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Safety of radioisotope power sources for space missions

Image: U.S. Department of Energy

Outline

- **Introduction**
  - Need for radioisotope power sources in space missions
  - European dimension
- **Types of radioisotope sources for space missions**
- **Specific safety aspects**
  - Specific hazards
  - Safety-related design features of sources
  - Other safety-related provisions
- **Safety evaluation and approval**
  - Perspectives for European approval appoach
  - General space nuclear safety goals

Introduction

- **Need for radioisotope power sources in space missions**
  - *Missions to outer planets* : Power supply, heat supply

    Examples:
    Galileo => Jupiter; Cassini => Saturn; New Horizons => Pluto
  - *Planetary surface missions*: Predominantly heat supply
  - *Examples:* Mars rovers
- USA, Russian Federation: **Established approval process**
- **European Dimension: Current situation**
  - No approval process for launches from Kourou
  - Common European safety framework needed

=> Common Study for a "European Space Nuclear Safety Framework" (ENSaF) by nuclear industry, space insustry and TSO's

Types of radioisotope sources for space missions (1)

- Preferred Isotope: Pu 238 (As PuO2 in ceramic Form)
  - α-Emitter (with some γ,n background due to impurities)
  - Non-fissile material
  - High thermal power density
  - Long half-life

Material Properties of Pu-238	
Specific activity [TBq/g Pu-238]	0.63
Half-time of decay $T_{1/2}$ [a]	87.7
Specific thermal power P_h [W/g Pu-238]	0.5
Ratio activity/thermal power [TBq/W]	1.26

