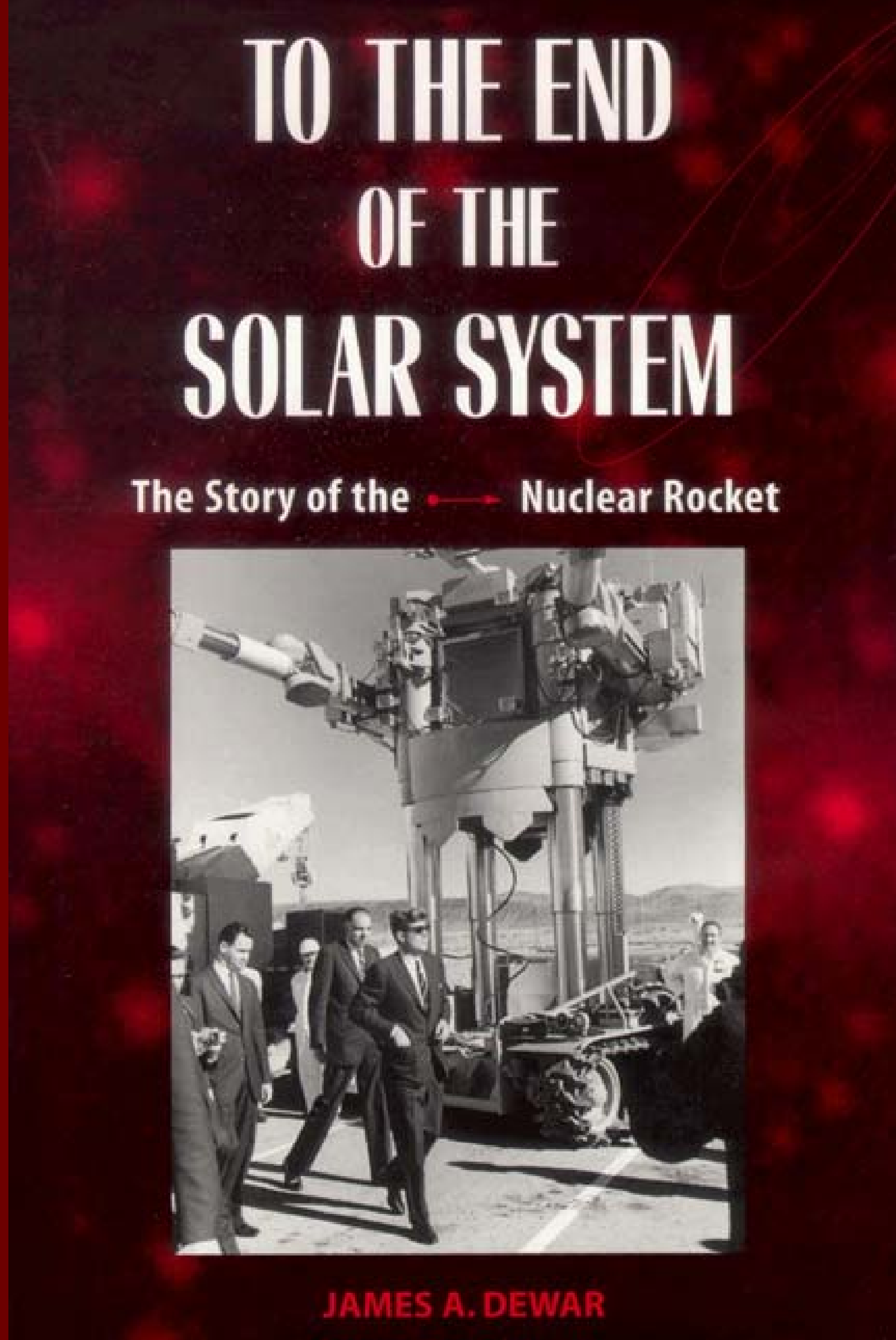
Nuclear Thermal Rockets
Lecture 24
G. L. Kulcinski
March 22, 2004


