Thermionic Programs of the Early 1990s – TFEVP and Topaz International Program

presented by

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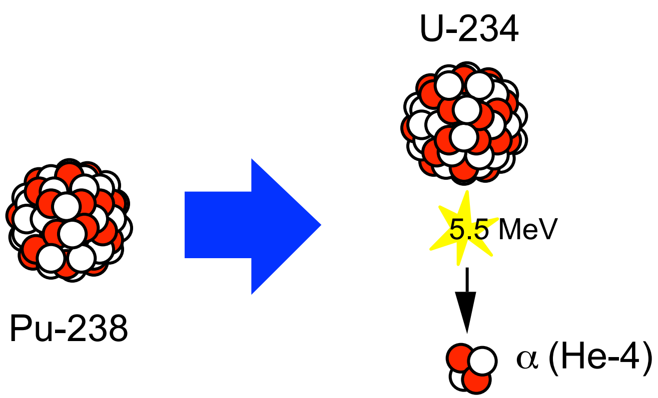
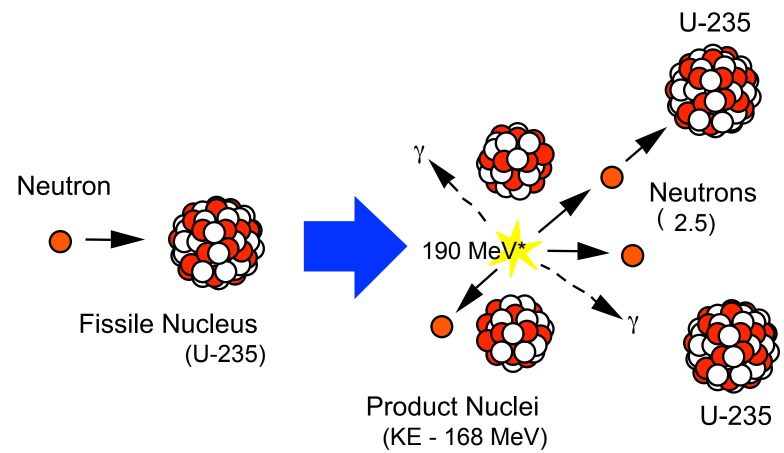
Basics of Nuclear Systems





Heat Energy = 0.023 MeV/nucleon (0.558 W/g Pu-238)

Natural decay rate (87.7-year half-life)

- Long history of use on Apollo and space science missions
  - 44 RTGs and hundreds of RHUs launched by U.S. during past 4 decades
- Heat produced from natural alpha (a) particle decay of Plutonium (Pu-238)
- Used for both thermal management and electricity production

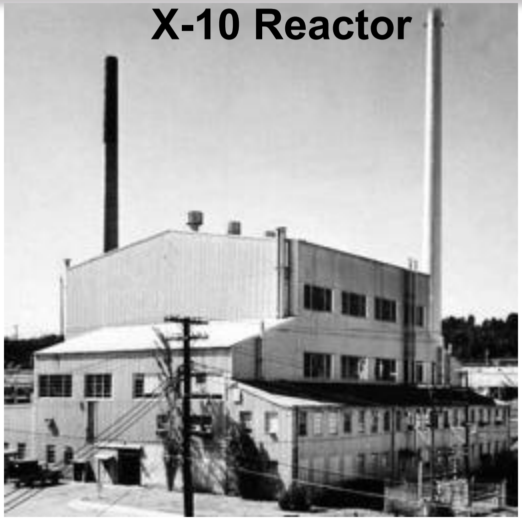
Heat Energy = 0.851 MeV/nucleon

Controllable reaction rate (variable power levels)

- Used terrestrially for over 65 years
  - Fissioning 1 kg of uranium yields as much energy as burning 2,700,000 kg of coal
- One US space reactor (SNAP-10A) flown (1965)
  - Former U.S.S.R. flew 33 space reactors
- Heat produced from neutron-induced splitting of a nucleus (e.g. U-235)
  - At steady-state, 1 of the 2 to 3 neutrons released in the reaction causes a subsequent fission in a “chain reaction” process
- Heat converted to electricity, or used directly to heat a propellant

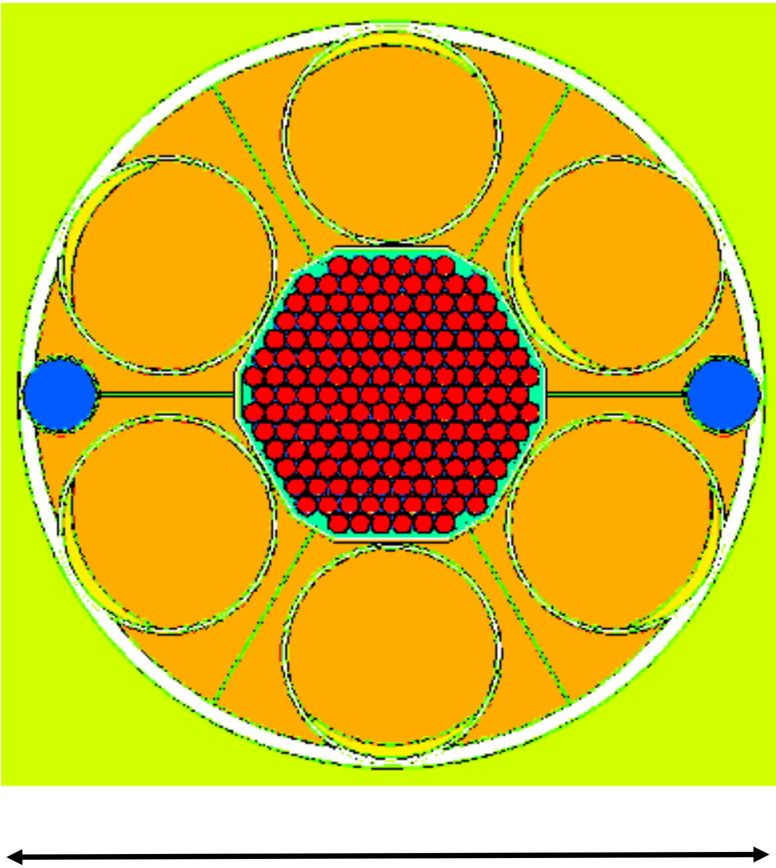
Fission Introduction

- **Creating a fission chain reaction is conceptually simple**
  - **Requires right materials in right geometry**
- **Good engineering needed to create safe, affordable, useful fission systems**



