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Committee on the Peaceful Uses of Outer Space
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Use of nuclear power sources in outer space

Collisions between nuclear power sources and space debris

Working paper submitted by the Russian Federation

1. The Russian Federation, taking into account the Scientific and Technical Subcommittee's opinion regarding the need for detailed research on the question of collisions between nuclear power sources and space debris followed by publication of the results, each year submits working documents containing the results of calculations performed for this purpose as part of its general programme of research on the safety of space nuclear power sources.

2. In the present paper a summary is given of the results of the calculations and theoretical work performed to investigate the consequences of possible collisions with space debris of nuclear power sources launched into space during the period 1970-1988. This paper supplements the Russian Federation's working paper of 9 February 2000 (A/AC.105/C.1/L.233).

3. Following launches of space vehicles carrying nuclear power units, the following objects containing a reactor and nuclear fuel are now in orbit at distances of 700-1,100 kilometres (km) from the Earth:

(a) Thermoelectric nuclear power units with withdrawal compartments (29 items, 16 of these with nuclear fuel in the reactor and 13 without), satellites of the Kosmos series beginning with the Kosmos-367 satellite and ending with the Kosmos-1932 satellite (figure 1 shows a general view of a nuclear power unit with a withdrawal compartment);

(b) Fuel element bundles containing nuclear fuel (13 items) in independent flight following ejection from the body of the reactor on a breakaway orbit (a

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schematic representation of the fuel bundle ejection can be seen in figure 2 and a general view of the fuel bundle following ejection in figure 3);

(c) Thermal emission nuclear power units on board a space vehicle (two items), the Kosmos-1818 and the Kosmos-1867 satellites (an overall view of a nuclear power unit on board the space vehicle can be seen in figure 4).

