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Use of nuclear power sources in outer space

Safety Practices of Space Nuclear Power Sources in China

Summary

The Chinese government attaches great importance to the safety of space nuclear power sources. China has been actively engaging in all kinds of tasks sponsored by Nuclear Power Sources Working Group (NPS WG), Scientific and Technical Subcommittee (STSC), Committee on the Peaceful Uses of Outer Space (COPUOS), United Nations (UN). During the practices of space nuclear power sources, *Principles Relevant to the Use of Nuclear Power Sources in Outer Space* adopted by the General Assembly in 1992 were closely referred to, in the meantime, guidance contained in *Safety Framework for Nuclear Power Source Applications in Outer Space* which was jointly published by STSC, COPUOS, UN and IAEA was applied widely.

Safety practices of space nuclear power sources were successfully carried out in Chang'E-3 (CE-3) mission. As for management aspects, regulations of space nuclear safety management were issued, a special coordination panel was formed, personnel safety measures were taken, an emergence response organization and the whole emergency response system were established, all kinds of levels of safety training and safety rehearsals were performed. As for technical aspects, safety design of space nuclear power sources was done, special safety experiments and tests were carried out, and radiation doses were measured. In the following missions, the Chinese government will make constant effort on improving the level of safety work of space nuclear power sources.

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I. Introduction

1. The Chinese government attaches great importance to the safety of space nuclear power sources. China has actively been engaged in all kinds of tasks sponsored by Nuclear Power Sources Working Group (NPS WG), Scientific and Technical Subcommittee (STSC), Committee on the Peaceful Uses of Outer Space (COPUOS), United Nations (UN). During the practices of space nuclear power sources, *Principles Relevant to the Use of Nuclear Power Sources in Outer Space* adopted by the General Assembly in 1992 were closely referred to, in the meantime, guidance contained in *Safety Framework for Nuclear Power Source Applications in Outer Space* which was jointly published by STSC, COPUOS, UN and IAEA was applied.

2. In order to endure the long moon night, Radioisotope Heater Units (RHUs) were used in the lander and rover of CE-3 mission, which were launched in 2013. Extensive work has been done to ensure the safety of the nuclear power sources during the mission, which has proved a great success.

II. Management Practices

3. China has a complete set of regulations, which comprise national laws, ordinance, standards and policies regarding the safety management of radioisotope products. Radiation safety licensing, occupational sanitation licensing, import and transfer, transportation, storage, protection, occupational health, personnel, retirement, emergency preparedness and response and others are covered by the regulations. Corresponding government bodies in charge are made clearly. Qualification and licensing processes, responsibilities and duties are also clearly stated in the regulations.

4. A special coordination panel was established, which acted on behalf of the national government to deal with all the high level management issues, such as safety reviews and compliance check-ups. Experts on nuclear safety and space technologies are part of the panel. The panel works under the guidance ——Ensure people and facilities safe, Make influence minimum. A series of actions has been taken to make sure that technical issues are all clear and full-mission-life management are effective.

5. Safety working items and responsibilities of corresponding action entities were clearly defined. With spacecraft, launch vehicle and launch site systems participating, a full-mission-life working flow of nuclear related products was made in consultation with prestigious experts of related fields. In the flow, working items, objects, emergency response, working sites and responsible entities were defined.

6. Personnel Safety Management:

(1) Transportation safety measures. Transportation undertakers should be qualified. Corresponding procedures should be strictly performed in accordance with national standards. Participating drivers and operators should have been trained and qualified. During transportation, protective containers should be used and radiation doses should be limited to an acceptable level. Participating vehicles should meet the safety requirements defined by corresponding standards and they should also be equipped with radiation monitoring and measuring devices.

(2) Safety measures for storage, tests and experiments. Those who would enter the storage, tests and experiments sites should receive safety training first and then get qualification certificates. The storage, tests and experiments sites of RHUs were constructed according to national standards and also qualified to store and deal with radioactive materials. Those who enter and get out of the sites would have to be booked in detail. Operations should be done according to signed documents. Security measures should meet the requirements of national standards. Radiation protection and doses measurement devices were necessary for these sites.