- ***1938 Fission Discovered***
- ***1939 Einstein letter to Roosevelt***
- ***1942 Manhattan project initiated***
- ***1942 First sustained fission chain reaction (CP-1)***
- ***1943 X-10 Reactor (ORNL), 3500 kWt***
- ***1944 B-Reactor (Hanford), 250,000 kWt***
- ***1944-now Thousands of reactors at various power levels***

Typical Space Fission System Operation

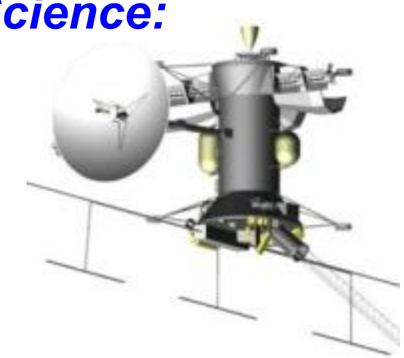


0.5 m

- System power controlled by neutron balance
- Average 2.5 neutrons produced per fission
  - Including delayed
- Constant power if 1.0 of those neutrons goes on to cause another fission
- Decreasing power if < 1.0 neutron causes another fission, increasing if > 1.0
- System controlled by passively and actively controlling fraction of neutrons that escape or are captured
- Natural feedback enables straightforward control, constant temperature operation
- 200 kWt system burns 1 kg uranium every 13 yrs

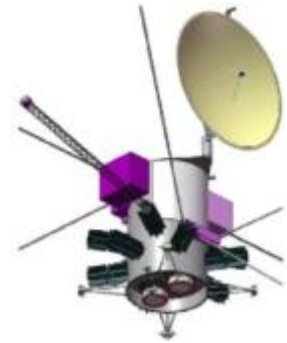
Safe, Compact, Near-Term Fission Power Systems Could Help Enable Higher Power Fission Propulsion Systems

Science:

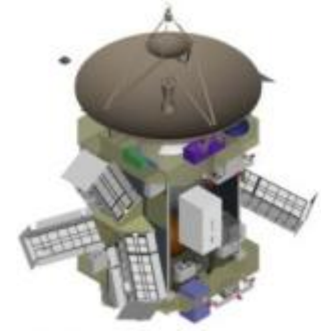


Jupiter Europa Orbiter
~600 We (5 to 6 RPS)

Neptune Systems Explorer
~3 kWe (9 Large RPS)



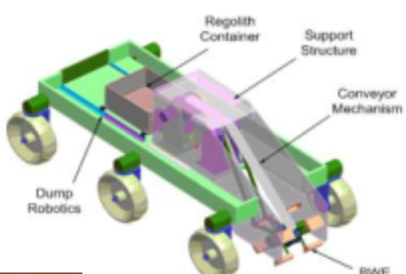
Kuiper Belt Object Orbiter
~4 kWe (9 Large RPS)



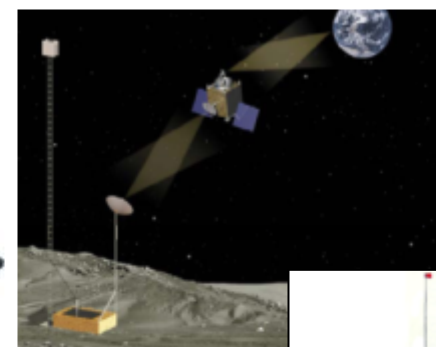
Trojan Tour
~800 We (6 RPS)

Exploration:

Teleoperated
Rovers



Comm Relay
Stations

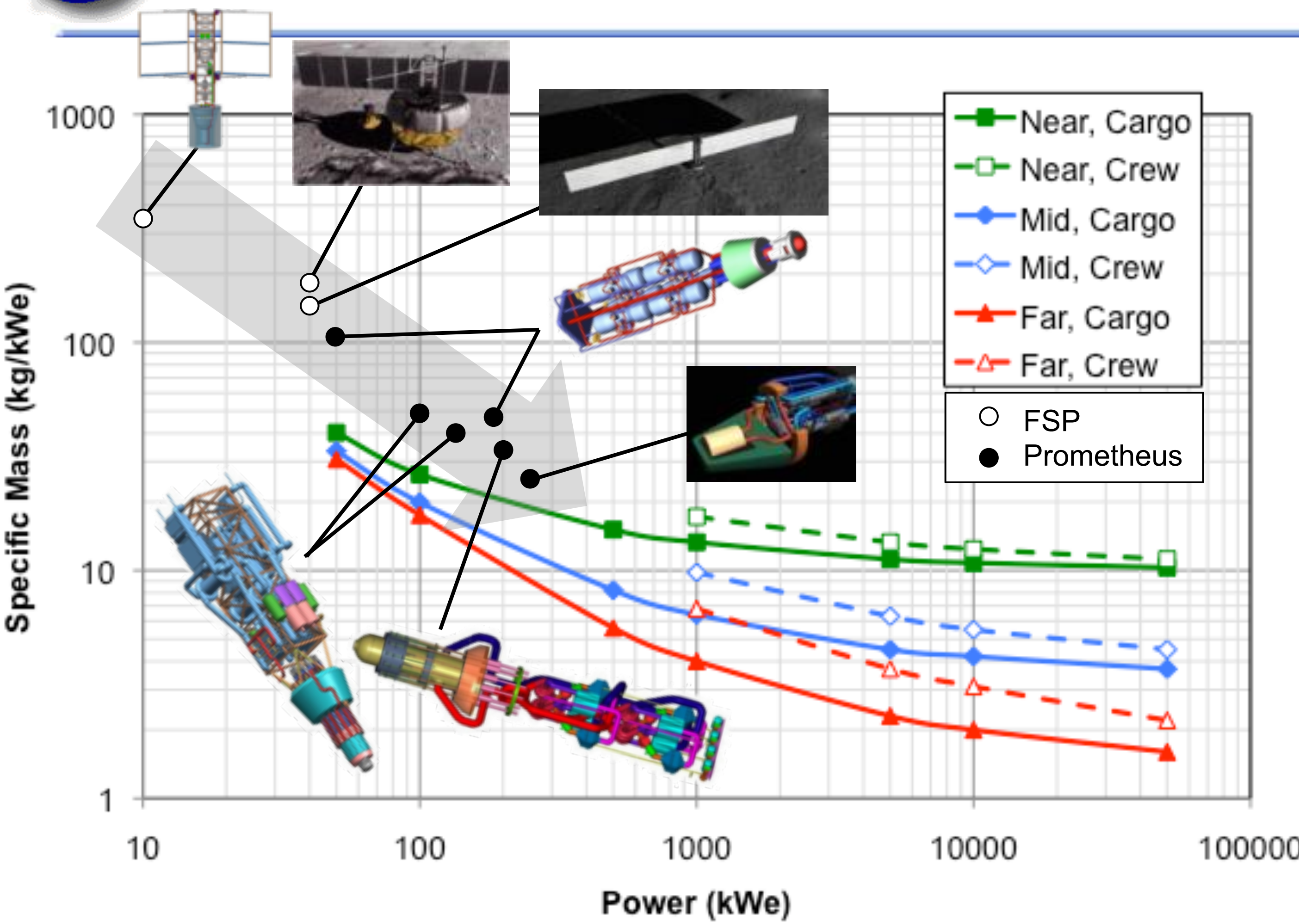


ISRU Demo
Plants

Site Survey
Landers

Remote Science
Packages

Fission Can Provide the Energy for Either Nuclear Thermal or Nuclear Electric Propulsion Systems

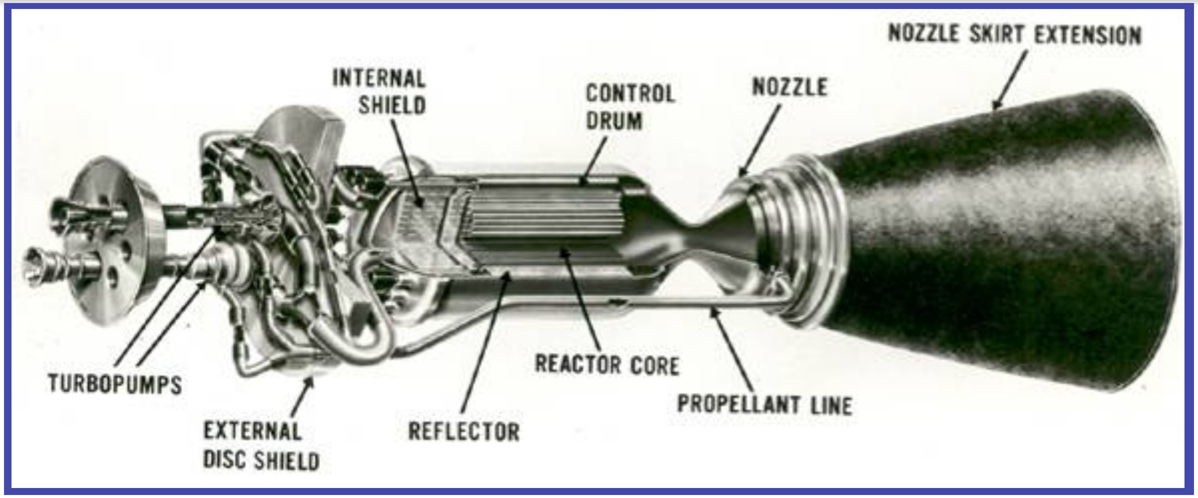


- NEP Power System Performance Projections from 2001 STAIF Conference
- Fission Surface Power and Prometheus Concepts Superimposed

Near=Liq Metal Rx, Brayton, 1300K, 6 kg/m2, 200 Vac (Available ~10 yrs)
Mid=Liq Metal Rx, Brayton, 1500K, 3 kg/m2, 1000 Vac (Available ~ 15-20 yrs)
Far=Liq Metal Rx, Brayton, 2000K, 1.5 kg/m2, 5000 Vac (Available ~ 25-30 yrs)
Cargo=Instrument rated shielding, 1.6x10^15 nvt, 1.2x10^8 rad @ 2 m
Crew=Human rated shielding, 5 rem/yr @ 100 m, 7.5° half angle

Chart courtesy Lee Mason, NASA GRC

NASA is Currently Funding an "Advanced Exploration Systems" Project Investigating Nuclear Thermal Propulsion (NTP)



- Nuclear thermal propulsion (NTP) is a fundamentally new capability
  - Energy comes from fission, not chemical reactions
  - Virtually unlimited energy density
- Initial systems will have specific impulses roughly twice that of the best chemical systems
  - Reduced propellant (launch) requirements, reduced trip time
  - Beneficial to near-term/far-term missions currently under consideration
- Advanced nuclear propulsion systems could have extremely high performance and unique capabilities
- A first generation NTP system could serve as the "DC-3" of space nuclear power and propulsion

In-Core Thermionic Space Power Systems

Potential Advantages

Extremely high temperatures (~1800 K) confined to fuel and clad. Remainder of system can use traditional materials.

