected lifetime of several hundred years to only nine months.

18. The third stage of the Ariane 4 launch vehicle was modified following the explosion in orbit of that stage that occurred nine months after Ariane 4 was used to launch SPOT 1 in 1986 (V16). Two pyrotechnic valves were designed and added to the pressurization circuit of the tanks, forcing the latter to open into the void at the end of the mission. Introduced in October 1993, this design modification has so far permitted 30 flights to take place without any anomaly, thus demonstrating the total effectiveness of the measures taken.

19. The Ariane 5 orbiter will also be rendered passive at the end of its mission through the opening of two pyrotechnic valves fitted on the pressurization circuit, connected to zero-torque nozzles. The main tanks have to be neutralized within 10 minutes.

20. The Ariane high-pressure helium tanks are designed to be emptied within a few hours via a calibrated orifice. The attitude-control system operating on hydrazine is to be emptied until a residual pressure reading is attained which safeguards the system against explosion under the impact of a micrometeoroid or orbital debris. The separation

systems are checked for cleanliness in the course of development in accordance with specifications from the satellite developers.

21. NASDA has implemented the draining of residual propellants (LOX, LH_2, N_2H_4) and residual helium gas of the second stage of the H-I and H-II launcher. In order to prevent the unintended destruction of the H-II second stages in space, the command destruct system is disabled immediately after injection into orbit and its pyrotechnics are thermally insulated to preclude spontaneous initiation. Other launchers, such as Proton, Zenit and Long March 4 vehicles, have also incorporated venting passivation measures.

III. DE-ORBITING AND REORBITING OF SPACE OBJECTS

A. Low Earth and highly eccentric orbits

22. One of the most important of the NASA guidelines is the planned disposal of spacecraft and upper stages at the end of their useful life. Following this guideline reduces the growth of mass in the most frequently used regions of space and reduces the potential for having on-orbit collisions become a significant source of debris. However, since planned disposal is a new concept in most cases, it is perceived as a significant added cost burden on new programmes. In general, the post-mission disposal options are as follows:

(a) Direct retrieval and de-orbit;

(b) Manoeuvre to an orbit for which atmospheric drag or gravitational perturbations will remove the object from orbit within 25 years;

(c) Manoeuvre to one of a set of disposal regions in which the objects will not interfere with future space operations.

23. Retrieval means the return to the Earth, without damage to the spacecraft or other space hardware, by a space vehicle capable of atmospheric entry, such as the United Space Shuttle or the Russian Federation Soyuz re-entry modules. Examples of retrieved space hardware are the European recoverable carrier Eureca, the Japanese Space Flyer Unit, the United States Long-Duration Exposure Facility, Palapa-A, Westar-B and a solar array from the Hubble Space Telescope. Because of the limited capacity of the Shuttle and the relatively high costs involved, this method of debris mitigation is used only rarely.

24. De-orbit is an efficient method for removing objects from space. This includes propulsive manoeuvres to force an immediate destructive entry into the atmosphere and also reduction of the orbital lifetime under a certain limit (for example, 25 years) by lowering the orbit using propulsive manoeuvres or other methods, such as increasing the area vulnerable to atmospheric drag. For some missions, the performance of the launch vehicle leaves a sufficient margin of propellant available for the stage to do a de-orbit burn. The stage usually needs to be modified to provide the guidance and control capabilities needed for a controlled de-orbit after fulfilling its primary mission (which is the delivery of the payload into orbit). However, this might have a negative effect on the cost of the mission.

25. A controlled de-orbiting over deserted regions of the Pacific Ocean is regularly performed by the Russian Space Agency after its cargo craft of the Progress type fulfil a mission to the Mir orbital station. This method was used even during servicing of previous orbital stations of the former Soviet Union, starting with Salyut 6 in 1978. All Salyut orbital stations have been de-orbited over the Pacific Ocean with the exception of Salyut 2 and Salyut 7, which malfunctioned. Controlled re-entry is also planned for the Mir station in 1999. NASDA has no experience with controlled re-entry of spacecraft from high altitude, but the Tropical Rainfall Measuring Mission is supposed to re-enter into the ocean from an altitude of 380 kilometres to provide that kind of data.