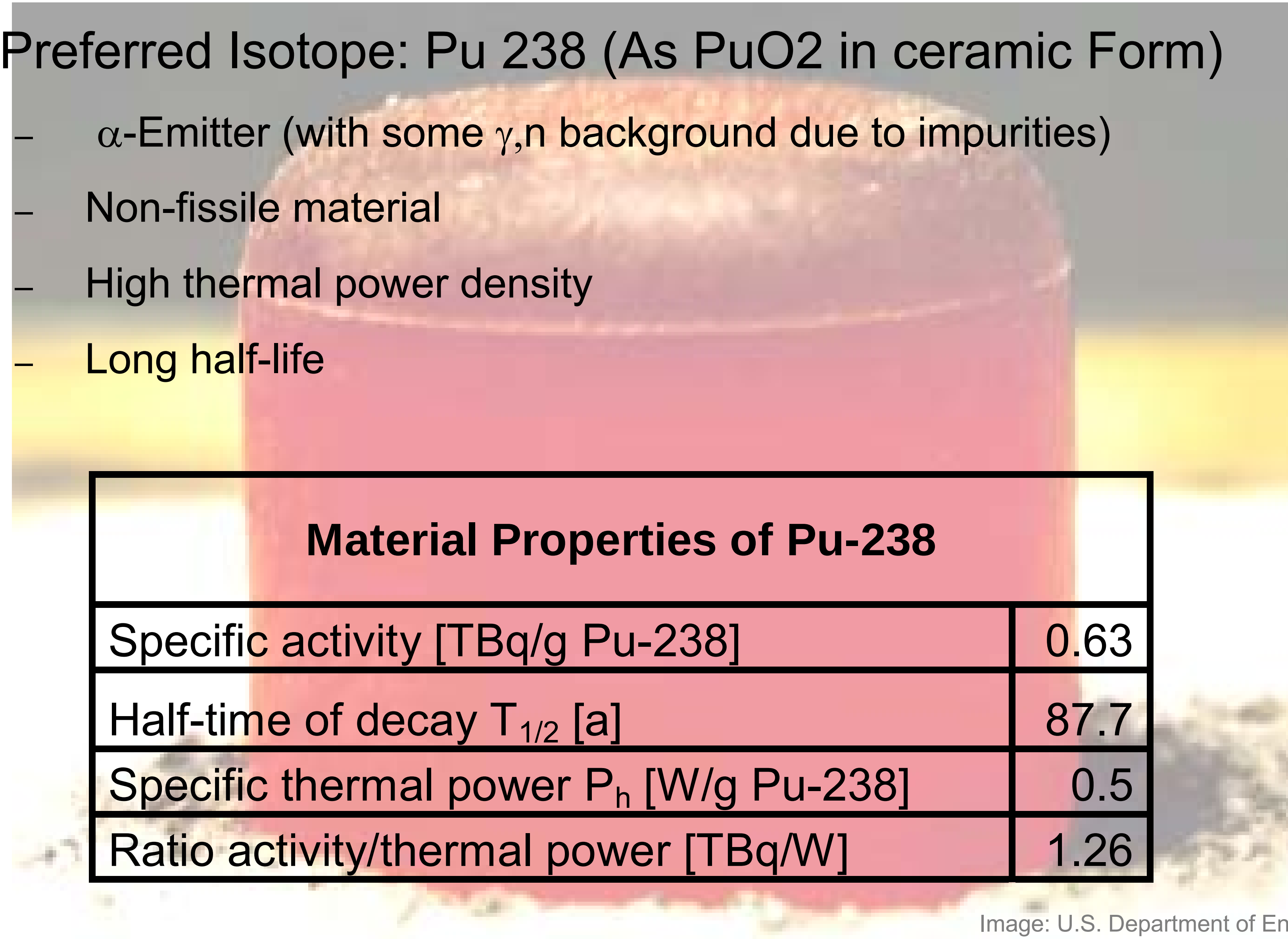


Image: U.S. Department of Energy

Types of radioisotope sources for space missions (2)

- **Example from U.S. production: RTG for New Horizons (2007) mission**
- 18 modules (General Purpose Heat Sources, GPHS)
- 10,9 Kg of PuO_2 with 4900 TBq (132500 Ci)
- Thermal power: 3800 W
- Electrical power: 290 W
- Total weight: 56 Kg

