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COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

NATIONAL RESEARCH ON SPACE DEBRIS

SAFETY OF NUCLEAR-POWERED SATELLITES

PROBLEMS OF COLLISIONS OF NUCLEAR-POWER SOURCES WITH SPACE DEBRIS

Note by the Secretariat

Addendum

1. The Secretary-General addressed a note verbale, dated 13 July 1994, to all Member States inviting them to communicate information on national research on space debris, safety of nuclear-powered satellites and problems of collisions of nuclear-power sources with space debris.

2. The present document contains information provided in replies received from Member States between 13 January and 2 February 1995.

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REPLIES RECEIVED FROM MEMBER STATES

RUSSIAN FEDERATION

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A. Report on the extent to which the requirements of the Principles Relevant to the Use of Nuclear Power Sources in Outer Space have been applied

The contemporary situation regarding the problem of ensuring the safety of nuclear power sources (NPSs) for spacecraft is characterized by the following:

1. Experience in the development and introduction of systems for ensuring the safety of reactor NPSs in low-orbit spacecraft in the form of systems involving aerodynamic and explosive dispersal as a back-up to the basic system of transfer of the power source to a long lifetime disposal orbit;

2. Experience in the development and introduction of special design features (heat shielding, heat insulation, impact-resisting mechanisms) for radioisotopic NPSs, ensuring safety for all spacecraft under normal operating conditions and in possible accident situations;

3. The adoption of international principles relevant to the use of NPSs in space, reflecting the experience gained in dealing with the problems of the safety of reactor-type and radioisotopic NPSs, containing a set of technical requirements and provisions regarding legal liability;

4. An understanding of the problems of ensuring NPS safety taking into account the consequences of possible collisions with space debris when NPSs are located in long lifetime disposal orbits after transfer in the case of low-orbit spacecraft or after the spacecraft is taken out of operation in the case of high-orbit spacecraft;

5. Availability of initial projects for prospective systems ensuring nuclear and radiation safety of reactor NPSs in accident situations;

6. Changes in the structure of the national authorities of countries taking decisions regarding the launching of spacecraft with NPSs, and regarding the composition of texts regulating the safety of space NPSs;

7. The commencement of international cooperation and broadening of the ranks of those involved in designing NPSs, particularly on a commercial basis, and as a result the potential inadequacy of technical documentation available as a basis to substantiate the safety of NPSs during operation and in accident situations.

In the Russian Federation, the problems of ensuring the safety of space NPSs have led to designs which meet safety requirements and are acceptable in terms of structural and technological realization, and which have been applied in practice by enterprises collaborating in joint projects for developing NPSs and have been internationally recognized.

Future projects for the development of space NPSs envisage a broader range of NPS types and at the same time judicious selection of the optimal trends in solving safety problems.

The Principles Relevant to the Use of Nuclear Power Sources in Outer Space were drafted at sessions of the United Nations Committee on the Peaceful Uses of Outer Space and at those of two of its Subcommittees: the Scientific and Technical and the Legal Subcommittees during the years 1979-1992.

At the session of the United Nations Committee on the Peaceful Uses of Outer Space in 1992, the set of Principles was adopted by consensus and submitted for approval by the United Nations General Assembly.

In resolution 47/68 of 14 December 1992, the General Assembly approved the Principles Relevant to the Use of Nuclear Power Sources in Outer Space.

Of all the 11 Principles contained in the set, the following are the ones fully possessing a technical orientation:

Principle 3. Guidelines and criteria for safe use;

Principle 4. Safety assessment;

Principle 5. Notification of re-entry;

and to a lesser extent:

The Preamble;

Principle 2. Use of terms;

Principle 6. Consultations;

Principle 7. Assistance to States.

Of the whole set of adopted principles it is the Preamble and Principles 2, 3, 4, 5, 6 and 7 reflecting the technical aspects of safety that bear on the problem of the safety of nuclear power sources in outer space.

The Preamble reflects the topical relevance of using nuclear power sources in outer space, the non-applicability of the principles to nuclear rocket engines and to nuclear power sources intended to power electropropulsion rocket engines, and the applicability of the principles to nuclear power sources similar to those used at the present time.

Principle 3 - Guidelines and Criteria for Safe Use - is the chief one and contains the general goals for radiation protection and nuclear safety as well as the requirements for nuclear reactors and radioisotope generators.

In this way the Principles adopted regulate the nuclear power source safety requirements when the sources are operated as part of a spacecraft and determine the volume of information to be published prior to the launching and, in particular, in emergency situations aboard spacecraft containing nuclear power sources.

The problems of ensuring safety in the use of nuclear power sources in outer space are linked to the limitation of the radiological impact on the population and environment (section 1 of Principle 3), when they are operated normally, during preparations on the ground, launching as part of the rocket and spacecraft, injection of the spacecraft into the calculated operating orbit, exhaustion of their service life as part of the orbiting spacecraft, completion of the active existence of the orbiting spacecraft and NPS, and also when there are potential and foreseeable emergency situations at all stages of operation of the power sources.