26. According to the NASA standard, another alternative to a controlled direct entry is a manoeuvre that lowers the perigee so that the inertial orbital lifetime is constrained to a period of 25 years. Such a manoeuvre quickly removes the object from the region of high hazard and therefore removes the mass and cross-section from orbit in a small fraction of the orbital lifetime without such a manoeuvre. This is significantly less costly than a targeted entry. It makes the eventual re-entry happen earlier, but raises questions regarding liability issues, because the geographic region of the entry into the atmosphere could not be accurately predicted.

27. To be in accord with the NASA standard, NASDA, in its standard STD 18, also adopted 25 years as an allowable lifetime until mission-terminated space systems will re-enter by natural force into the atmosphere. For most systems, this occurs if the orbit is lower than 750 kilometres. In the case of higher orbits and if the re-entry risk would be allowable, the most feasible measure to avoid collision risk with other operating space systems is to reduce the orbital lifetime by reducing the perigee height of the orbit. However, this manoeuvring may require a propulsion system that might complicate the design of the system.

28. An alternative to natural atmospheric re-entry and controlled disposal over the ocean is relocation to a disposal orbit. In low Earth orbit, this is not an advantageous strategy because it generally requires a two-burn manoeuvre that is more costly in terms of fuel than the single burn that is required for entry. During the 1980s and early 1990s, the former Soviet Union used near-circular orbits at altitudes of 900 to 1,000 kilometres to dispose of 31 nuclear power sources. The NASA guidelines recommend manoeuvring to the storage orbit with a perigee above 2,500 kilometres and an apogee below 35,288 kilometres (500 kilometres below geostationary altitude).

29. For missions using the elliptical geostationary transfer orbit (GTO), the pertinent considerations for disposal of the upper rocket stage are the launch date, launch azimuth, and the perigee of the transfer stage. For multi-burn systems, positive ocean disposal can be achieved with an apogee burn of a few metres per second if the stage has sufficient battery lifetime and contains an attitude reference and control system.

30. In addition, there are sets of launch times to GTO aligning the orbit of the transfer stage so that natural forces, such as the properties of the Sun, Moon and Earth, act to lower or raise the perigee of the stage. Consideration of the effect of these forces can minimize the cost of active control of liquid propellant stages and is a low-cost technique for the disposal of solid rocket motor stages. The only alternative strategy for the disposal of solid rocket motors is to orient the thrust vector of the rocket in a direction so that the perigee of the transfer orbit resulting from the burn is at a low enough altitude to cause the stage to eventually re-enter (sometimes referred to as an off-axis burn). This strategy results in a performance of about 15 per cent for the stage.

31. The measures adopted for the NASDA programmes seem to be relatively inexpensive and have proved to be very effective. For example, the orbital life of the Japanese ETS-VI H-II second stage (1994-056B) was reduced to about seven months as a result of de-orbiting.

B. Geostationary orbit

32. There is an ever-increasing number of satellites in geostationary orbit (GSO). Since atmospheric friction is no longer a factor at this altitude, objects abandoned in this orbit do not move out of the region, thus presenting a hazard to other satellites, both the hazard of collision with operational satellites and also that of an accidental explosion which would result in the creation of an extremely large number of debris fragments. The use of disposal orbits is currently the only technically feasible strategy for clearing the GSO region. However, it requires planning and reserving the necessary propellant resources to effect the manoeuvre. Preliminary studies indicate that the orbit needs to be raised by about 300 kilometres to serve the intended purpose, not by the 40 to 70 kilometres that have been used by some operators. The performance cost for reorbiting is 3.64 metres per second for each 100 kilometres, or 1.69 kilograms of propellant for each 1,000 kilograms of spacecraft mass. To reboost for 300 kilometres is comparable to three months station-keeping.

33. Study Group 4 of the Radiocommunication Bureau of the International Telecommunication Union (ITU), in which many satellite operators participated, endorsed the recommendation that all geosynchronous orbit satellites be boosted no less than 300 kilometres above the geosynchronous orbit at the end of life, and that the spacecraft then be made inert by discharging any residual propellants and gases and by “safing” of the batteries.

34. The International Telecommunications Satellite Organization (INTELSAT) incorporates self-imposed policies and procedures to properly decommission expended satellites and to prevent the generation of space debris. The existing policies and procedures on satellite decommissioning are as follows:

(a) At decommissioning, all satellites are placed into a safe, passive mode. This includes depressurization and venting of propellant systems as part of orbit raising, discharge of batteries and turning-off of all RF units to preclude interference with any other satellite owners and operators;

(b) For older satellites, sufficient propellant is held back for a decommission orbit raising to a minimum altitude of 150 kilometres above GSO. This manoeuvre is normally done in multiple parts over several days to guarantee a good parking orbit. For newer satellites, starting with INTELSAT VI, a minimum decommissioning altitude of 300 kilometres has been adopted. Because of conservative propellant budgeting, INTELSAT normally exceeds the targeted decommissioning altitude.

