

National Aeronautics and Space Administration

NASA

Pushing the Limits: Thermal and Fluids Challenges in Space Nuclear Propulsion

SPACE NUCLEAR PROPULSION

NESC Thermal Control & Protection Webinar

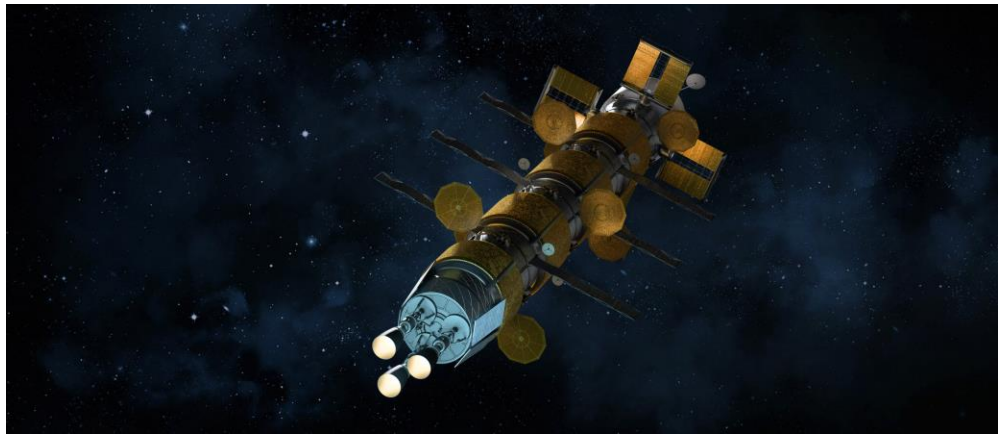
Dr. Kurt Polzin, Chief Engineer, Space Nuclear Propulsion, Marshall Space Flight Center

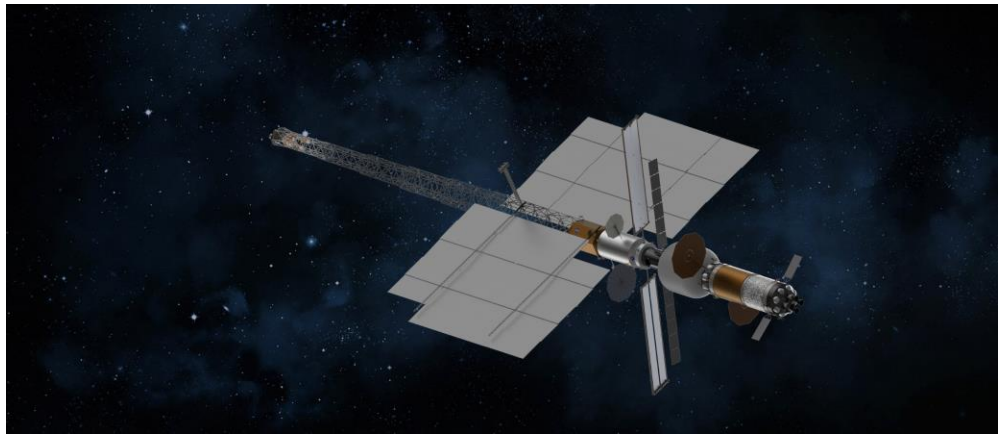
21 October 2026

Why Nuclear Propulsion?

Nuclear changes the game for propulsion

- High thrust **and** relatively high specific impulse
- High power for long-duration missions
- Very high specific impulse
- Multi-year / multi-decade operation
- Capability beyond solar electric and chemical propulsion