The problems of ensuring safety in the use of nuclear power sources in outer space have been raised at international level and interpreted in terms of radiation doses on the basis of the latest ICRP recommendations, which have been taken into account when designing and launching nuclear power sources in our country and are reflected in national regulatory documents.

Requirements relating to the means and ways of ensuring the safety of the nuclear power sources used in outer space are governed by the provisions of Principle 3 and are envisaged for high- and low-orbit spacecraft carrying reactor NPSs and for spacecraft with radioisotope generators (sections 2 and 3 of Principle 3).

The main requirements for any reactor type nuclear power source are:

1. Use of uranium with high uranium-235 enrichment (more than 90 per cent) so as to preclude the build-up of plutonium-239 (section 2 (c) of Principle 3).

2. Bringing the reactor into the critical state after it has reached the calculated operating orbit (section 2 (d) of Principle 3), while permitting physical start-up of the reactor prior to launching the spacecraft so as to check the reactor control systems (last sentence in section 3 of Principle 2), which is achieved in practice by restricting the power output, for example, to a level of 20 W/h.

3. Ensuring that the reactor remains subcritical should it fall as a result of an accident to the rocket and spacecraft over the area where it is injected into the calculated operating orbit (section 2 (e) of Principle 3).

Selection of the period of passive existence and height of the disposal orbit as a function of the ballistic coefficient when disposing of nuclear power sources for low-orbit spacecraft, and of the operating orbit for high-orbit spacecraft is determined from the decay of the activity built-up in the reactor to the permissible level and with allowance for the radiological consequences of a collision between the spacecraft and space debris (section 2 (b) of Principle 3). As the permissible level we can take the alpha activity of uranium-234, uranium-235 and uranium-238 in the reactor, and the beta activity of a small quantity of fission products from the uranium isotopes.

In the case of low-orbit spacecraft containing NPSs it is mandatory to use an NPS disposal system (section 2 (a), subsection (iii) of Principle 3) with high reliability (section 2 (f) of Principle 3). If the disposal of nuclear power sources containing a reactor fails, it is legitimate to use reactor dispersal systems that are also highly reliable (section 2 (f) of Principle 3) and ensure contamination levels over the area of fallout with permissible exposure doses (section 1 (c), second paragraph, of Principle 3).

Radioisotopic NPSs can also be used for interplanetary missions in Earth orbits (section 3 (a) of Principle 3). Radioisotopic NPSs should have heat shielding and heat insulation systems ensuring the integrity of the ampoules containing the radioisotope when descending through the atmosphere after re-entry at the first and second cosmic velocities (section 3 (b) of Principle 3). During impact on the ground it must be ensured with the requisite reliability that none of the radioisotope is released into the atmosphere and that measures to find the NPSs, to recover them and to clear up the consequences of the event are carried out (section 3 (b) of Principle 3).

These requirements coincide in effect completely with those of the national regulations, with allowance for which the radioisotopic NPSs and sources containing fast and thermal neutron reactors have been designed and operated in outer space, and on the basis of which the future nuclear power sources are being designed.

A probability analysis of potentially serious radiological hazards (fourth paragraph of the Preamble to the Set of Principles) carried out for the case of a specific power plant as a function of the purpose and flight programme of a spacecraft by combining different methods of ensuring NPS safety enables us to confirm and justify the minimal degree of risk involved in launching nuclear power sources. This type of probability analysis will also enable the central organizations of the United Nations to prepare and publish a final report on nuclear power source safety in accordance with Principle 4.

The published safety assessment of nuclear power sources should contain information on the launching of spacecraft carrying such sources, a description of them and confirmation that the provisions of the adopted Principles on the Use of Nuclear Power Sources in Outer Space have been applied, mainly as regards the requirements of Principle 3.

The safety assessments should not disclose data concerning a country's security, or any data relating to property.

The safety assessment should cover the following:

- Information on the launching of spacecraft with nuclear power sources;
- A description of the power sources;
- Correspondence between the provisions of the Principles and the requirements of national regulatory documents adopted when designing and constructing nuclear power sources;
- Data on the design features and safety-related systems ensuring the safety of nuclear power sources during normal operation and in emergency situations at all stages of operation;
- Analysis of possible emergency situations and parameters describing the effect of emergency conditions on power sources;
- State of stressed design features of the NPSs and systems responsible for ensuring their safety under emergency conditions;
- Data on the radiation conditions and possible exposure doses during normal operation of spacecraft with nuclear power sources and as affected by emergency situations;
- Theoretical and experimental justification for the effectiveness of safety systems and design features under emergency conditions;
- Confirmation of the reliability of the safety systems and design features of NPSs by tests on NPS models;
- Risk of radiological and chemical contamination of the environment when there is an accident, taking into account the probability of emergency situations, the probability of the accident impact parameters being reached, the reliability of the safety systems and safety-related design elements of the nuclear power sources;

A set of organizational and technical measures to clear up the consequences of accidents, including prediction of the area where the spacecraft falls, the search for, discovery and recovery of the nuclear power source and its parts from the site of the fall, and the decontamination operations involved, if necessary.