35. France has decided to introduce a voluntary policy of reorbiting of geostationary satellites at end of life in order to free the useful orbit. The solution adopted is to place satellites that have completed their mission in an orbit situated 300 kilometres above GSO. This policy has already been applied a number of times by CNES, which is responsible for monitoring a number of national satellites in orbit. The Telecom 1A telecommunications satellite was removed into this orbit in September 1992, followed by the Telecom 1C satellite at the beginning of 1996 and subsequently the TDF 1 direct television broadcasting satellite.

36. The United States National Oceanic and Atmospheric Administration, NASA and several programmes of the Department of Defense regularly boost satellites that are no longer functional into orbits above GSO to prevent the creation of additional debris by inadvertent collisions with other drifting satellites and to free valuable orbital slots.

37. The technology of removal of Russian Federation spacecraft from GSO at the end of their active lifetime is based on the use of the remaining fuel (for satellites of the Statsionar-D, Ekran-M and Gorizont series) and the provision of the necessary amount of additional fuel to ensure an increase of the mean altitude of the orbit by 200 kilometres (for new types of spacecraft).

38. The following ESA geostationary satellites have been reorbited so far: OTS 2 (orbiting at 318 kilometres above GSO), GEOS 2 (260 kilometres), Meteosat 2 (334 kilometres), ECS 2 (335 kilometres) and Olympus 1 (because of a failure, this satellite has been left in an orbit 213 kilometres below GSO).

39. To evaluate the adequate distance for disposal of the GSO spacecraft, the effects of long-term orbital perturbations was studied in Japan. The resulting value of the minimal distance is almost the same as that recommended by both ITU and NASA Code-Q, namely about 300 kilometres.The current minimum requested by NASDA is 150 kilometres and the target is 500 kilometres. Actual reorbiting is often more than required to eliminate the influence of possible errors arising from the measuring system.

IV. PROTECTION BY SHIELDING

40. For small debris that cannot be tracked from the ground, the only alternative to collision avoidance is protection by shielding. The international space station (ISS) is shielded to defend against a 1-centimetre impactor. The Space Shuttle was not designed for the orbital debris environment, but has been modified to make it more robust for the ISS assembly and operations missions.

41. For current Shuttle operations, flight rule A2.1.3.-32 minimizes the time with the payload bay forward or nose forward and payload bay up or out of the orbital plane, since these are more vulnerable positions. The most protected orientation is with the payload bay toward Earth and the aft of the orbiter in the forward direction. There is a factor of 20 between the worst and best orientation. The orbiter has experienced a significant number of impacts, with on average one window being replaced in every flight.

42. To achieve the requested reliability of ISS (maximum 10 per cent probability of penetration over 10 years), different shield designs are used to protect various critical components. More effective shields are placed in forward-facing areas where most impacts are expected, and less capable shields are located in aft and nadir-facing areas that are expected to be hit less frequently. In addition to being capable of preventing penetration by nominal threats, shields for ISS must be lightweight, low in volume (to fit the space shuttle payload bay) and durable in the space environment. ISS is also designed to allow for future shield augmentation if the threat increases or if the life of the station is extended.

43. More than 100 different shields have been designed to protect various critical components of ISS, although all of the designs are modifications of three primary shielding configurations: the Whipple bumper, the multishock (or stuffed Whipple) shield and the mesh double-bumper shield. The Whipple bumper, the simplest shield configuration, consists of a single plate of material (typically aluminium), called the bumper, spaced some distance from the underlying module wall (often called a catcher). The role of the bumper is to break up, melt or vaporize a high-velocity object on impact. The smaller, slower remnants of the object then travel between the bumper and the catcher and spread the remaining energy of the impact over a larger area on the catcher. This configuration has been studied experimentally for over half a century. The Whipple bumper is most effective at high-impact velocities.

44. The stuffed Whipple bumper consists of an outer bumper, a catcher and one or more underlying layers of materials spaced between the bumper and the catcher to further disrupt and disperse the impactor. This arrangement results in an improved performance over the standard design and, with some bumper materials (like Nextel), reduced production of secondary ejecta. In current ISS designs, the outer bumper is made of aluminium and the shield is usually stuffed with six layers of Nextel and six layers of Kevlar. The module wall serves as the catcher. The mesh double-bumper is the newest NASA derivative of the Whipple bumper concept. Developed during the early 1990s, this shield has a metallic mesh disrupter in front of each of two bumpers. This design also provides significantly improved performance over the standard Whipple bumper.

