Chemical Engineering 412

Introductory Nuclear Engineering

Lecture 22

Other Nuclear Power Systems

Spiritual Thought

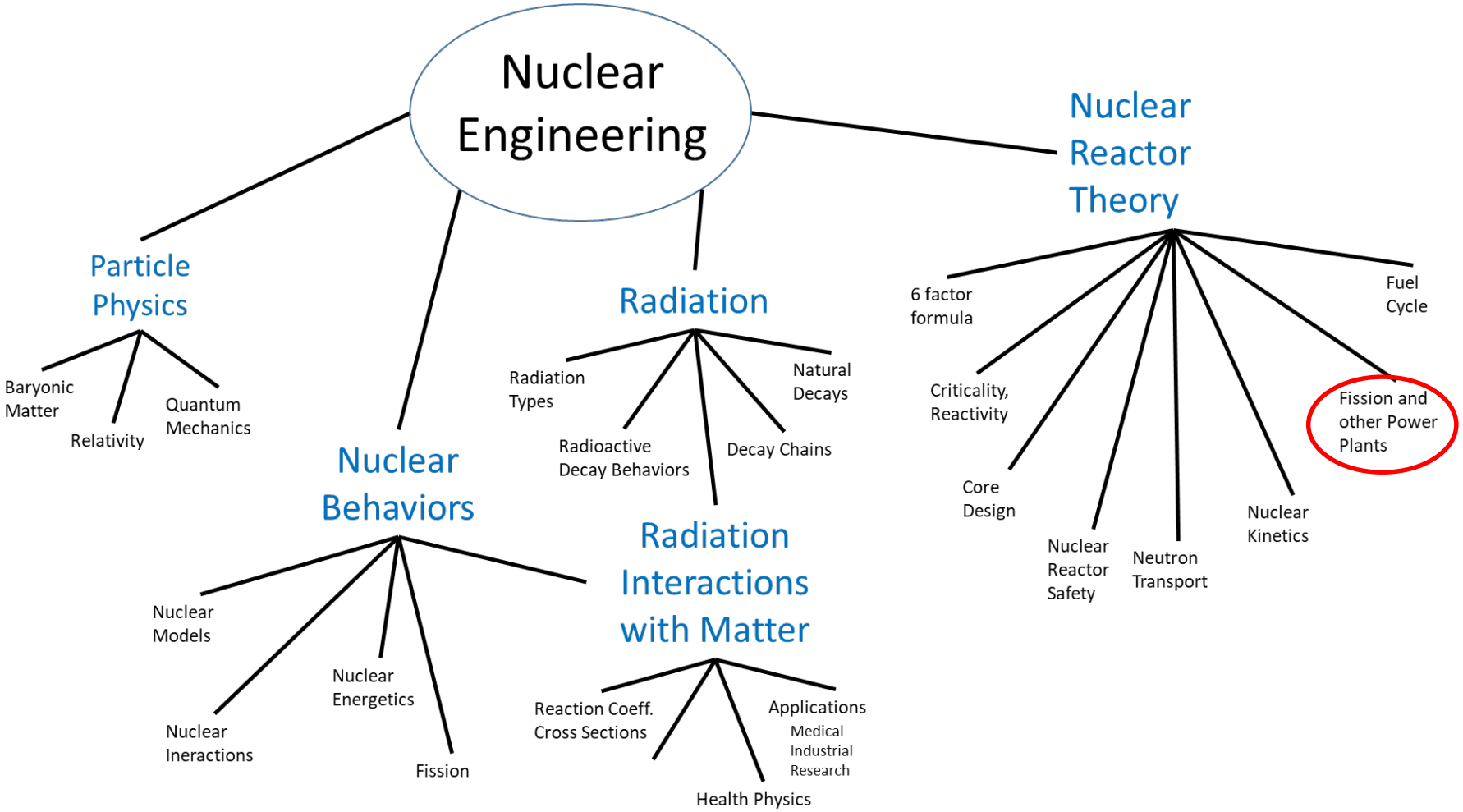
"It is that our Eternal Father enjoys this high status of glory and perfection and power because His faith is perfect and His priesthood is unlimited.

It is that priesthood is the very name of the power of God, and that if we are to become like Him, we must receive and exercise His priesthood or power as He exercises it. …

It is that we have power, by faith, to govern and control all things, both temporal and spiritual; to work miracles and perfect lives; to stand in the presence of God and be like Him because we have gained His faith, His perfections, and His power, or in other words the fulness of His priesthood."