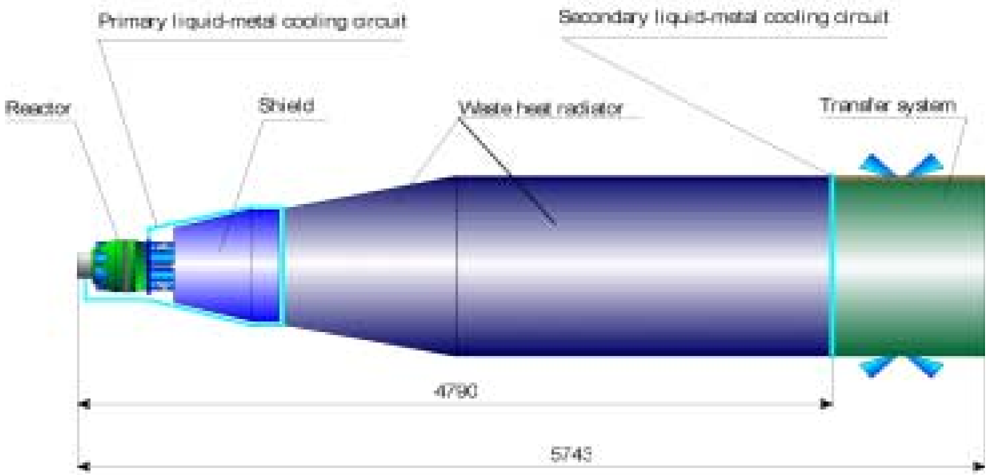

Figure 1 - Space Reactor System

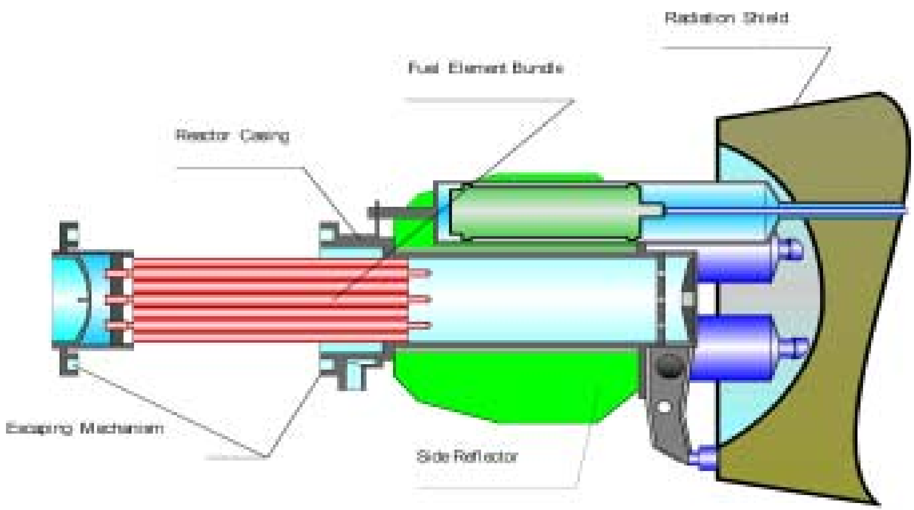

Figure 2 - Sceme of Escaping for Fuel Element Bundle

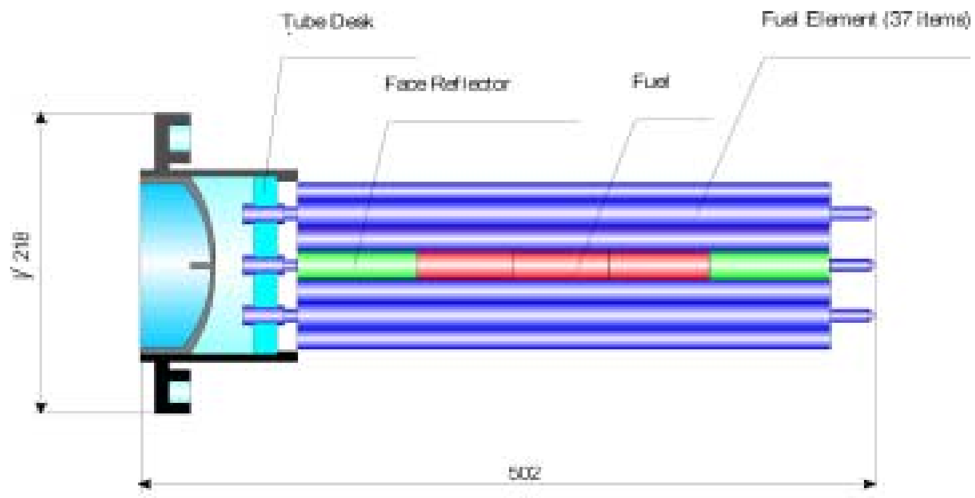

Figure 3 - Fuel Element Bundle

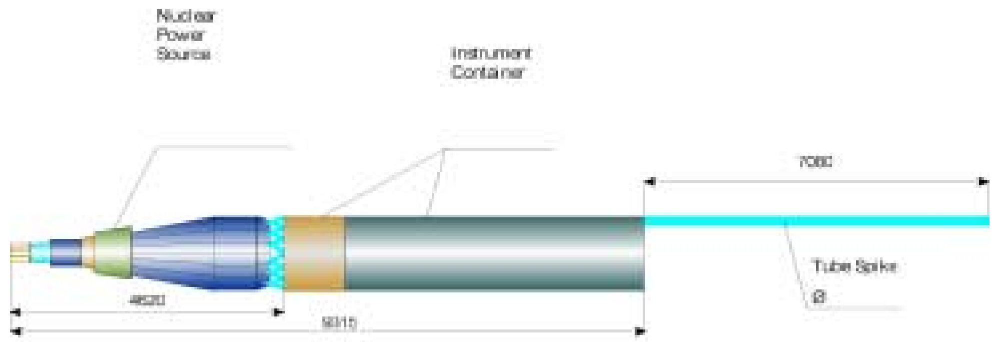

Figure 4 - Spacecraft "Cosmos - 1818, 1867 "

4. The consequences of possible collisions of the above objects containing reactors and nuclear fuel with space debris when the nuclear power units remain in fairly high orbits for long periods of time constitute a potential hazard in terms of radioactive contamination of the environment, including outer space, and also because of the accumulation of space debris in orbit. Such consequences could result from the following events:

(a) Premature dislodging of a nuclear power unit with its withdrawal compartment and of independent fuel bundles and nuclear power units on board space vehicles from their long-term orbits as a result of a braking effect, aerodynamic destruction of the nuclear power unit in the atmosphere and fallout of particles of radioactive material and structural elements of nuclear power units onto the surface of the Earth;

(b) Formation and scattering in orbit of radioactive and non-radioactive particles from nuclear power units as well as structural fragments resulting from the destruction of nuclear power unit components.

5. For calculations relating to the destruction of a nuclear power unit following a possible collision with space debris, the space debris model of the Russian Space Agency (the Nazarenko model) was used with a distribution density of space debris fragments (size and altitude distributions) and with a predicted change in the distribution density over time dependent on the intensity of future launches of space vehicles. The mode of the destruction of space objects and the probabilities of collisions between such objects and space debris were calculated for the most probable collision angles (60-70°) and an impact velocity of about 12 km per second, account being taken of the dimensions and mass of the objects in high orbit with an inclination of 64.7-66.1° and the dynamics of their movement around the centre of mass in orbital flight.