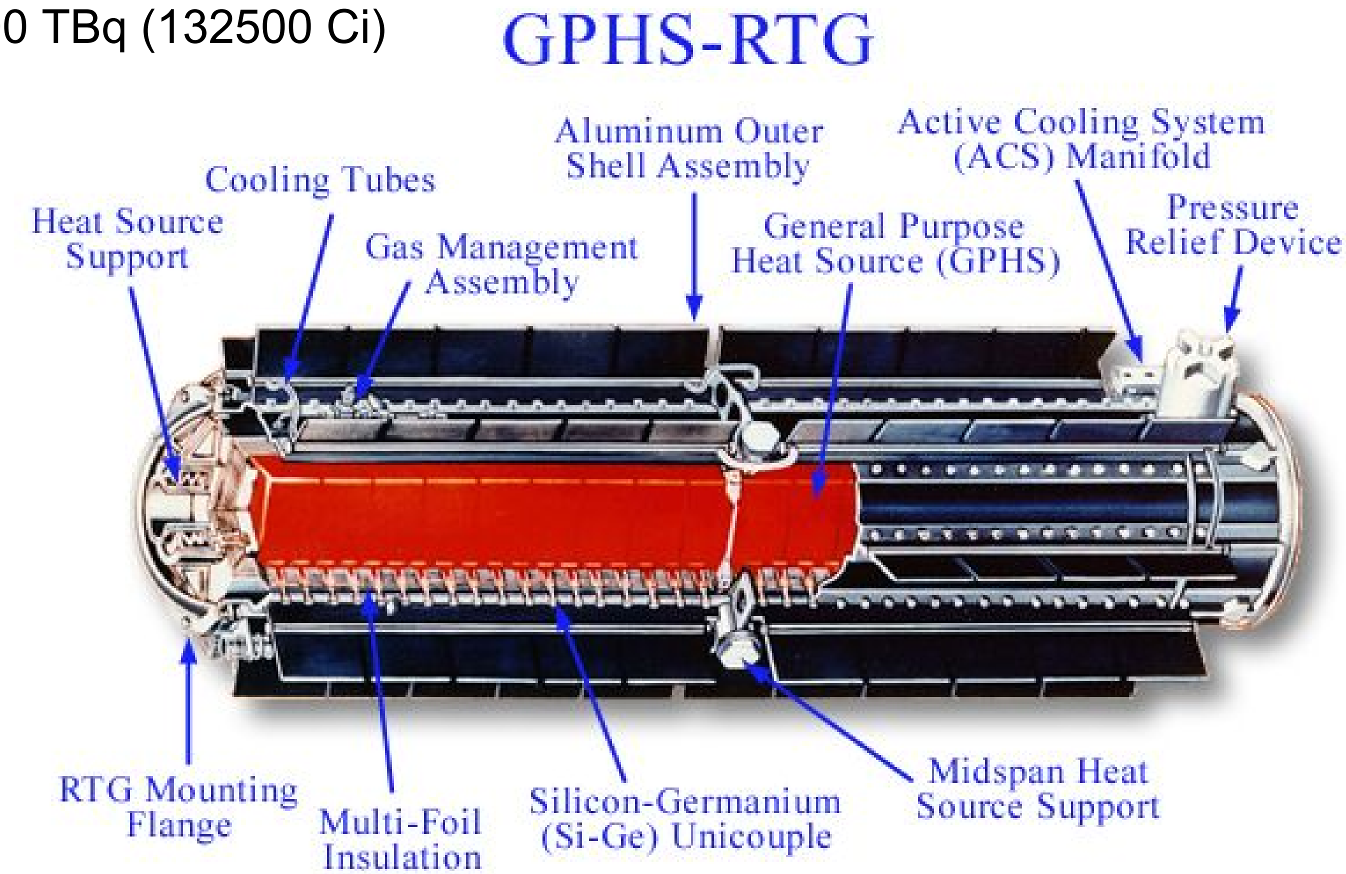


Image: U.S. Department of Energy

Types of radioisotope sources for space missions (2)

- **RTG integrated in spacecraft**

Image: NASA

Types of radioisotope sources for space missions (4)

- **GPHS**
- 600 g of PuO_2
- 69% Pu-238, 14,5% other Pu-isotopes 4,5 % actinide impurities, 12% Oxygen
- 270 Tbq