Bruce R. McConkie

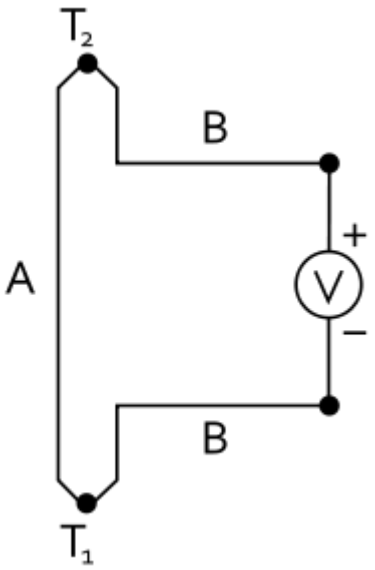
The BIG Picture



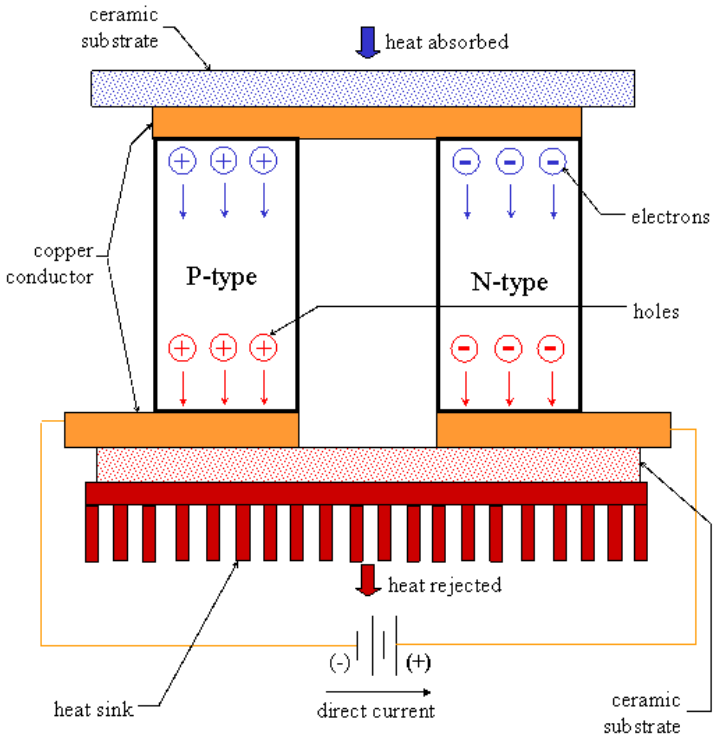
Thermoelectric Generators

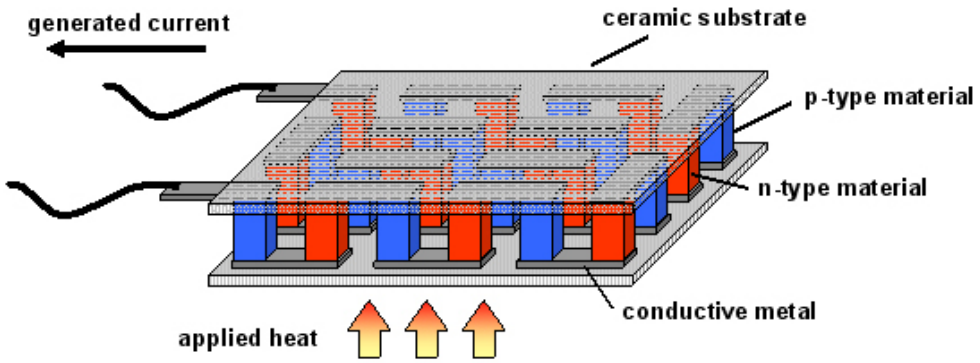
- Low-efficiency (5-10%) and high cost conversion of heat to electricity.
- Applicable primarily where traditional heat engines, which are more efficient and less costly but bulkier, will not work (space, remote locations, etc.).
- Based on the Seebeck effect, the same principle as a thermocouple, except most commonly use p-n junctions instead of dissimilar metals.
- Connected in series in thermopiles.

Thermoelectric Generators



Thermocouple (10s of microvolt/K potential)





Advantages and Disadvantages

Advantages

- No moving parts (except possibly a fan or pump)
- Works with relatively low-grade heat (up to 300 ˚C for consumer use, higher for industrial use).
- Reasonably compact and simple.