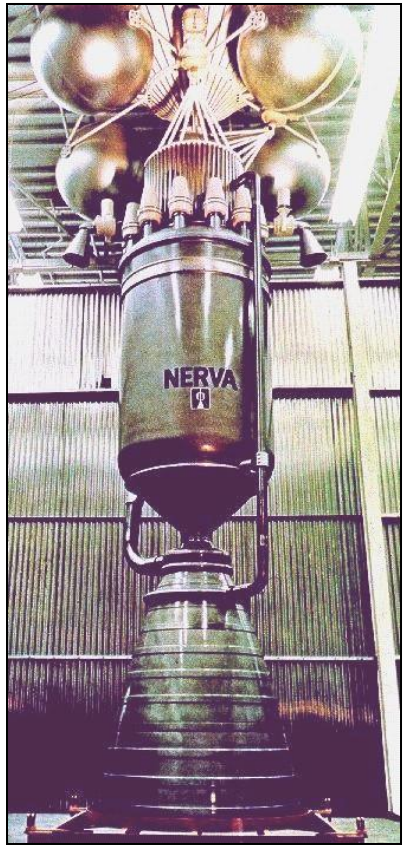




Two Architectures, One Fundamental Problem

NTP

Nuclear heat → propellant kinetic energy



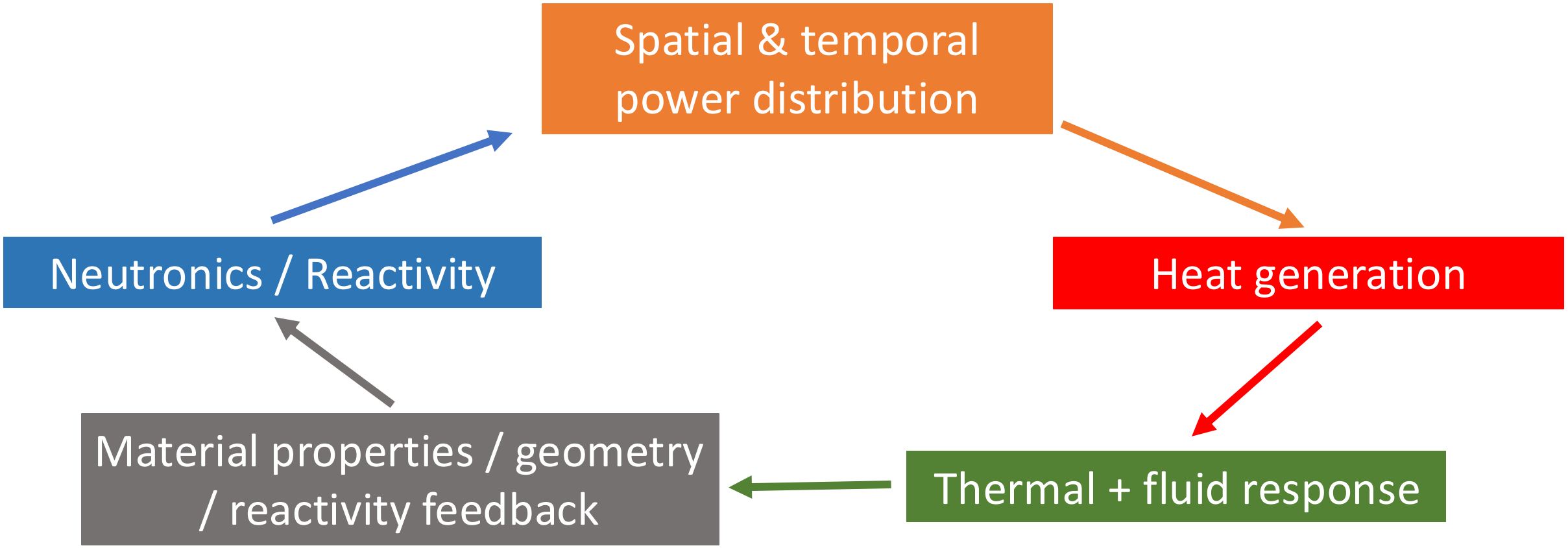
NEP

Nuclear heat → electricity → thrust



Everything starts with nuclear heat

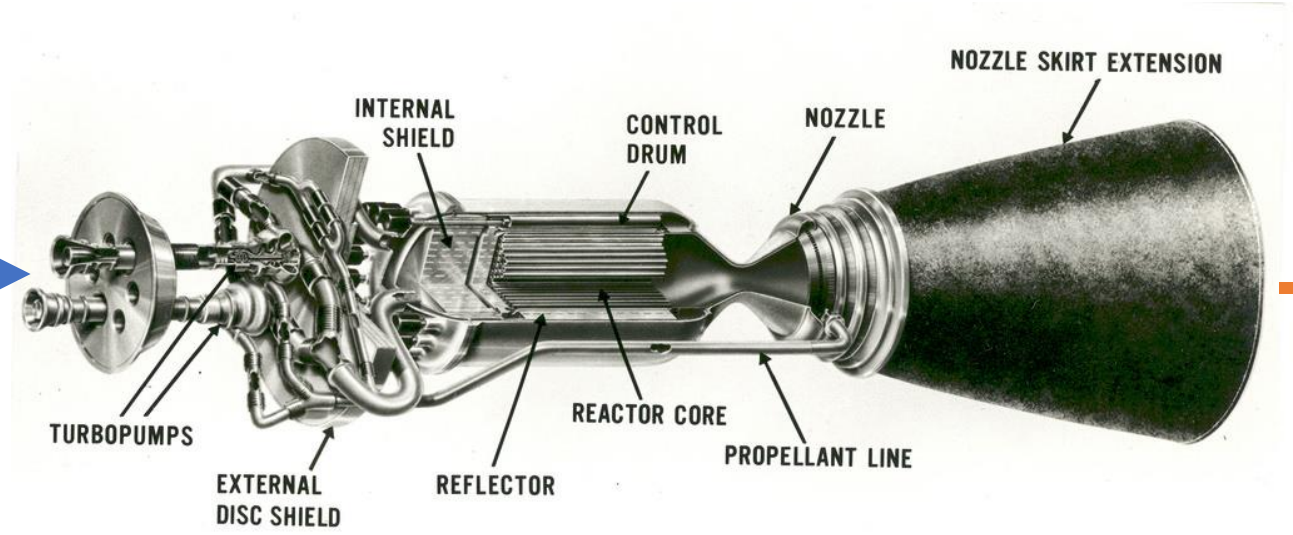
The Common Modeling Problem



A tightly coupled multiphysics system

NTP: The Problem of Extremes

NTP: A Simple Concept with Difficult Physics

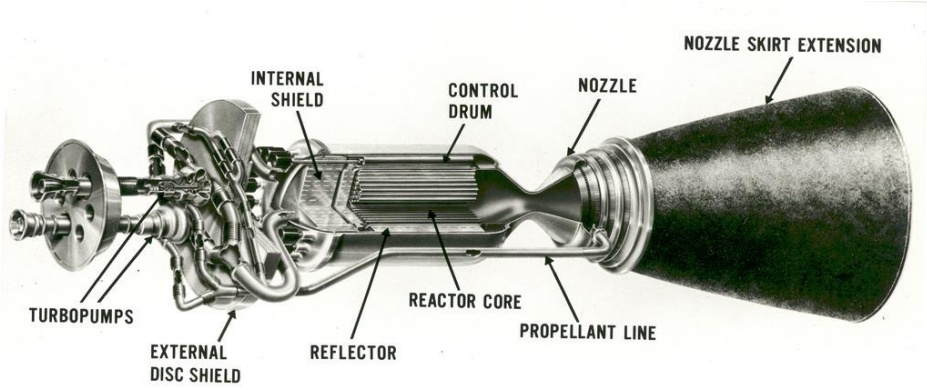
LH_2 In → 

→ Thrust

Nuclear heat + hydrogen flow + extreme temperature + extreme gradients

NTP: The HOT Challenge

Fuel temperature > 2700 K



Hydrogen chemically reactive

> 2700 K

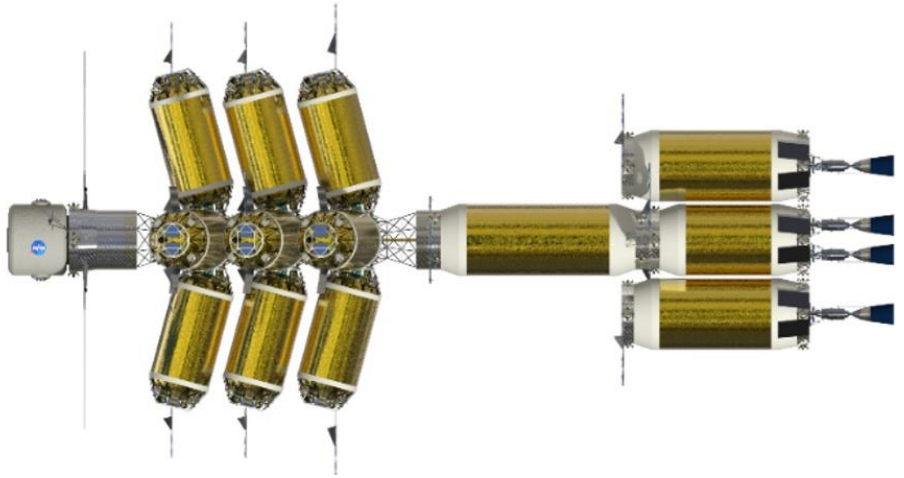
Material / coating limits

Extreme heat transfer

Large temperature gradients

NTP: The COLD Challenge

Possible Multiple Tanks



~20 K

Low Boil-Off Losses

LH_2

>2700 K

Reactor / hydrogen

Potential Multiple Restarts

Thermal Stresses / Shocks

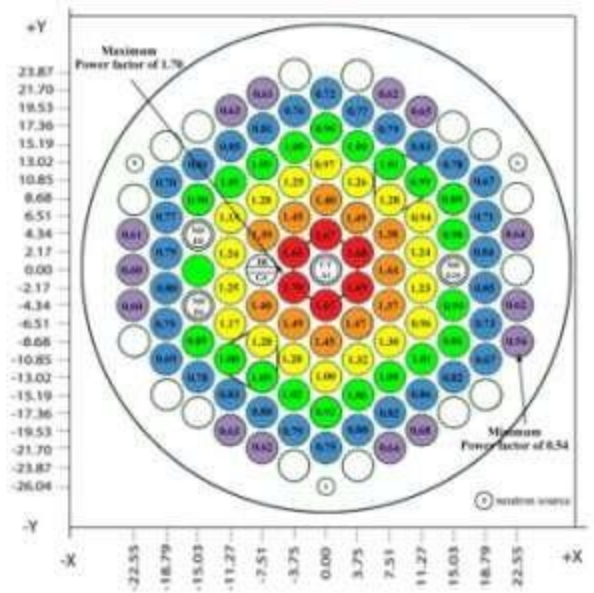


The Reactor Is Not a Uniform Heater

Local power density matters

- Axial power shape
- Radial power shape
- Temperature feedback
- Flow redistribution
- Material-property variation

Radial power factor distribution



From: S Sangkaew, T Angwongtrakool, B Srimok, *J. Phys.: Conf. Ser.*, **860** 012033 (2017).