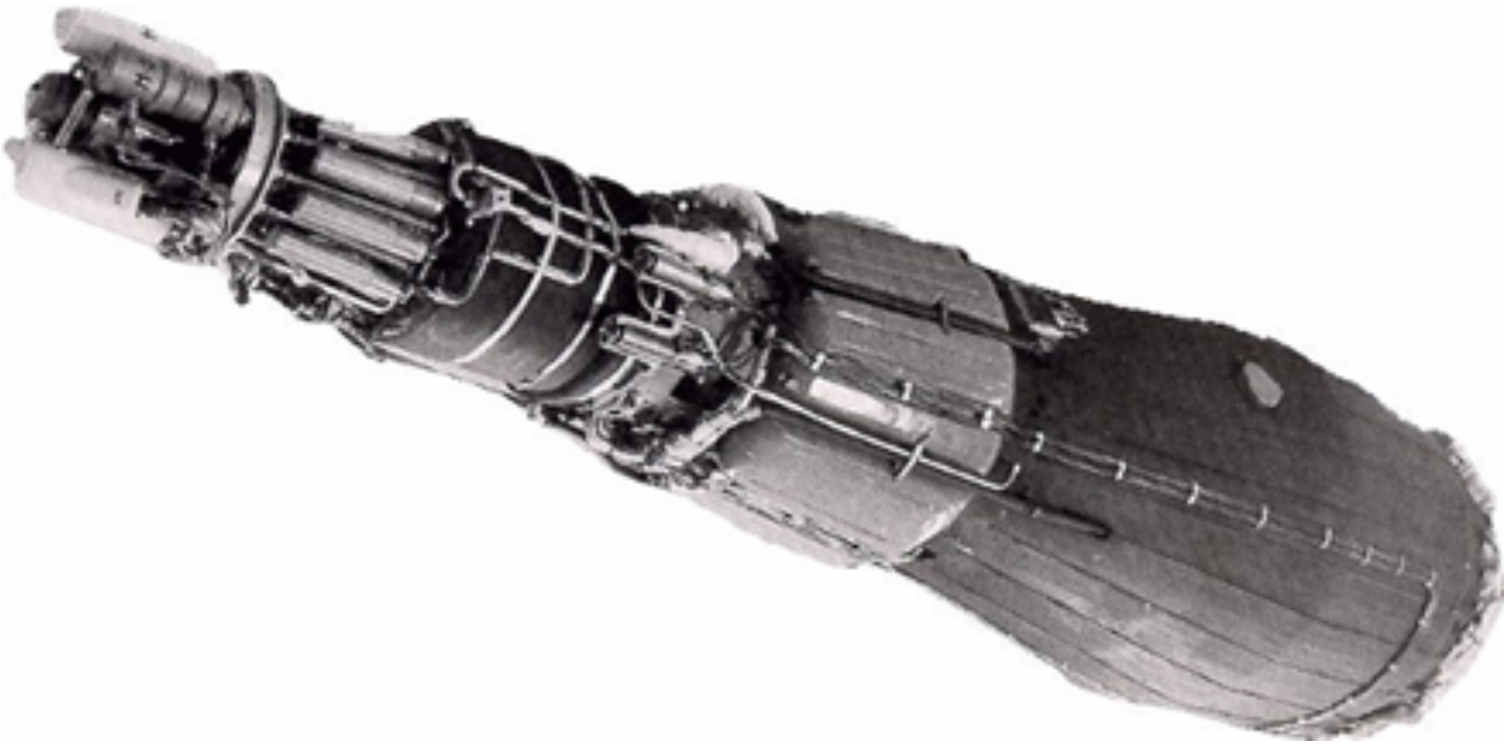
Good efficiency and high heat rejection temperature (~900 K) results in small radiator.

Potential Concerns

All thermionic converter materials must have adequate radiation resistance.

Changes in thermionic converter design directly affect reactor design.

Russian 5 kWe TOPAZ Thermionic Space Reactor



Thermionic Fuel Element Verification Program (TFEVP)

Goal:

Demonstrate the technological readiness of a Thermionic Fuel Element (TFE) suitable for use as the basic element in a thermionic reactor having an electric power output in the 0.5– to 5-MWe range and a full-power life of 7 years.

4×10^{22} n/cm^2 (E > 0.1 MeV)

5.3% burnup

Insulator seals, sheath insulators, fueled emitters, cesium reservoirs, interconnective TFE components

Thermionic Fuel Element Verification Program (TFEVP)

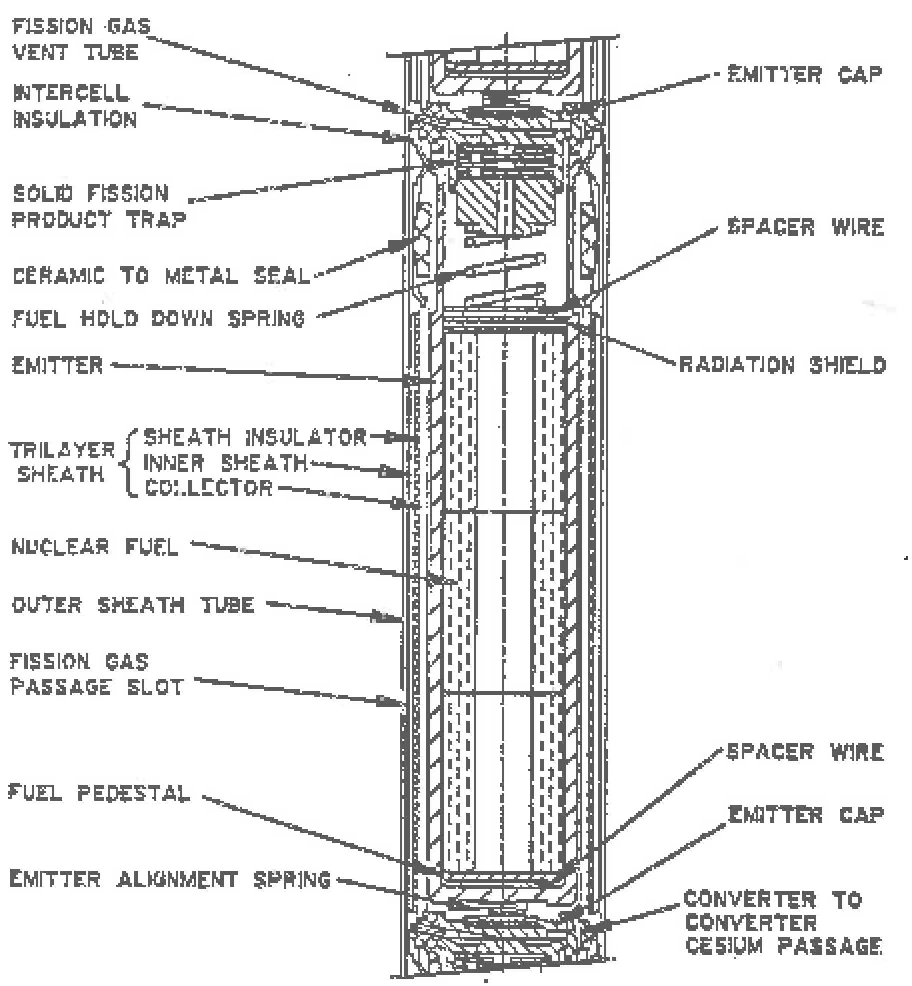


FIGURE 1. Schematic of a Typical TFE, Showing Fuel, Emitter, Ceramic-to-Metal (Insulator) Seal, and Other Components.

Thermionic Fuel Element Verification Program (TFEVP)

Accomplishments:

Preliminary design of a 2 MWe system. 9.3% efficiency, 24,000 kg. Emitter OD 12.7 mm, length 50.8 mm, 7 A/cm^2 current density, 1800 K emitter, 1000 K collector.

