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Use of nuclear power sources in outer space

Discussion on the safety of space nuclear power sources

Submitted by China***

1. Introduction

Since the successful launch of the Chang-e 1 lunar probe in October 2007, China has continued to accelerate its exploration of outer space and has made additional progress in terms of the format of explorations and the distances involved. A lunar probe, scheduled to be launched in 2013, will carry landing gear and a surveying device to enable it to land on the moon and study the moon's surface. As space technology continues to progress, China will progressively explore deeper space providing that conditions are suitable in order to increase man's understanding of outer space.

The main issue to be considered in outer space exploration is which power source a spacecraft should use. The increased distance involved in the exploration of planets located at great distances from Earth leads to a marked decrease in the solar constants. Solar-powered technology therefore has virtually no capacity to support a mission of that kind. Nuclear power sources (NPS) are consequently a logical alternative given present technological conditions. Currently, isotope batteries and reactors are the main NPS used in space. The nuclides used are Pu-238 and Pu-235. The former is radioactive in its own right while the latter's reactive yields are

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radioactive. It is vital to study the safety of those nuclides in order to protect people and the environment.

The international community has been engaged in space exploration and the use of nuclear power for over forty years. NPS have been used both in near-Earth orbits and in outer space. Space NPS are essential in outer space exploration as they enable the exploration of cosmic bodies located in areas of the solar system beyond Jupiter. It is also paramount to minimize the safety risks associated with such power sources both on Earth and in space.

In view of those considerations, the United Nations Office of Outer Space Affairs (OOSA) and the International Atomic Energy Agency (IAEA) jointly published the Safety Framework for Nuclear Power Source Applications in Outer Space in 2009. The document contains guidance for the safe use of NPS in outer space by the international community and provides administrative and technical suggestions on how countries can develop space NPS in a safe manner.

2. The use of nuclear power sources in space

In the soft landing mission of the lunar exploration project currently being carried out by China, both the landing gear and the surveying device use Pu-238-based isotope power sources to enable the landing gear and the surveying device to function in night-time temperatures on the moon.

3. Analysis of the potential for using nuclear power sources in outer space

Currently, the main power sources that can be used in spacecraft are chemical, solar and nuclear energies. The main types of nuclear energy used to generate electricity are radioisotope and reactor NPS. The size of the opening mechanism and the configuration of a solar or nuclear power device have a direct impact on the size and dynamic characteristics of the space vehicle system. The selection of a suitable power source helps reduce the overall size of the spacecraft and the complexity of the design of the attitude and temperature controls and structural configuration.

Early recoverable Earth observation satellites tended to use chemical power sources, but such satellites would not spend more than a month in orbit.

Solar energy, in the form of solar battery panels, is currently the most commonly used power source in space. The use of solar power systems with moderate conversion efficiency in relation to output efficiency is highly developed. Their mass-power ratio and area-power ratio have both reached relatively advanced technological levels.

As power requirements increase, so do the requirements for the standard solar wings used in solar power systems. The technical complexity of the system to lock in place the opening mechanism is also increasing. The structure also needs to be reinforced to ensure that it is sufficiently rigid. Structural reinforcement tends to cause a significant increase in the total mass of the power source system. Once the power requirements for a spacecraft reach a certain level, the total mass and size of the solar power system required pose serious technical challenges for the systematic design and manufacture of the flight mission and spacecraft. It thus becomes necessary to find a new power source to increase the efficiency of the whole system.

As a spacecraft increases its distance from the sun, the advantage of using a space nuclear power source over a solar power source becomes increasingly clear. Analysis has shown that solar battery units, once they have reached a distance of five astronomical units from the sun, will decrease in efficiency to a level that is no longer acceptable (and, theoretically, the solar constant at that distance will also decrease to 1/25 of the reference value close to the Earth). That phenomenon makes it a priority to use space NPS when sending spacecraft to Jupiter and other more distant planets in the solar system.

The above-mentioned factors demonstrate that space NPS are the logical choice for the exploration of planets located at greater distances from Earth than Jupiter. The exploration of space, and outer space in particular, needs to opt for space NPS in view of the fact that solar power is not available owing to the effects of natural conditions such as moon-lit nights and the fact that chemical power sources are insufficient to meet requirements.

4. Understanding the safety of space nuclear power sources

The presence of radioactive materials or nuclear fuels in space NPS and any accidents caused by them pose a danger to people and the environment in the Earth's biosphere. The public at large are therefore concerned about the safety implications of space NPS.

A number of nuclear accidents have taken place across the world in previous years. Accidents at nuclear power plants include the Three Mile Island nuclear accident in 1979, the Chernobyl nuclear accident

in 1986 and the accident at Fukushima in 2011. Accidents involving space nuclear reactors re-entering the Earth's atmosphere include the crash of the RORSAT NPS into the Pacific Ocean to the north of Japan following its failed launch in 1973, the re-entry of a COSMOS satellite into the atmosphere over north-west Canada in 1978, which scattered radioactive debris over an area covering one hundred thousand square kilometres, and the crash of a COSMOS satellite into the Atlantic Ocean upon re-entry in 1983. All the accidents became subjects of public concern and debate and led to widespread concern about nuclear safety.

NPS have been used in space for over 40 years and have been powering a range of spacecraft, from ocean observation satellites on lower-Earth orbits to those designed to explore the planets on the outer edges of the solar system. The majority of the spacecraft completed their missions successfully and met the design requirements and thus did not release radioactive pollution into the environment in which they had been operating. The safety measures adopted for those spacecraft were therefore feasible and effective and can serve as reference points for the use of space NPS in the future.

