Preliminary Safety Research of Space Nuclear Power Source

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COTENTS

1 Introduction

- Deep space exploration missions need RHU/RTG
  - Long time lunar surface mission
  - Long time Mars surface
  - Jupiter and beyond exploration
- China has always attached great importance on the safety of NPS.
- This paper
  - Objectives of NPS safety design
  - Analyzes the working environment of NPS, extreme conditions in unexpected circumstances, and the corresponding safety measures.
  - Verification tests are proposed for safety measures

2 Safety Objective

- **Total safety objective**: Establish and maintain a set of effective defensive measures to protect people and the environment in the Earth's biosphere from potential radiological hazards from the development and application of nuclear-powered spacecraft.
- **Radiation protection objective**: Ensure that radiation caused by any radioactive material in the NPS or by any radioactive material planned release from the NPS is below the prescribed limit in all operating conditions. Ensure that the radiological consequences of any accident can be mitigated.
- **Technology safety objective**: Take all reasonable and feasible measures to prevent the NPS from accident and to mitigate its consequences in the event of an accident. For all possible accidents, including those with very low probabilities, ensure that any radioactive consequences are small and below the prescribed limit with high credibility. Ensure that the probability of accident with serious radiological consequences is extremely small.

3 Operating Environment and Extreme Conditions

- 3.1 **Normal Operating Environment**
  - Ground phase
    - Environment during manufacture, assembly, test, transportation and storage of the NPS equipment.
  - Launch site phase
    - Environment during the installation of the NPS into the probe and launch vehicle.
  - launch phase
    - Mainly including vibration, shock, acceleration, noise and pressure.
  - Operation phase and End of life phase
    - Environment includes the radiation generated by the NPS and the space radiation, space debris, low temperature, vacuum

3 Operating Environment and Extreme Conditions

- **3.2 Extreme/Abnormal Conditions**
  - Ground phase
    - include manmade accidents and transport, such as collision, fire, explosion, inundation, loss of cooling.
    - 包括人为制造事故和撞击、火灾、爆炸、淹没、丧失冷却等导致同位素燃料散布的运输事故。
  - Launch site phase
    - include damage and dispersal caused by propellant fire, propellant explosion and falling of NPS.
    - 包括推进剂起火、推进剂爆炸、放射源跌落等原因造成的毁坏和散布

3 Operating Environment and Extreme Conditions

- **3.2 Extreme/Abnormal Conditions**
  - Launch phase
    - include damage and dispersal caused by high-speed impact, propellant fire, propellant explosion, and launch termination.
    - 包括有高速撞击、推进剂起火、推进剂爆炸、发射中止等原因造成的损毁和散布.
  - Operation phase and End of life phase
    - Reentry
    - 再入

4 Safety Test and Testing Technical

- **Ground phase**
  - Storage: the climatic environment test such as temperature, humidity and heat cycling which may experience in the storage phase.
  - Transport: the transport mechanics environment test such as atmospheric pressure change, linear overload, vibration and shock.
- **Launch phase**
  - Mechanical environment during launch is more rigorous, including the mechanical environment induced by rocket launch, the vibration environment produced by the uneven combustion of the engine, the vibration environment produced by the interaction between the rocket structure and the atmosphere, the impact produced by the rocket stage separation and the fairing separation.

4 Safety Test and Testing Technical

- **Extreme/Abnormal Conditions**
  - Extreme/abnormal environment, such as the launch site fire, reentry into the earth atmosphere, impact on the ground or water surface.
  - 发射场火灾、再入地球大气、撞击地面或水面等异常环境
  - The environment tests include fire test for simulating launch site fire accident, aerodynamic heating test for simulating reentry into the Earth's atmosphere， impact test for simulating high speed impact, thermal shock test for simulating impact on water surface, pressure and corrosion test simulating long time immersion on the seabed.
  - 环境试验包括：模拟发射场火灾事故的火烧试验、模拟再入地球大气的空气动力加热试验、模拟高速撞击障碍物的高速撞击试验、模拟坠落海面的热冲击试验及模拟坠海后长期浸没在海底的压力及腐蚀试验。

4 Safety Test and Testing Technical

- A safety analysis example
  - Abnormal reentry into the Earth's atmosphere
  - The spacecraft's solar wing and cabin structure will disintegrate at high altitude, and the NPS will be exposed to the impact of high-speed airflow until burnt or crashed on the Earth's surface.
  - 异常故障工况下，探测器再入地球大气层，其太阳翼在120~130km高度发生解体，舱体结构在80km附近完全解体，将同位素核源曝露在高速气流的冲击中，直至坠落地球表面。
  - The centroid movement, flow field and nonequilibrium process of high temperature atmosphere are analyzed with the numerical analysis method. The trajectory, aerodynamic characteristics and thermal environment during reentry are obtained, and the heat transfer, ablation analysis, aerodynamic heating, ground impact, thermal shock and other safety tests conditions are determined.
  - 分析同位素核源高速再入地球大气过程的质心运动、绕流流场、大气化学非平衡过程等物理问题，获得同位素核源故障再入情况的飞行弹道、气动特性及热环境，提供同位素核源包壳传热、烧蚀分析及气动加热、地面撞击、热冲击等安全性试验的条件。

5 Safety measures

- **Safety management measures**
  - Formed safety management regulations of NPS (national and enterprise)
  - Identified the management government agencies
  - Defined the procedure of obtaining permission, and the duties and obligations of the relevant entities.
- **Safety technology measures**
  - NPS products safety technology, Normal Operating Environment/ Extreme/Abnormal Conditions
  - Radio-isotopic safety protection technology
  - Supervise technology, and Emergency safety technology

6 Conclusion

- Space NPS is the key technology to support the exploration of the universe, but the safety problem is always an important part of the design and application of space NPS.
- China has a similar understanding of the *Safety Framework for Nuclear Power Source Applications in Outer Space*.
- China will continue to carry out safety technology research of space NPS, and enhance the safety and application level of space NPS technology.
- China calls on all countries in the world to strengthen the research and cooperation in the safety technology of space NPS, and guide the healthy and safe development of space NPS.