SPACE TRIPS SUMMER SCHOOL

Theme 9: SPACE

Riga Latvia
June 17-20 , 2 0 1 4

Nuclear testing, integration, launch and decommissioning

Tim Tinsley
National Nuclear Laboratory, UK

Agenda

- History
- Manufacture and testing of RTGs
- Integration
- Launch safety
- Principles of nuclear power sources in space

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Radioisotope power systems

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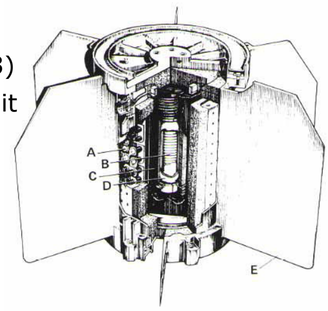
- 1961 first use, onboard US Navy transit 4A (System for Nuclear Auxiliary Power, SNAP 3)
- 1964 first failure, SNAP 9A did not make orbit (~1kg of Pu^{238})
- 1968 Nimbus B1 failure, Pu^{238} material recovered
- 1969 Apollo missions
- 1970 Lunokhod lunar rover (RHUs Po^{210})
- 1972 Pioneer 10
- 1976 Viking landers (RHUs)
- 1977 Voyager 1
- 1997 largest mass of Pu^{238} launched, Cassini-Huygens (33kgs)
- 2013 China became 3rd country to launch (RHUs)



A THERMOELECTRICS
B FUEL CAPSULE
C REENTRY HEAT SHIELD
D FUEL DISCS
E HEAT RADIATING FINS

Image courtesy of NASA

Reactor power systems

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- 1965 SNAP 10A launched. First (and only) USA reactor in space. 590We maximum operation
- 1967 RORSAT series launched
- 1987 TOPAZ launched, 5kWe
- Russia has launched 33 reactors (31 BES-5), 2 TOPAZ)

- All NaK cooled

Image courtesy of NNL

What is a RPS?

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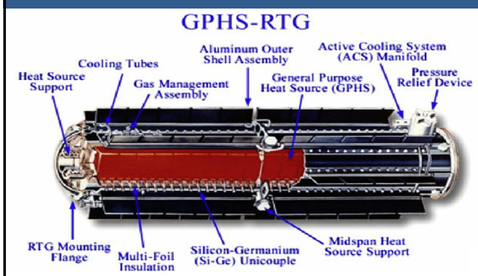

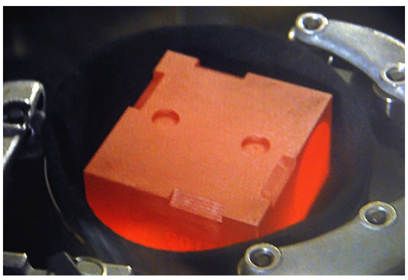

- 2 pellets per GIS
- 2 GIS per GPHS module
- 18 module per GPHS-RTG
- 7.8kg of Pu^{238}

