SPACE TRIPS SUMMER SCHOOL

SEVENTH FRAMEWORK PROGRAMME

Theme 9: SPACE

Riga Latvia

June 17-20 , 2 0 1 4

Some elements of Space reactor and Radio Isotopic Power System.

Gérard Poli **AREVA TA**

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- **Why Nuclear Power in Space**
  - **Far from sun**
    - Sunlight decreases as the square of the distance from sun
  - **No direct sun light**
    - In shadow places on planets

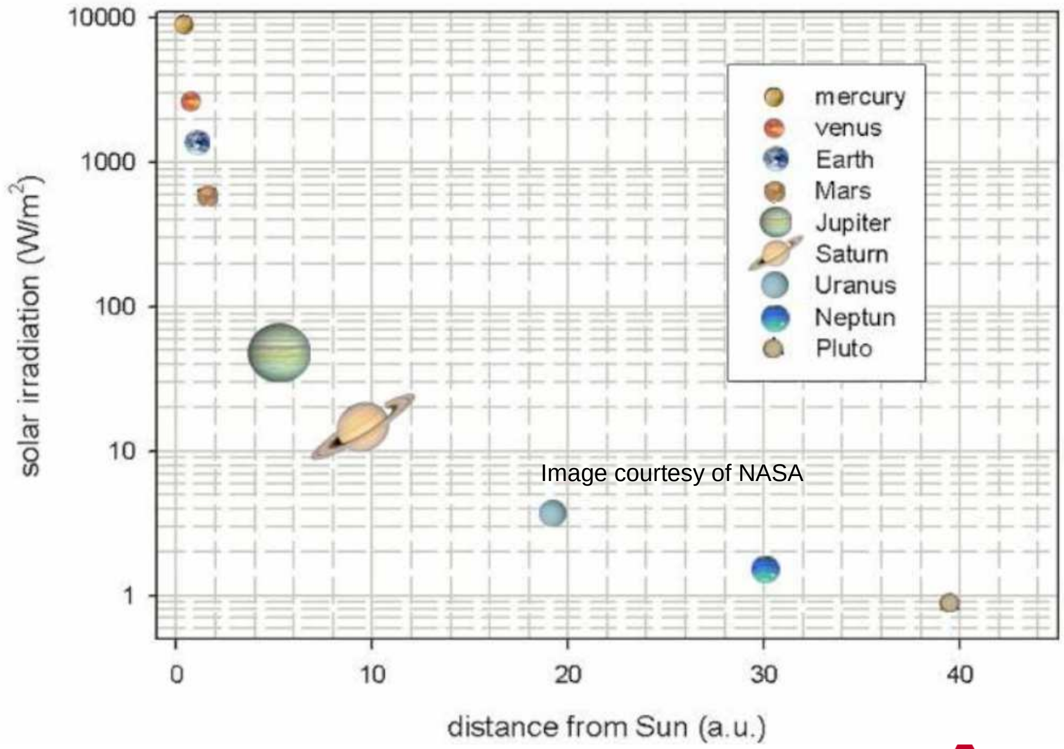

Image courtesy of NASA

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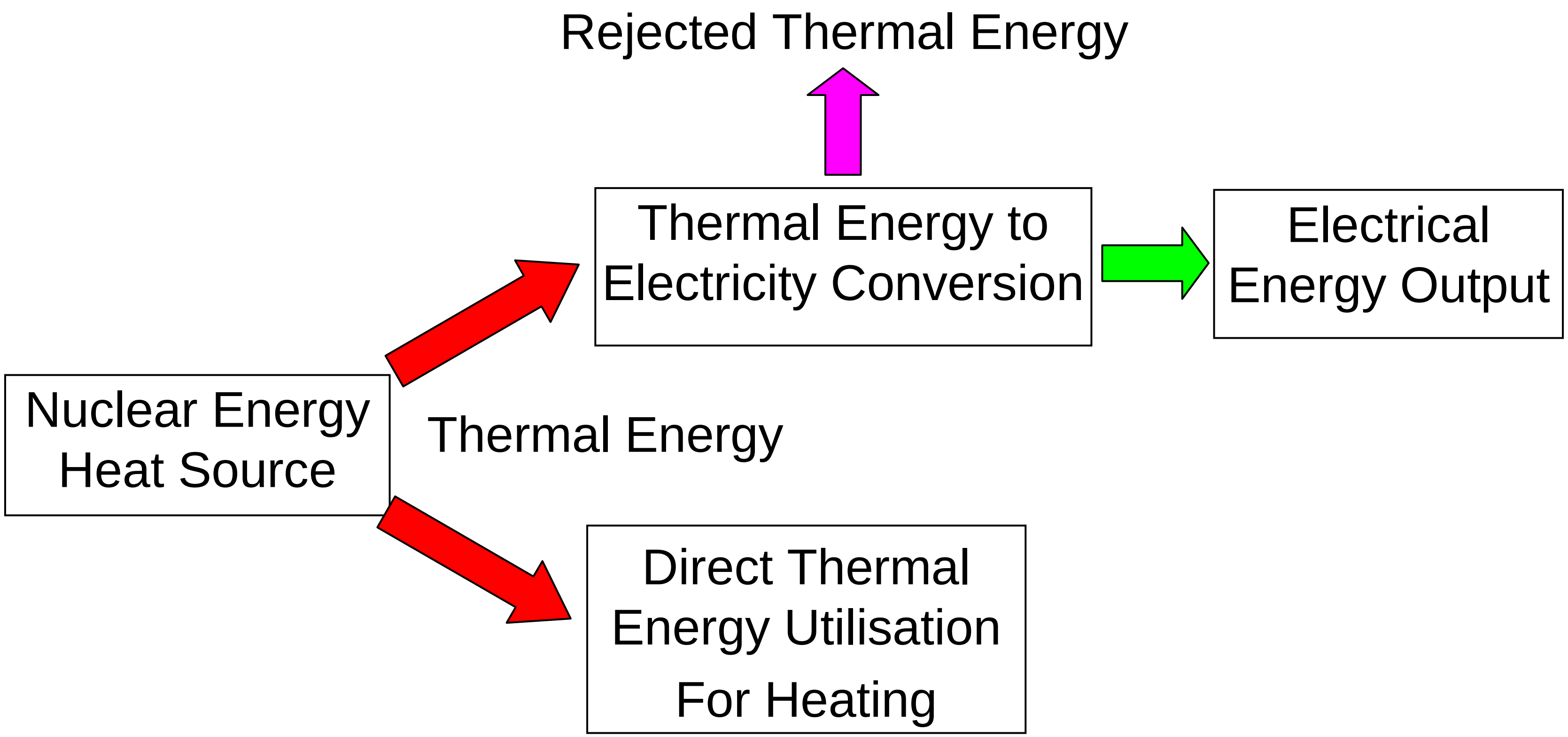
How to use nuclear energy



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Space Reactors & RPS
Introduction

- **To date, three types of nuclear energy sources have been used in space applications**
  - **Radioisotope Heater Units (RHU)**
    - Direct use of the thermal energy supplied by the radioisotope
  - **Radioisotope Thermoelectric Generators (RTG)**
    - Conversion into electricity of the thermal energy supplied by the radioisotope
  - **Nuclear reactors**
    - Complex thermal system associated with thermal to electricity converter

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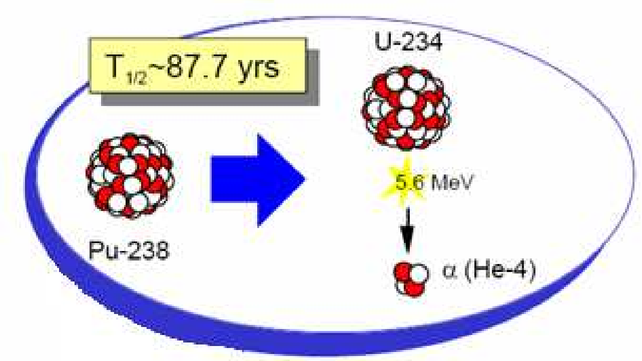
- **RHU is the simplest nuclear power system**
  - **Radioisotope natural decay provides heat directly used to keep sensible devices warm.**