DOI: 10.1088/1742-6596/860/1/012033

License: CC BY 3.0

NTP: From Neutrons to Thrust

Fuel temperature → Hydrogen heating

Hydrogen heating → Mass flow / pressure

Mass flow / pressure → Nozzle conditions

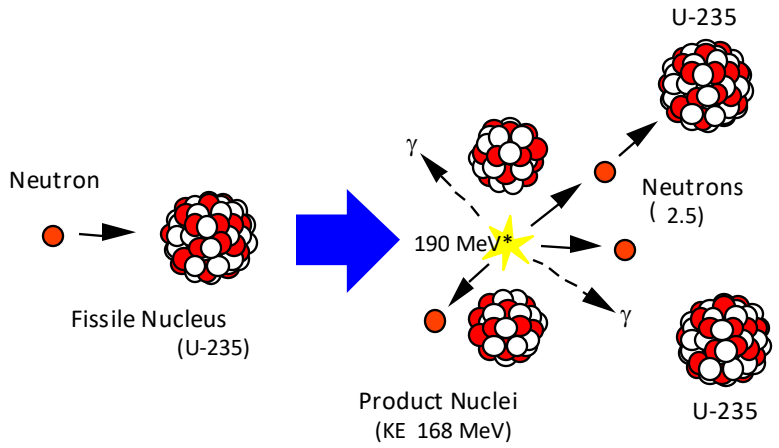
Nozzle conditions → Thrust & I_{sp}

Thrust & I_{sp} - - - Neutron transport

Neutron transport → Fission rate

Fission rate → Power distribution

Power distribution → Fuel temperature



NTP Is a Transient Problem

Startup

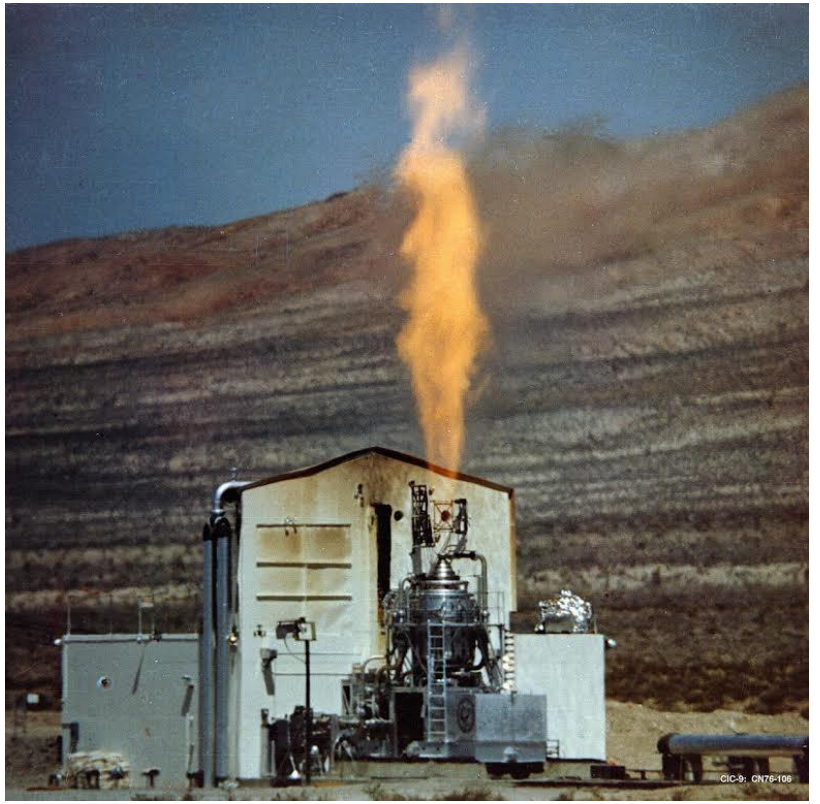
→ Power ramp

→ Thermal response

→ Flow response

→ Steady operation

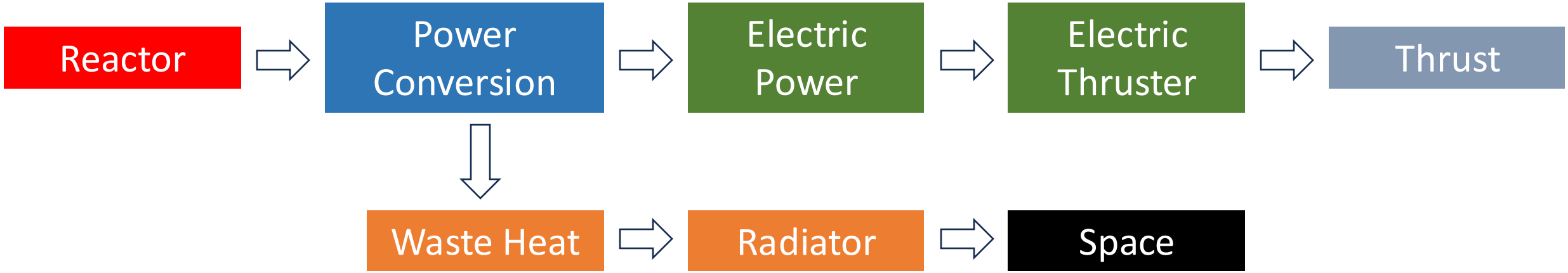
→ Shutdown / Restart



Minutes to Tens of Minutes

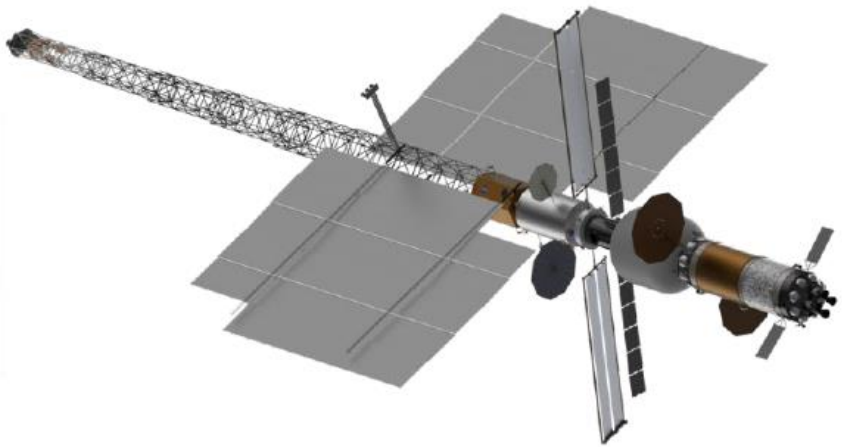
NEP: The Problem of Endurance

