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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. Following the launch of space vehicles carrying nuclear power units during the period 1970-1988, the following objects containing a reactor and nuclear fuel are now in orbit at distances of 700-1,100 km from the Earth:

(a) Nuclear power units with a withdrawal compartment (29 items), satellites of the Kosmos series beginning with the Kosmos-367 satellite and ending with the Kosmos-1932 satellite;

(b) Fuel element bundles (13 items) in independent flight, following ejection from the body of the reactor, on a breakaway orbit: this happened beginning with the Kosmos-1176 satellite; for the Kosmos-1670, Kosmos-1677 and Kosmos-1900 satellites, no fuel bundles have been identified as independent objects;

(c) Nuclear power units on board a space vehicle (2 items), the Kosmos-1818 and Kosmos-1867 satellites.

2. The forecast lifetimes of objects with a reactor and nuclear fuel in orbit at 700-1,100 km are as follows: nuclear power units with a withdrawal compartment, about 1,000 years; fuel bundles, over 2,000 years; and nuclear power units on board space vehicles, at least 400 years. An exception is the Kosmos-1900 satellite, the lifetime of which is estimated at 120 years in orbit at 700-750 km.

3. The orbital inclination is 64.70-66.10° for nuclear power units and 64.78-65.66° for fuel bundles.

4. The consequences of possible collisions between nuclear power units and space debris when the nuclear power units remain in fairly high orbits for long periods of time could represent a potential hazard in terms of radioactive contamination of the environment, including outer space, and also further accumulation of space debris.

5. In the event of a collision between a nuclear power unit and fairly large fragments of space debris, the following consequences could be of decisive importance:

(a) Premature dislodging of the nuclear power unit from its long-term orbit as a result of a braking effect;

(b) Destruction of the radiator of the nuclear power unit, followed by an outflow of liquid metal coolant (sodium-potassium) from the secondary (non-radioactive) circuit;

(c) Destruction of independent fuel bundles, scattering of the resultant material in orbit and fallout of nuclear fuel fragments on the Earth's surface.

6. Calculations indicate that a nuclear power unit could be dislodged from high orbit by a collision with a space debris fragment of at least 60 mm for steel and at least 85 mm for aluminium if a probable impact velocity of 12 km/s is assumed.

7. Once the nuclear power unit leaves orbit and falls into denser layers of the Earth's atmosphere, aerodynamic destruction of the nuclear power unit structure takes over at altitudes of 64-74 km (see figure 1), followed by destruction of the reactor and fuel rods at altitudes of 50-64 km (see figure 2) and dispersion of the nuclear fuel at altitudes of 47-50 km (see figure 2), broken down into particles less than 1 mm in diameter. Fallout of such fuel particles will not alter the radiation situation in the fallout area by comparison with the natural gamma background, given the decay of uranium fission products that will have occurred by the time of a possible collision.

8. Destruction of the radiator of the nuclear power unit can lead to a coolant leak and to the formation of sodium-potassium droplets that move away from the radiator if there is an increase in pressure—caused by centrifugal forces due to rotation of the nuclear power unit around its transverse axis—above the pressure due to surface tension of the droplets formed in the crater at the site of puncture of the radiator, account being taken of the fact that the velocity of rotation of the nuclear power unit around its transverse axis diminishes by 50 per cent every 3.5 years from the moment of its insertion into high orbit.

9. Studies on the destruction of radiator elements (tubes and collectors) of the nuclear power unit (see figure 3) upon collision with space debris have shown that tube puncture in a collision occurring at a velocity of 12 km/s perpendicular to the radiator surface can take place with steel space debris particles larger than 0.25 mm and aluminium space debris particles larger than 0.45 mm, although there is no outflow of sodium-potassium through the crater as a result of collisions with such particles.