Disadvantages

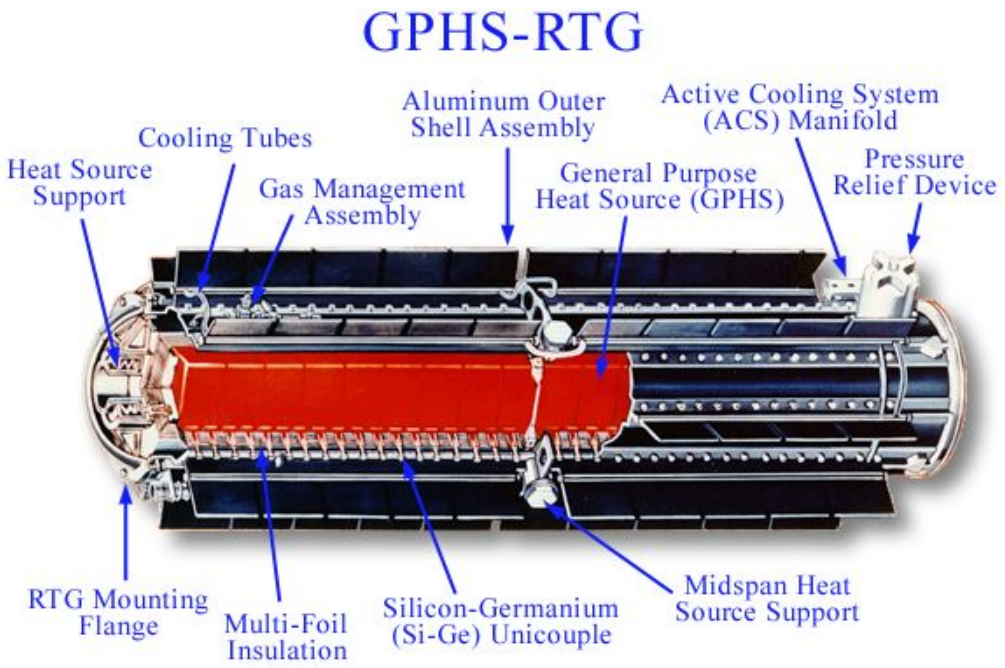
- High cost
- Inefficient – Stirling cycles or other heat engines less costly and more efficient
- High source impedance (can only supply small current before source decreases voltage).
- Poor conductivity/heat sink.

Radionuclide Thermoelectric Generators

Use decay heat from radionuclides on hot side and ambient (or space) temperature on cold side.

- ^{90}Sr and ½ -
  - 1 ton total mass (1-2 kg fuel)
  - Common on earth

- ^{238}Pu and 2-60 kg total
  - (1-8 kg fuel)
  - common in space
  - 2-60 W_e typical output.



GPHS-RTG for many space probes (Viking, Pioneer, Voyager, Galileo, Ulysses, Cassini, New Horizons)