Converter performance models correlated to test data

Alumina taper seals (5×10^{21} n/cm^2, E >0.1 MeV)

Alumina-based trilayer seals (5×10^{22} n/cm^2, E>0.1 MeV)

Alumina insulators (5×10^{21} n/cm^2, E >0.1 MeV)

Thermionic Fuel Element Verification Program (TFEVP)

Accomplishments:

Cesium reservoirs ($1.5 \times 10^{22} n/cm^2$)

Fueled emitters (2% burnup)

Single TFE tests (1H1, 1H2, 1H3) and multicell TFE tests (3H1, 3H5)

TOPAZ International Program

90 tons of equipment from Russia, including 2 unfueled TOPAZ 2 reactors

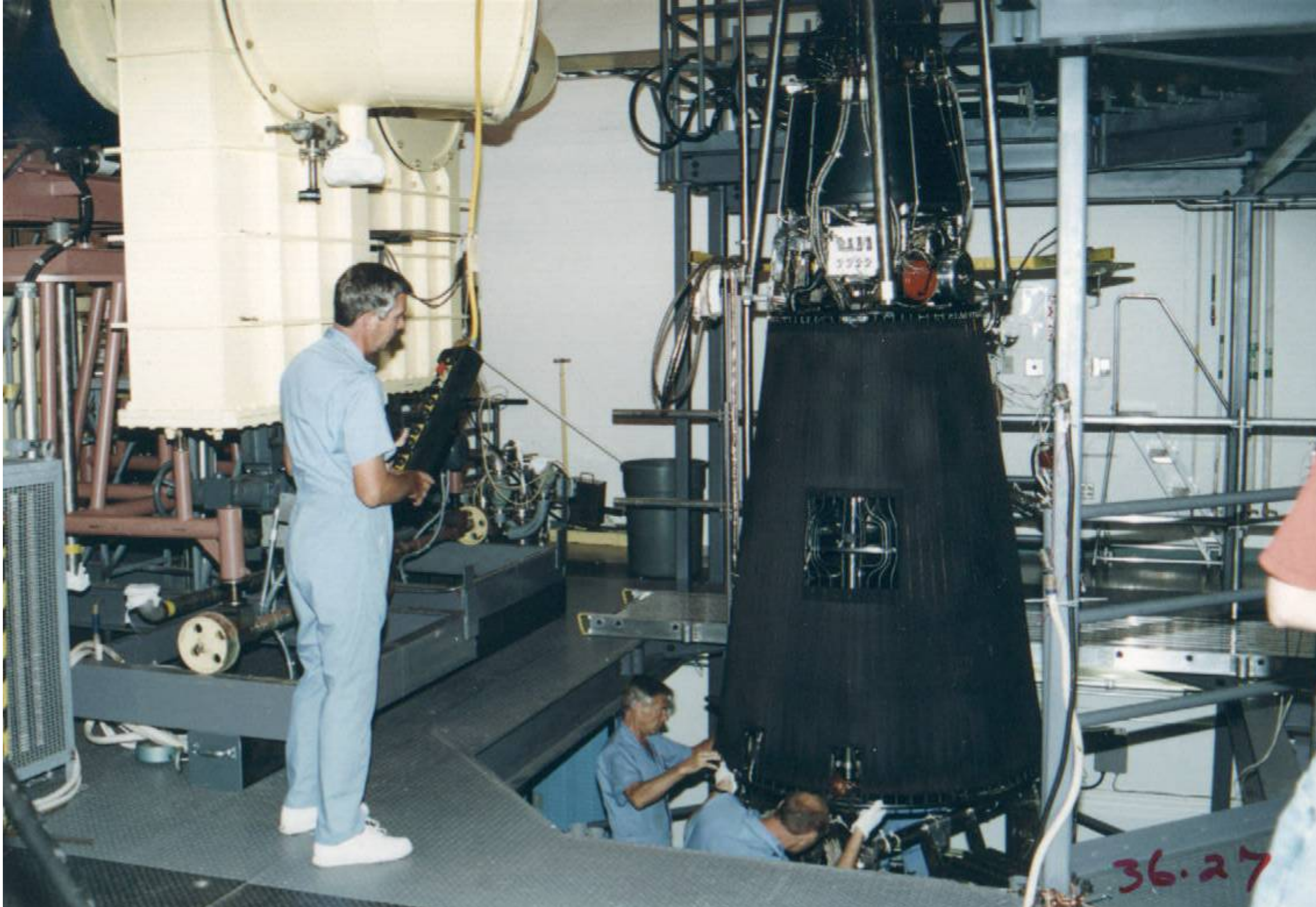
TOPAZ II test facility (Baikal Rig)