For the foreseeable future, NPS will become the essential technological solution for powering spacecraft designed to explore outer space. However, more attention must be paid to space nuclear safety so that safety considerations are fully taken into account in the design and use of space NPS. Safety issues must be considered at all stages, with regard to the space NPS, spacecraft, launch system, design of the flight mission and flight control. Studies must be conducted on the control and technology aspects of nuclear protection and accident policies in order to increase safety capacity, identify measures to deal with problems and find appropriate solutions as part of efforts to reduce safety risks and potential accidents in the use of NPS.

5. Reflection on the safe use of space nuclear power sources

Space NPS are essential technological components for supporting missions to explore outer space and have a role to play in enhancing man's understanding and exploration of the universe. As space NPS are brought into use, it is also vital to take measures to limit injury and damage to people and their living environment to levels that are acceptable even in the worst-case scenario.

In order to further develop space nuclear technology, it is useful to draw on the successful experience of those countries that have launched NPS into space and to learn from past accidents so as to ensure space nuclear safety and radiation protection. As far as policy measures and administrative checks are concerned, a regime for the design, construction and operation of space NPS should be established at national level to regulate nuclear activities in space, develop technologies to ensure the safety of NPS and radiation protection, analyse the possible consequences of a failure of a space NPS, conduct thorough risk assessments and develop policies for dealing with accidents to reduce risks to an acceptable level.

5.1 Safety assessment and control

The safety of a space NPS is assessed throughout a project, beginning with the decision on the project and then during the programme design, research and development, construction and launch stages. A safeguards and emergency plan report for the nuclear power unit forms part of the assessment of the safety of the flight mission. The report, which is a requirement for evaluating whether a project can go ahead is submitted to a review group. Once adopted by the group, it is presented to the competent State administrative agency for approval. The project may only proceed to the development stage on the basis of agreement and approval.

The standards and regulations for safety assessments refer to and draw on the work of the State in relevant areas. The safety standards for space NPS are divided into a number of sections and cover all areas relating to space nuclear safety. They mainly include radiation safety and occupational health certificates and requirements relating to staff qualifications, transport, storage, protection, retirement and emergency measures.

5.2 Safety control of space nuclear power sources

Safety control of space NPS is divided into four parts, namely the start-up of the NPS, operation control, disposal at the end-of-service phase and safeguards.

In China, responsibility for the safety of a space NPS lies mainly with the manufacturer. The developer of the NPS, the developer of the space vehicle and the authority that manages the launch site also have their own respective responsibilities in relation to safety control.

(1) Start-up of the nuclear power source

The start-up and operation of the space reactor will only commence after the spacecraft enters the safety orbit. The reactor remains shut down until entry into orbit. An outer space probe fitted with a nuclear device is also present in the safety orbit. The flight path will not include a return to Earth, nor will the spacecraft re-enter the Earth's orbit during the leveraging flight.

(2) Flight control

When the space NPS is in normal operation mode the amount of radiation released from the power source into the spacecraft must not exceed the levels set by the State and must not have any marked impact on the space environment in which the spacecraft is operating, beyond a specified period of time.

The design of the flight path of a spacecraft fitted with an NPS must not include a return to Earth. Payload stability should be maximized in order to help minimize the probability of the spacecraft's accidental re-entry. If an accidental re-entry occurs, the NPS must be designed in such a way that it remains undamaged.

(3) Disposal at the end-of-service phase

Once a spacecraft with an NPS on a lower-Earth orbit reaches the end-of-service phase it will be sent into a special orbit for disused spacecraft. Nuclear-powered spacecraft operating in outer space must also follow a clear plan for safe disposal.

(4) Safeguards

The design of space NPS incorporates safety specifications. As far as the NPS on the spacecraft is concerned, the container used for the power source on Earth is specially designed to help identification and specially designed signs are used on the power sources to help ensure safety and facilitate identification. Strict measures are also adopted to control the nuclear devices and materials and to protect them from theft, removal, loss or damage.

5.3 Technology and relevant work to safeguard space nuclear power sources

The reliability of NPS should be increased to prevent critical safety accidents. Important measures to protect the NPS should also be adopted to ensure the safety of the environment and the spacecraft.

At the programme design stage, relevant nuclear safety requirements will be added to the functions and performance requirements and the resulting design will be reviewed and evaluated.

At the prototype stage, special tests will be carried out to assess the safety of the space NPS in addition to the routine environmental tests. They should include assessments of a power source's response to heavy vibration and resistance to heat, burning, pressure, impact and corrosion. Once the tests have been completed, the results will be reviewed and evaluated.

At the stage when the product is finalized, and in addition to the tests and experiments conducted on the spacecraft as a whole, tests will also be carried out to assess the safety of the NPS. The results will be reviewed and evaluated.

Conclusion

As regards the safety of space NPS, China takes a similar view to that contained in the Safety Framework.

When it comes to space NPS, special attention should be paid to technology relating to safety and radiation protection. The safety of the space NPS should be taken into account in the design of the power source. Safeguards should be put in place and tested in the development process. Relatively accurate risk assessments of space NPS can be made on the basis of the technology used for conducting risk assessments of civilian nuclear facilities in China. All possible measures should be adopted in accordance with accident plans in order to minimize the consequences of a potential accident.

Space NPS are an essential technological development that facilitate the exploration of space and the universe. However, they also pose a threat to the environment of the Earth's biosphere. As space nuclear power is developed, China is committed to supporting the efforts of OOSA and IAEA relating to the safety of space NPS and is convinced that the safety of such sources is a key issue in the development of space nuclear power technologies.

China appeals to countries across the world to strengthen research and cooperation in developing technologies that ensure the safety of space NPS in order to increase the safety and use of such technologies, remove any uncertainty about the safety of space NPS and ensure adequate protection for people and the environment, while also ensuring that the benefits of those new advanced technologies are widely enjoyed.