NEP: Same Heat. Very Different Problem



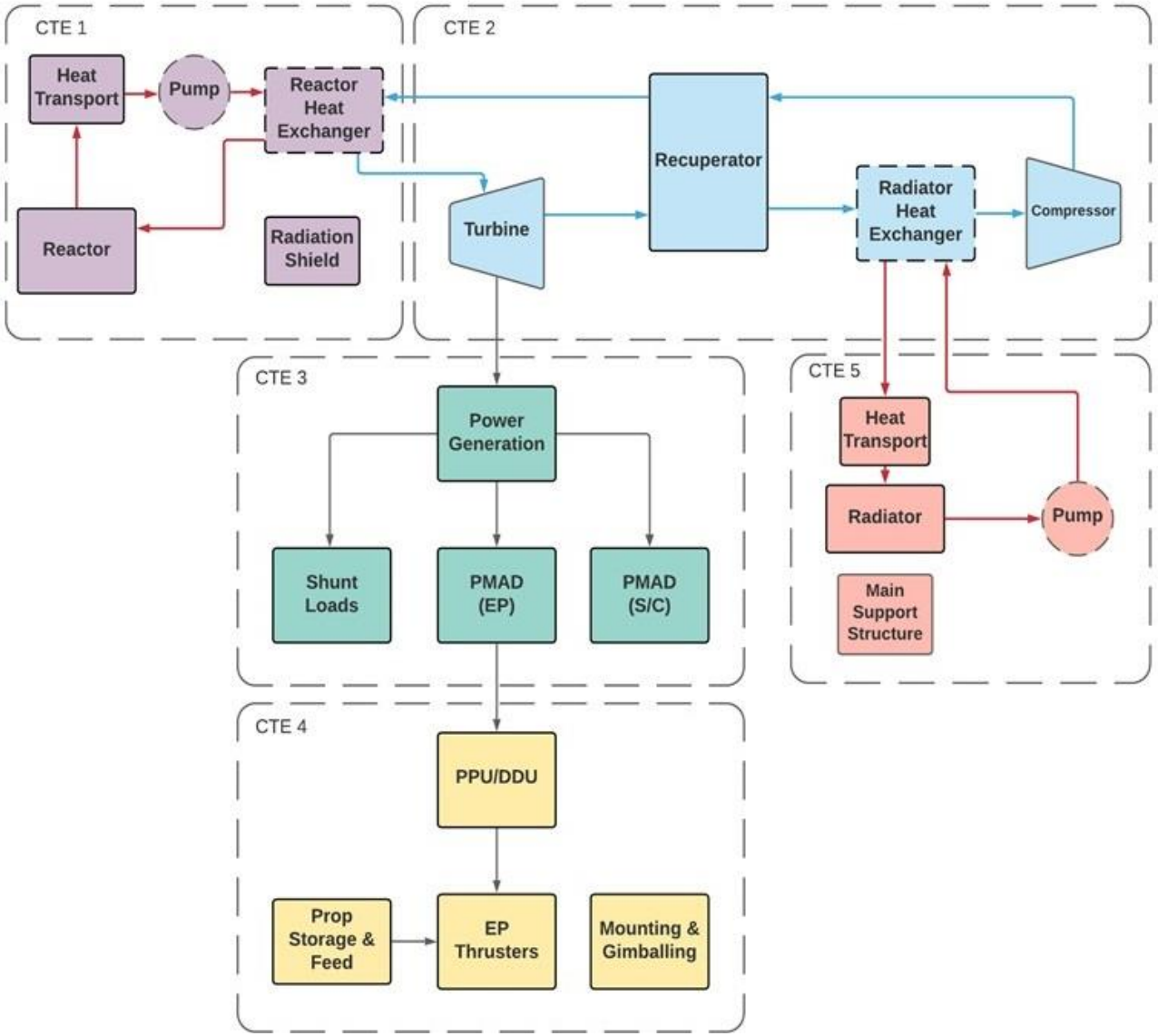
Can we keep doing this for **years**?

NEP: The System Is the Thermal Problem



- Structures
- Avionics
- Payload

Every subsystem produces heat



The Radiator Problem

$$\dot{Q} \propto \varepsilon \sigma A T^4$$

Higher T → smaller A

Lower T → larger A



Project Prometheus Jupiter Icy Moons Orbiter NEP concept vehicle

At high power, radiator mass can dominate the power system

NEP Design is a Vehicle-Level Trade

Reactor temperature

→ Power conversion efficiency

→ Waste heat

→ Radiator temperature

→ Radiator area

→ Radiator mass

→ Vehicle mass

→ Mission performance



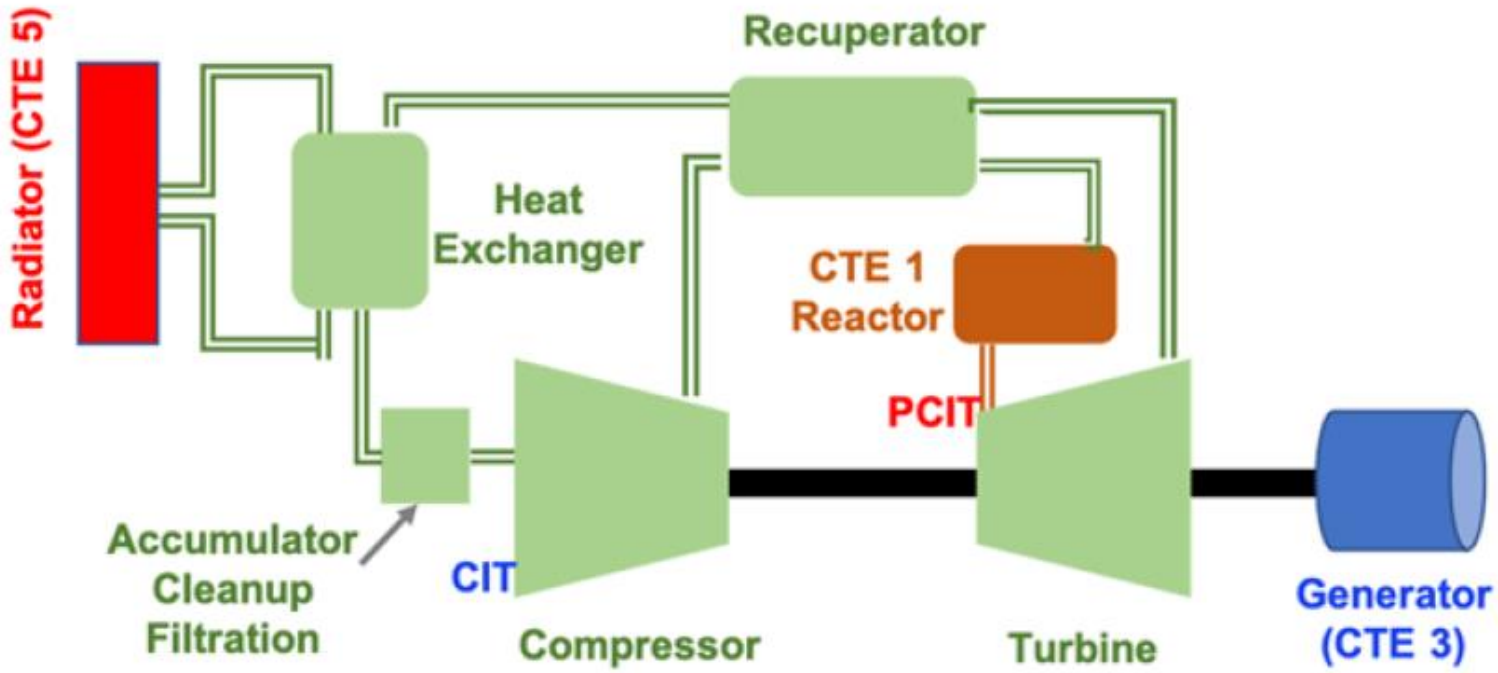
NEP Enceladus Sample Return

Image: GRC Compass – Eric Mindek (artist)