Main barriers against release

- Ceramic fuel matrix
- Iridium cladding
- Graphite shell

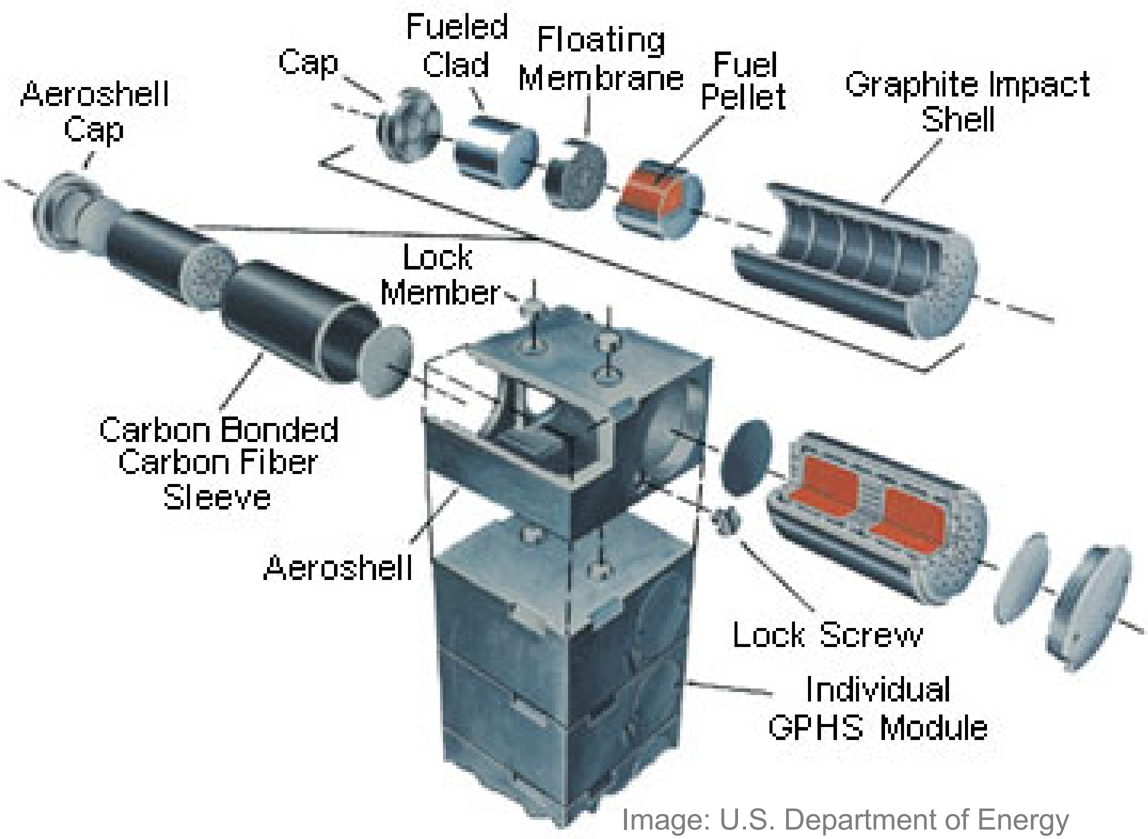


Image: U.S. Department of Energy

Types of radioisotope sources for space missions (5)

- Manufactured by Russian enterprise
- Weight 0.5 kg (if used as RTG)
- Up to zu 23 g PuO_2 with total activity up to 9.6 TBq
- Thermal power 8.5 W
- Electrical power 200 mW

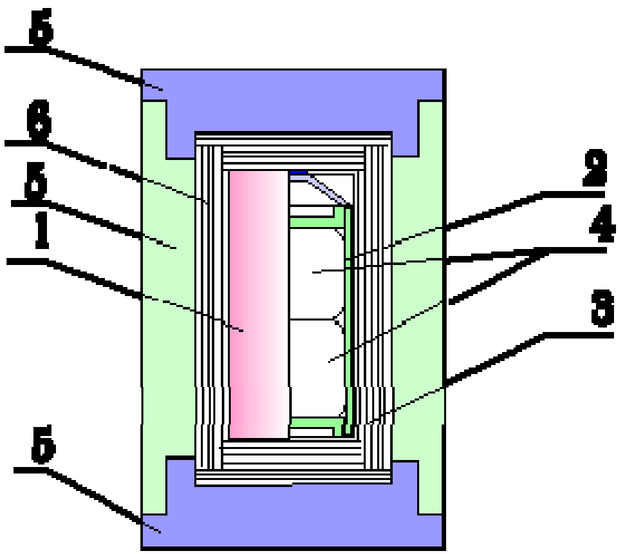


Image: BIAPOS

1-Radioisotopic heat unit (RHU)	4-Tablet of PuO_2
2-Corrosion protection casing	5-Heat insulation shell
3-Safeguard casing	6-Heat insulation insertion

Specific safety aspects (1)

Life cycle stage of source	Radiological Hazards
Fabrication	Like terrestrial applications
Procurement, transport, intermediate storage	Like terrestrial applications
Equipment integration	In general like in terrestrial applications Exceptional circumstances (e.g. proximity to explosive, flammable or corrosive substances) might imply specific hazards
Spacecraft integration	
Launcher integration	**Specific hazards due to proximity to launcher fuel, explosives, engines, corrosive substances**
Launch Early flight phase (possible re-entry)	**Specific hazards due to proximity to launcher fuel, explosives, engines, corrosive substances** **Special thermal and mechanical loads**
Late flight phase (re-entry excluded)	None for population and terrestrial environment