(3) Safety measures for equipment mounting. All workers should receive safety training first and then get qualification certificates. During assembly, integration and testing (AIT), RHUs are replaced by electric heating simulators. The checking-up of real RHU nuclear power sources were done in separate rooms with radiation protection conditions. Real RHU nuclear power sources were not mounted until the spacecraft had been loaded onto the launching tower so as to reduce radiation exposure of workers. Shielding, time and distance protection methods were used to reduce radiation doses of personnel. Workers were working in a duty-shifting manner so that per person dose would be minimized. Long-distance operations were also effective measures to reduce doses. Besides, all the operations were carried out under the guidance of nuclear safety experts. Radiation dose monitoring devices were used in the working sites. Simulations and on-the-site rehearsals were carried out before mounting real nuclear powers sources. The working sites were qualified. Those who enter and get out of the sites would have to be booked in detail. Operations should be done according to signed documents. Different alarming and monitoring measures were taken according to different levels of radiation danger.

7. Emergency preparedness and response:

(1) National Command for Special Nuclear Emergency Tasks was established under the leadership of The National Office for Nuclear Emergencies, with Luna Exploration and Space Engineer Center (a subsidiary of SASTIND) and other mission related entities participating. The Command was responsible for nuclear emergency rehearsals, emergency forces deployment and notification of launching.

(2) A special nuclear emergency plan for CE-3 mission in launching phase was made and authorized by National Committee on Nuclear Emergencies. Emergency tasks were carried out according to possible radioisotope accident scenarios. According to different scenarios, different emergency response working flows were made, equipment, responsibilities and working procedures of every working group were detailed in the plan.

(3) Nuclear emergency response teams (front-line and back-line ones respectively) were formed. Each team consisted of radiation detection, prediction and evaluation, protection and medicine, pollution removal, communication and logistics groups. The teams were responsible for radiation monitoring, radiation prediction and evaluation, protection and medical care, pollution removal, experiments, analysis and technical guidance.

(4) A special comprehensive nuclear emergency drilling was conducted in 2013. The drilling was based on presumed radioisotope accident scenarios and the whole emergency response flow was examined. Through the drilling, the applicability of the special nuclear emergency plan for CE-3 mission and in-the-field capabilities of related emergency rescue forces were evaluated.

(5) Emergency equipment used solely for nuclear emergency was allocated. Fixed-line telephones, interphones, mobile phones, satellite phones and navigators comprised of communication equipment. Different kinds of radiation analysis devices, radiation source detection devices, detection devices used at night and nuclear material recycling devices comprised of radiation processing equipment.

(6) Before launching, the public who might be influenced according to careful analysis were evacuated and hidden in safe areas.

8. Training:

(1) Special radiation safety handbooks were compiled and then used as preliminary training materials for all related personnel.

(2) For the radiation safety training of the management and designers, related effective regulations were compiled while some new ones were specially issued for the mission.

(3) Special operation procedures were made. Workers, who were responsible for nuclear products related operations, would not be allowed to change their posts unless there were no other choices, in order to make sure that they were proficient in the operations. Mock-up operations were specially designed to train the workers.

(4) For those engaged in emergency response, training courses were carried out, which included fundamentals of radiation safety, radioisotope accident scenarios, emergency response working flow, performance and operations of emergency response equipment.

III. Technical Practices

9. Safety design. The types of rays and their characteristics were analyzed. Radiation safety analysis and protection designs were made. Safety analysis and protection designs were also carried out for accident conditions.

10. Safety verification. 9 special safety experiments and tests were carried out, which were free falling, mechanical impact, high temperature tolerance, thermal shock, external overpressure, aerodynamic overheating, high temperature ablation, mechanical impact in high temperature and seawater erosion. RHUs of CE-3 past all the experiments and tests.