NEP: Power Conversion Is a Thermal-Fluid Problem

Potential Challenges

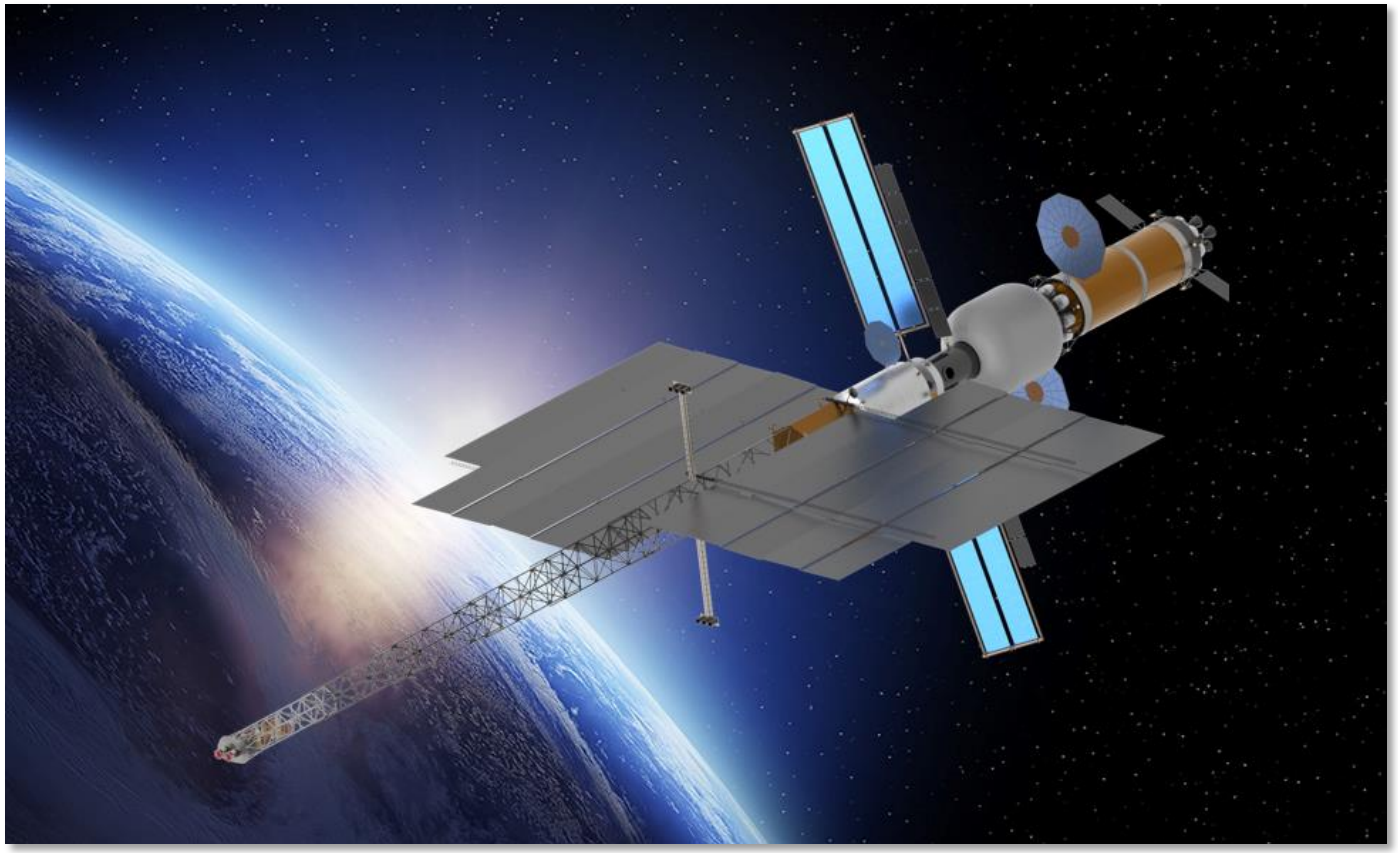
- High temperatures
- High pressures
- Heat exchanger effectiveness
- Turbomachinery
- Creep / material life
- Fluid-property uncertainty
- Long-duration degradation



