For participants only
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Committee on the Peaceful Uses of Outer Space
Scientific and Technical Subcommittee
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Item 9 of the provisional agenda*
Use of nuclear power sources in outer space

Joint United Nations/International Atomic Energy Agency technical workshop on the objectives, scope and general attributes of a potential technical safety standard for nuclear power sources in outer space (Vienna, 20-22 February 2006)

Design safety considerations for launch, normal operations and mission accidents (covering specific design approaches to assure safety and mitigate risk given foreseeable environment conditions)

Working paper submitted by the Russian Federation

Note by the Secretariat

1. In accordance with paragraph 16 of General Assembly resolution 60/99 of 8 December 2005, the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space will organize, jointly with the International Atomic Energy Agency, a technical workshop on the objectives, scope and general attributes of a potential technical safety standard for nuclear power sources in outer space, to be held in Vienna from 20 to 22 February 2006.

2. The working paper contained in the annex to the present document was prepared for the joint technical workshop in accordance with the indicative schedule of work for the workshop, as agreed by the Working Group on the Use of Nuclear Power Sources in Outer Space during the intersessional meeting held in Vienna from 13 to 15 June 2005 (A/AC.105/L.260).

* A/AC.105/C.1/L.283.

Annex I

Design safety considerations for launch, normal operations and mission accidents (covering specific design approaches to assure safety and mitigate risk given foreseeable environment conditions)

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I. Emergencies involving spacecraft with nuclear power sources on board

1. Emergencies arising during the launch and operation of spacecraft with reactor and radioisotope nuclear power sources on board result from accidents caused by launch vehicle and spacecraft failures at lift-off, during the launch vehicle flight phase or during acceleration of the spacecraft to operational orbit or to an interplanetary flight trajectory.

2. During the insertion phase of launch vehicles and spacecraft with nuclear power sources on board, the following types of accident may occur at lift-off and during the launch vehicle flight phase:

(a) Toppling from the launch pad prior to launch of a launch vehicle that is empty or loaded with propellant components, or lift-off and fallback of the launch vehicle following the launch as a result of uneven thrust of first-stage engines;

(b) Failure of the first stage of the launch vehicle (spontaneous engine shutdown) prior to initiation of the "abort" command and engine cut-off;

(c) Failure of the first stage of the launch vehicle and engine cut-off in response to the "abort" command;

(d) Failure of the separable part of the first stage of the launch vehicle to eject and non-ignition of second-stage engines, or ejection of the separable part of the first stage and non-ignition of second-stage engines;

(e) Failure of the second stage of the launch vehicle and engine cut-off prior to or following nose cone ejection;

(f) Similar failures in the operation of the second and subsequent stages;

(g) Explosion of the launch vehicle (blast wave pressure and debris bombardment) at lift-off, on the flight trajectory or during fall to Earth following engine cut-off;

(h) Fire on board the launch vehicle (flame temperature during combustion of propellant components, duration of combustion and change in flame temperature over time);

(i) Chemical effect of launch vehicle and spacecraft propellant components.

3. During the acceleration phase of a spacecraft with a nuclear power source on board, when the upper stage is in operation following separation from the launch

vehicle, failures may occur involving the shutdown of upper-stage engines and/or of the spacecraft propulsion system at various points during the flight, or failure of spacecraft navigation and stabilization systems.

4. Analysis of the consequences of such accidents is carried out on the basis of calculations and analytical research to determine the parameters of the impact of accidents on nuclear power source structures, with account taken of the destruction of the launch vehicle and spacecraft structures, which alters the structure of the falling object during ballistic descent of the launch vehicle and during the orbital re-entry of the spacecraft with nuclear power source on board into the Earth's atmosphere.

5. In the case of reactor nuclear power sources, such accidents cause the "cold" non-activated reactor (a reactor that is partially destroyed or destroyed down to individual fuel assemblies or to the core) to fall in a state of predetermined subcriticality; fragments and nuclear fuel particles may also fall following aerodynamic destruction and dispersal.

6. During normal operation of reactor nuclear power sources on board spacecraft, emergencies are caused by failures in nuclear power source systems (though these are unlikely), accompanied by depressurization of the reactor's liquid-metal circuit, partial loss of coolant, melting (thermal destruction) of nuclear fuel and radioactive emissions into outer space.

7. If a nuclear power source remains in space for a prolonged period in a relatively high orbit following its withdrawal from operation, emergencies may arise only in the event of a collision of a spacecraft and nuclear power source with a fragment of space debris, as a result of which the reactor (in the case of reactor nuclear power sources) or the radionuclide ampoule (in the case of radioisotope nuclear power sources) may be destroyed, causing radioactive emissions into outer space or the premature descent from high orbit and entry into the Earth's atmosphere of the spacecraft with nuclear power source on board (or of an autonomous nuclear power source).

II. Consequences of emergencies involving spacecraft with nuclear power sources on board

8. The scale of the impact of emergencies involving spacecraft with nuclear power sources on board is determined by the parameters of the effects of accidents on the nuclear power source structure in the event of failure of the launch vehicle, spacecraft or nuclear power source.