TO THE END
OF THE
SOLAR SYSTEM
The Story of the Nuclear Rocket
JAMES A. DEWAR

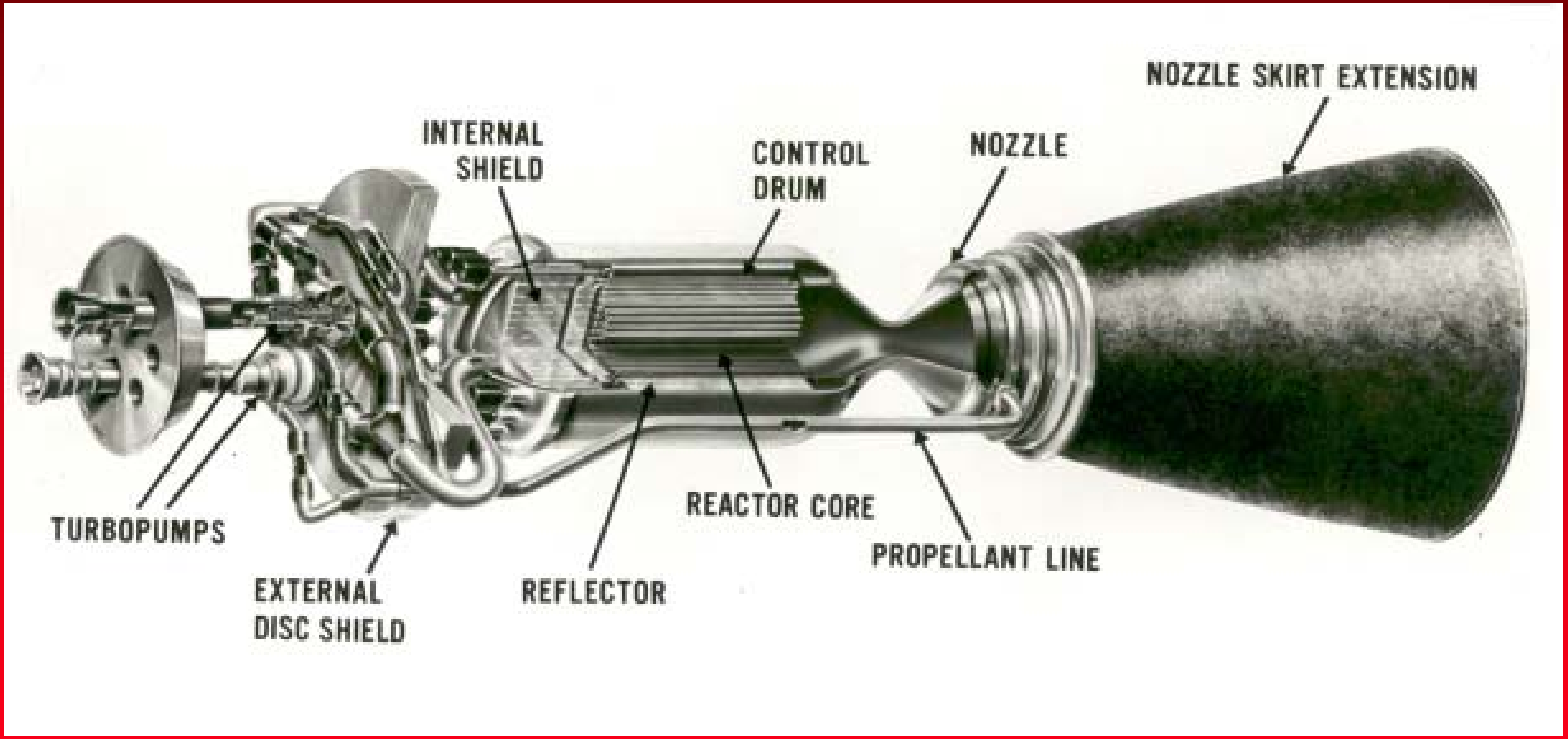
The Basis for Nuclear Thermal Propulsion is the Specific Impulse Equation