11. Monitoring and analysis of radiation doses. To ensure the safety of workers on the launching tower, radiation doses of CE-3 nuclear power sources were quantitatively predicted using numerical models. The results were used to design safety protection measures on the launching tower. Statistics of doses were also made for workers based on possible working time and working places. It was found that for mounting workers the worst case radiation dose was 2.16mSv, while the natural annual effective radiation dose for Chinese residents in 2010 was 3.1mSv. Results of the above analysis showed that the safety measures of CE-3 which were taken before launching were effective, and radiation doses were controlled to an acceptable level and met the requirements of radiation protection standards of China.

IV. Conclusion

12. RHUs were used for CE-3 mission. Related guidance in *Safety Framework for Nuclear Power Source Applications in Outer Space* was implemented accordingly. China has gained successful experiences in management and technical practices of space nuclear power sources.

中国的空间核动力源安全实践

中国国家航天局

摘要

中国政府一贯重视空间核动力源的安全工作。中国积极参与联合国外空委科技小组主导的空间核动力源工作组（NPS WG）相关活动。在空间核动力源的相关实践工作中，参考了 1992 年联合国大会通过的《关于在外层空间使用核动力源的原则》，应用并推广了联合国外空委科学和技术小组委员会与国际原子能机构于 2009 年联合发布的《外层空间核动力源应用安全框架》。

在嫦娥三号（CE-3）任务中，中国成功开展了空间核动力源安全实践。在管理方面，建立了安全管理规章制度，组建了专项协调小组，实施了人员安全防护管理，建立了应急管理机构并形成了应急响应机制，开展了多层次的安全培训及安全演练；在技术方面，开展了空间核动力源安全性设计，实施了安全性专项试验，进行了辐射剂量分析和监测。在后续任务中，中国政府还将努力提升空间核动力源安全工作水平。

一、 导言

1. 中国政府一贯重视空间核动力源的安全工作。中国积极参与联合国外空委科技小组主导的空间核动力源工作组相关活动。在空间核动力源的相关实践工作中，参考了 1992 年联合国大会通过的《关于在外层空间使用核动力源的原则》，应用并推广了联合国外空委科学和技术小组委员会与国际原子能机构于 2009 年联合发布的《外层空间核动力源应用安全框架》。

2. 2013 年发射的 CE-3 探测器分别在着陆器和巡视器上使用了同位素热源组件（RHU），以渡过漫长的月夜。在嫦娥三号任务中，针对空间核动力源，中国采取了严格的安全措施并取得了很好的效果。

二、 管理实践

3. 中国形成了相对完善的放射性同位素产品安全管理规章制度。这些方面包括辐射安全许可，职业卫生许可，进口与转让，运输，储存，防护，职业健康，人员要求，退役，事故应急等。在这些管理规章制度中，均明确了相关业务的国家管理机构，承担单位所必须具备的资质，承担单位获得许可的程序，承担单位必须承担的职责与义务。

4. 针对嫦娥三号的放射性同位素产品管理，组建了专项协调小组，包括放射性领域专家、有关研制单位专家，专项协调小组代表国家负责处理嫦娥三号放射性同位素产品的所有审查、监督、检查等管理工作。本着“确保人员、设备设施安全，控制范围最小化”为原则，组织开展了一系列工作，技术上做到完全摸底，管理上做到全周期管控。

5. 明确工作内容和责任。组织探测器、运载火箭、发射场系统，并邀请该领域权威专家咨询把关，编制了涉核产品的全生命周期流程图，明确各个环节的工作内容、工作对象、应急预案、工作地点和责任单位。

6. 人员安全防护管理：

（1）运输安全措施。运输承担方应具有相应资质，运输过程办理相关手续并严格按照国家有关标准执行。参与运输的司机和相关操作人员经过培训并具有相应资质。运输过程均采用带有防护能力的包装箱，保证辐射剂量在规定范围内。运输车辆满足相关安全要求，配备相关辐射监测、检测设备。

（2）储存、测试安全措施。进出储存、测试场地的人员经过培训，取得相应资质证书。RHU 的储存、测试场地建设严格按照国家有关标准进行。储存、测试场所具有相应资质。进出储存、测试场地执行进出登记制度。储存、测试过程中的操作严格按照有关文件规定进行。场地内安防措施满足国家安全标准的规定。配置相应的防护装置和辐射剂量监测设备。

