ENSAF - STEPS TOWARDS A EUROPEAN SPACE NUCLEAR SAFETY FRAMEWORK

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ABSTRACT

Following a recommendation by the European Working Group on Nuclear Power Sources for Space in 2005 and in line with the effort within UN COPUOS to develop an international safety framework for the use NPS in space, ESA has initiated the development of a European space nuclear safety framework (ENSaF), focussing on radioisotope power sources.

This paper describes the drafting method and process for such a framework as well as its preliminary conclusions and recommendations.

Key words: NPS; nuclear safety.

1. INTRODUCTION

Nuclear power sources (NPS), including radioisotope power source (RPS) and nuclear reactors have been used in space missions since 40 years. [FW99] ESA missions containing nuclear power sources, e.g. *Ulysses* [Eur05] and *Cassini/Huygens* [Jet93], have so far been cooperative missions with NASA, conducted under a US nuclear safety framework and launched from US territory. Therefore, ESA had not yet established its own nuclear safety framework.

Space missions containing nuclear power sources involve hazards not present in non-nuclear launches. As with all activities involving significant quantities of radioisotopes, space missions containing nuclear power sources require dedicated procedures, controls and processes in order to keep the associated risk as low as reasonably achievable (ALARA principle). Due to the potential cross-border risk these activities are subject to international conventions and recommendations agreed upon within the United Nations framework.

1.1. Definitions

The term "space nuclear power sources" or "nuclear power sources for space" (NPS) usually comprises:

nuclear fission reactors: small fission reactors that are in principle similar to terrestrial reactors but with different retained design options especially for reactor cores, cooling, moderation and control systems;

radioactive power sources (RPS): generally relatively small devices using the natural decay heat of radioisotopes either for thermal control (*radioisotope heating units (RHUs)*) or converted into electricity (*radioisotope thermo-electric generators (RTGs)*).

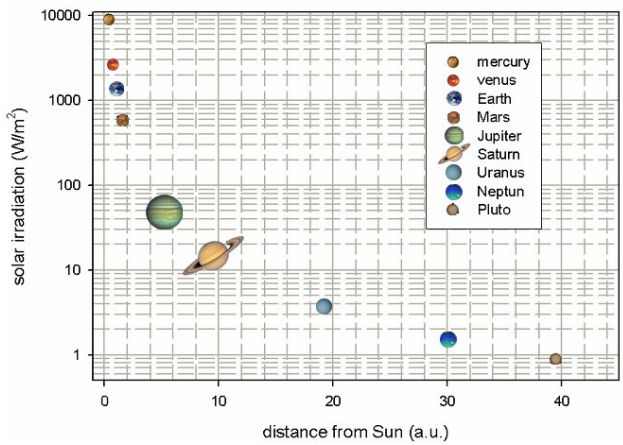

Figure 1. Semi-logarithmic graph showing the decrease of solar intensity with the square of the distance to the sun, resulting in a 60% decrease at Mars orbit and more than 95% decrease at Jupiter orbit compared to its intensity at Earth distance.

1.2. Power level range of nuclear power sources

Fig. 2 shows the approximate power level range of different nuclear power sources (from small RHUs emitting mW_{th} to nuclear thermal propulsion reactors in the GW_{th} range) and the comparison with terrestrial nuclear power sources (surface and submarine reactors).