Initial 300 W_e, 4.4 kW_{th}, 6.8% efficient

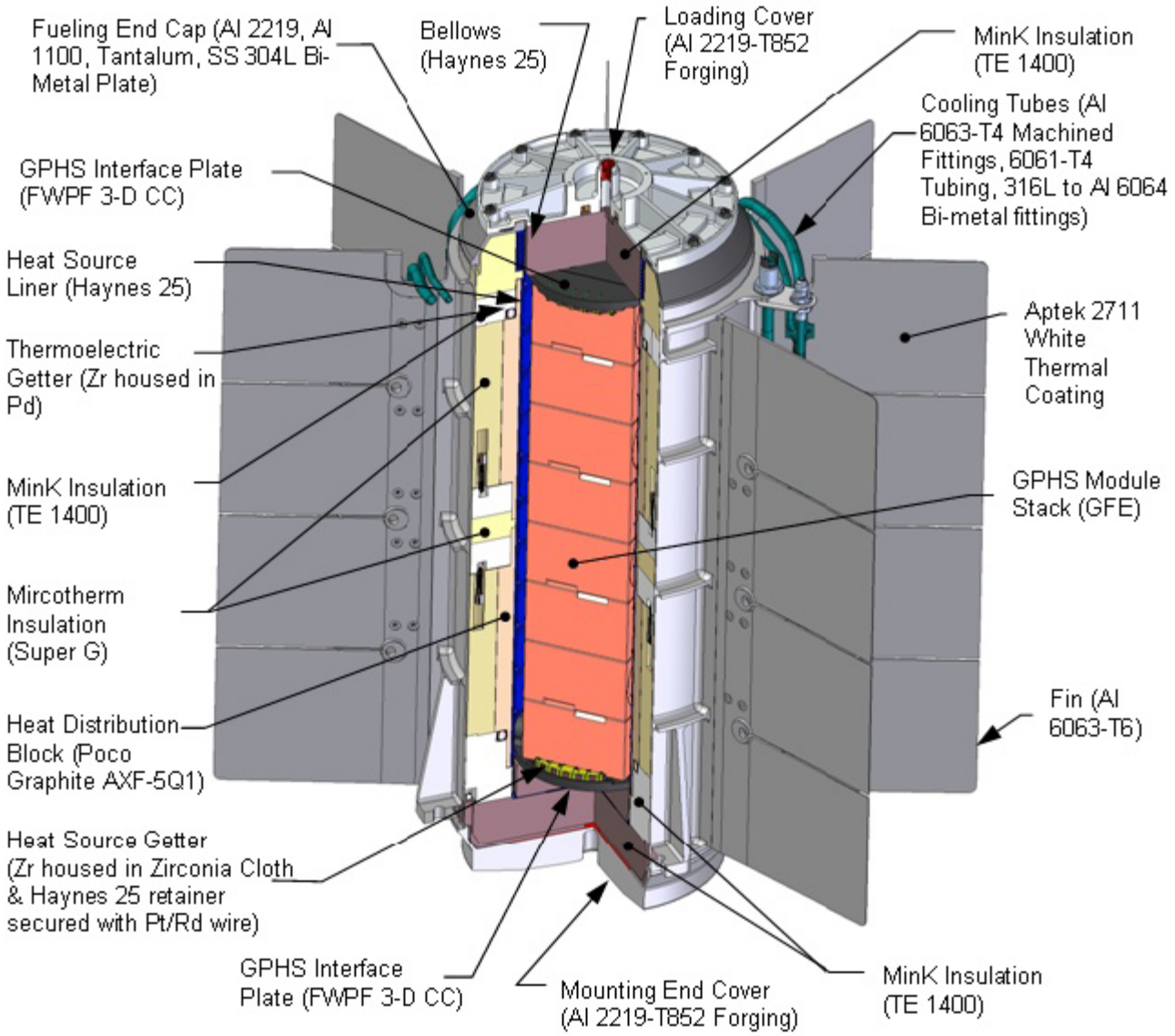
^{238}Pu

1 x ½ m

57 kg (5.2 W_e/kg)

SiGe elements

Multi-mission RTG



RTG for future probes (lower power density but safer)

125 W_e, 2 kW_{th}, 6.5% eff.

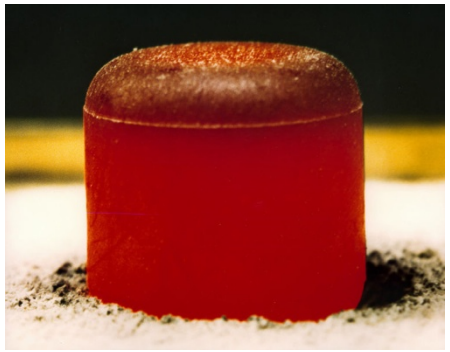
^{238}Pu

1 x ½ m

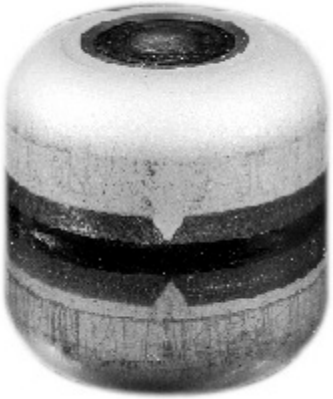
43 kg (2.9 W_e/kg)