Pu-238 decay

  - **Other radioisotopes can be used**
    - Po-210
    - Sr-90
    - Am-241

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- **Even if the RHU is simple from a functional point of view, its design is nevertheless complex**
  - **the RHU must withstand various constraints**
    - Explosion on launch pad
    - Fire
    - Falling from orbit

without spreading radioactive material

Withstanding

High thermal flux during atmosphere re-entry

High speed impact on earth

In this aim the fuel compound is surrounded by various protective layers

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- **Examples of RHU**

LWRHU (USA)

P = 1 W

Pellet mass	**2.6g**
Pellet volume	**0.3cm^3**
RHU mass	**40g**
RHU volume	**16cm^3**

RHU Angel (Russia)

P = 8.5W

Pellet mass	**21g**
Pellet volume	**2.5 cm^3**
RHU mass	**200 g**
RHU volume	**75 cm^3**

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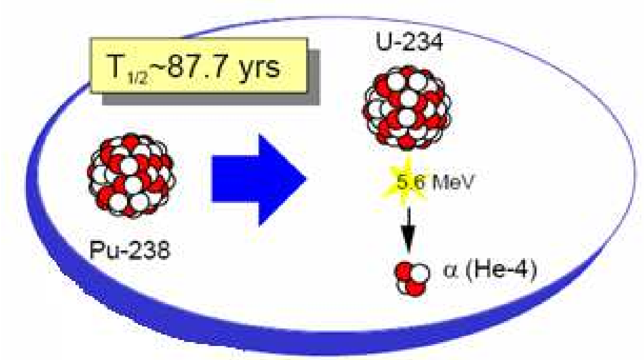
Space Reactors & RPS
RTG

- **RTG is similar to RHU with an additional thermoelectric converter**
  - **Radioisotope natural decay provides heat**
  - **This heat is converted into electricity by a thermoelectric converter**



+ Seebeck effect

- **Thermal to Electric energy conversion**
  - **Usually thermoelectric converter (Seebeck effect)**
  - **Other kinds of converter could be used but have never flown**
    - Stirling, Thermoacoustics, ….

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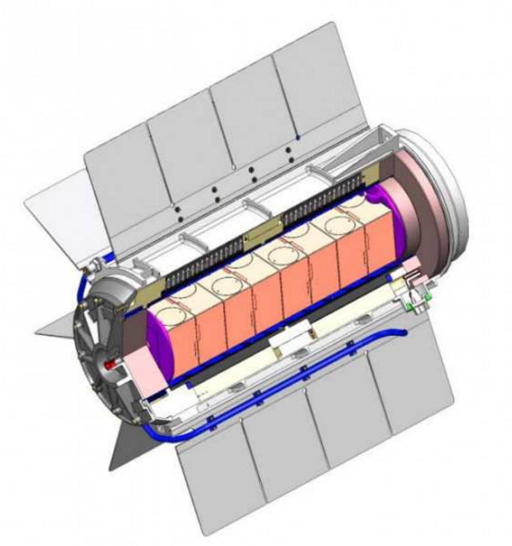
Space Reactors & RPS
RTG

- **Examples of RTG**



MMRTG (USA)

P = 120 We

Mass	**45 kg**
Heat source	**2000 Wth**
η_{RTG}	**6%**

RTG Angel (Russia)

P = 0.2 We

Mass	**0.5 kg**
Heat source	**8.5 Wth**
ηRTG	**2%**

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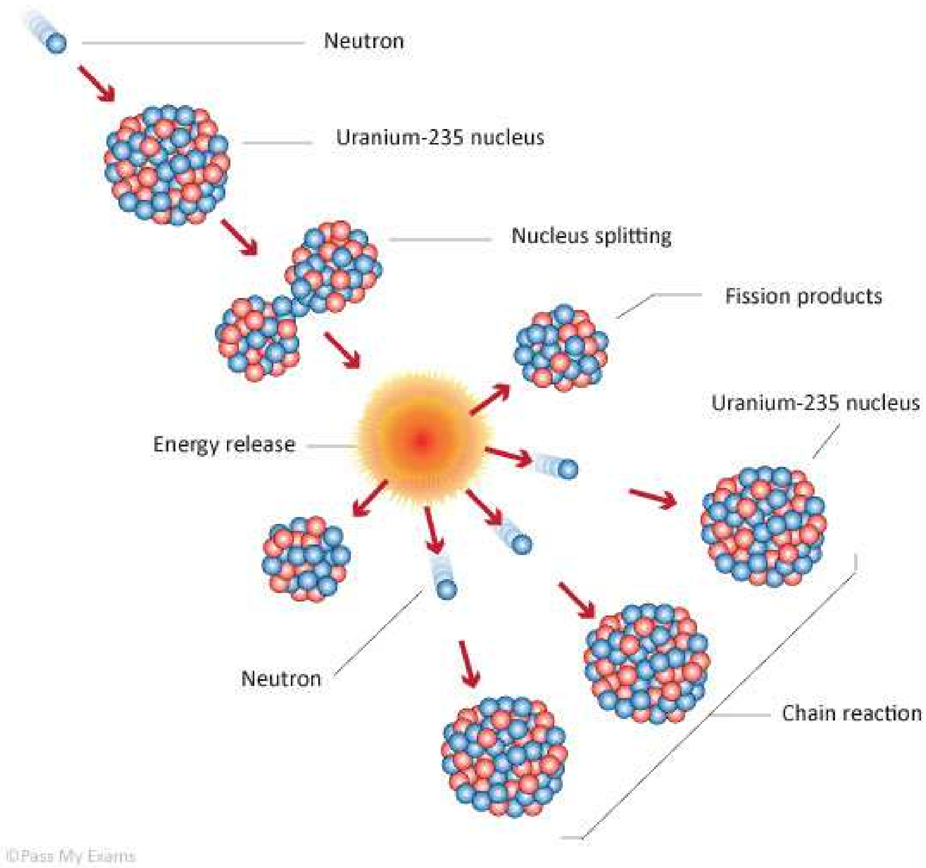
Space Reactors & RPS
Reactor

- **Reactors are fundamentally different from RHU and RTG**
  - **Heat is provided by a nuclear fission chain reaction**
  - **A nuclear chain reaction occurs when one nuclear reaction causes an average of one or more nuclear reactions, thus leading to a self-propagating number of these reactions.**



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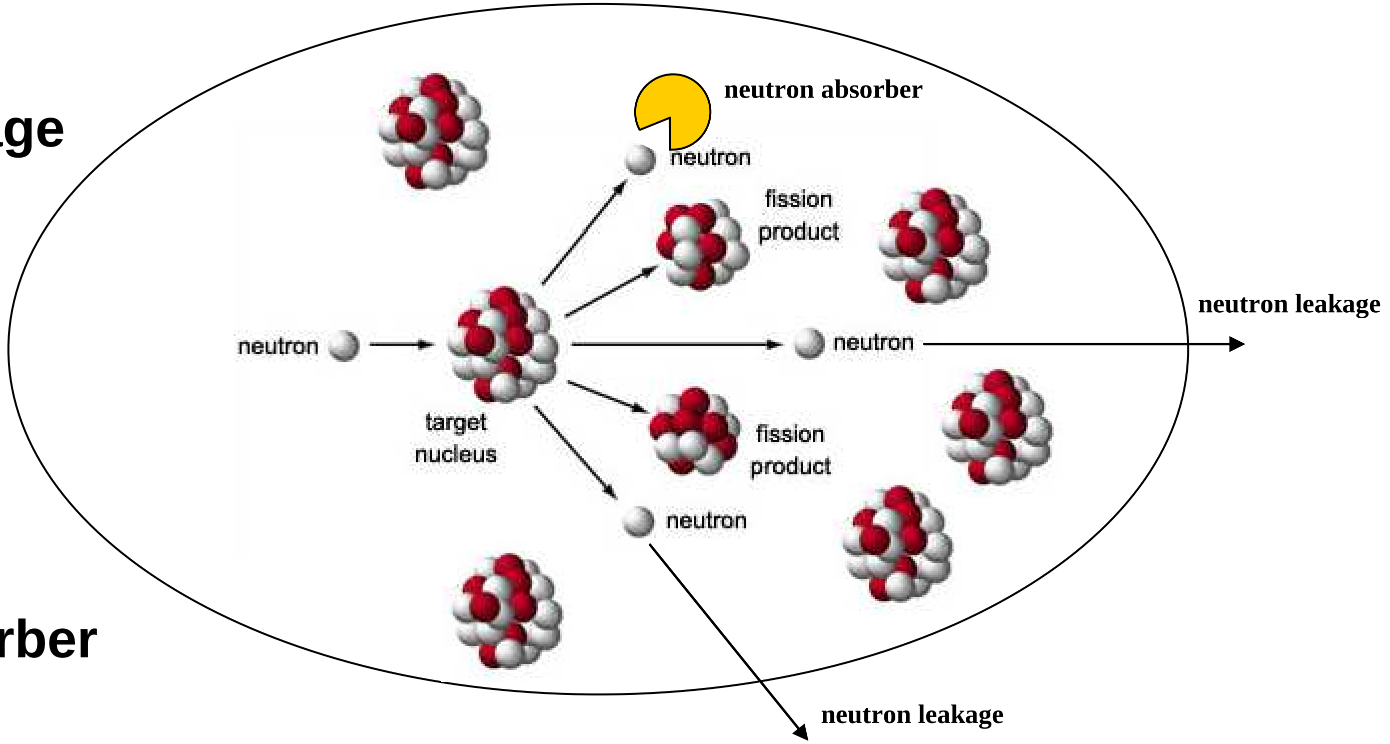
- **Conditions are needed for a sustainable chain reaction**
- **Limitation of neutron leakage**
- **Limitation of neutron absorber**