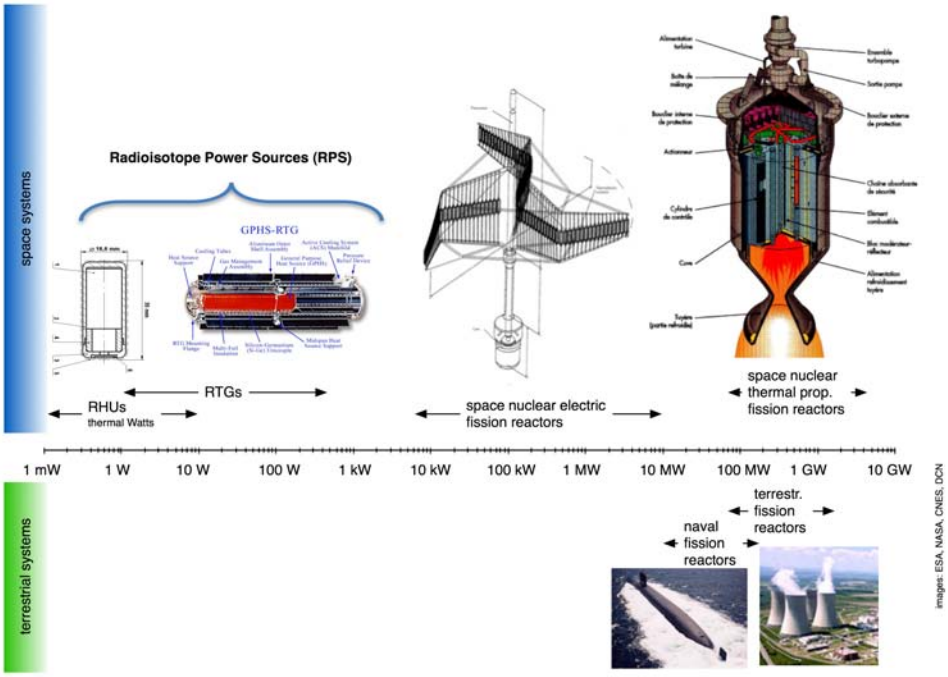

Figure 2. Power range of nuclear power sources for space applications, and comparison with standard terrestrial nuclear power applications.

1.3. General use of nuclear power sources in space

For interplanetary exploration beyond the Earth' distance from the Sun, solar power quickly reaches its limits (Figure 1), making radioisotope devices the only currently known practical power source for a whole range of missions: RPS have been used on all interplanetary spacecraft to Jupiter and beyond as well as on-board most planetary landers. [US 87, US 08, Eur05, Haa84, ESA05, Jet05c, Jet93, Jet05b, Jet05a, NAS05, FSB04, Jet05d]

The first space mission involving an RTG was the US *Transit 4a* spacecraft launched in 1961; at least 24 further missions into Earth orbit, interplanetary space and to planetary surfaces followed.

While the US have focussed their effort in the field right from the start of space activities on radioisotope power sources, the Soviet space nuclear programme has given priority to the development of space fission reactors, of which over 30 have been flown in the last 40 years. All of these have been used on experimental and defence related satellites in low Earth orbit. Soviet radioisotope power sources have been used in Earth orbits and on lunar missions. [US 87, L70̈]

2. RELEVANT EUROPEAN COMPETENCE

Europe has developed and maintained a well-functioning institutional and industrial nuclear base for terrestrial and maritime applications of nuclear energy. Several European states made early prototypes and in-depth studies on NPS for space already in the 1960s and Europe gained experience on their integration and use during the *Ulysses* and *Cassini/Huygens* missions.

2.1. Well-functioning European industrial and institutional nuclear base

A number of Member States of the European Union and ESA have developed world-renowned expertise in nuclear power systems in general. Terrestrial nuclear power plants deliver 35% of the European electricity need. Europe has developed and partly implemented the full nuclear fuel cycle and successfully operates a large variety of different nuclear power plant designs. [IEA02]

2.2. Early European work on NPS for space

In parallel to the US and Russian efforts for the development of nuclear power sources for space, Europe has started small research and development programmes for

both radioisotope power systems and nuclear fission reactors. These have resulted in early prototypes of radioisotope thermo-electric generators, including nuclear fuelled testing during the 1960s and advanced studies on space fission systems in the late 1960s/early 1970s and late 1980s/1990s. [L70̈, Rae02, MBB+03]

2.3. RPS application experience in space

European industry and agencies gained experience with the application of radioisotope power sources in space during two co-operative space missions with the US: *Ulysses* and *Cassini/Huygens*. For both missions, the radioisotope power sources were provided and taken care of by the US partners and both missions were launched from US territory and on US launchers following US launch approval processes. [ESA05, Jet93]

3. CURRENT FRAMEWORK

While Europe has no dedicated space nuclear safety framework for ESA missions wih nuclear power sources, several international and national regulations, standards and requirement relevant to the safety of space nuclear power sources exist. ESA member states have furthermore comprehensive national safety frameworks related to radiation protection and nuclear safety of terrestrial activities involving radioisotopes and nuclear processes.