NEP: The Long-Duration Problem

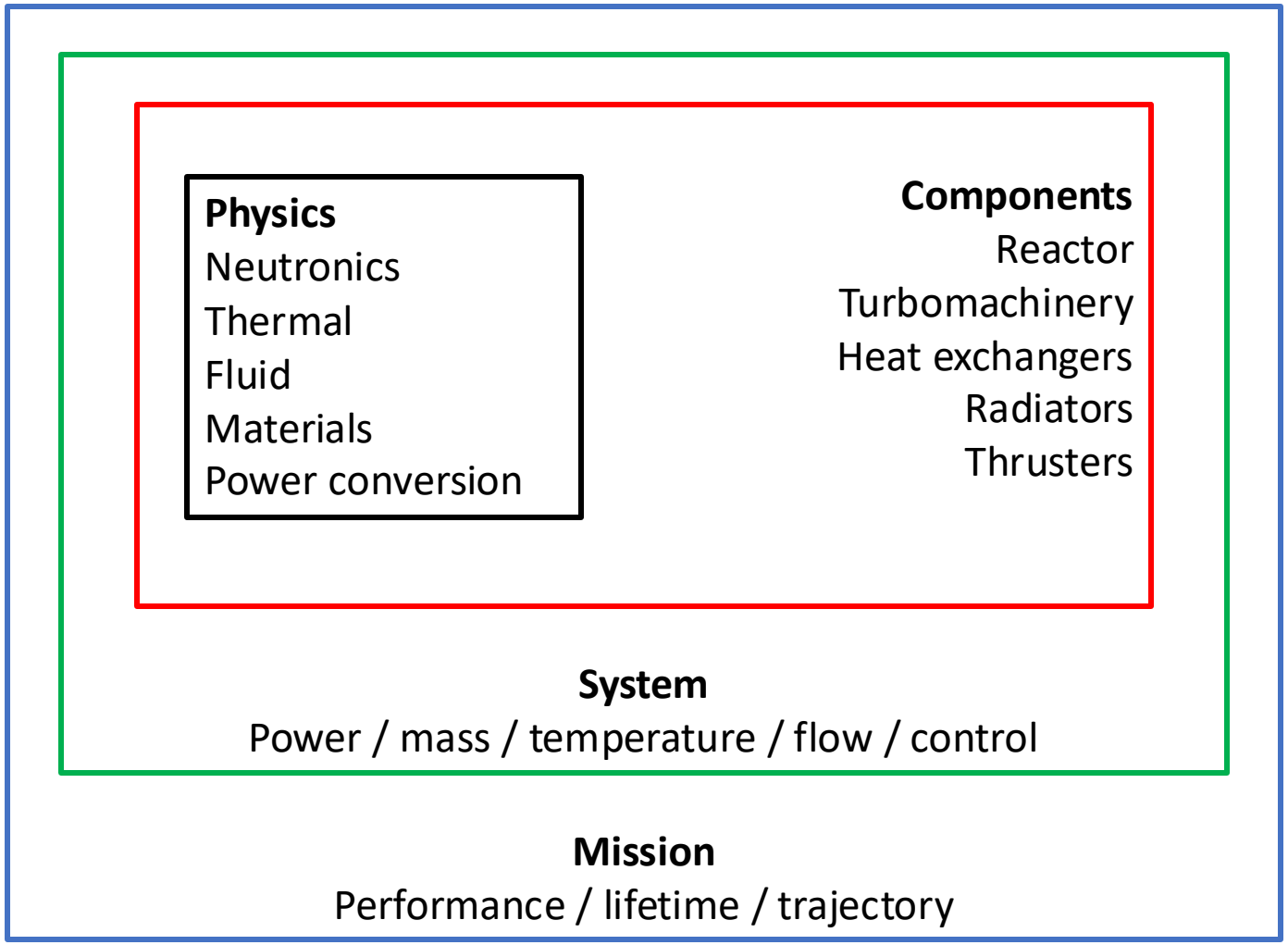
YEARS

- No maintenance
- Radiation exposure
- Material degradation
- Lubrication / bearings
- Turbomachinery life
- Electronics
- Thruster erosion
- Radiator degradation



The Modeling & Simulation Challenge

What Are We Actually Trying to Model?



Fidelity Has a Cost

High-fidelity
- Expensive
- Detailed
- Localized
- difficult to run parametrically

Reduced-order models
- Fast
- system-level
- uncertainty
- assumptions

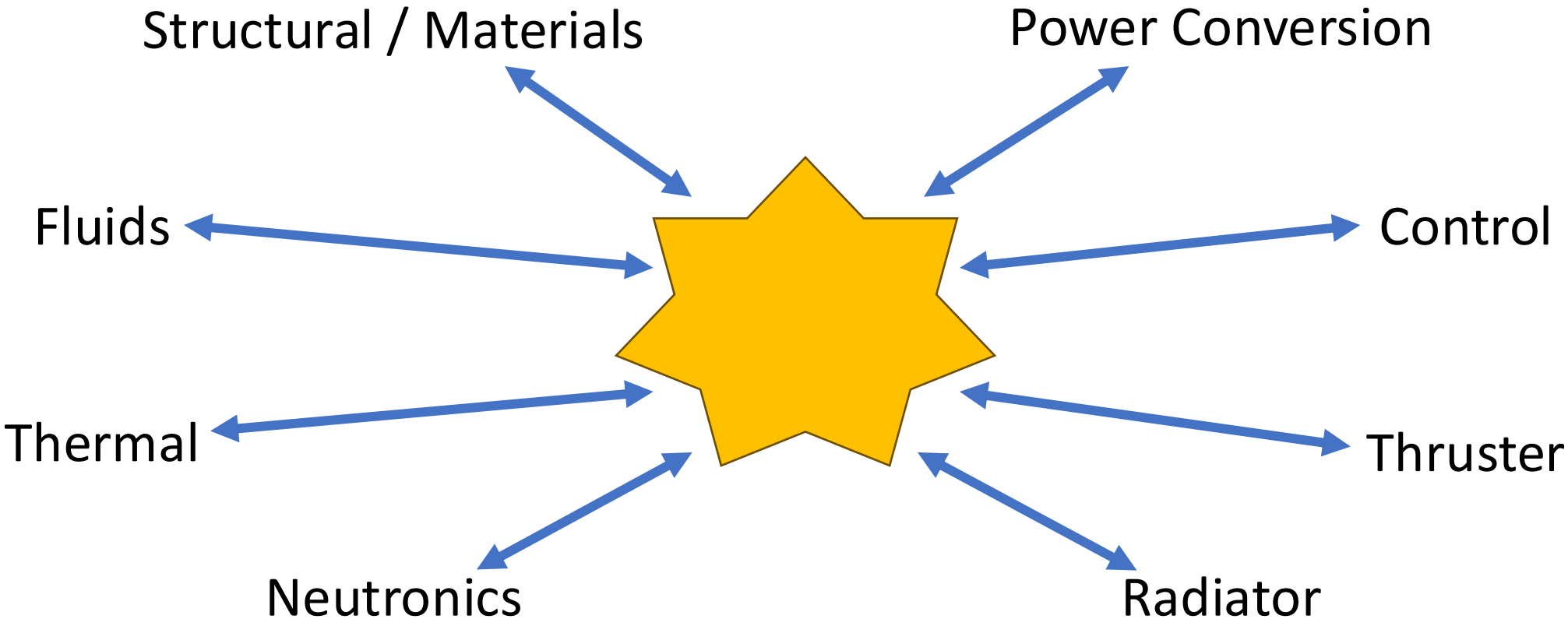
Mission / design models
- very fast
- broad trades
- simplified physics

Examples
- high-fidelity CFD
- thermal network models
- system codes
- reduced-order models
- surrogate models
- lookup tables
- coupled solvers.

The challenge is not choosing the "best" model

It is choosing the right model for the question

The Coupling Problem



What should be tightly coupled?
What can be reduced?
What must be validated independently?

Validation: The Model Is Only as Good as the Evidence

MODEL
What we predict

$$\frac{dn(t)}{dt} = \frac{\rho(t) - \beta}{\Lambda} n(t) + \sum_i \lambda_i C_i$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda} n(t) - \lambda_i C_i(t)$$

$$\rho = \rho_0 + \rho_C(t) + \alpha_T^F T_F + \alpha_T^C T_C$$

$$m_F c_{pF} \frac{dT_F}{dt} = a_F n(t) - h(T_F - T_C)$$

$$m_C c_{pC} \frac{dT_C}{dt} = +h(T_F - T_C) - 2\dot{m}_C c_{pC}(T_C - T_{C,in})$$