PbTe/TAGS elements

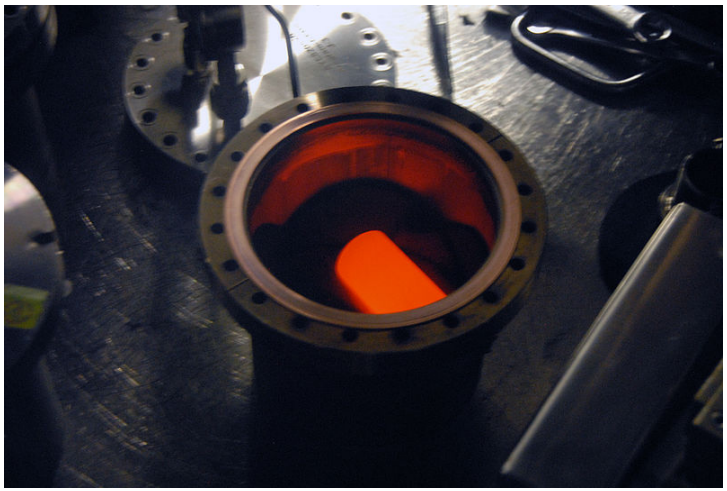
GPU components



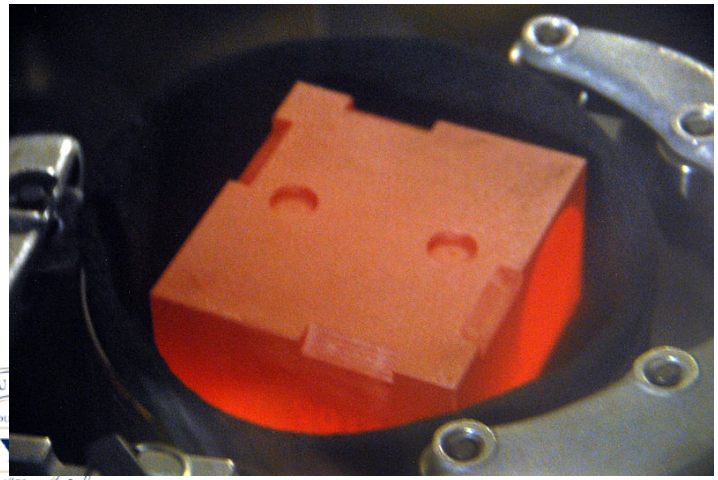
^{238}Pu pellet



Ir cladding

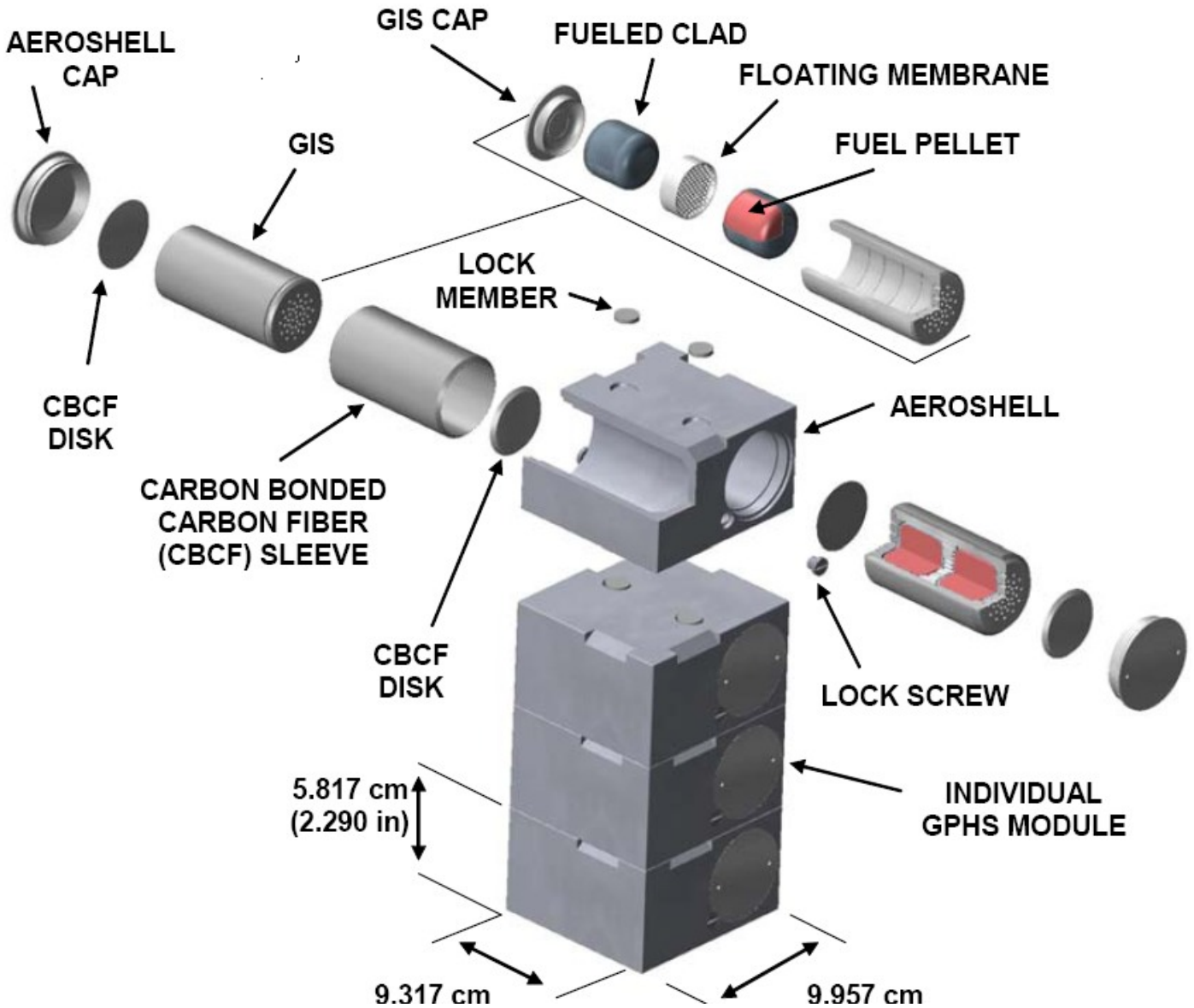


Graphite Impact Casing



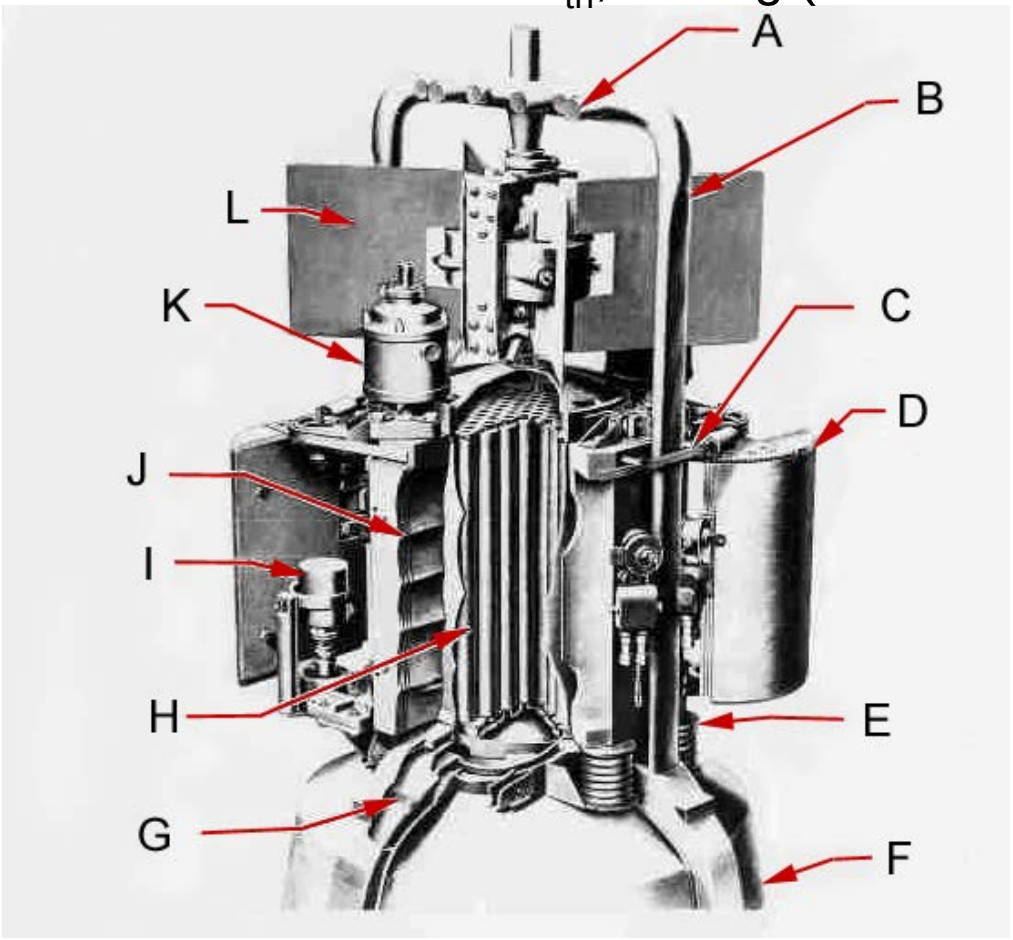
Assembled GPH cell

General Purpose Heat Source



Reactor Thermoelectric Generator