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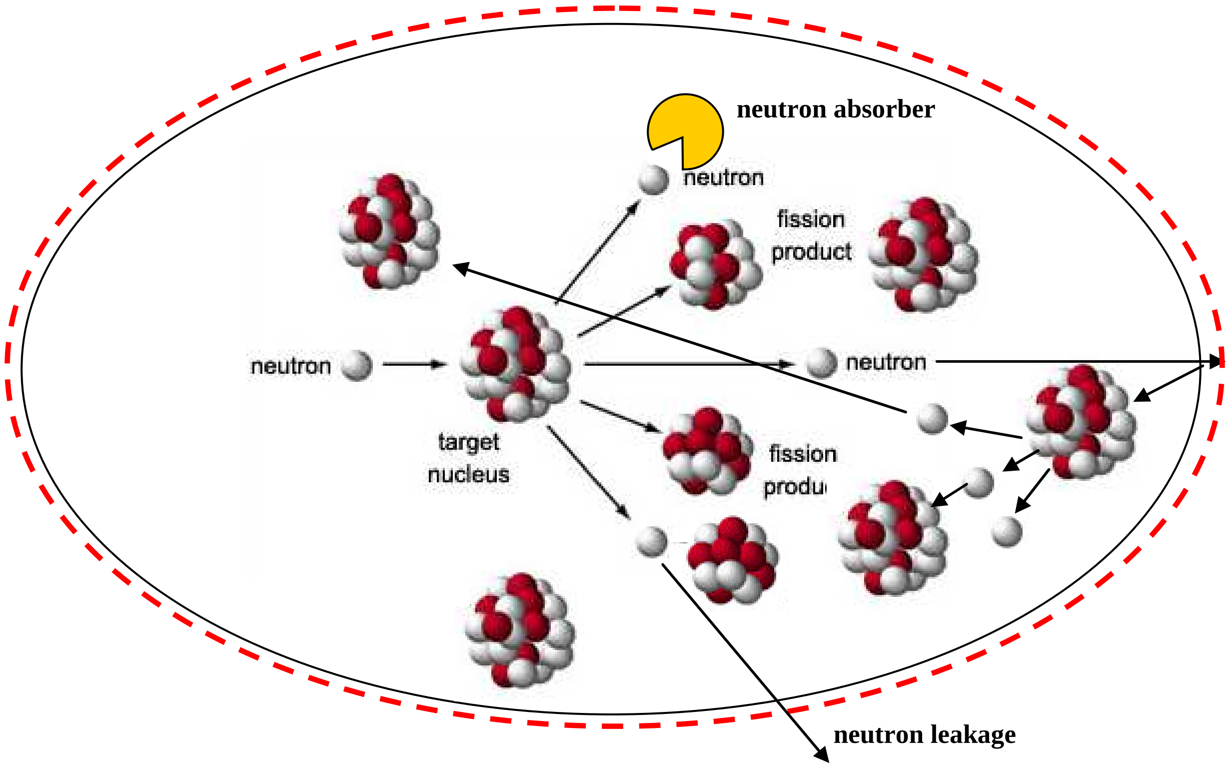
- **Conditions are needed for a sustainable chain reaction**

- **Limitation of neutron leakage**
  - **Reflector**
  - **Mass of fuel**

- **Limitation of neutron absorber**
  - **Avoid absorber materials**



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- **Chain reaction must be controlled so that the delivered power remains stable**
  - **Modifying the reflector position**
  - **Modifying the neutron absorber quantity**
- **Of course Reactors also need**
  - **Thermal to Electric Converters**
  - **Cold source**

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Space Reactors & RPS
Reactor

- **Examples of reactor**

SNAP 10A (USA)
P = 0.5 kWe

TOPAZ II (USSR)
P = 5 kWe

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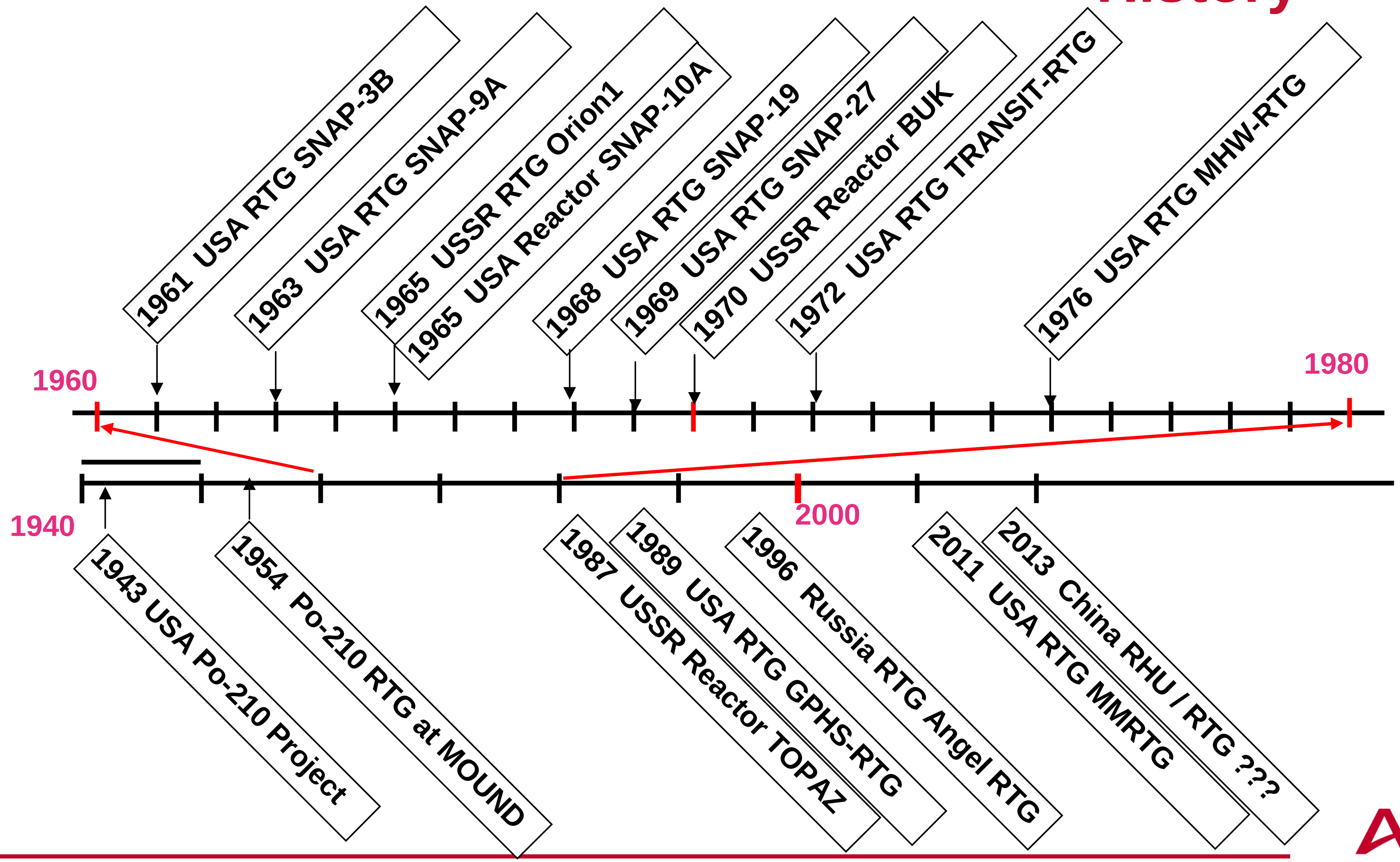
Space Reactors & RPS History