3.1. International Framework

Transport Regulations

Radioactive material is part of the special cargo group "dangerous goods". International regulations for the carriage of dangerous goods are based on the UN Model Regulations [UN:92] and have been concretised by the different transport organisations (e.g. OTIF, ICAO and IMO). For the transport of radioactive material in general, international standards are given by the IAEA Safety Requirements No. TS-R-1 (Regulations for the Safe Transport of Radioactive Material) [IAE05c]. These recommendations are not legally binding but are implemented in many national legislations (e.g. by all European Union Member States).

The objective of the IAEA regulations is to protect persons, property and the environment from the effects of radiation during the transport of radioactive material. This protection is achieved by requiring:

- containment of the radioactive contents;
- control of external radiation levels;
- prevention of criticality; and
- prevention of damage caused by heat.

General provisions for the safe transport of radioactive materials are given, covering radiation protection, emergency response, quality assurance, compliance assurance, non-compliance, special arrangement and training.

International security regulations and guidance for import and export

For nuclear material used for peaceful purposes the "Convention on the Physical Protection of Nuclear Material" was adopted in 1979 and strengthened during a conference in 2005. The convention applies to nuclear material while in international nuclear transport, in domestic use, storage and transport as well as to import, export and transit procedures. In particular, it describes different levels of physical protection to be applied in international transport of nuclear materials depending on the category of the nuclear material. [IAE05a]

More detailed, the IAEA Safety Series recommendation "Physical Protection of Nuclear Material and Nuclear Facilities" describes requirements for physical protection against sabotage, unauthorized removal of nuclear material in use and storage, and during transport. [IAE05a]

Security of nuclear material suitable for use in nuclear weapons is additionally assured by the "Treaty on the non-proliferation of nuclear weapon". [IAE70]

Basic requirements for security of sources are defined in the "International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources". [IAE96b] It requires sources to be kept secure so as to prevent theft or damage and to prevent any unauthorized legal person from carrying out specific actions.

For radioactive sources that could pose a significant risk to individuals, society and the environment the "Code of Conduct on the Safety and Security of Radioactive Sources" was issued by IAEA in 2005. [IAE05b]

Within the EU, the Council Directive 2003/122/Euratom on the control of high-activity sealed radioactive sources and orphan sources defines measures for control and security of high-radioactive sources. [EU:03] While the IAEA Code of Conduct is not legally-binding, EU Member States were requested to bring into force laws, regulations and administrative provisions necessary to comply with this Directive, which thus became binding for activities within EU member states.

Furthermore, some other international conventions related to nuclear materials might be relevant.

International Liability

Several international documents deal with the question of liability in the field of nuclear energy: the *Paris Convention*: "Convention on Third Party Liability in the Field of Nuclear Energy" [OEC82] with the supplementary Brus-

sels Convention and the *Vienna Convention on Civil Liability for Nuclear Damage*. [IAE96a]

The "Convention Relating to Civil Liability in the Field of Maritime Carriage of Nuclear Materials" [IMO71] supplements the Paris Convention for this special case.

Notification of accidents

Notification and information procedures about a nuclear accident are regulated by the "Convention on Early Notification of a Nuclear Accident". [Uni86b] This convention applies in the event of any accident involving facilities or activities from which a release ofradioactive material occurs or is likely to occur and which has resulted or may result in an international transboundary release that could be of radiological safety significance for another State.

The use of radioisotopes for power generation in space objects is explicitly mentioned as one of the affected activities.

Assistance in case of accidents

To facilitate prompt assistance in the event of a nuclear accident or radiological emergency to minimize its consequences and to protect life, property and the environment from the effects of radioactive releases, the "Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency" was adopted. [Uni86a]

International Environmental Impact Assessments

A large number of activities dealing with nuclear material are subject to environmental assessment as required on an international and European level.

For example, the *Espoo-Convention*: "Convention on environmental impact assessment in a transboundary context" [EIA91] has identified "*the need to give explicit consideration to environmental factors at an early stage in the decision-making process by applying environmental impact assessment, at all appropriate administrative levels, as a necessary tool to improve the quality of information presented to decision makers so that, environmentally sound decisions can be made paying careful attention to minimizing significant adverse impact, particularly in a transboundary context*".