10. The condition of an increase in pressure due to centrifugal forces above the pressure owing to surface tension forces on the droplets is fulfilled when a tube (5 mm in diameter) is ruptured transversely by a collision with space debris particles larger than 6 mm. This has happened only with the Kosmos-1900 and Kosmos-1932 satellites, which were placed in high orbits in 1988. If the hole produced in the tube is larger than the transverse cross-section of the tube, which can happen in collisions with space debris particles larger than 6 mm at small angles to the radiator surface, a leak of sodium-potassium melt can occur at lower centrifugal force pressures for nuclear power units placed in high orbits from 1984 onwards, beginning with the Kosmos-1579 satellite.

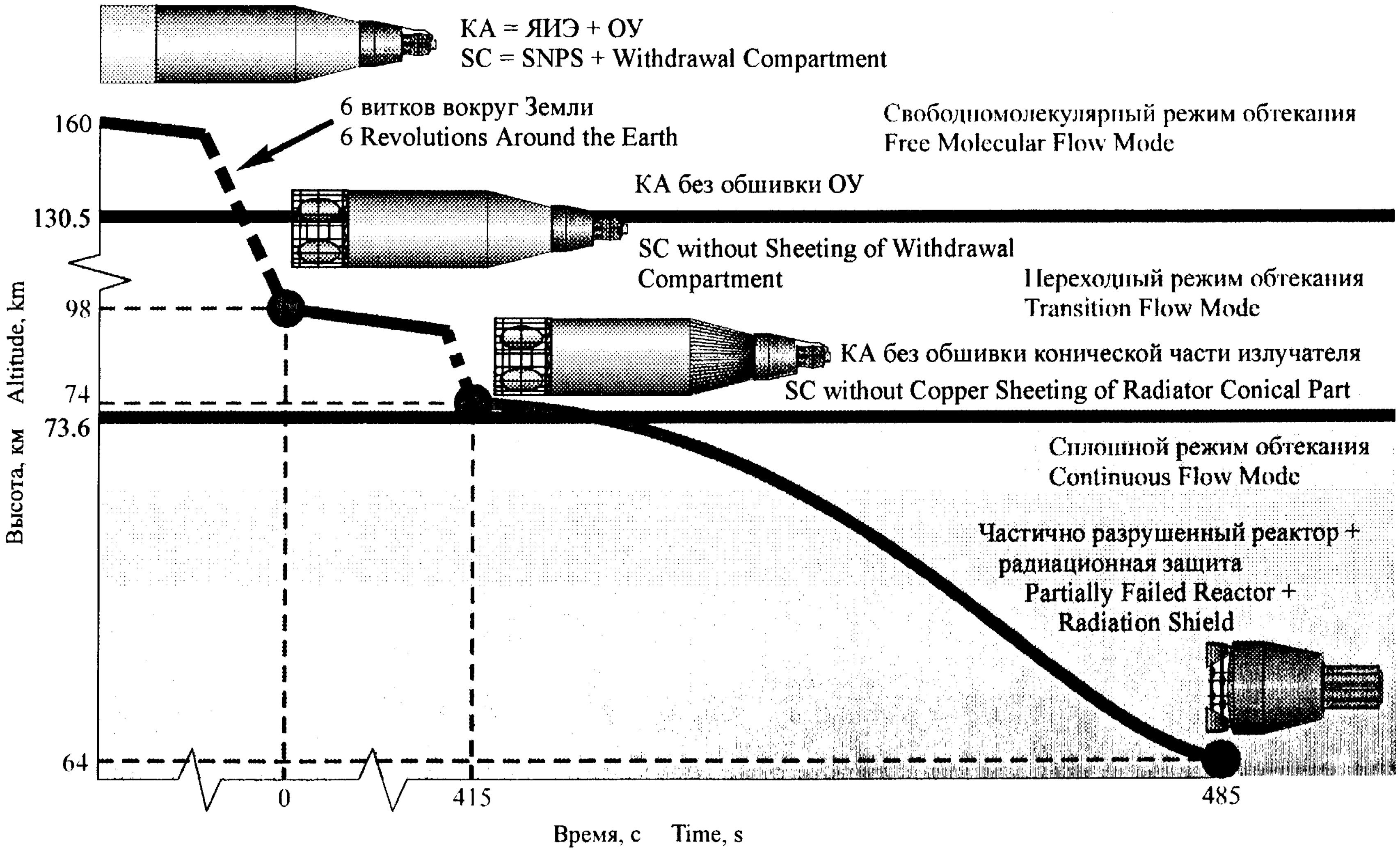

Рисунок 1 - Последовательность разрушения КЯИЭ при спуске в плотных слоях атмосферы
Figure 1 - Sequence of Disruption for SNPS under Re-entry