6. Premature dislodging of objects containing a reactor and nuclear fuel from their long-term orbits by collisions with space debris and the creation of a braking effect could occur:

(a) For a thermoelectric nuclear power unit with a withdrawal compartment (mass 1,254 kilograms (kg)) in collision with a fragment of space debris larger than 155 millimetres (mm) (a steel fragment), with a probability of 0.032 in 100 years;

(b) For an independent fuel element bundle (mass 53 kg) in collision with a space debris fragment larger than 55 mm (a steel fragment), with a probability of 0.0021 in 100 years. In these conditions, a collision with a steel fragment of space debris greater than 22 mm, having a probability of 0.0215 in 100 years, would lead to substantial destruction of the fuel bundle (more than 10 per cent in terms of mass);

(c) For a thermal emission nuclear power unit on board a space vehicle (mass 3,090 kg) in collision with a space debris fragment greater than 180 mm (steel fragment), with a probability of 0.014 in 100 years.

7. Once a nuclear power unit with its withdrawal compartment leaves high orbit and falls into dense layers of the Earth’s atmosphere, aerodynamic destruction of the nuclear power unit and withdrawal compartment structure ensues at altitudes between 98 and 64 km, destruction of the steel reactor structure and fuel elements at altitudes between 64 and 50 km, followed by dispersion of the nuclear fuel (uranium-molybdenum alloy) at altitudes between 50 and 47 km with breakdown into particles having final dimensions less than 1 mm and finally impact on the Earth’s surface of elements of the beryllium side and end reflectors of the reactor and of the lithium hydride radiation shield.

8. When an independently orbiting fuel bundle leaves high orbit and re-enters the atmosphere, aerodynamic destruction of the steel bundle structure occurs at altitudes between 88 and 87 km, followed by dispersion of the nuclear fuel (uranium-molybdenum alloy) at altitudes of 86-85 km with breakdown into particles having

final dimensions in the 0.06-0.88 mm range and destruction of the beryllium end reflectors at altitudes between 77 and 67 km. Another point to be noted is that collision of an independently orbiting fuel bundle with a sizeable fragment of space debris could destroy the fuel elements in high orbit. Destruction of a single fuel element in a bundle could occur in collisions with space debris fragments greater than 2.5 mm in size (steel fragments), with a probability of 0.4 in 100 years, and this event is accompanied by the ejection of nuclear fuel fragments in a size range from 7 to 20 mm. The scattering of these fragments can lead, depending on the size and direction of the effect, to the insertion of nuclear fuel fragments into elliptical orbits (900-7,000 km) and ultimately to the penetration of nuclear fuel fragments into dense layers of the Earth’s atmosphere, with subsequent aerodynamic heating and dispersion of the nuclear fuel into particles with final dimensions of 1-8 mm.

9. When a thermal emission nuclear power unit carried in a space vehicle is ejected from high orbit and re-enters the atmosphere, the following effects will occur:

(a) Destruction of the aluminium structure of the space vehicle’s instrument compartments at an altitude of about 84 km;

(b) Destruction of the steel outer casing of the nuclear power unit at altitudes between 81 and 73 km;

(c) Dislodging of the reactor and destruction of steel reactor structural elements at altitudes between 73 and 45 km;

(d) Impact on the Earth’s surface of the lithium hydride radiation shield and the partially destroyed reactor structure containing the moderator (zirconium hydride), the electrogenerating channels (EGC) containing uranium dioxide, the beryllium end reflectors and the beryllium side reflectors with regulating cylinders at the position of maximum reactor subcriticality.

10. For thermal emission nuclear power units on board space objects attention has also been given to the consequences of a possible collision of a space debris fragment with a reactor resulting in destruction of the reactor in a high orbit, the ejection of one or more EGC and the consequent re-entry of the latter into the dense layers of the atmosphere. Such may be the consequences of a collision with space debris particles larger than 80 mm (steel fragments) with a probability of 0.0027 in 100 years.

11. In the case of independent EGC re-entry into the dense layers of the atmosphere, aerodynamic destruction of the external steel EGC structural elements takes place at an altitude of 80 km, with the EGC breaking up into individual electrogenerating elements (EGE) and the EGE cathodes containing uranium dioxide in molybdenum cladding breaking away and falling to the Earth’s surface.