9 ft diameter x 20 ft high vacuum chamber, all associated equipment

TFE test rig

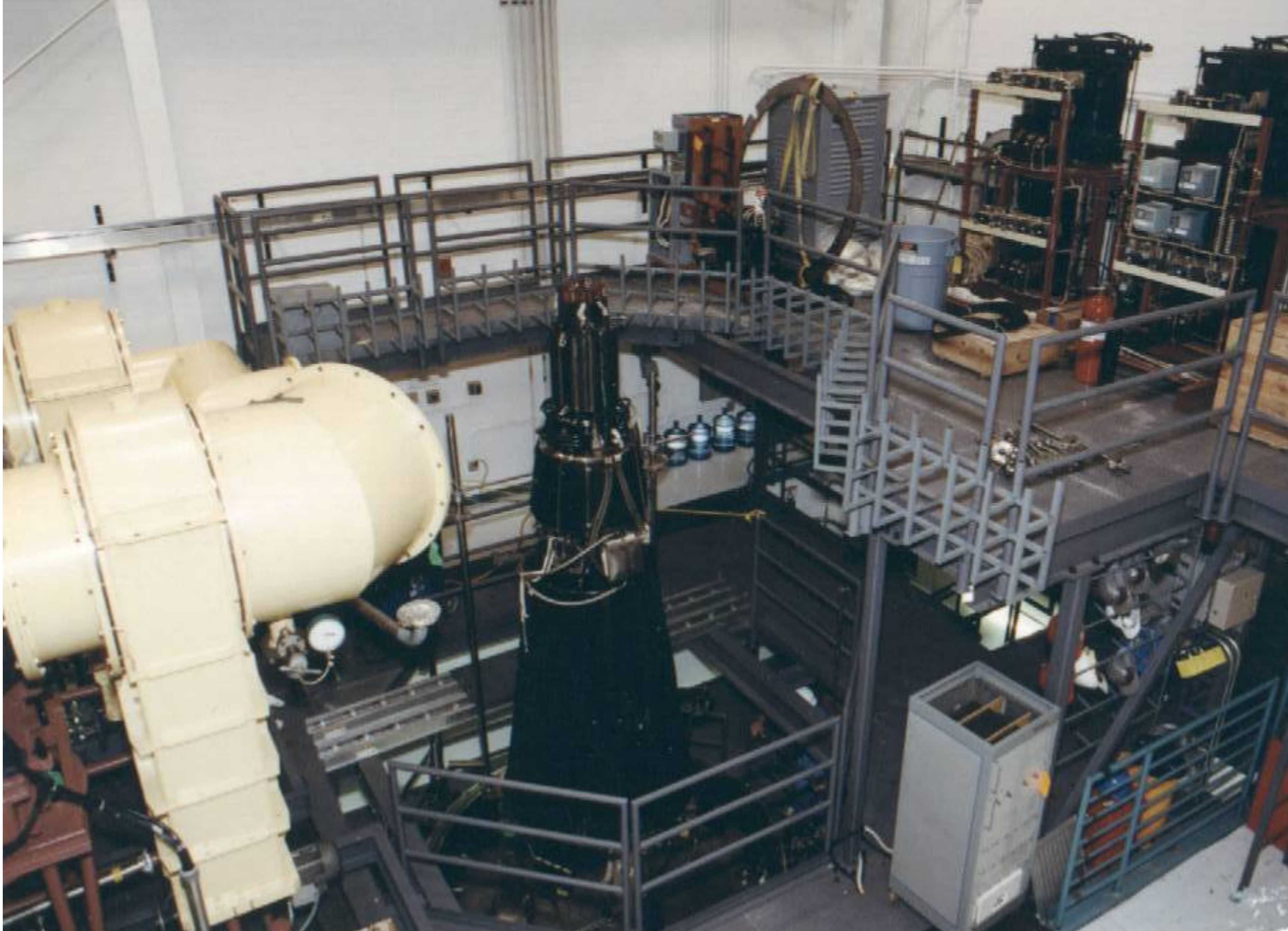
TISA test stand

Cesium test rig