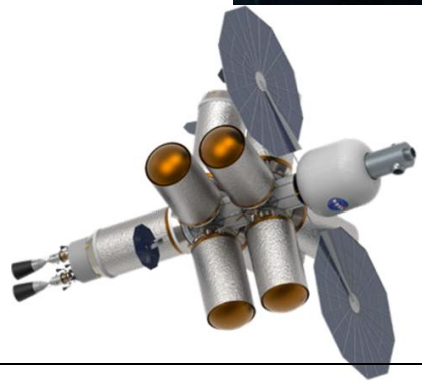
EXPERIMENT
What we measure





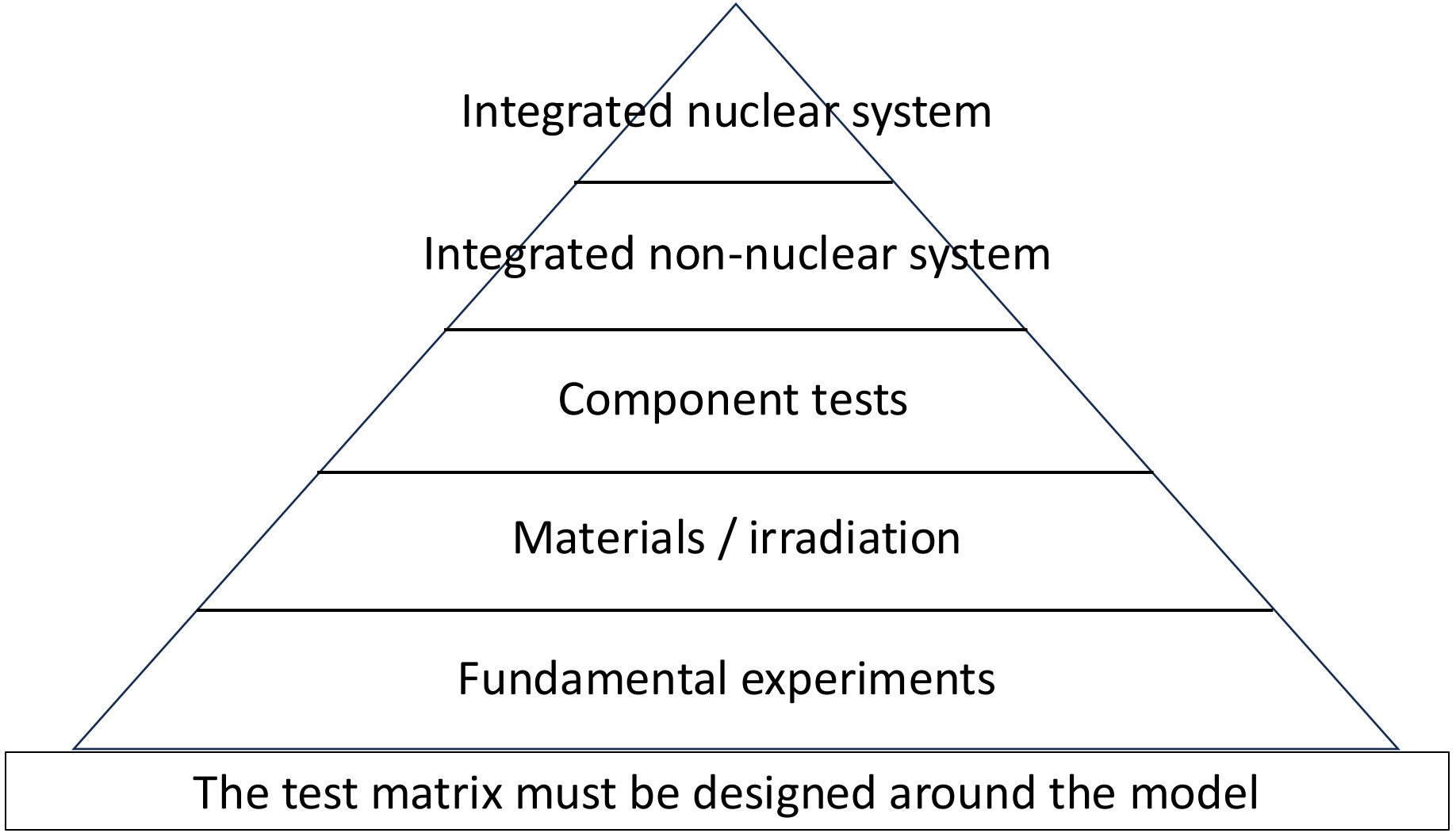
FLIGHT
What we ultimately experience





Validation → calibration → uncertainty → confidence

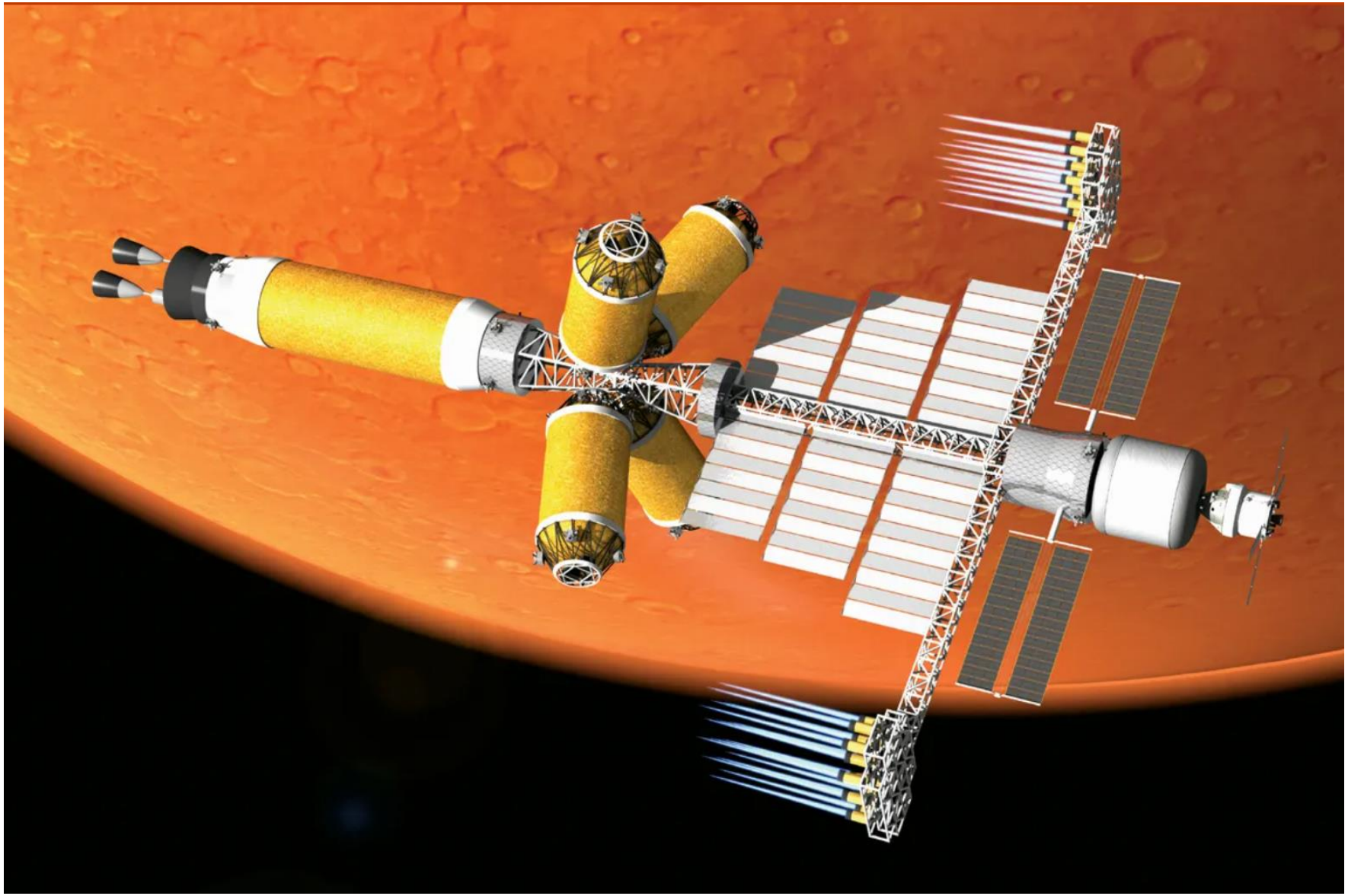
We Cannot Test Everything



What uncertainty in our model is preventing us from making a design decision?