12. The radiological consequences of collisions of space debris with objects containing a reactor and nuclear fuel have been examined on the assumption of a 100-year stay of such objects in high orbit, that is, for a period of time corresponding to a significant (in the order of 0.01-0.03) probability of collision with space debris. For such a period in high orbit, the activity of the nuclear fuel is determined by its caesium-137 and strontium-90 content, these being the fission products of uranium-235. Induced activity in the reactor’s structural materials and in

the beryllium reflector, zirconium hydride moderator and lithium hydride radiation shield decays almost completely over a period of more than 30 years.

13. The radiation situation in the fallout area affected by nuclear fuel particles and fragments and parts and components of the reactor structure and nuclear power unit arising from a collision with space debris and after aerodynamic destruction on re-entry into the atmosphere is determined by the size of the fragments, the level of radioactivity in them and the possible conditions for external gamma-irradiation of individuals among the population in the fallout region.

14. Following a collision with space debris and re-entry into the dense layers of the atmosphere, a thermoelectric nuclear power unit with a withdrawal compartment and an independent fuel bundle may break up into particles of 1-8 mm and fragments with a diameter of 20 mm and thickness of 3 mm (account being taken of prior oxidation of the uranium during flight at high atmospheric levels). Caesium-137 activity, which determines the level of gamma radiation from the nuclear fuel (the contribution of braking gamma radiation from strontium-90 is insignificant), is as follows: in particles—from 1.5 microcuries (μCi) to 0.75 millicuries (mCi), in fragments—less than 2.5 mCi. Under the standard assumptions regarding irradiation of individuals among the population, the resulting annual exposure doses would be less than 0.2 millisieverts (mSv) (0.02 rem), which is within the permissible dose limit (1 mSv per year).

15. On collision with space debris and after re-entry into the dense layers of the atmosphere, the reactor in a thermal emission nuclear power unit carried in a space object may be destroyed down to the core containing the EGC and partially dehydrogenated moderator, with the side and end reflectors, or down to an individual EGE cathode, the activity of which would be 17 Ci and 43 mCi, respectively. The possible annual exposure doses under standard assumptions for the irradiation of individuals among the population would be 250 mSv (25 rem) from a partially destroyed reactor (subcriticality of the reactor is guaranteed when it is submerged in water and filled with water and sea sand) and up to 3 mSv (0.3 rem) from the EGE cathode, which is higher than the permissible dose limit (1 mSv per year) and should be viewed as constituting irradiation of the population as a result of a radiation accident, thereby entailing the necessary protective measures.

16. In accordance with domestic and international legislation, the following set of protective measures is envisaged if confirmation is received of an incident involving the fall of a space object from high orbit:

(a) Tracking of the descent trajectory parameters of an object containing a reactor and nuclear fuel ejected from high orbit after collision with space debris;

(b) Forecasting of the area of re-entry of such an object into the upper layers of the atmosphere and of the possible regions of impact on the Earth’s surface of a partially destroyed reactor structure and individual reactor and nuclear power unit fragments;

(c) Notification of the competent authorities of a potential situation in the impact region and measures for implementing radiation safety precautions, including the creation of a restricted-access zone around the fallen object and individual fragments on their discovery;

(d) Search, discovery and removal of the object and fragments from the impact site;

(e) Organization of radiation monitoring at the impact site and, where necessary, clean-up of radiological contamination;

(f) Examination and counting of members of the public located in the impact zone of the object and fragments and evaluation of possible individual radiation doses, assistance to the public being provided where necessary.

17. The probability of irradiation of individuals among the population in the event of the fall of an object containing a reactor and nuclear fuel following a collision with space debris and aerodynamic destruction during re-entry into the atmosphere is fairly small (in the order of 0.00002-0.0009) and is determined not only by the probability of collision (0.01-0.03 in 100 years) with a space debris fragment of fairly large size but also by the probability of the object's falling into an inhabited area, which could be between 0.002 (infrastructure) and 0.003 (land-use system) for space objects with an orbital inclination of 65°.

18. Accordingly, the consequences of the destruction of the reactor and nuclear fuel of a thermoelectric nuclear power unit with a withdrawal compartment in orbit at 700-1,100 km on collision with space debris and the subsequent formation of nuclear fuel particles and fragments dispersed at high orbits and falling to the Earth's surface do not represent a radiation hazard even if the nuclear fuel particles and fragments fall into an inhabited area. It is unlikely that the destruction of a thermal emission nuclear power unit reactor on board a space object in orbit at 789-806 km on collision with space debris will have hazardous consequences and if a partially destroyed reactor and/or reactor fragments should fall into an inhabited area, the radiological consequences would be eliminated by carrying out the envisaged set of protective measures.