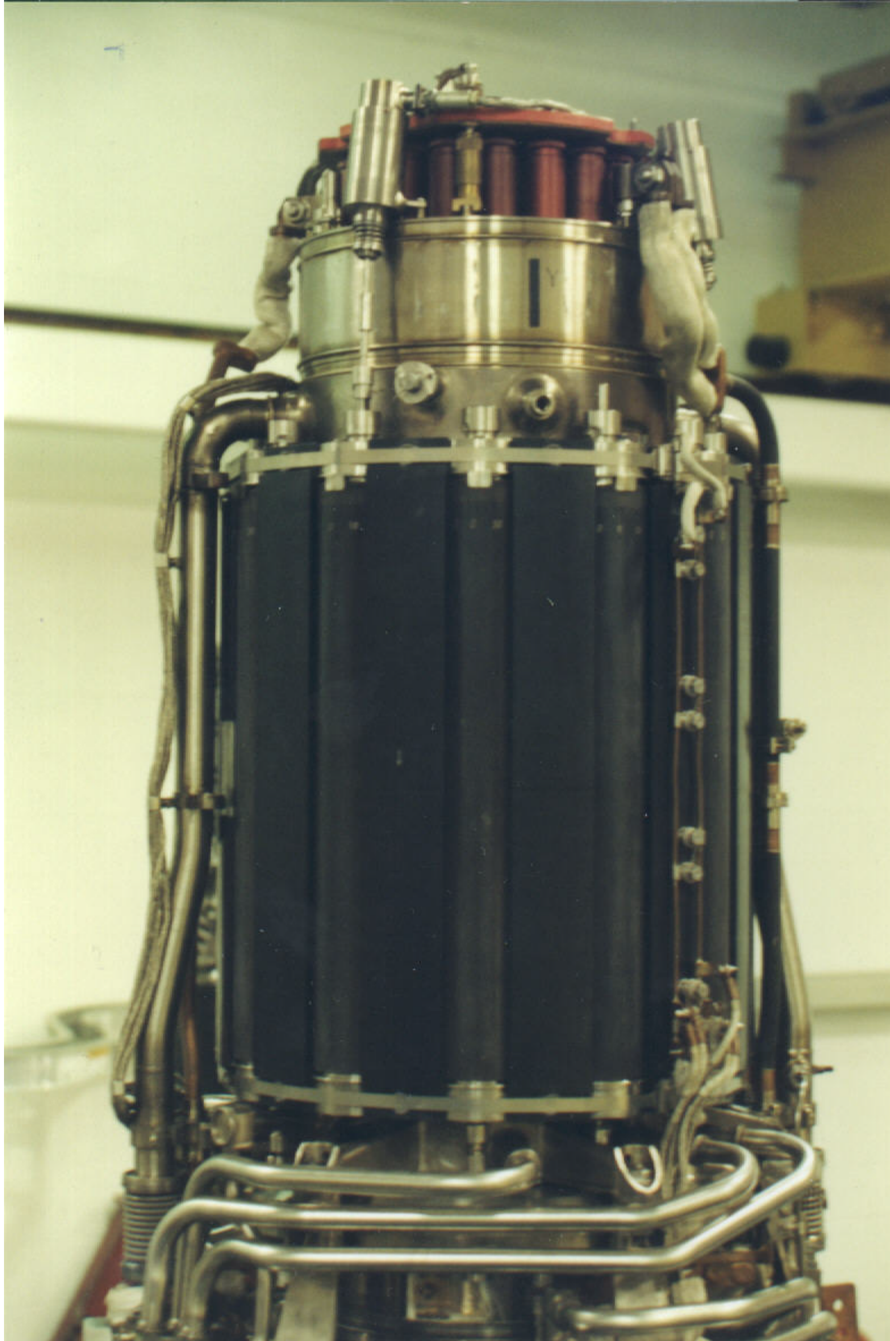


Topaz International

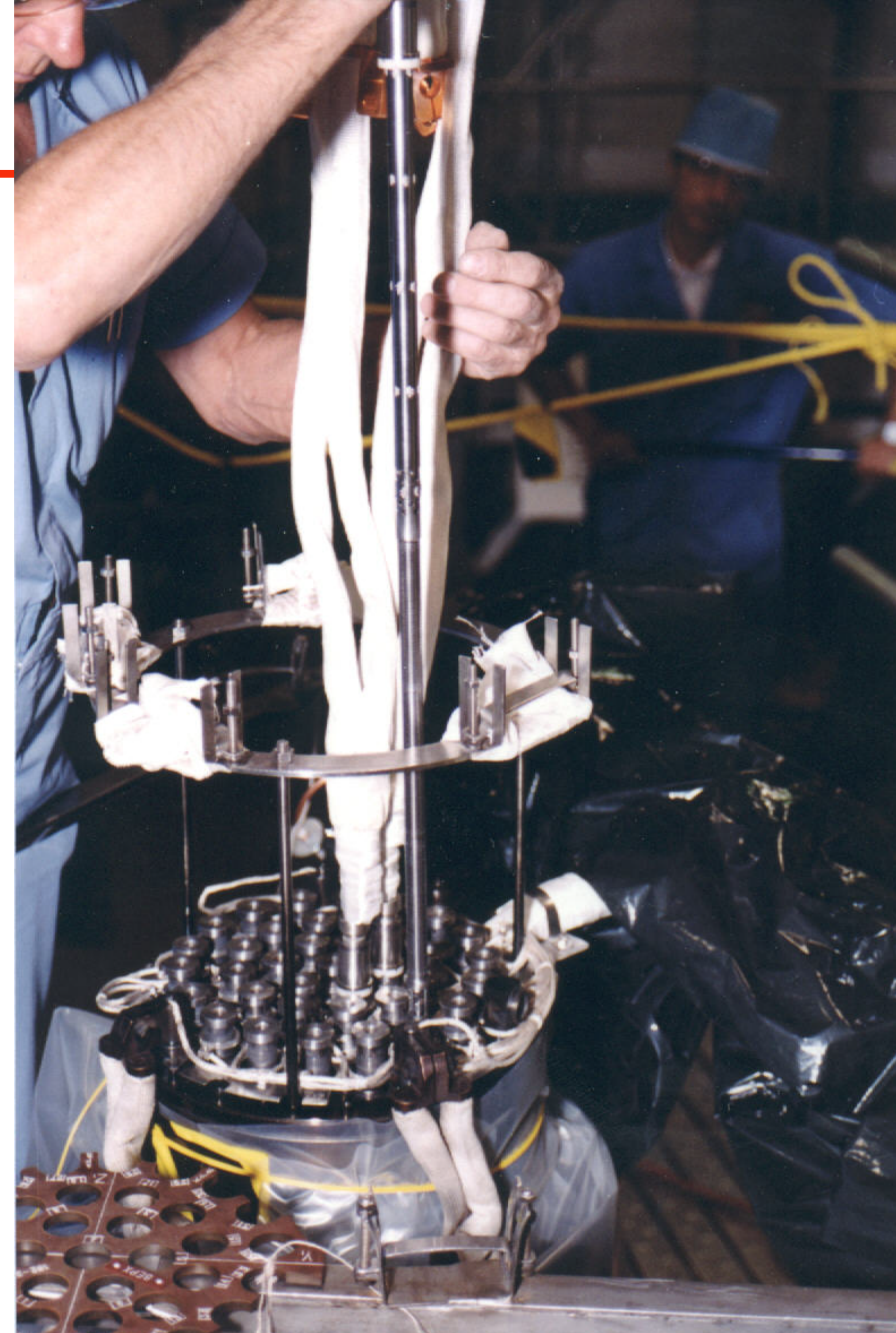
Personnel preparing TOPAZ II for testing