When describing nuclear power sources it is advisable to give the fullest details on their power, service life, design, and radioactive and toxic material content, as this will prevent the possibility of incompetent statements to that effect and will make for objective evaluations on the part of independent experts.

Having taken part in the sessions of the Scientific and Technical and the Legal Subcommittees of the United Nations Committee on the Peaceful Uses of Outer Space when discussing principles governing the use of nuclear power sources in outer space, the International Atomic Energy Agency (IAEA) drew up a special document over the years 1992-1994 entitled "Emergency planning and preparedness for the case of re-entry of a satellite containing a nuclear device", which contains both information and recommendations. The IAEA document and the action that the IAEA could possibly take in the event of an accident to a spacecraft containing a nuclear power source, as coordinated with the launching State and countries possessing the relative technological potential, can help to generate specific information on the accident and to prepare joint coordinated action for prognosis of the development of the situation, as well as to provide warning of and clear up the consequences.

B. Collisions of nuclear power sources with space debris

Taking account of the opinion of the Subcommittee on the need for detailed research on the problem of collisions of nuclear power sources (NPSs) with space debris and of the publication of the results of these investigations, the Russian Federation is continuing each year to submit a working document containing the results of calculations carried out on this problem in the context of the overall programme of research on the safety of NPSs in space.

This working document contains the results of calculations carried out in 1994 using computer programs for the two-dimensional modelling of the destruction process occurring upon collision with space debris of reactor NPSs launched into space between 1970 and 1988 and located in orbits of 700-1,000 km.

Consideration is given to collisions with space debris of a reactor NPS with a mass of 1,250 kg, a diameter of 1.3 m and a length of 5.7 m, including the reactor, radiation shield, liquid metal cooler-radiator circuit, thermo-electric generator and disposal system, and other units. The analysis relates to collisions with space debris whose dimensions and mass, upon collision with a reactor NPS, are capable of originating a retarding impulse which will lead to a substantial change in the trajectory parameters of flight of the NPS and its premature departure from the initial orbit in which it had been moving prior to the collision.

Velocities of collision, angles of impact and dimensions (mass) of the space debris are assumed which allow one of two conditions to be satisfied:

- Disintegration of 10 per cent of the mass of the reactor NPS into small fragments;

- Shortening of the time in orbit of the NPS, through the retarding impulse, to 30-50 years (duration of virtually complete disintegration of the activity for which the reactor is designed).

The calculations showed that the most probable relative velocity of impact for the conditions assumed is 11.7 km/sec. The most probable azimuth of collision in the local horizontal plane is 8° and 84°. The limit size of space debris is more than 3-8.5 cm for aluminium and more than 2-6 cm for steel, depending on the point of application of the impact in the design of a reactor NPS.

Preliminary calculations of the radiation consequences of the collision of reactor NPSs with space debris of the dimensions indicated showed that aerodynamic disintegration of the fuel (uranium-235) of the reactor would take place at altitudes of 60-40 km and that the fallout of partially disintegrated steel components of the structure and of the beryllium reflector was possible.

For the purpose of assessing the probability of reactor NPSs colliding with space debris, an analysis has been made of the distribution in terms of height and latitude of catalogued space debris and a methodology has been selected for calculating the distribution of non-catalogued space debris over the range 0.5-15 cm. Applying a theoretical prognosis of the growth of space debris in the future with two values for the coefficient of technology policy in space of 0.1 and 0.4 (the coefficient of technological policy is assumed equal to 1 for the years 1960-1993), probabilities have been estimated for collision with a reactor NPS located in a circular orbit of 950 km with an angle of inclination of 65°. The probability of a collision with space debris greater than 0.5 cm in size comes to approximately one in 75 years, given a technology policy coefficient of 0.1, and in 55 years for a technology policy coefficient of 0.4.

The specific probability of collision in an orbit of 950 km with an angle of inclination of 65° in 1993 was $3.4 \times 10^{-4} m^{-2}$ year for space debris of dimensions above 0.5 cm, and $1.3 \times 10^{-6} m^{2}$ year for space debris with dimensions over 15 cm. This enables us to predict a substantially lower probability of collisions of NPSs with space debris of large dimensions (more than the indicated limit dimensions) and the formation of a retarding impulse sufficient to shorten the period of existence in space of reactor NPSs launched.

Analyses of the interaction of space debris with NPSs upon collision (probabilities, velocities, angles of impact, disintegration of NPSs upon collision) and of the consequences of this interaction (time of existence of fragments of the NPS after impact or of damaged NPSs up to the time of re-entry into the atmosphere, combustion in the atmosphere, fallout of particles of NPS materials or partially disintegrated components of NPSs) require broad-scale computer calculations and depend on the specific NPS design and actual flight trajectory parameters.