The Bimodal Challenge

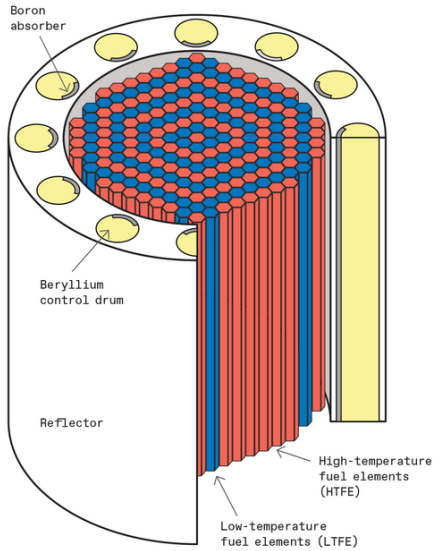
Bimodal: What If One Reactor Could Do Both?

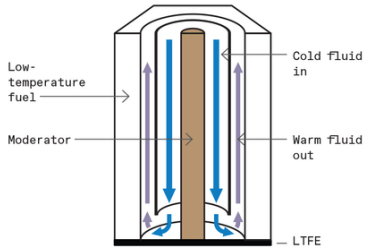


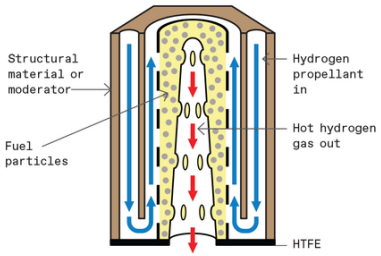
NTP + NEP

- One reactor
- Two propulsion modes
- One integrated thermal system

Bimodal: A New Modeling Challenge







NEP

Low/moderate power

Long duration

NTP

Very high power

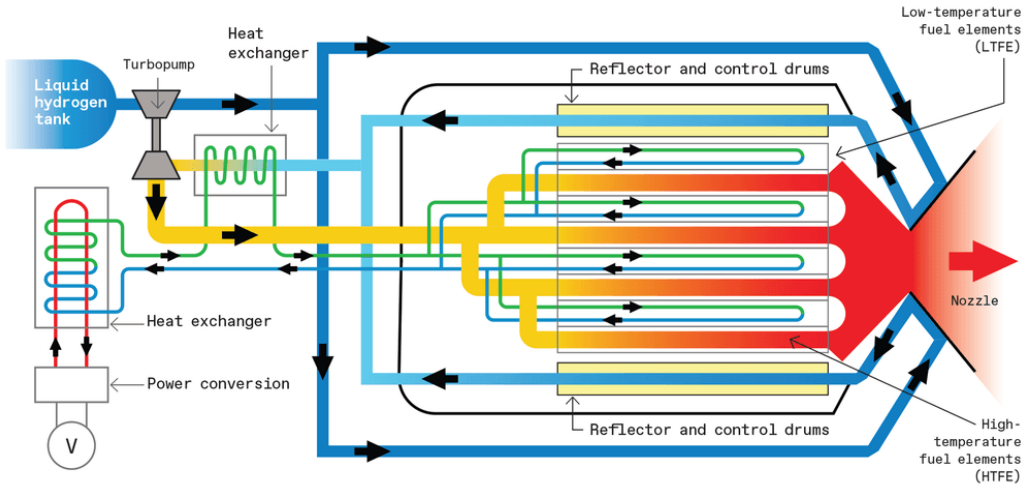
Extreme temperature

Short duration

Bimodal

Simultaneous operation

Multiple power levels



Neutronics

Thermal

Fluids

Power conversion

Control

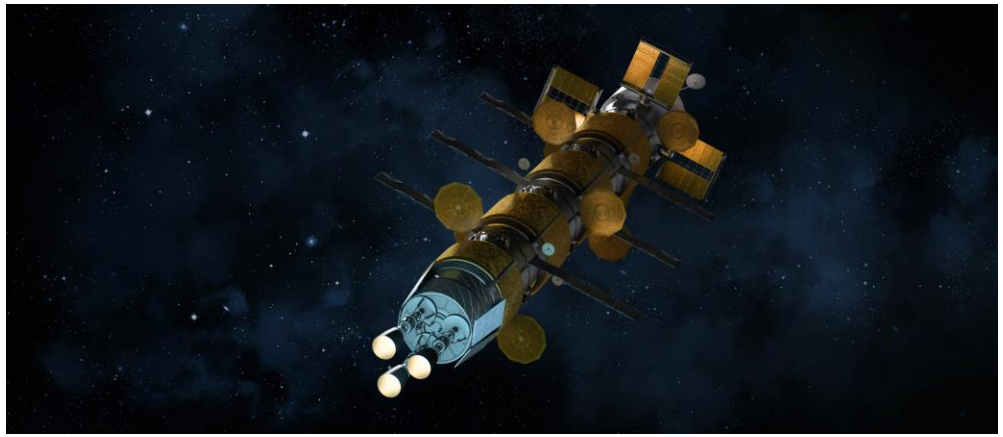
One vehicle - A huge operating envelope

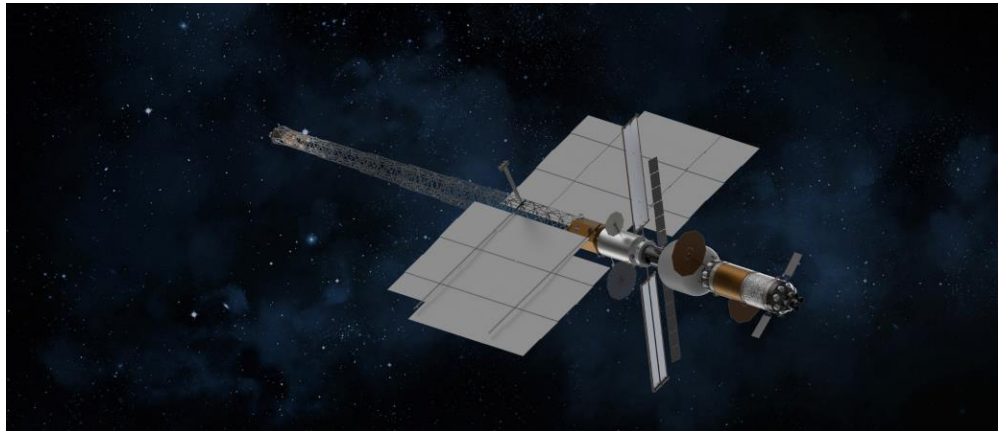
https://spectrum.ieee.org/bimodal-nuclear-spacecraft
also Sept 2026 issue of *IEEE Spectrum*

The Challenge for Thermal Control

Where can thermal & fluids analysis make the biggest difference?

- **Predict**
  - Extreme environments
- **Couple**
  - Physics across disciplines
- **Reduce**
  - Complex models to usable system tools
- **Validate**
  - Predictions against experiments
- **Enable**
  - Integrated nuclear propulsion systems





The future of nuclear propulsion will be built with models—and proven with data



National Aeronautics and Space Administration

NASA

Pushing the Limits: Thermal and Fluids Challenges in Space Nuclear Propulsion

SPACE NUCLEAR PROPULSION

NESC Thermal Control & Protection Webinar

Dr. Kurt Polzin, Chief Engineer, Space Nuclear Propulsion, Marshall Space Flight Center

21 October 2026