30 W_{th}, 290 kg (unshielded)

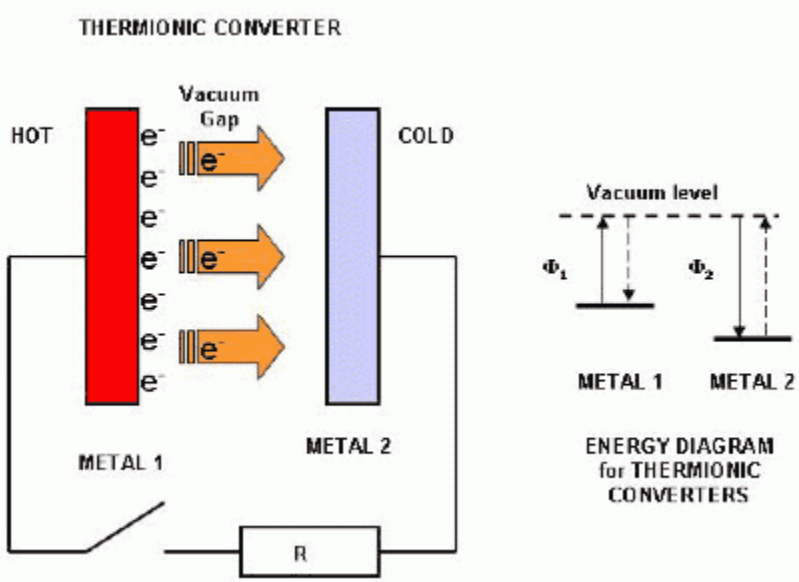


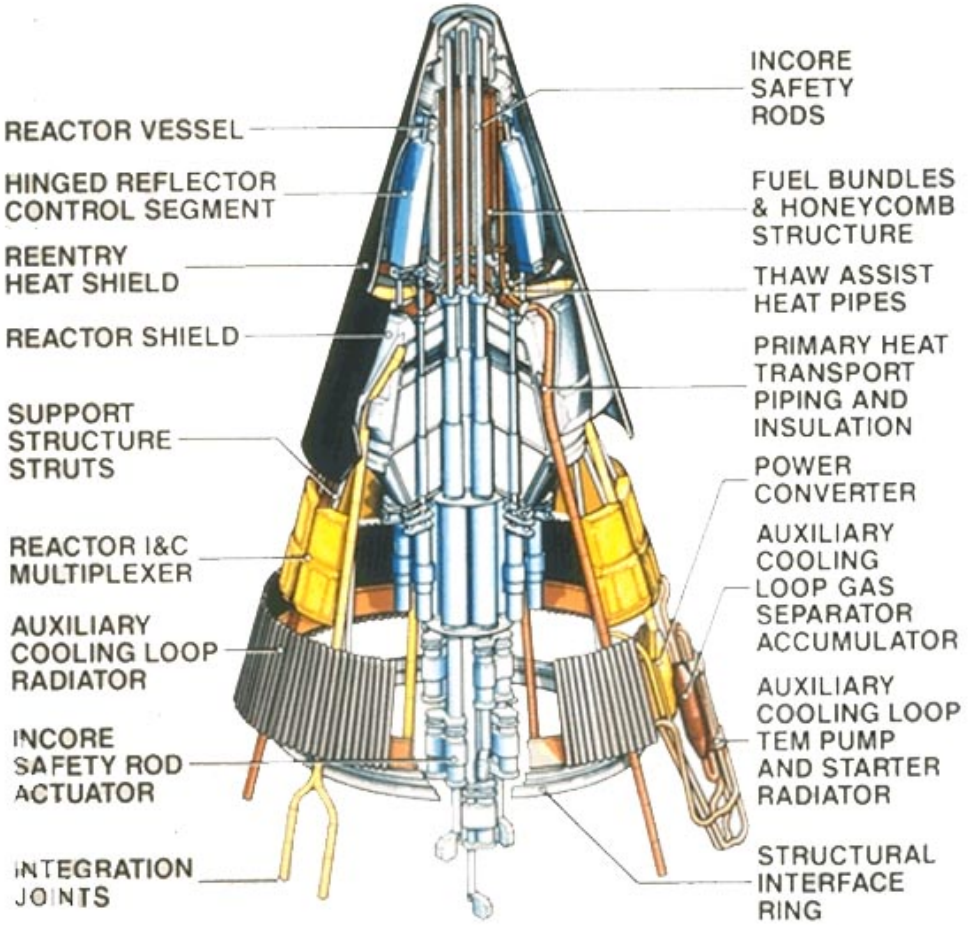
SNAP-10a – K/Na reactor and TE generator – known launch 4/3/1965 in low-earth orbit – design: 500 W_e for 1 year – satellite (not reactor) failed after 43 days – placed in 4000 year (1300 km) orbit – broke up in 1979

Topaz systems