Topaz International

TOPAZ II ready for installation of vacuum chamber

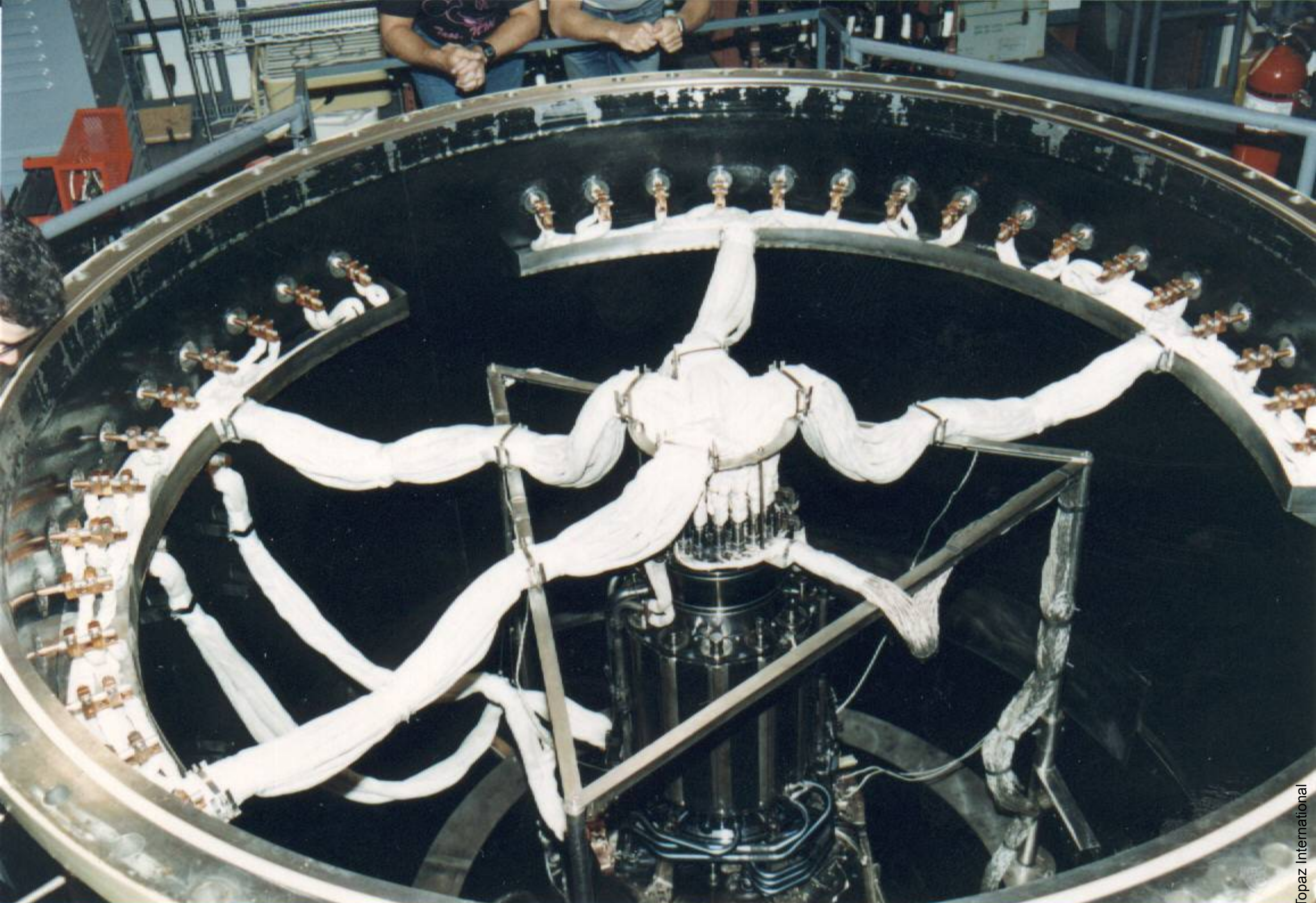


Close up of TOPAZ II reactor



Topaz International

Installation of heater



TOPAZ II with resistance heaters installed

Out-of-Core Thermionic Reactor

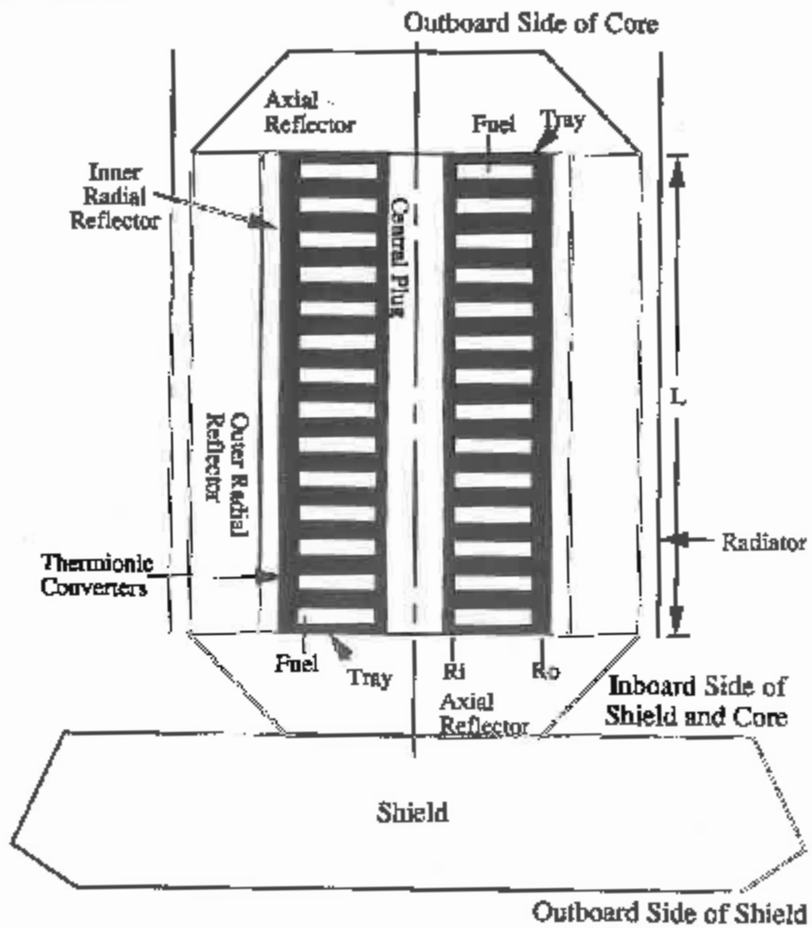


FIGURE 2.1. Reference OTR Showing Inner Core Radius (Ri), Outer Core Radius (Ro), Core Length (L), and the Location of the Central Plug, Fuel Rings, Fuel Trays, Thermionic Converters, Inner Radial Reflector, Outer Radial Reflector, Radiator, Axial Reflector, and Shadow Shield.

Out-of-Core Thermionic Converter

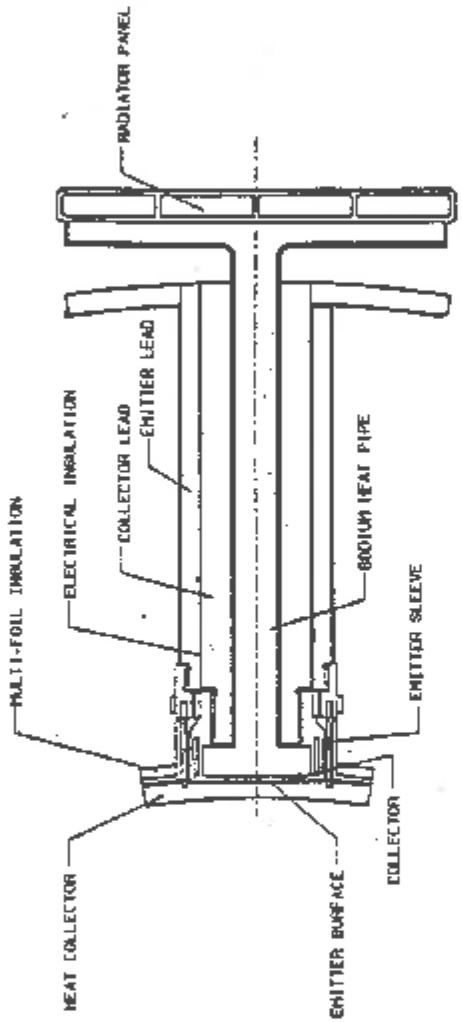


FIGURE 2.2. Thermionic Power Conversion System Showing the Tungsten Heat Collector, Thermionic Emitter, Emitter Sleeve/Electrical Lead, Thermionic Collector, and Sodium Heat Pipe (from GA Technologies, 1987).

Observations

Space nuclear power and propulsion systems can be enhancing or enabling for ambitious space missions.

Thermionic technology has potential advantages for certain applications.

Thermionic reactors have flown in space.

Previous programs have conducted research and development related to both in-core and out-of-core thermionic systems.