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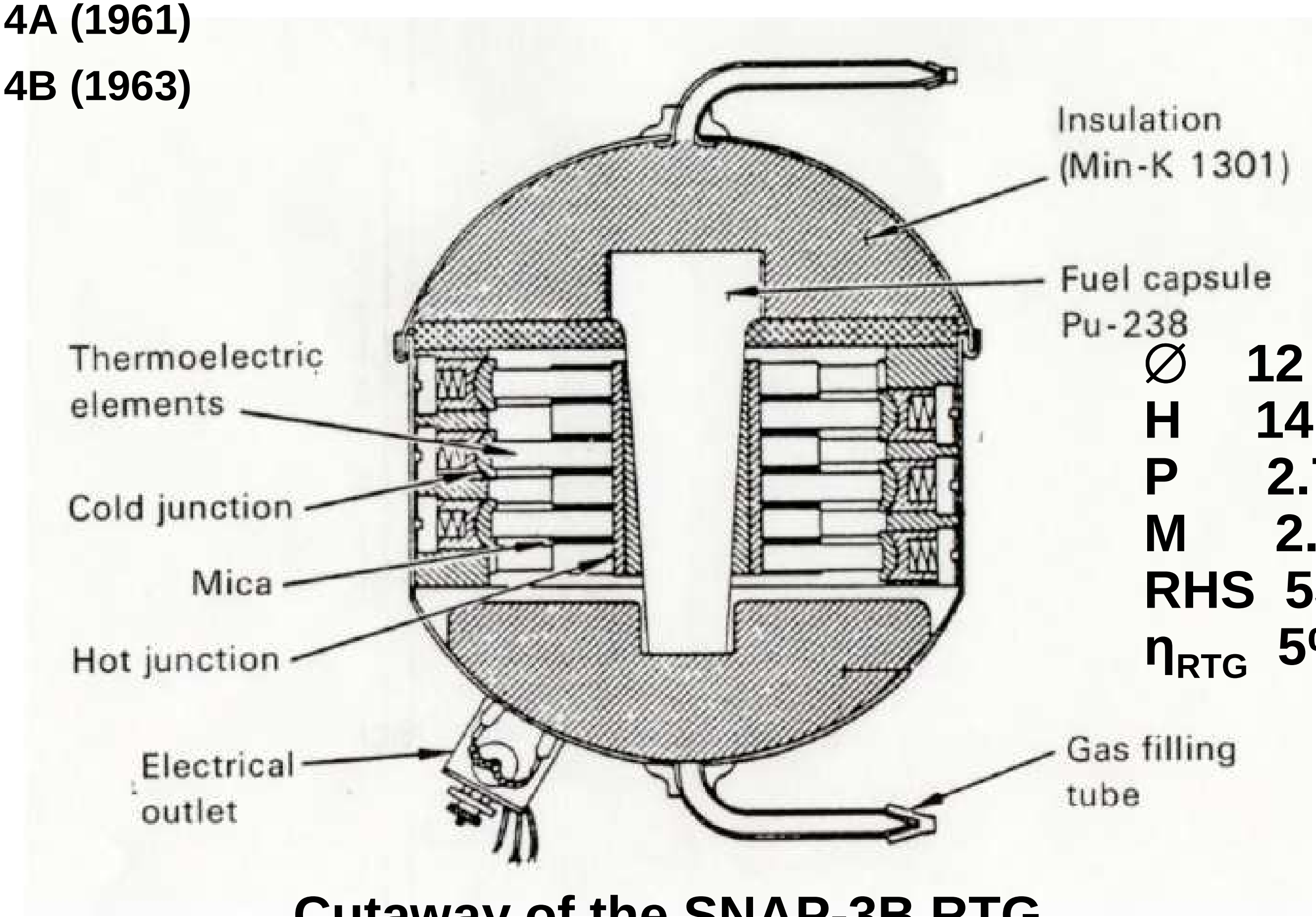
RTG SNAP 3B

Used on:

- **Transit 4A (1961)**
- **Transit 4B (1963)**



Cutaway of the SNAP-3B RTG

- **∅ 12 cm**
- **H 14 cm**
- **P 2.7 We**
- **M 2.1 kg**
- **RHS 53 Wth**
- **η_{RTG} 5%**

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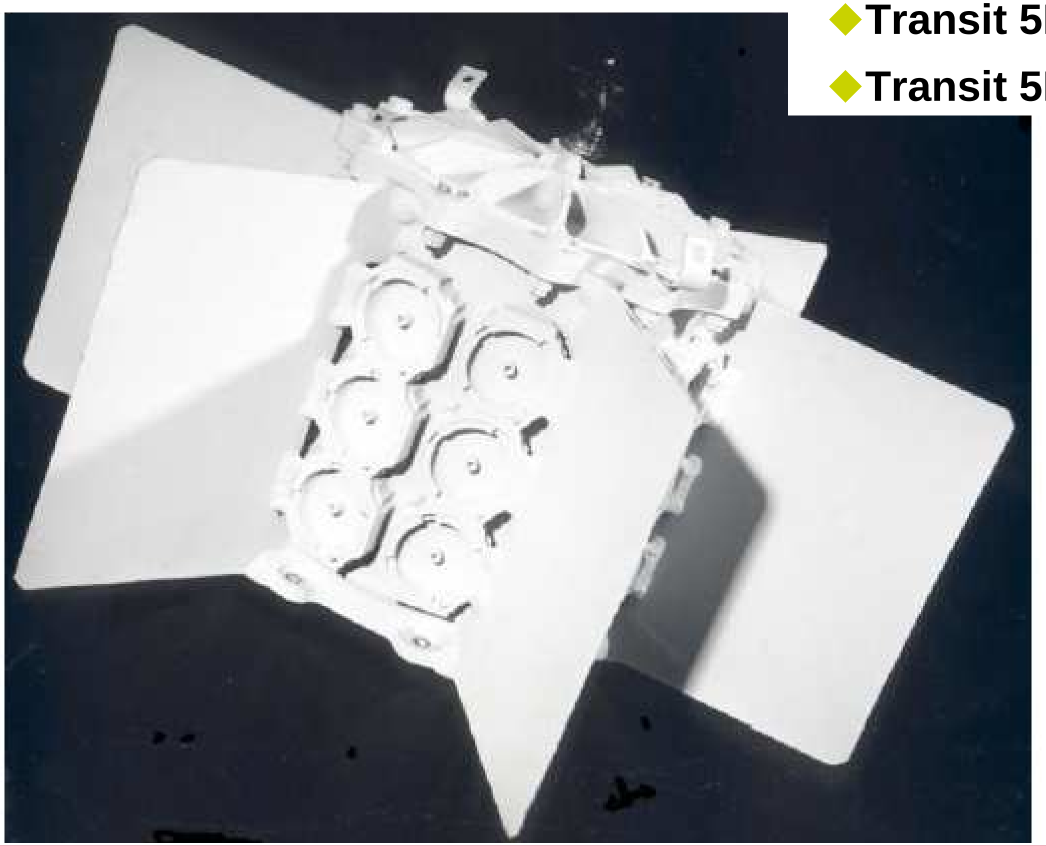
Space Reactors & RPS
RTG SNAP 9A

∅ 51 cm (main body 23 cm)
H 27 cm
P 27 We
M 12 kg
Ri Pu-238
RHS 525 Wth
η_{RTG} 5%