Soviet BES-5 (US-A/Rorsat satellites) 33-38 known launches – 5 known failures and 16 spurts of NaK-78 – US bought Topaz-II technology for further development

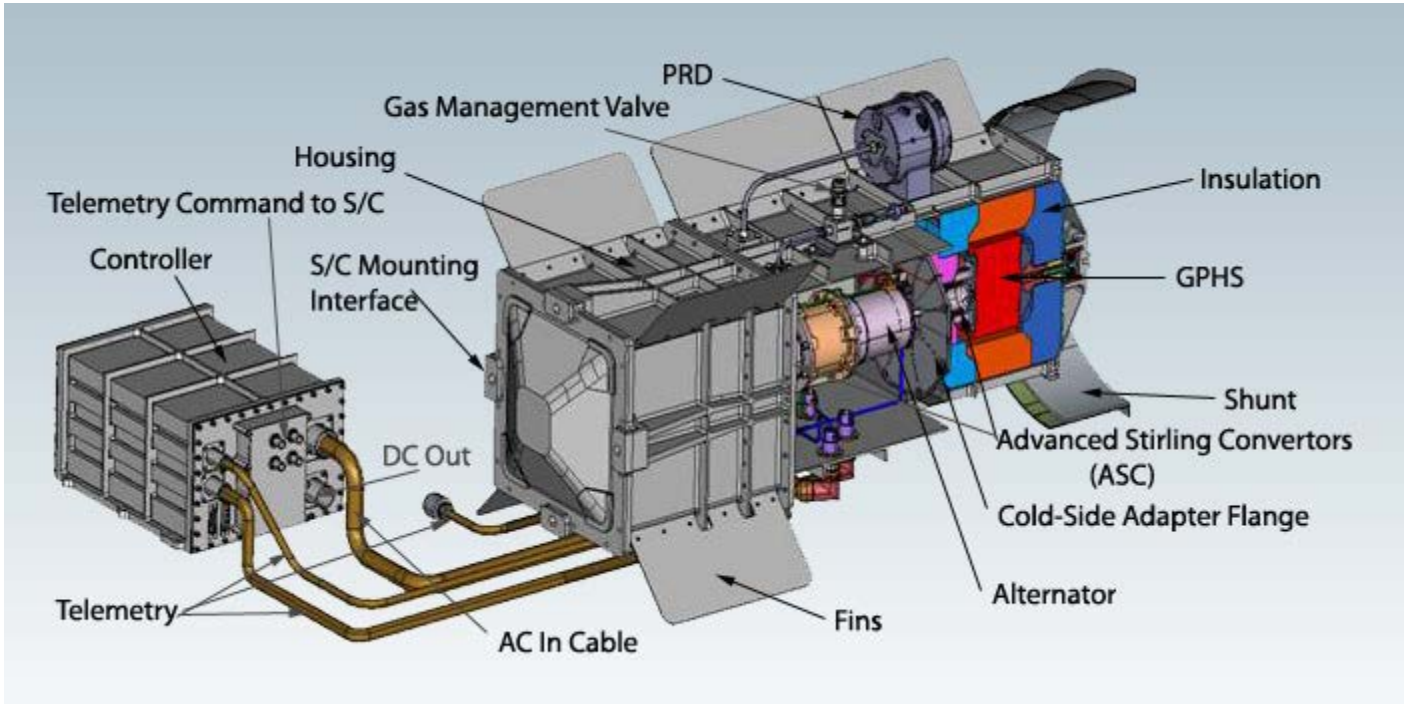
Thermionic Emission





Requires high temperature and detailed construction – 2 known Soviet-designed systems orbited – US bought Topaz-II technology for further development