9. The scale of the impact also depends on the type of nuclear power source (reactor or radioisotope), for which two fundamentally different methods are used to ensure nuclear and radiation safety during normal operation of the nuclear power source and in the event of a mission accident:

(a) In the case of radioisotope nuclear power sources: maintenance of the integrity and leak-tightness of the radionuclide ampoules;

(b) In the case of reactor nuclear power sources: maintenance of subcriticality of the "cold" non-activated reactor prior to insertion of the spacecraft with a nuclear power source on board into operational orbit in the event of various types of deformation or partial or aerodynamic destruction of the reactor structure, or dispersal of nuclear fuel or structural materials.

10. If a launch vehicle explodes, neither the resulting shock wave—with a pressure, for example, of 60-80 kg/cm^2—nor the dispersing structural fragments directly affect the reactor, which is shielded by the spacecraft, nuclear power source and radiation shield structures. The explosion of a launch vehicle will lead to destruction of the spacecraft, deformation of the reactor vessel and ejection and fall of the reactor to Earth at equivalent impact velocity.

11. Fire on board the launch vehicle is accompanied by the effect of the flame temperature from the burning liquid propellant components on the reactor, on the radiation shield and on the nuclear power source, change in which—for example, from 3,600 K to 400 K within 4,000 seconds in the case of the Proton launch vehicle—will lead to melting of the reactor vessel and destruction (melting) of the steel thin-walled elements of the reactor structure, the radiation shield and the nuclear power source. In the event of fire on board the launch vehicle, the beryllium elements of the side reflector of a low-mass reactor with a developed surface may melt, and the outer lithium hydride layer of the radiation shield may dehydrogenate, with a liquid film of lithium forming on the surface of the radiation shield structure. The formation of a cloud of particles (drops) of beryllium and lithium, which are toxic elements, may lead to chemical contamination in the launch vehicle impact area if the beryllium and lithium particles are not radioactive. Destruction of the nuclear power source’s liquid-metal coolant circuit and of the caesium system of the thermal-emission converter reactor will lead to chemical contamination with sodium-potassium (lithium) and caesium. In the event of explosion of the launch vehicle and a fire, the nuclear fuel will not be destroyed because of the high-temperature uranium compounds used. In the case of thermal reactors, the reactor may also become subcritical as a result of dehydrogenation of the outer layer of the zirconium-hydride moderator.

12. In the event of failures during the launch vehicle’s flight phase, resulting in cut-off of the engines in response to the “abort” command, the following may occur, depending on the flight altitude and velocity of the launch vehicle and the time at which its nose cone is ejected:

(a) Axial acceleration of up to 10 units and lateral acceleration of up to six units affecting the launch vehicle, spacecraft and nuclear power source;

(b) Earth impact velocity of 60-260 m/s;

(c) Mechanical and aerodynamic destruction of launch vehicle, spacecraft and nuclear power source structures and of the outer elements of the reactor structure;

(d) Aerodynamic destruction of the fast reactor structure down to individual fuel assemblies or fuel elements or, in the case of a thermal converter reactor, down to the core, which contains a zirconium-hydride moderator and electrogenerating channels with nuclear fuel.

13. Failures during acceleration of a spacecraft with a nuclear power source on board to operational orbit or to an interplanetary flight trajectory will lead to the orbital re-entry of the spacecraft into the atmosphere, aerodynamic destruction of the spacecraft structure at altitudes of 70-90 km, and destruction of the nuclear

power source structure and the outer structure of the “cold” non-activated reactor at altitudes of 50-60 km. By the time a fast reactor reaches altitudes of 35-40 km, almost total aerodynamic destruction of the reactor occurs as a result of the absence of a metal-hydride moderator, and the fuel assembly structure is destroyed down to individual fuel elements (electrogenerating channels) or to individual parts of fuel elements (electrogenerating channels) containing nuclear fuel made from high-temperature compounds. The thermal converter reactor with zirconium-hydride moderator will be destroyed down to the core, and the outer layer of the moderator will be dehydrogenated.

14. In accordance with national regulations and international instruments concerning the use of reactor and radioisotope nuclear power sources in space, the following set of protective measures is envisaged if confirmation is received of an incident involving the accidental return of a spacecraft and nuclear power source or the fall of a spacecraft and nuclear power source from high orbit:

(a) Tracking of the descent trajectory parameters of an object containing a reactor and radionuclide ejected from high orbit after collision with a fragment of 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 part of the destroyed reactor structure and individual reactor and radioisotope nuclear power source 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.

15. The following criteria are used to determine the probability of exposure of individual members of the public to ionizing radiation in the event of the accidental fall of an object containing a reactor and nuclear fuel or a radionuclide ampoule following the failure of spacecraft insertion equipment or a collision of the spacecraft and nuclear power source with fragments of space debris and the subsequent aerodynamic destruction of the object’s structure during re-entry into the Earth’s atmosphere:

(a) The probability of insertion equipment failure and the probability of collision with a fragment of space debris of fairly large size;

(b) The probability of the object falling into an inhabited area, which, taking into account the launch vehicle’s flight path and the spacecraft’s orbital inclination, could be between 0.002 (infrastructure and water supply system) and 0.03 (land-use system).

16. The probability of a final event resulting from the accidental fall of a space nuclear power source into an inhabited area and the possible irradiation of individual members of the public could be of the order of 10^{-5}.