Used on:

- **Transit 5BN-1 (1963)**
- **Transit 5BN-2 (1963)**
- **Transit 5BN-3 (1964)**

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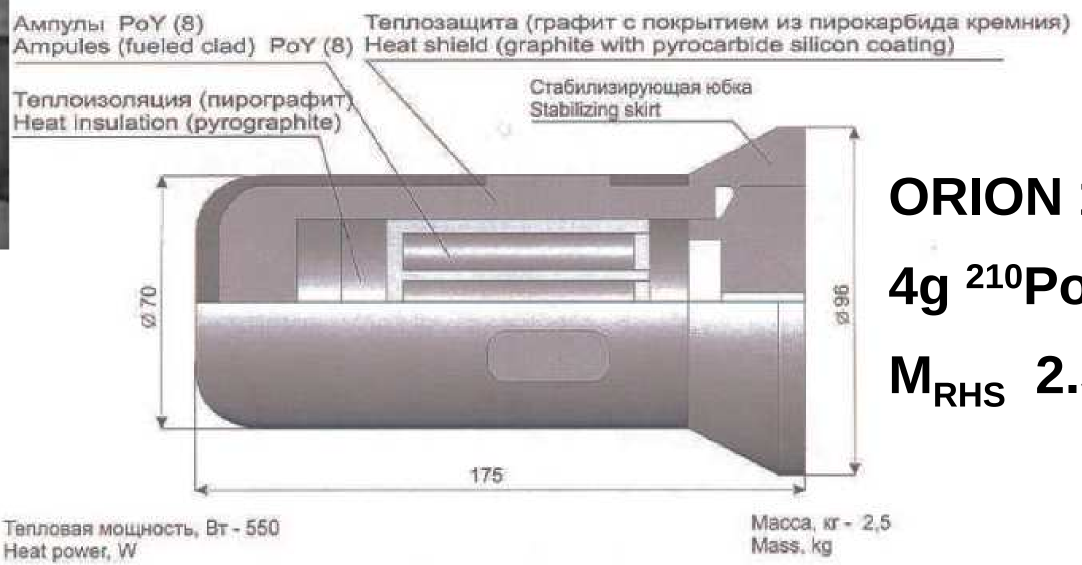
Space Reactors & RPS
USSR RTG ORION1

P 20 We
RHS 550 Wth
η_{RTG} 3.6%

Used on:

- Cosmos 84 (1965)
- Cosmos 90 (1965)



ORION 1 RHS

4g ^{210}Po

M_{RHS} 2.5 kg

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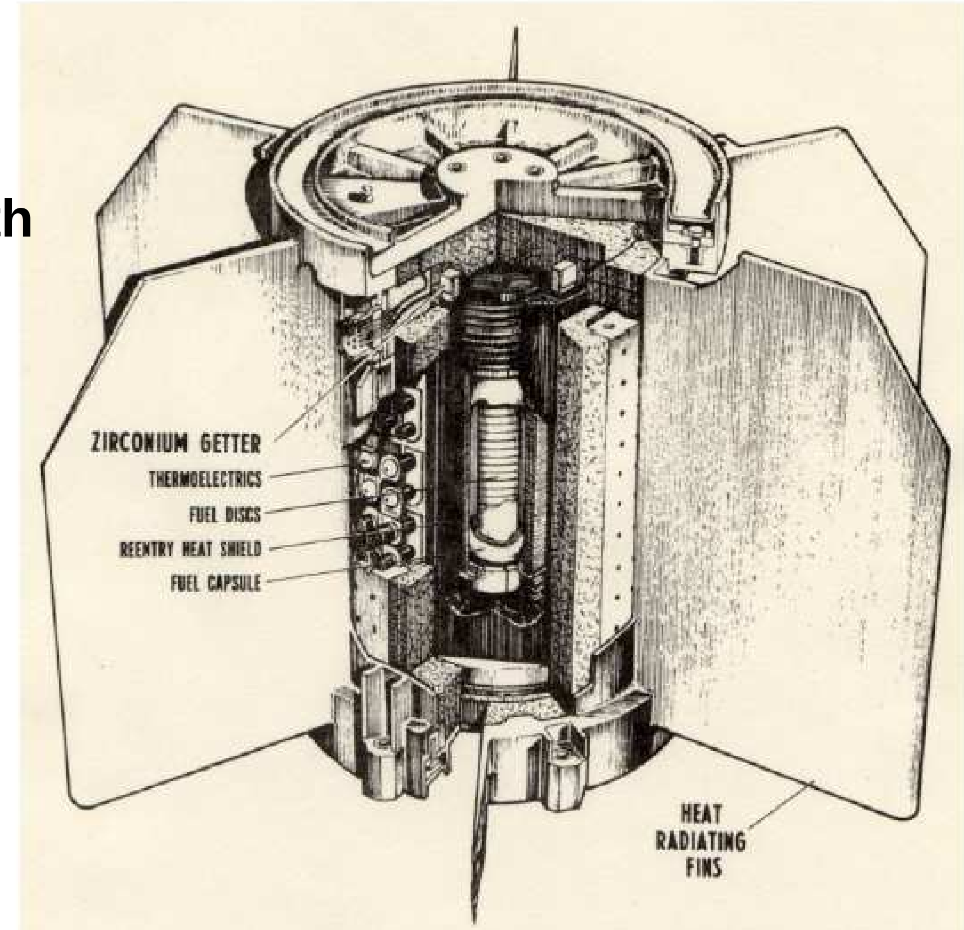
Space Reactors & RPS
RTG SNAP 19

- ∅ 58 cm (Main core 17 cm)
- H 27 cm
- P 44 We
- M 13 kg
- Ri Pu-238
- RHS 675 Wth
- η_{RTG} 6.5%



Used on:

- Nimbus B1 (1968)
- Nimbus 3 (1969)
- Pioneer 10 (1972)
- Pioneer 11 (1973)
- Viking Mars Lander 1 & 2 (1975)

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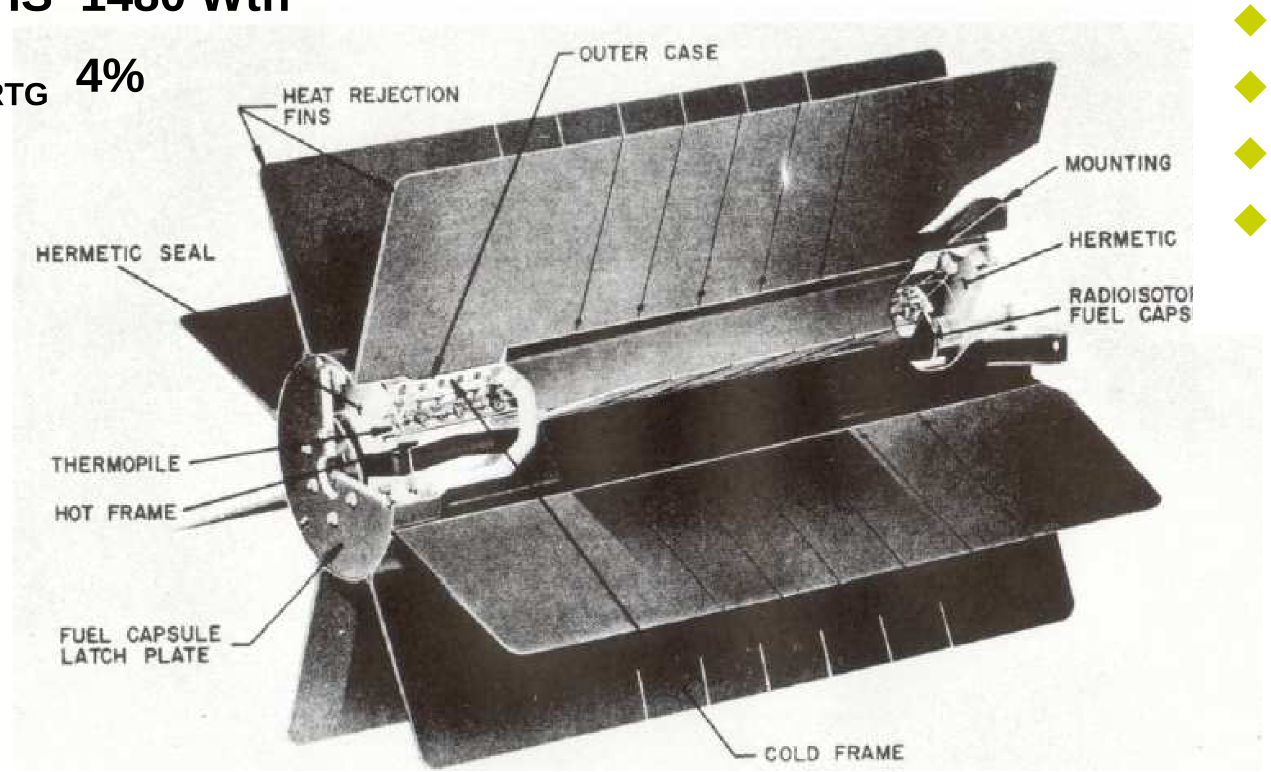
Space Reactors & RPS
RTG SNAP 27

