United Nations A/AC.105/C.1/L.388

General Assembly

Distr.: Limited
16 September 2020
English
Original: Russian

Committee on the Peaceful Uses of Outer Space
Scientific and Technical Subcommittee
Fifty-eighth session
Vienna, 1–12 February 2021

Experience in the practical application of the Principles Relevant to the Use of Nuclear Power Sources in Outer Space and the Safety Framework for Nuclear Power Source Applications in Outer Space

Working paper prepared by the Russian Federation

The present working paper has been prepared in accordance with paragraph 8 of the report of the Working Group on Nuclear Power Sources (A/AC.105/C.1/NPS/2019/L.1) for submission to the Working Group on Nuclear Power Sources of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space.

The working paper has been prepared for the purposes of implementing objectives 1 and 2 of the Working Group's multi-year workplan (A/AC.105/1138, annex II, paras. 8 and 9).

Compliance with international and national requirements makes it possible to ensure the safe use of nuclear power sources (NPSs) at all stages of the life cycle of spacecraft carrying such power sources, both during routine operation and in the event of an accident. Thus, the use of NPSs in outer space may be regarded as an effective means of enhancing possibilities for the exploration and use of outer space.

In accordance with the recommendations of the United Nations, the Russian Federation has established a system of regulatory documents and has developed technical measures to ensure the safe operation of spacecraft with NPSs on board.

For spacecraft using NPSs, safety at all stages of the life cycle is a key aspect and an inherent part of design and application. The Safety Framework for Nuclear Power Source Applications in Outer Space (A/AC.105/934) (hereinafter "the Framework") states that safety should be considered from the earliest stages of design of NPSs and spacecraft on the basis of the Framework.

The ExoMars space mission, a joint Mars exploration programme of State Space Corporation "Roscosmos" and the European Space Agency, is currently being implemented. The ExoMars-2016 space probe was launched under the programme. In 2020, it is planned to launch the ExoMars-2020 space probe for the delivery to Mars of a Russian surface platform with a European rover on board, both of which will be equipped with NPSs in the form of radioisotope heat sources.

V.20-05085 (E)

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The absolute requirement for the safe use of radioisotope power sources (RPSs) in outer space is that the design of such sources must be compliant with current international requirements for the safe use of NPSs in outer space, in particular with the safety guidelines and criteria set out in the Principles Relevant to the Use of Nuclear Power Sources in Outer Space (hereinafter "the Principles"), approved by the United Nations General Assembly in its resolution 47/68 of 14 December 1992. During the design of an RPS, scientific, technical and organizational measures are implemented to ensure the safety of the RPS at all stages of operation and in the event of an accident.

The safety of the RPSs for ExoMars is based on the approaches of the Russian Federation to ensuring the safety of radioisotope thermoelectric generators and radioisotope heater units at all stages of the life cycle. Those approaches have been developed according to the recommendations contained in the Framework and comply with the principles and criteria for the safe use of NPSs as set out in the Principles.

At the preliminary stage of design, the risks of an accident involving the RPS during its use are comprehensively assessed and, on that basis, the impact on the RPS and the likelihood of radiological consequences are determined. At the same stage, assessment and testing needs in respect of development of the RPS design are also determined.

In accordance with the Principles, RPSs are constructed to withstand heat and aerodynamic forces in the event of an accident, including upon re-entry into the upper atmosphere from highly elliptical or hyperbolic orbits and subsequent impact on the Earth's surface. The containment system and the physical form of the isotope ensure that no radioactive material is scattered into the environment at levels exceeding those established in the relevant IAEA standards (*Regulations for the Safe Transport of Radioactive Material*, Safety Requirements No. TS-R-1, 2009 edition) so that the impact area can be completely cleared of radioactivity by an RPS recovery operation.

At the stage of preparation of the RPS design documentation, a series of assessments and tests are carried out in order to ensure that the design meets safety requirements, those activities having been defined at the preliminary stage of design and including the following main steps:

- Development of a reliability protocol, safety protocol and quality assurance protocol for the RPS
- Issuance of design and operational documentation concerning the RPS
- Failure modes, effects and criticality analysis
- Performance of assessments (including thermal, strength and ballistic analysis and assessment of radiation exposure)
- Testing of behaviour under operating conditions (impact of climatic, thermal, vibratory, static and other effects)
- Testing of behaviour under accident conditions (including fire at the launch site, aerodynamic heating, collision with an obstacle, thermal shock upon immersion in water and the effect of external hydrostatic pressure)
- Assessment of RPS reliability and safety indicators
- Issuance of technical specifications

During development of the reliability and safety protocols, special attention is paid to the content of measures to confirm the reliability and safety indicators of the RPS design at all stages of the life cycle.

During the failure modes, effects and criticality analysis, on the basis of the design features of the RPS, possible failure modes and effects are identified with regard to various RPS design elements, the criticality of those modes is assessed, a list of critical elements of the design is drawn up and organizational, technical and design measures to prevent and detect potential failures of the identified critical elements are

formulated. The results of the analysis are used throughout the series of assessments and tests to confirm the reliability and safety of the RPS.

Testing of behaviour under operating and accident conditions is carried out on RPS models. Testing of behaviour under accident conditions is carried out on RPS models that have undergone the tests for behaviour under operating conditions. This enhances the information available and provides a more accurate assessment of the safety of the RPS.

Positive results from the entire series of assessments and tests form the basis for the safe use of the RPS, as they include confirmation of the reliability and safety of the design under all operating and accident conditions.

Once positive results are obtained for the whole series of assessments and tests conducted to fine-tune the RPS design, preparations for the production of standard RPSs designed for use in outer space are initiated.

The technology used to manufacture standard RPSs in terms of control methods is based on the technology for manufacturing the RPS models used during design development. This ensures the continuity of production techniques and makes it possible to control the uniformity of RPS model and standard product characteristics. Each RPS that is manufactured undergoes acceptance tests, which include testing of the effects of operational loads. Acceptance tests are conducted to verify compliance with technical specifications. In addition, the results of these tests are compared with the results of the tests conducted at the working design documentation stage.

Each RPS designed for use in outer space is subject to certification by the Federal System for Space Technology Certification. If the outcome of their assessment is positive, a certificate is issued certifying that each RPS has been designed in accordance with the requirements for the safe use of NPSs in outer space as set out in the Principles.

Thus, all RPSs are subject to 100 per cent control.

On the whole, the Principles and the practical recommendations set out in the Framework constitute an adequate tool for States and intergovernmental organizations seeking to ensure the safety of the development and use of NPSs in outer space.

Compliance with international and national requirements makes it possible to ensure the safe use of NPSs at all stages of the life cycle of spacecraft carrying such power sources, both during routine operation and in the event of an accident. Thus, the use of NPSs in outer space may be regarded as an effective means of enhancing possibilities for the exploration and use of outer space.