（3）安装过程安全措施。操作人员经过培训并具有相应资质。在正样所有 AIT 环节，RHU 均采用电加热模拟核源的工艺核源，RHU 核源真实核源在具有防护措施的场所进行单独的检测，RHU 核源真实核源安装在上塔后进行以尽量减少操作人员的接触时间。安装过程中对辐射剂量的防护可以采取时间防护、距离防护的措施，即尽可能减少操作时间、值班人员轮岗、远距离操作等方式，在专业人员的监测和指导下进行。现场配备辐射剂量监测

设备。安装操作正式执行前进行仿真和实际环境演练。安装场所具有相应资质。执行进出登记制度。严格按照相关文件进行规定操作。对不同级别的辐射危险区采取相应的警示、监控措施。

7. 应急准备和响应：

（1）由国家核应急办（国防科工局）牵头，工程中心及相关单位参加，成立国家核应急专项任务现场指挥部，组织开展应急演练，部署应急处置力量，并履行发射有关通告义务。

（2）编制了《嫦娥三号任务发射阶段核应急专项预案》，并报国家核应急委员会批准实施。各项应急工作根据放射性同位素产品事故场景展开。根据场景的不同，制定了完整的应急响应流程，细化了每一个工作小组的工作设备、工作范围和工作步骤。

（3）针对可能发生的核突发事件，成立了嫦娥三号的核应急现场响应队伍，以及核应急后方响应队伍，分为辐射检测组、预测评价组、防护与医学组、回收去污组和通讯与保障组。应急响应队伍开展辐射监测、预测评价、防护医学、回收去污、试验分析和技术指导等工作。

（4）组织了 2013 专项核事故应急演习，根据应急预案设定的放射性同位素事故场景，开展全过程应急演习，有效检验了嫦娥三号任务专项预案的适用性和相关核应急救援技术支持力量的现场处置能力。

（5）为应急响应配备了专用的应急物资器材。通讯设备包括固定电话、对讲机、移动电话、卫星电话和导航仪。辐射监测与放射源回收设备包括各种辐射分析仪器，各种辐射源探测仪器，夜间探测设备，专用回收设备等。

（6）运载火箭发射前，进行公众安全疏散和隐蔽。

8. 培训：

（1）编制了专门的辐射安全手册，针对所有可能涉及的相关技术人员，开展普通级的辐射安全培训工作。

（2）整理制定专门的条例和部门规范，针对产品和型号研制的管理和设计人员，开展辐射安全培训工作。

（3）制定专门的操作规程，固定操作队伍，开展辐射安全及模拟操作培训工作。

（4）对参与应急响应的人员，培训辐射安全基础知识，放射性同位素产品

事故场景及对应的应急处理措施，相关应急响应程序，应急响应设备的性能和操作。

三、 技术实践

9. 安全性设计。针对放射性同位素产品，开展了包括射线种类及其特性分析，辐射剂量分析，辐射安全分析与防护设计，意外事件中的安全分析与防护设计等工作。

10. 设计验证。共开展了 9 项安全性专项试验，分别是自由落体、冲击、热试验、热冲击、外部压力、气体动力过热、高温烧蚀、高温冲击和海水腐蚀。CE-3 的 RHU 顺利通过了上述所有试验。

11. 辐照剂量分析。为保证安装放射性产品后发射塔架上操作人员的安全，对 CE-3 核动力源的辐射剂量进行了定量计算，并据此采取了有针对性的安全性防护措施。根据发射场工作人员实际工作时间和工作部位进行统计，在发射前工作人员受照剂量最大值为 2.16mSv，而我国居民所受天然辐射年有效剂量 2010 年约为 3.1mSv。分析及最终测量结果表明，空间核动力源的地面操作是安全的，符合国家辐射防护标准。

四、 结束语

12. 中国实施的 CE-3 任务成功使用了 RHU，实践了《外层空间核动力源应用安全框架》的相关规定，中国在空间核动力源安全管理和技术实践方面积累了成功经验。