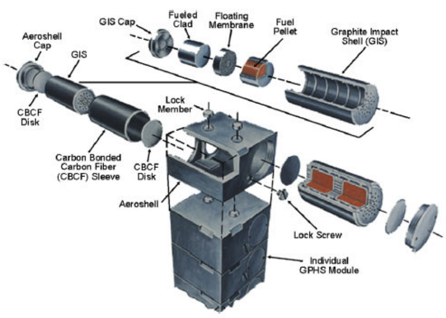

Image courtesy of NASA and US DoE

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Manufacturing process flow

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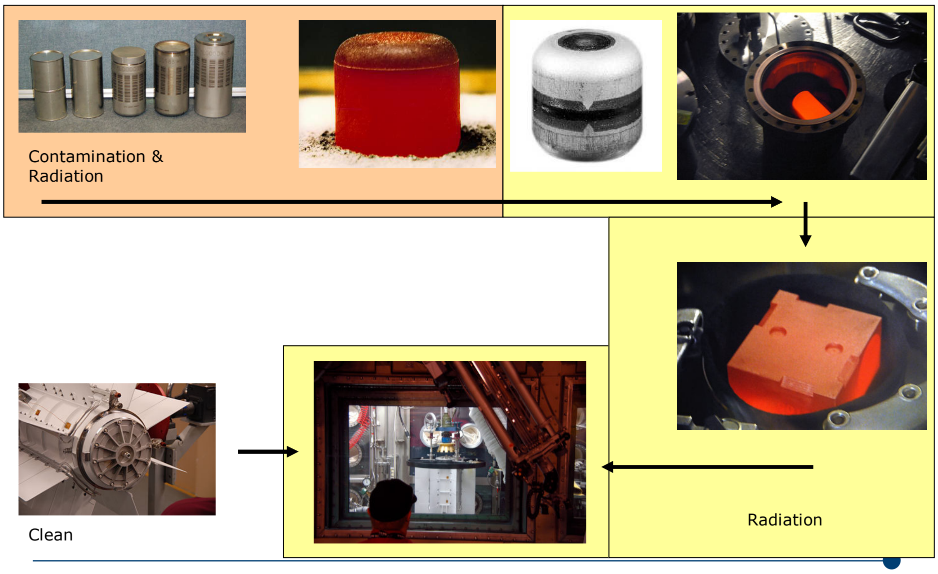

Image courtesy of NASA

Radioisotope power source

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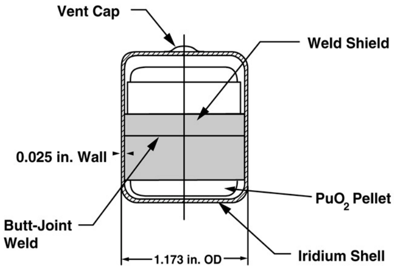

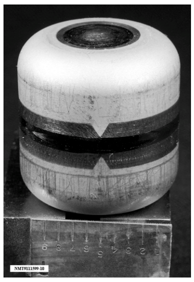

- $^{238}PuO_2$ pellet
- 151g ^{238}Pu per pellet
- 62.5 W_{th} per clad pellet
- Primary containment (Iridium alloy)
- Operating temperature ~ 1400°C

Image courtesy of US DoE

RPS Non-Destructive Testing

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Calorimetry
Radiography
Helium Leak Testing

Image courtesy of US DoE

RPS safety Testing

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Impact test

- Temperature range: 25 ° C to ~1200 ° C
- Velocity range: 30 to 150 m/s
- Catch tube design and size

Image courtesy of US DoE

General Purpose Heat Source

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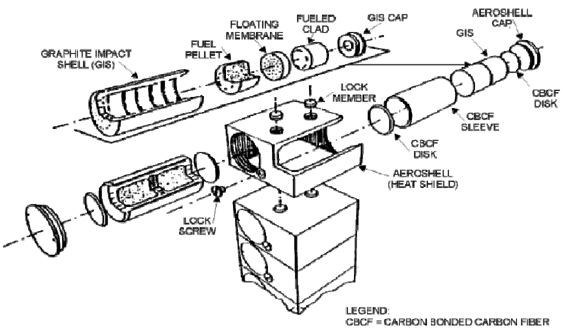

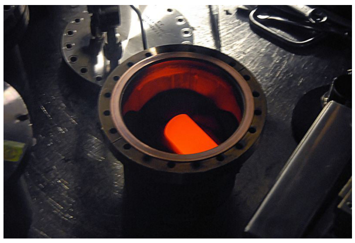

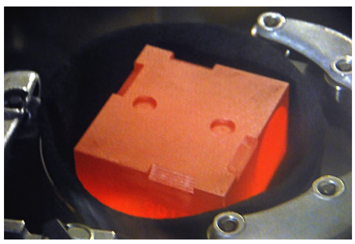

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Environmental testing

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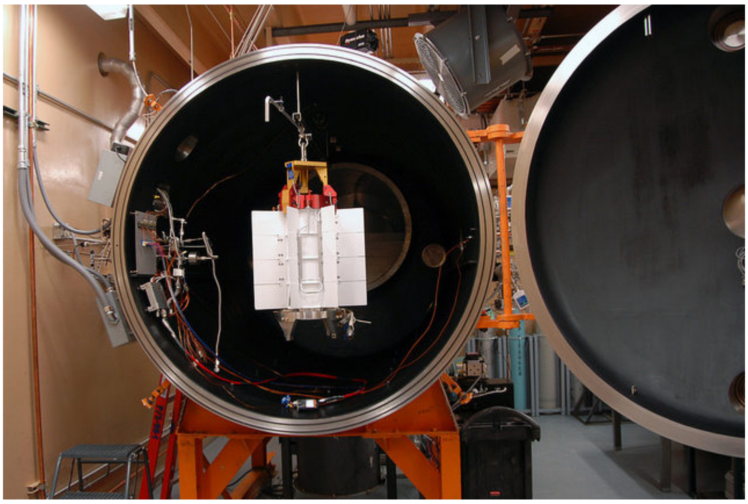