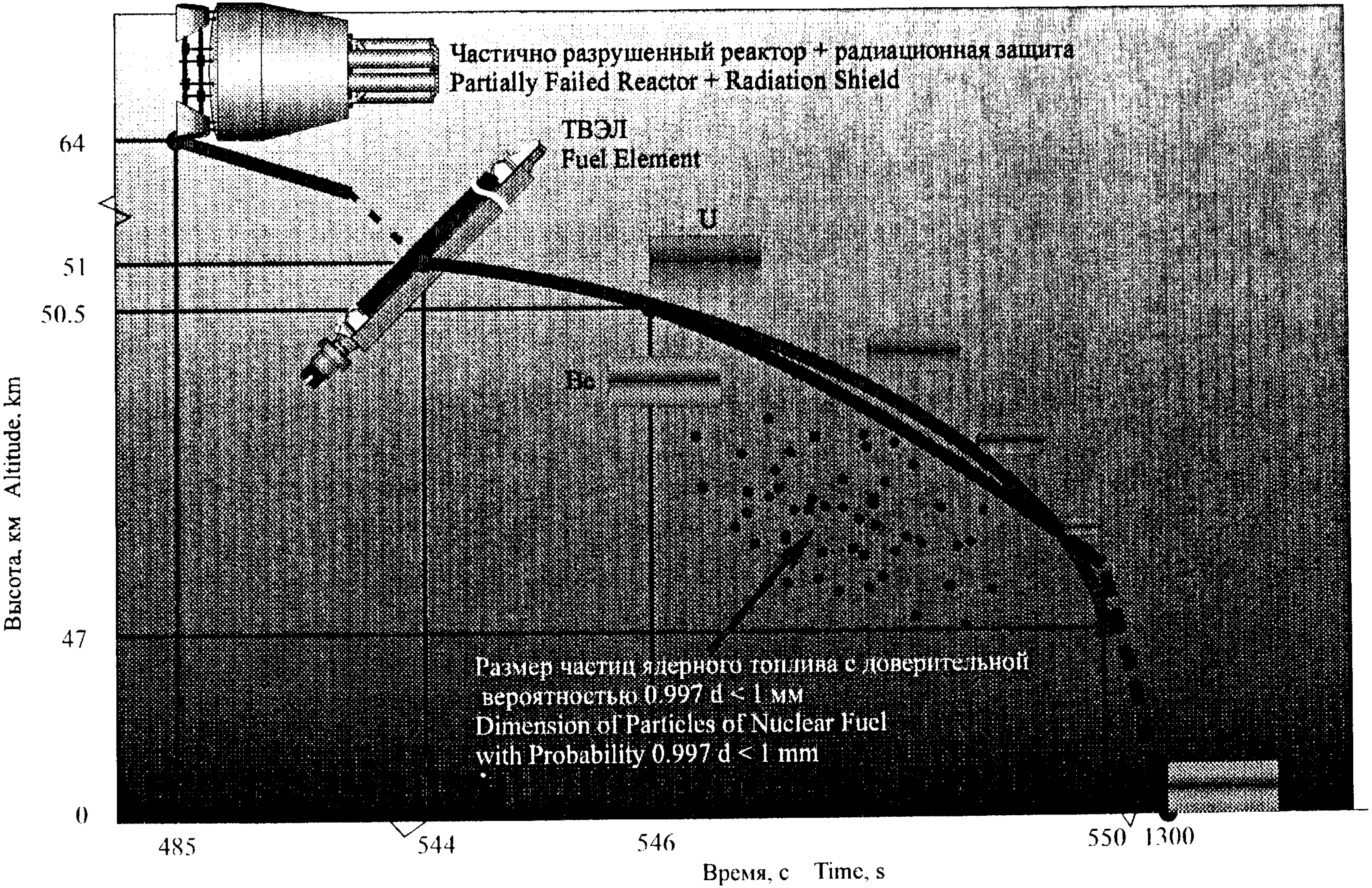

Рисунок 2 - Последовательность разрушения КЯИЭ при спуске в плотных слоях атмосферы
Figure 2 - Sequence of Disruption