Radiation Protection

There are furthermore international principle related to standards of radiation protection, essentially based on the scientific work of the *ICRP - International Commission on Radiological Protection*, e.g.ICRP-60. [ICR90, ICR08]

The IAEA has implemented most recommendations in, among others, the IAEA Safety Fundamentals Nr. 120 "Radiation Protection and The Safety of Radiation Sources". [IAE96c]

The European Commission has issued the Directive 96/29/Euratom. [EU:96]

Space Law

Within the UN COPUOS framework several articles and provisions in the space treaties are relevant for the use of nuclear power sources in space. [Uni84, Uni67, Uni68, Uni72, Uni76]

The only recommendation entirely dedicated to space nuclear power sources are the "Principles Relevant to the Use of Nuclear Power Sources in Outer Space", adopted in 1992. [Uni92]

For a more comprehensive review, it is referred to a report by the COPUOS *Working Group on the Use of Nuclear Power Sources in Outer Space* , published in 2002 of "international documents and national processes potentially relevant to the peaceful uses of nuclear power sources in outer space". [COP02] For a legal assessment specific to questions related to space exploration, it is referred to a recent article by Bohlman. [Boh05]

3.2. Relevant ESA and CNES standards

While it does not contain a specific document or standard on the use of nuclear power sources on European space mission, the European Cooperation for Space Standardization (ECSS), an initiative established in 1993 to develop a coherent, single set of user-friendly standards for use in all European space activities, contains several provisions fully relevant for the use of NPS. [ECS08]

CNES has developed in 2002 a Nuclear Safety Requirement document. [CNE02]

4. EUROPEAN SPACE NUCLEAR SAFETY FRAMEWORK

Following a clear recommendation by the European Working Group on Space Nuclear Power Sources from 2005, ESA has initiated within its General Studies Programme, the drafting of a European space nuclear safety framework.

The activity required the involvement of entities and expertise with little traditional overlap, especially nuclear safety, launch safety and spacecraft design and integration. In order to make full use of the existing European expertise, experts from eight organisations from four ESA member states and covering the entire spectrum of relevant space and nuclear expertise worked together and in consensus during 2006 and 2007 to draft possible basic principles of a European space nuclear safety framework (ENSaF). Alongside ESA, the French space agency CNES and the French Centre d'Energie Atomique (CEA) have followed the study.

In order to take advantage of the considerable US expertise in the space RPS safety, and in conjunction with the ongoing effort at UN COPUOS level to develop an international space nuclear safety framework, representatives from JPL, NASA and the US Department of Energy assisted the study by providing valuable input on the methodology, the process and its organisation.

After establishing a common understanding of the terms and references among the space and nuclear safety experts, the consortium assessed in several workpackages nuclear safety relevant aspects of a typical spacecraft integration cycle, analysed applicable regulations in France, Germany, UK and Italy as well as international regulations, analysed the US and Russian space nuclear safety approval processes, the role and mandate of national nuclear safety authorities and derived general nuclear safety objectives for European space missions.

Based on this assessment, the consortium then described a proposed consensual European space nuclear safety approval process, which is strongly centred around the standard French nuclear safety approval process but taking into account the particularities of ESA space missions.

Based on all the different workpackage reports and additional analysis, an ENSaF synthesis report was drafted by representatives from ESA, CNES and Areva TA.

5. CONCLUSIONS

Safety is of primary importance for all space missions. Space missions using nuclear power sources involve potential hazards not present in non-nuclear launches.

The presence of radioactive material and their potential for harm to people and the environment require safety to be an inherent part of their design and application. Nuclear safety needs to be achieved at system level and not at componenet level: It needs to address the whole system, including the spacecraft, the launch system, as well as the mission design and flight rules.

Contrary to safety requirements that need to establish certain tolerated maximum levels, nuclear safety requires missions using NPS also to *minimize* radiological risks (ALARA principles). This requirement has significant repercussion.

Missions with nuclear power sources onboard require the additional competences and the participation of organisations not involved in regular launch approval processes, and therefore require additional activities, reviews and approvals throughout and embedded in the standard project phases of space missions.

For European missions from the European spaceport CSG in French Guyana, the French space and nuclear safety authorities, CNES and ASN can be expected to play central roles.

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