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Vibration testing

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Magnetic testing

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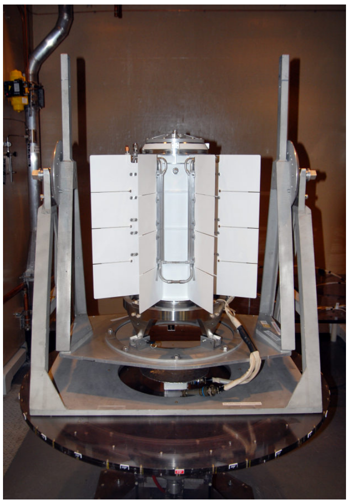

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Radiation testing

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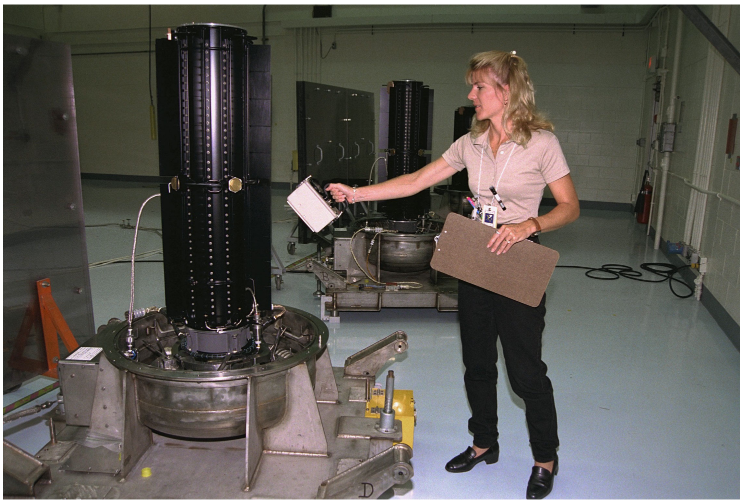

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Transportation

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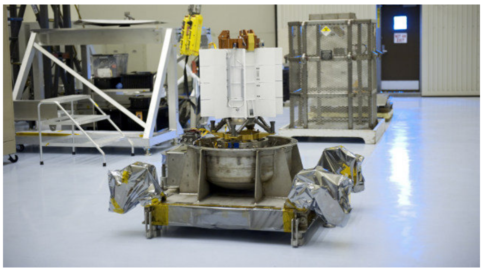
- Nuclear regulation requirements
- Security
- Protection and thermal management



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Test assembly

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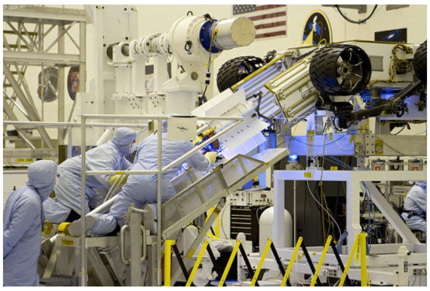
- Check it fits!
- Practice
- System performance testing



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Integration

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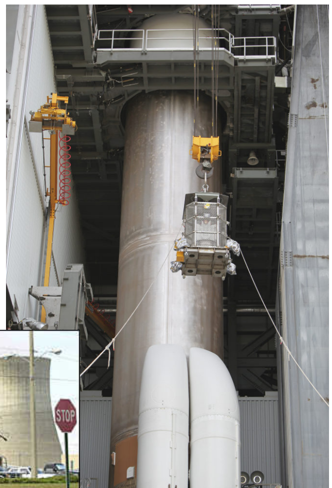
- Integration facility temporary under nuclear regulation
- One of the last items fitted



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Safety principles

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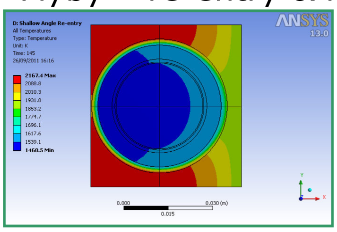
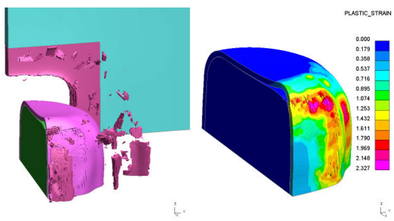
- Multi layer approach
  - Pellet
  - GIS
  - Module
  - Unit
- Launch accident – Fire & external impact
- Failure to reach orbit – re-entry & impact
- Flyby – re-entry & impact