∅ 40 cm
H 46 cm
P 64 We
M 20 kg
Ri Pu-238
RHS 1480 Wth
η_{RTG} 4%



Used on:

- **Apollo 12 ALSEP (1969)**
- **Apollo 13 ALSEP (1970)**
- **Apollo 14 ALSEP (1971)**
- **Apollo 15 ALSEP (1971)**
- **Apollo 16 ALSEP (1972)**
- **Apollo 17 ALSEP (1972)**

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Space Reactors & RPS
RTG TRANSIT-RTG

∅ 61 cm

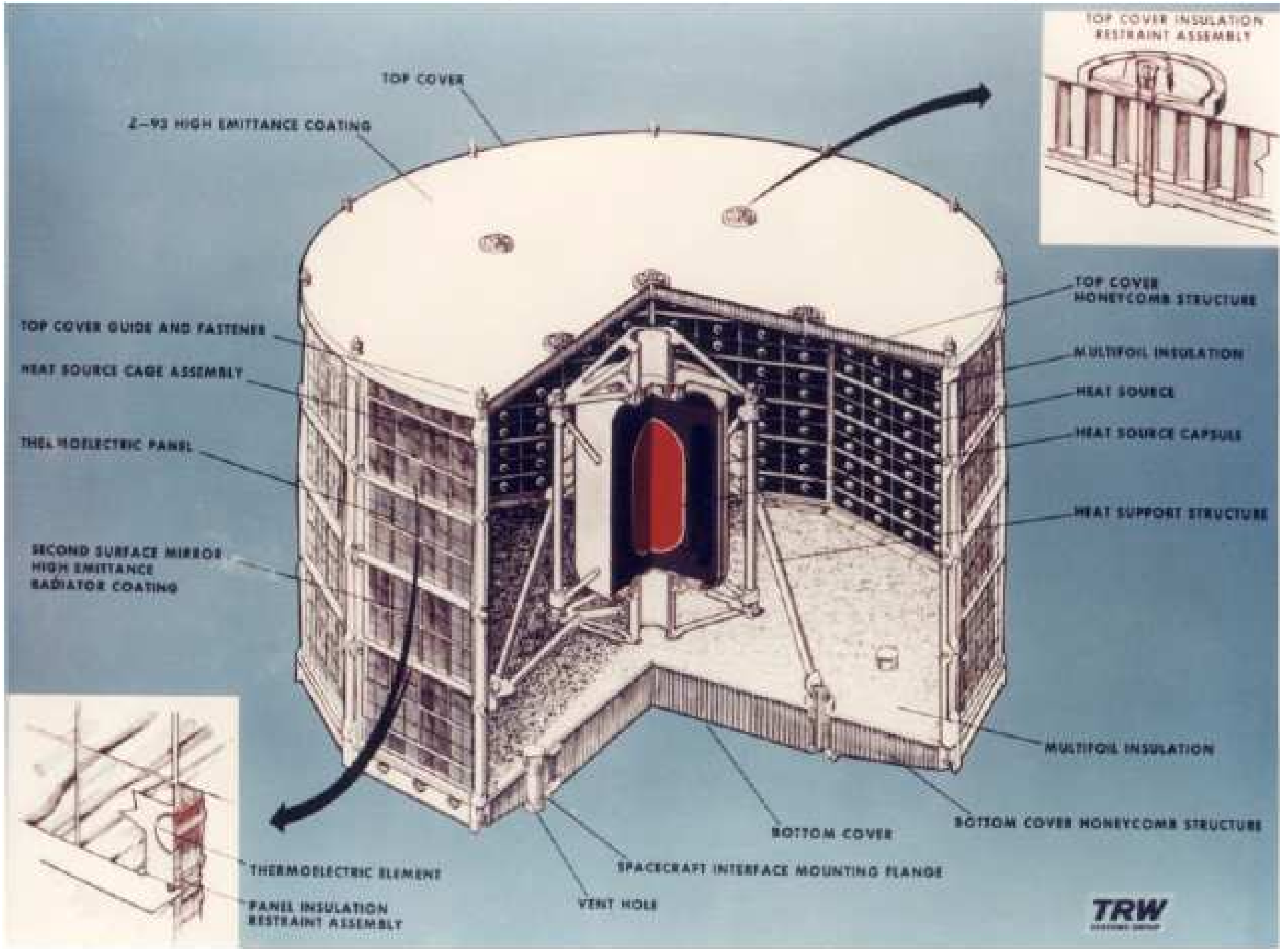
H 36 cm

P 36 We

M 14 kg

RHS 850 Wth

η_{RTG} 4%



Cutaway of the TRANSIT RTG

Used on:

- **TRIAD (1972)**

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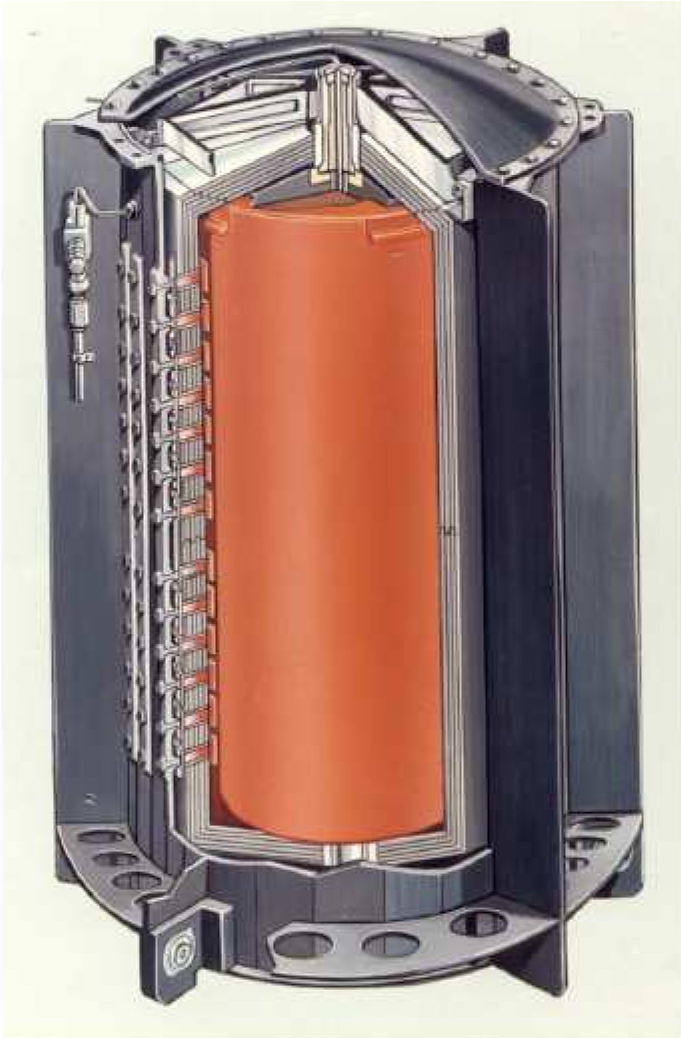
Space Reactors & RPS
RTG MHW-RTG

∅ 40 cm
H 58 cm
P 154 We
M 38 kg
Ri Pu-238
RHS 2400 Wth
η_{RTG} 6%



Used on:

- **LES-8 (1976)**
- **LES-9 (1976)**
- **Voyager 1 (1977)**
- **Voyager 2 (1977)**

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Space Reactors & RPS
RTG Angel-RTG

- ∅ 9 cm
- H 12 cm
- P 0.2 We
- M 0.5 kg
- Ri Pu-238
- RHS 8.5 Wth
- η_{RTG} 2%

Used on:

- **Mars 96 (1996)**

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Space Reactors & RPS
RTG GPHS-RTG

∅ 42 cm

H 114 cm

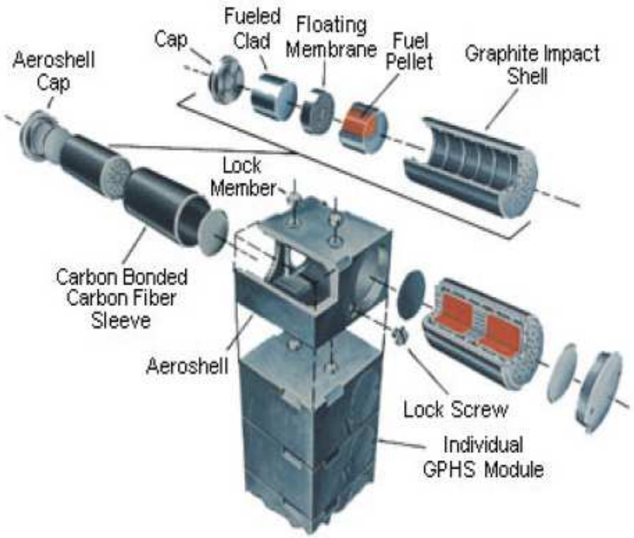
P 285 We

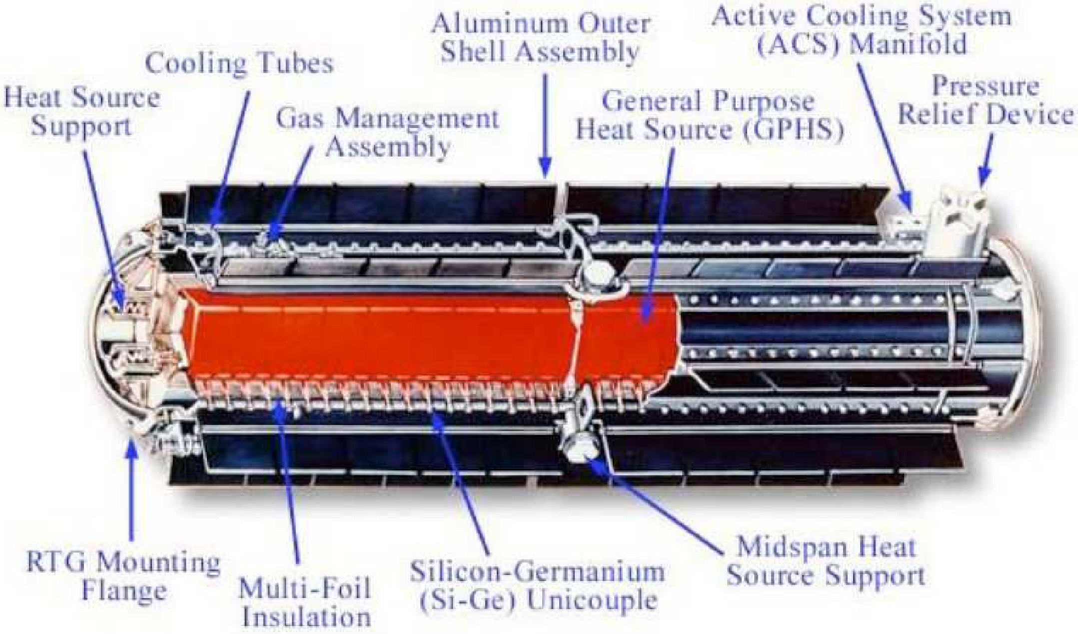
M 56 kg

Ri Pu-238

RHS 4500 Wth

η_{RTG} 6%





Used on:

- **Galileo (1989)**
- **Ulysses (1990)**
- **Cassini (1997)**
- **New Horizon (2006)**

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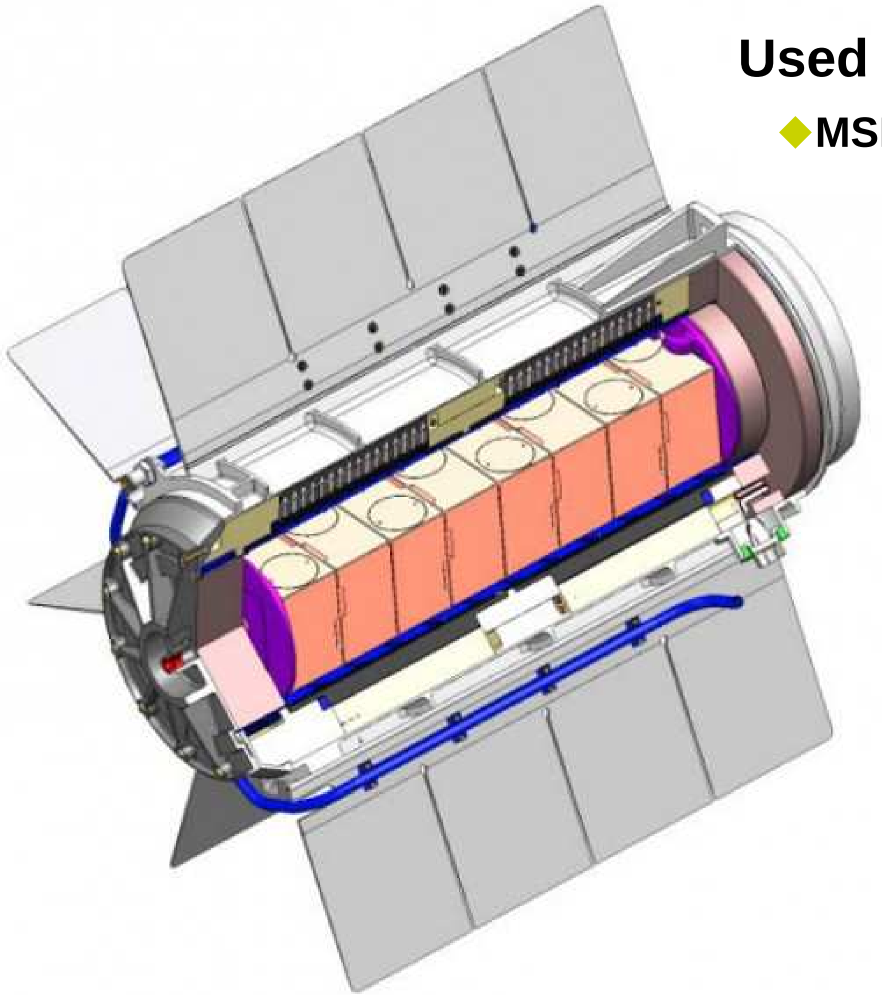
Space Reactors & RPS
RTG MMRTG

∅ 42 cm
H 114 cm
P 120 We
M 56 kg
Ri Pu-238
RHS 2000 Wth
η_{RTG} 6%



Used on:

- **MSL - Curiosity (2011)**

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Space Reactors & RPS
Reactor SNAP-10