Specific safety aspects (2)

Specific Incidents

- Falling of payload from the launcher followed by explosion/fuel fire
- Falling of launcher from launching pad followed by explosion/fuel fire
- Mechanical impact followed by fuel fire after failure in launching phase
- Accidental re-entry from suborbital or orbital flight path

Specific mechanical and thermal loads

- Explosion overpressure
- Fragment impact at very high velocity
- Fuel fire (e.g. up to more than 3000°C by solid propellant fuel fires)
- Friction heat upon accidental reentry
- Mechanical impact on ground after re-entry
- Long-term exposure to corrosive environment (e.g. immersed in sea water)

Specific safety aspects (3)

Safety design features of RTG and RHU for space missions

Modular Construction:

- Breakup into modules to limit loads by re-entry

3 Barriers

- **First barrier: PuO_2 ceramic matrix**
  - low solubility in water
  - high melting point
  - fractures into large, non-respirable chunks
- **Second barrier: Metallic cladding (often Iridium)**
  - low chemical reactivity
  - high melting point
  - high resistance against breakup
- **Third barrier: Graphite impact shell**
  - absorbs mechanical and thermal loads during re-entry,
  - Absorbs impact and fire exposure in early launch phase

Specific safety aspects (4)

Safety provisions for accidents with possible releases

Pre-launch or early launch failure with violent mechanical impact and subsequent extensive fuel fire

- Separation of spacecraft with RTG/RHU from launcher
  - Explosive ejection mechanism (implies more weight and failure risks)
  - Reduces probability of longer exposure to intense fire

Re-entry with possible impact on hard target

- Emergency preparedness (detailed guidance by UN, IAEA)
  - Early warning, notification of countries in affected area
  - Search and retrieval of radioactive sources
  - Interventions for protection of the public

Safety evaluation and approval (1)

- Approval processes on the national level in U.S.A and Russian Fedaration are well established
- No such process for launches of European missions from Guyana Space Center in Kourou

Perspectives for approval process on the European level

- No competent authority on the European level
- Approval decision for all lifetime stages will rest with resp. national authority
- Launch approval (from radiological point of view) by launching state

But:

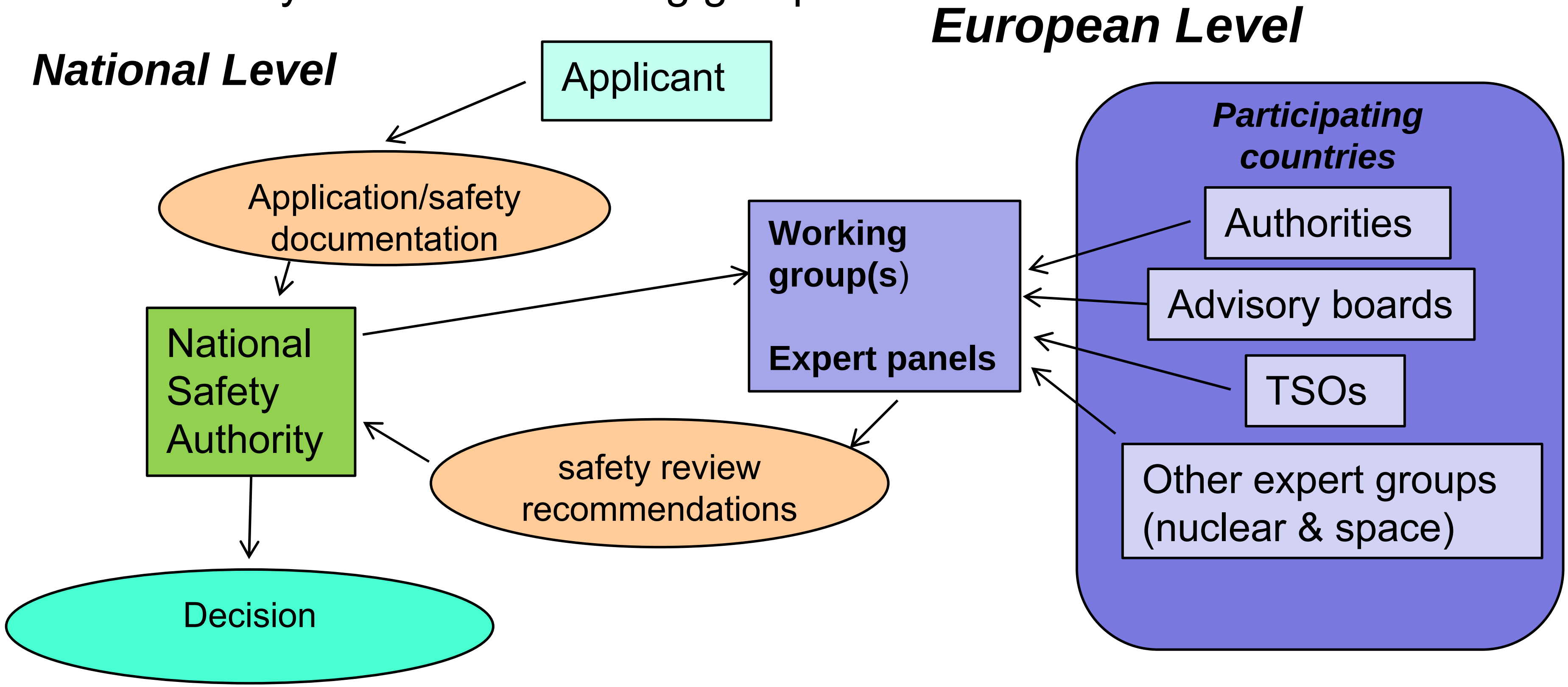
- Consensus from all participating nations about employment of RTG/RHU would be vital for mission success
- Not only launching nation but all participating nations would be liable for damage

=> *All participating nations could be involved in safety evaluation*

Safety evaluation and approval (2)

Perspectives for approval process on the European level

- Preparation of *one* common safety review by all participating nations
- Preparation of *common recommendations* by all participating nations
- TSOs of participating European countries could contribute to safety assessment by a common working group



Safety evaluation and approval (3)

- Common reference for safety assessment would be helpful

=> *General Space Nuclear Safety Goals (GSNSG)*

Objectives

- Cover all aspects unique to the use of RTG/RHU in space missions
- No overlapping with established safety goals for terrestrial applications
- Establish safety level comparable to practices involving radioactive material in general
- Account for peculiarities of space missions
  - Isolated events in time
  - Hazards are often mission-specific

Framework for General Space Nuclear Safety Goals (GSNSG)

- Scope: accidental conditions specific to space missions
- Distinction between design basis accidents and accidents beyond the design basis seems viable

Safety evaluation and approval (4)

GSNSG for design basis accidents (DBA):

- A release of radioactive material is prevented or limited
- Either no release only minor radiological consequences
- No need for emergency protective actions for the population

GSNSG for accidents beyond the design basis:

- Probability of accident is kept acceptably low
- Reasonable countermeasures to mitigate radiological consequences available
- Accidents with potential early health effects excluded with sufficient confidence.
- Limited necessity for incisive emergency protective actions such as evacuation or permanent resettlement.

Conclusions/Outlook

- **No alternative to use of RTG/RHU for some space missions**
- **Europe would need its own safety approval process to carry out such missions independently**
- **Within this context, the ENSaF study was carried out**
  - Options for approval process with international participation drafted
  - Focus on radiological safety during launch and early flight phase
  - Mandatory basis: National requirements of launching state
  - International participation by common safety evaluation
  - General space nuclear safety goals could provide proper reference

Next steps

- Find consensus by all actors involved for such an approval process
- Allocate responsibilities and roles within such a process