for SNPS under Re-entry

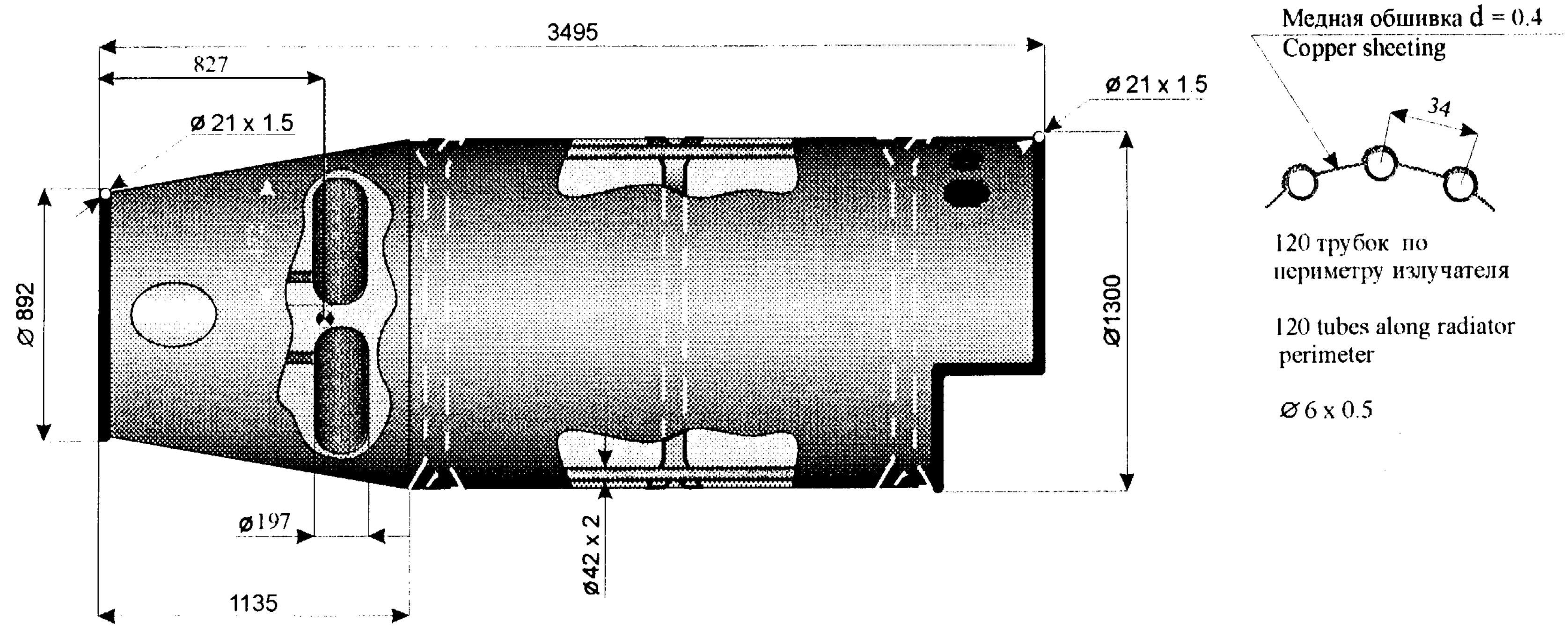

Рисунок 3 - Расчетная схема излучателя ЯЭУ.
Figure 3 - Calculation scheme of NPS radiator.