Pe 580 We

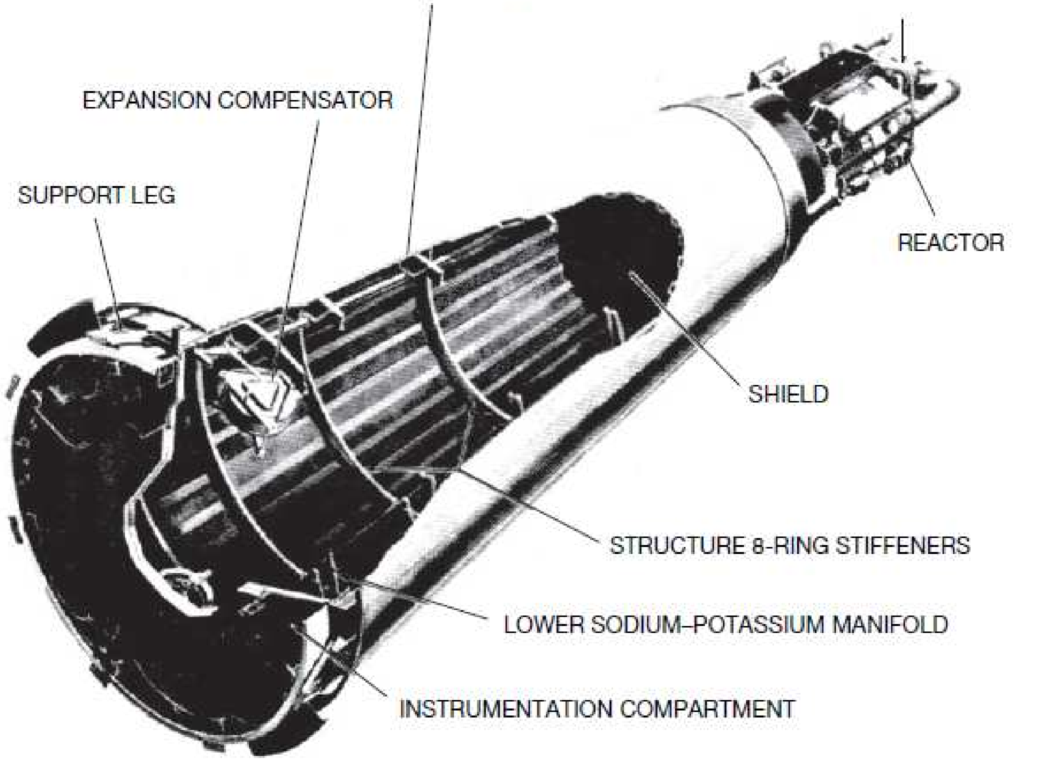
M 295 kg (without shield)

Fuel U-ZrH

Pth 43 kWth

Conv Thermoelec

$\eta_{Reactor}$ ~1%



Launched 1965

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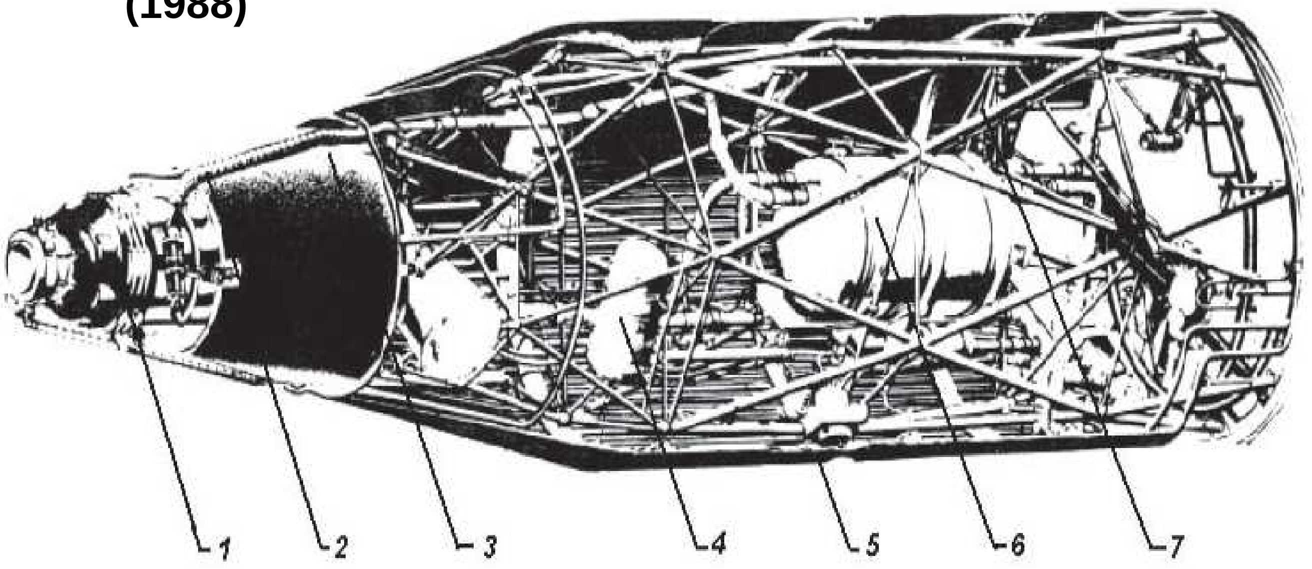
Space Reactors & RPS
Reactor BUK

Used on:

- Cosmos-367 (1970)
- And 31 later on till (1988)



Pe 3 kWe

Conv Thermoelec

M 900 kg

Pth 100 kWth

$\eta_{reactor}$ 3%

The BUK NPS layout:

**(1) nuclear reactor, (2) liquid metal circuit pipeline, (3) reactor shielding,
(4) liquid metal circuit expansion tanks, (5) radiator, (6) TEG,**

(7) load bearing frame structure. Source: Kurchatov Institute.

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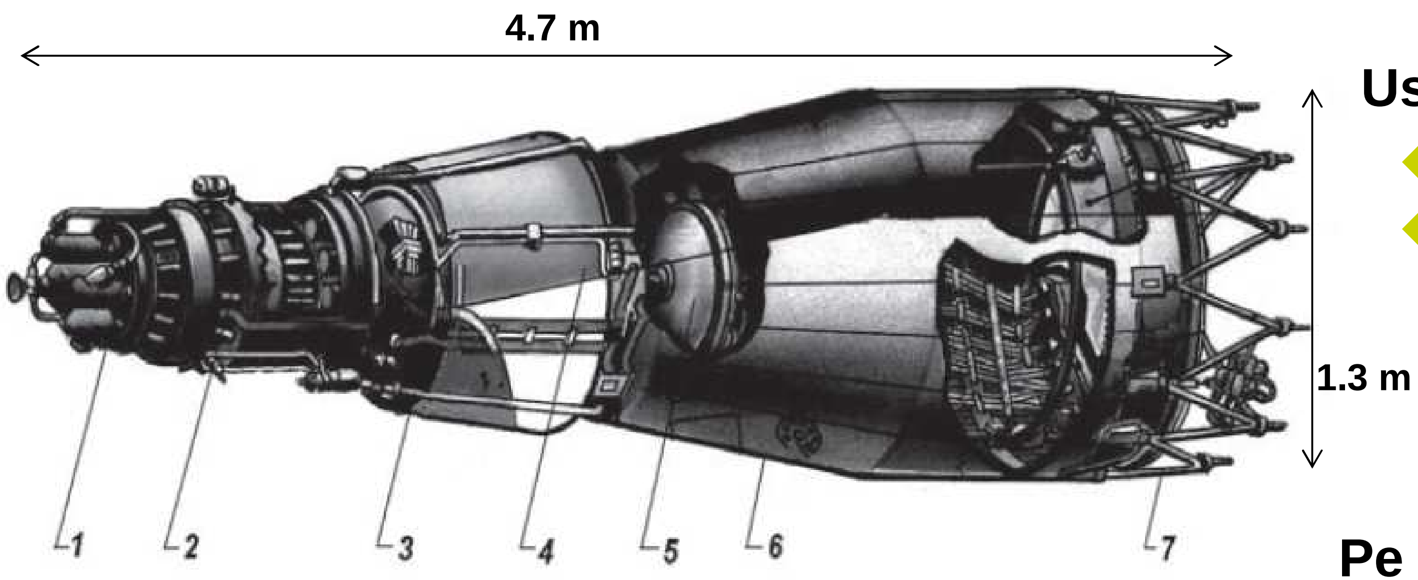
Space Reactors & RPS
Reactor TOPAZ



Used on:

- Cosmos-1818 (1987)
- Cosmos-1867 (1987)

Pe ~6 kWe

Conv Thermoionic

M 12900 kg

Pth ~100 kWth

$\eta_{reactor}$ 5.5%

The TOPAZ NPS layout:

(1) caesium vapour supply system and control drum drive unit,
(2) thermionic reactor converter, (3) liquid metal circuit pipeline,
(4) reactor shielding, (5) liquid metal circuit expansion tank,

(6) radiator, (7) frame structure. Source: Kurchatov Institute.

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