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Differences, terrestrial vs space

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- Launch and related constraints
- Duration of hazard risk
- Operating environment
- Autonomy
- Mass constraints
- Frequency and operating lifetime
- Reliability, no service option
- End of service

Image courtesy of ESA

Similarities, terrestrial and space

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- Safety number 1
- Same basic technologies
- Advanced science and engineering
- Consequences of accident on wider population
- Reliability requirements

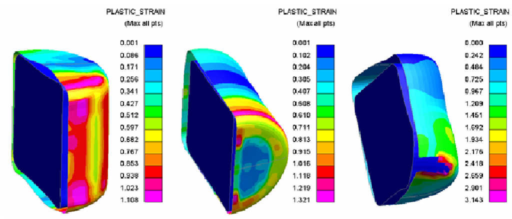

Image courtesy of Associated Press and NNL

Flyby

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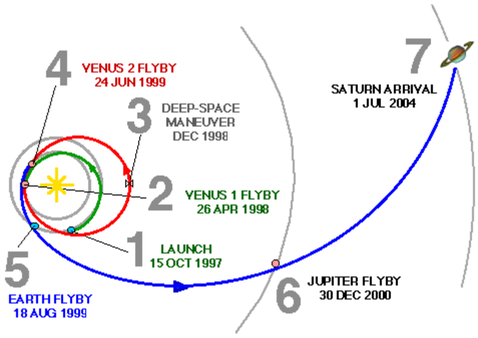
- Some missions require flyby
- Compromise required between mission and safety to reduce re-entry risk



Sometimes it goes wrong

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- Apollo Lunar Surface Experimental Package (ALSEP) ~3.8kg Pu^{238}
- Apollo 13, 20000 feet under the sea - Tonga Trench

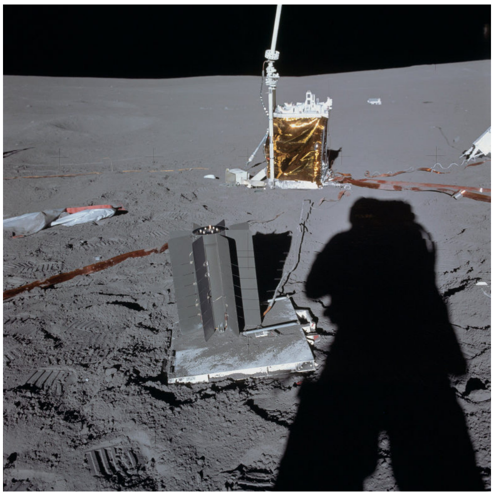

Image courtesy of NASA

Sometimes it goes wrong

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- The May 1968 launch of the Nimbus B-1 weather satellite was aborted shortly after launch
- The fuel container was retrieved intact and reused on Nimbus III

Image courtesy of NASA

When it goes right, Cassini - Huygens

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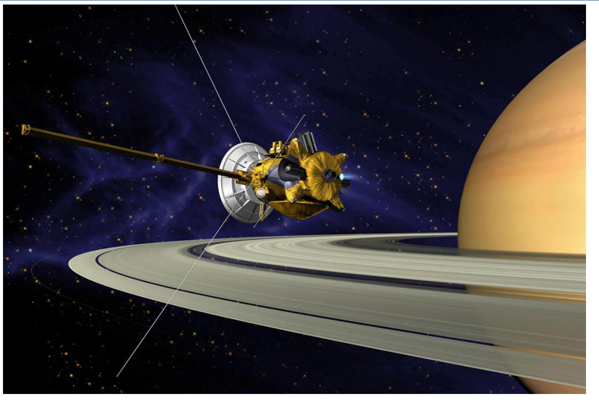
- Launched 1997
- Furthest ever landing in the solar system (Titan 2005)
- Extended until 2017
- Found 7 new Saturn moons



- 3 RTGs (GPHS–RTG)
- 82 RHUs on Cassini
- 35 RHUs on Huygens
- 32.7Kg of Pu^{238}