45. For the foreseeable future, the non-Russian ISS crew will use the extravehicular activity mobility unit currently used by space shuttle astronauts. This space suit is protected by multiple layers of material and a single bladder that together provide a pressure vessel and a degree of protection from the thermal extremes of space and from meteoroids and debris. A secondary oxygen pack will provide at least 30 minutes of supplementary oxygen, should a hole up to 4 millimetres in diameter develop in the suit. There are multiple-failure recovery modes from other impact-induced failures. Analysis shows that more than 75 per cent of the hazard will result from penetrations of soft parts of the suit (that is, arms, gloves, and legs). The ISS programme is considering augmenting the arms and legs with removable gauntlets and “chaps” to reduce this hazard.

46. The Canadian Radarsat spacecraft, successfully launched on 4 November 1995, is protected from the existing space debris environment. Protective measures were undertaken in order to ensure, to the best extent possible, that the Radarsat spacecraft does not prematurely become space debris as a result of a space debris impact. The measures involved defining the space debris environment to be encountered by Radarsat using the NASA ENVIRONET database. Individual spacecraft components were then examined to determine their vulnerability to the predicted environment. The vulnerability assessment included using hypervelocity impact equations as well as actually subjecting spacecraft hardware to hypervelocity impact tests at the NASA Johnson Space Center. Where required, shielding was added to the spacecraft in order to bring the survivability of the spacecraft to an acceptable level. The shielding included adding Nextel (a 3-M ceramic fibre cloth) to thermal blankets, adding bumpers in front of exposed hydrazine lines and wire bundles and thickening some component boxes in order to protect their enclosed circuits.

V. COLLISION AVOIDANCE

47. The United States launch planning is also affected by projections of the Collision Avoidance on Launch Program which warns of potential collisions or near misses for manned or man-capable vehicles before they are launched. The procedure is executed by the United States Eastern Test Range and provides clearance of 200 kilometres along the orbit and 50 kilometres both radial and out of orbital plane for manned vehicles. Should this procedure indicate a possibility of conjunction, the launch is held to the next even minute.

48. For United States manned Shuttle missions, mission rule A4.1.3.-6 addresses on-orbit debris avoidance. The Space Control Center (SCC) of the United States Space Command runs a computer program evaluating the next 36 hours of the Shuttle flight to determine possible trackable conjunctions of space objects within a radius of 100 kilometres around the orbiter. If an identified object is predicted to pass within the warning box near the orbiter (25 kilometres along the orbit and 5 kilometres both radial and out of orbital plane), the Space Surveillance Network is requested to make additional observations and use them to compute a more accurate orbit of that object. When improved prediction confirms the conjunction within the avoidance manoeuvre box (5 kilometres along the orbit and 2 kilometres both radial and out of orbital plane), an assessment is made as to whether to execute the manoeuvre or not. If a manoeuvre is executed, it is nominally 0.3 metres per second at an expenditure of 12 to 20 kilograms of propellant. Since 1986, on the eight occasions when the avoidance box was entered, three avoidance manoeuvres were executed. On the other occasions, mission objectives precluded the opportunity to manoeuvre, or the tracking trend indicated that it was not necessary.

49. When NASA crew are stationed on board the Mir orbital station for missions of long duration, a procedure developed to provide advisories to the Russian Mission Control Centre (CUP) at Korolov, near Moscow, is used, just as in the case of the Shuttle. When SCC identifies an advisory condition, a laptop is used with any available telephone line to establish an Internet and fax connection to CUP and a warning message is sent. Since the procedure became operational, five advisories have been provided. Since the Mir station cannot manoeuvre, the only crew action feasible is to take refuge. On 15 September 1997, the Mir crew took up position in the Soyuz re-entry module at the time of the forecast conjunction with the United States satellite MSTI 2 (1994-028A). The development of this procedure has given some insight into the procedures that will be needed for the future ISS. It is estimated that 16 conjunctions a year will occur for ISS if the same criteria are used for it as for the Shuttle.

Notes

[1]*Official Records of the General Assembly, Fifty-second Session, Supplement No. 20* (A/52/20), para. 85.