11. Destruction of an independent fuel element bundle has been studied on the assumption of a hole in a fuel element up to half the size of its diameter (20 mm), resulting in the ejection of particles and fragments of nuclear fuel. These conditions would be realized at an impact velocity of 12 km/s for steel space debris particles larger than 2.5 mm and aluminium space debris particles larger than 5 mm, with the subsequent ejection of nuclear fuel (uranium) fragments having a particle size distribution in the range of 7-20 mm.

12. The scattering of nuclear fuel fragments with velocity pulses of 60-1,000 m/s may, depending on the direction of the pulse, be accompanied by:

(a) Entry of the fuel fragments into dense layers of the atmosphere about an hour after the collision with space debris;

(b) The appearance of nuclear fuel fragments in elliptical orbits with a perigee at the altitude of the fuel bundle's flight at the instant of collision (900 km) and an apogee of up to 7,000 km.

13. Entry of nuclear fuel fragments into the dense layers of the atmosphere is followed by aerodynamic dispersion of the fragments into particles having final dimensions of 0.9-8.0 mm—in other words, material that can hardly represent a radiological hazard from the standpoint of external gamma exposure in the fallout area, taking into account the Caesium-137 content of the fuel, which determines the level of gamma radiation from the fuel and its fragments (and assuming that the fuel lifetime at the moment of collision with space debris is greater than 50 years).

14. The picture of aerodynamic dispersion of the nuclear fuel fragments upon entry into dense layers of the Earth's atmosphere will change if there has been preliminary oxidation of the uranium in the course of the flight at high atmospheric levels.

15. The formation of a refractory uranium dioxide film on the surface of the uranium fragments will lower the altitude at which the aerodynamic dispersion of fragments begins, delaying dispersion until the film is broken and the uranium melt splashes out. For uranium fuel fragments with a diameter of 20 mm and a length of 5-55 mm, the final size of the fallout particles will be 2.4-4.5 mm. Fragments having a diameter of 20 mm and a thickness of less than 3 mm with surface oxidation are not broken down upon entry into dense layers of the atmosphere.

16. For independent fuel bundles from the Kosmos-1176 and Kosmos-1932 satellites, an undestroyed nuclear fuel fragment would, as of 1999, have an activity of no more than 10 mCi in Caesium-137, which, under the standard assumptions regarding gamma irradiation of individuals among the population, would yield an annual exposure dose of 1 mSv.

17. The probabilities of these consequences of collisions of nuclear power units and independent fuel assemblies with space debris actually occurring are determined by the size of the objects in question, the size of the space debris fragments and the distribution of space debris at orbits in the range of 700-1,100 km and also by forecasts of space debris accumulation.

18. The probabilities of the consequences we have considered occurring as a result of collisions between space debris and objects containing a reactor and nuclear fuel are as follows:

(a) Premature departure of nuclear power units from their long-term orbits: 0.2 in 100 years;

(b) Destruction of the radiator of the nuclear power unit and formation of coolant (sodium-potassium) droplets: 0.007 per year until 2010 only. After 2010, the formation and release of sodium-potassium droplets is ruled out unless a situation arises that involves substantial destruction of radiator elements (collectors) in a collision with a space debris fragment larger than 12 mm, which has a probability of 0.002 per year;

(c) Destruction of an independent fuel bundle: 0.12 in 100 years.

19. Thus, it can be said that studies of the destruction of nuclear power units and independent fuel bundles as a result of collisions with space debris have shown that any possible fallout of nuclear fuel fragments on the surface of the Earth would not represent a radiological hazard.