Image courtesy of NASA

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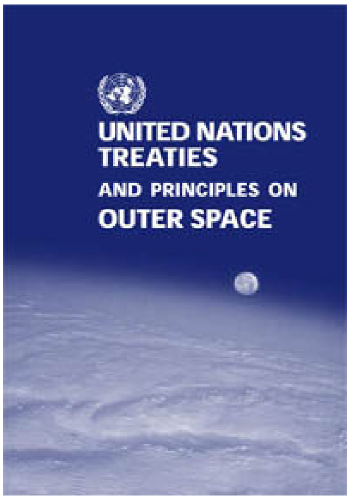
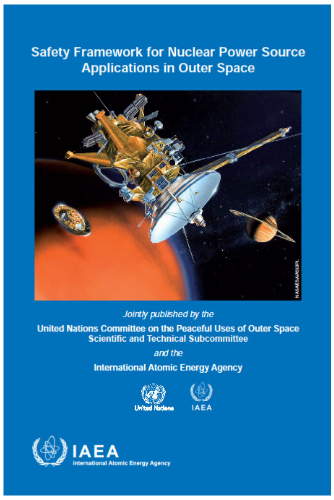
Safety & Regulation



1992 NPS Principles



2009 Safety Framework

Requirements

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- *Recognizing* that for some missions in outer space nuclear power sources are particularly suited or even essential owing to their compactness, long life and other attributes,
- *Recognizing* also that the use of nuclear power sources in outer space should focus on those applications which take advantage of the particular properties of nuclear power sources,
- *Recognizing* further that the use of nuclear power sources in outer space should be based on a thorough safety assessment, including probabilistic risk analysis, with particular emphasis on reducing the risk of accidental exposure of the public to harmful radiation or radioactive material,
- *Recognizing* the need, in this respect, for a set of principles containing goals and guidelines to ensure the safe use of nuclear power sources in outer space,

Office for Outer Space Affairs
United Nations Office at Vienna

General principles

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- States launching space objects with nuclear power sources on board shall endeavour to protect individuals, populations and the biosphere against radiological hazards.
- Such design and use shall also ensure with high reliability that radioactive material does not cause a significant contamination of outer space.

Image courtesy of NASA

Nuclear reactors

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- Nuclear reactors may be operate
  - On interplanetary missions
  - In sufficiently high orbits
  - In low-Earth orbits if they are stored in sufficiently high orbits after the operational part of their mission
- The sufficiently high orbit is one in which the orbital lifetime is long enough to allow for a sufficient decay of the fission products to approximately the activity of the actinides.
- Nuclear reactors shall use only highly enriched uranium 235 as fuel. The design shall take into account the radioactive decay of the fission and activation products.
- Nuclear reactors shall not be made critical before they have reached their operating orbit or interplanetary trajectory.

Image courtesy of NASA

RTG

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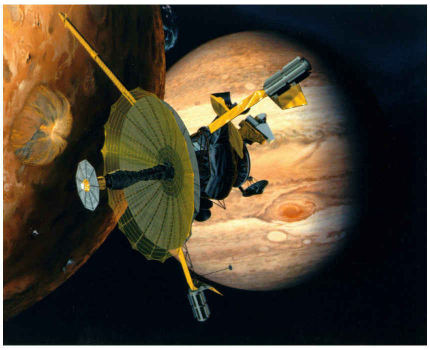
- Radioisotope generators may be used for
  - interplanetary missions
  - other missions leaving the gravity field of the Earth
  - They may also be used in Earth orbit
    - ultimate disposal is necessary
- Radioisotope generators shall be protected by a containment system that is designed and constructed to withstand the heat and aerodynamic forces of re-entry in the upper atmosphere under foreseeable orbital conditions, including highly elliptical or hyperbolic orbits where relevant. Upon impact, the containment system and the physical form of the isotope shall ensure that no radioactive material is scattered into the environment so that the impact area can be completely cleared of radioactivity by a recovery operation.

Image courtesy of NASA

End of life

- Must avoid contamination of earth
  - High orbit
- Planetary protection
  - 1967 United Nations Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Bodies
  - COSPAR. Committee on Space Research
- Covers contamination of other bodies with nuclear material



Galileo orbiter de-orbited after 8yrs (planetary protection)

Image courtesy of NASA

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Thank you for your time

Any Questions?