Advanced Sterling Radioisotope Generator



≥14 year lifetime

Nominal power : 140 W_e

Mass ~ 20 kg (7 W_e/kg)

System efficiency: ~ 30 %

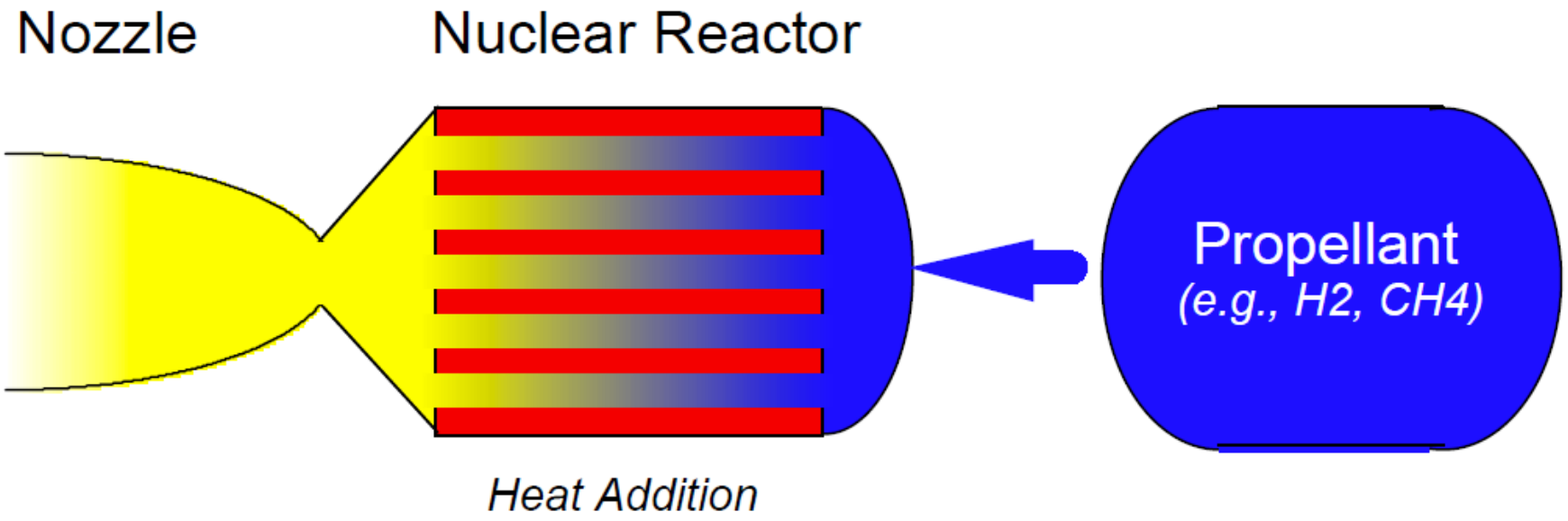
2 General Purpose Heat Source (“Pu238 Bricks”) modules

Uses 0.8 kg plutonium-238

SAFE

- Safe Affordable Fission Engine (SAFE) are small experimental fission reactors.
- The SAFE-400 reactor produces 400 kW thermal power, giving 100 kW of electricity using a Brayton cycle gas turbine.
- Uranium nitride fuels the reactor in a core of 381 rhenium-clad pins clad with rhenium.
- The reactor is about 50 centimeters (20 in) tall, 30 centimeters (12 in) across and weighs about 512 kilograms (1,129 lb).
- It was developed at the Los Alamos National Laboratory and the Marshall Space Flight Center.

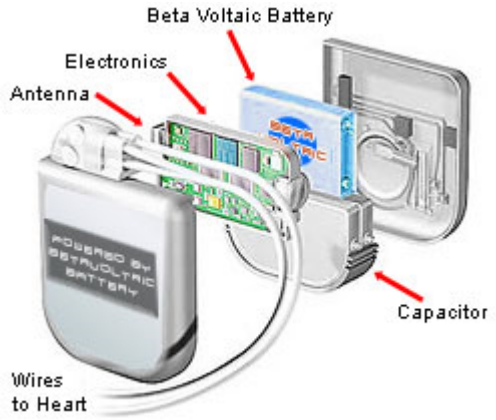
SAFE



SAFE Demonstration

Direct Devices

- Not heat engines
- Use radiation directly, as in a photovoltaic (called betavoltaic) cell
- Low efficiency and low capacity, but relatively maintenance free
- Used in medical and some space research applications



Example

- You friend wants to power his private island (96 kW) using 137Cs, and he asks you to make the RTG for him. How much 137Cs is required? Assuming you use enough for 192 kW initially, how long will this power source power his island sufficiently?