$$I_{sp} = \frac{F}{\dot{m}} = AC_f \sqrt{\frac{T_c}{M}}$$

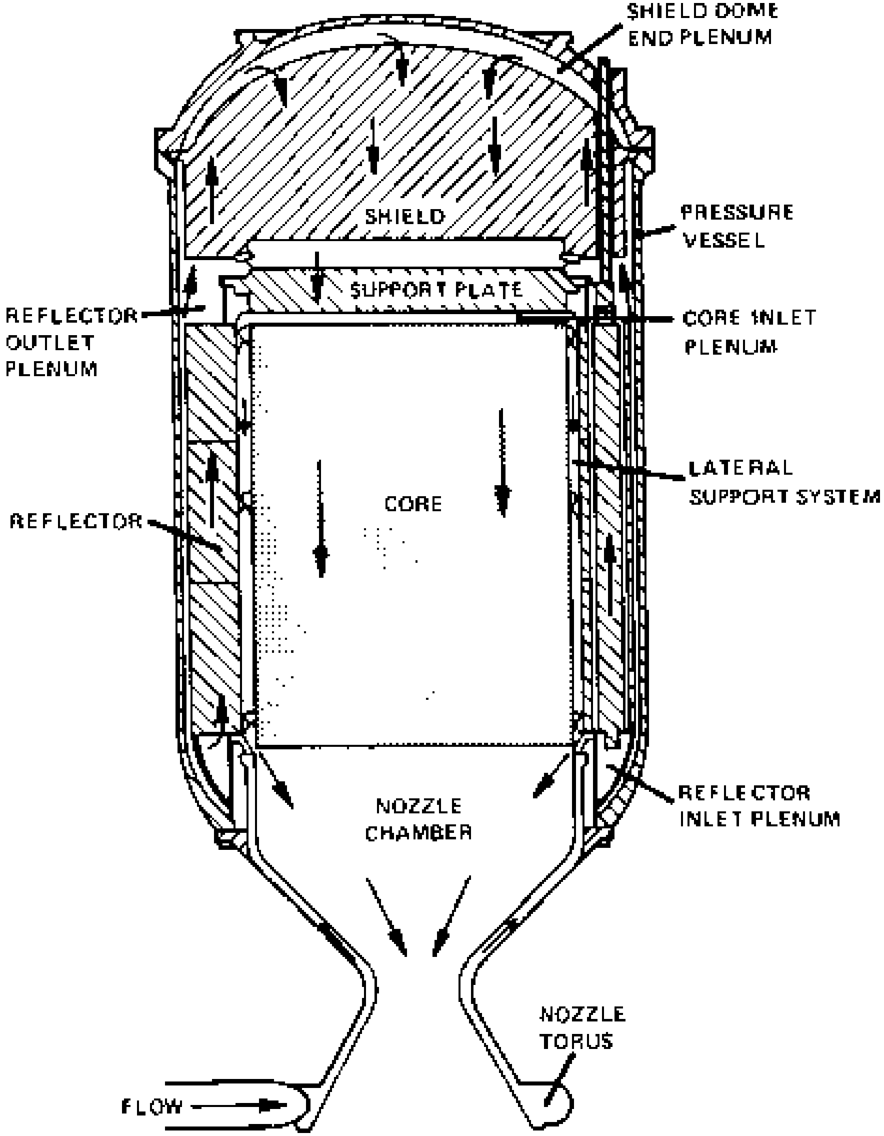
Where:

- I_{sp} = Specific Impulse, sec
- F = Thrust, newtons
- $\dot{m}$ = Propellant mass flow, kg/s
- A = Performance factor (nozzle)
- C_f = Thrust coefficient (nozzle)
- T_c = Chamber temperature
- M = Molecular wt. of exhaust gas

The Operation of a Nuclear Thermal Rocket is Quite Straightforward



Nuclear Rockets Simply Provide a Heat Source to Heat Hydrogen to Very High Temperatures



Source: Westinghouse , (1967) "NRX-A6 Test Predictions", WANL-TME-1613

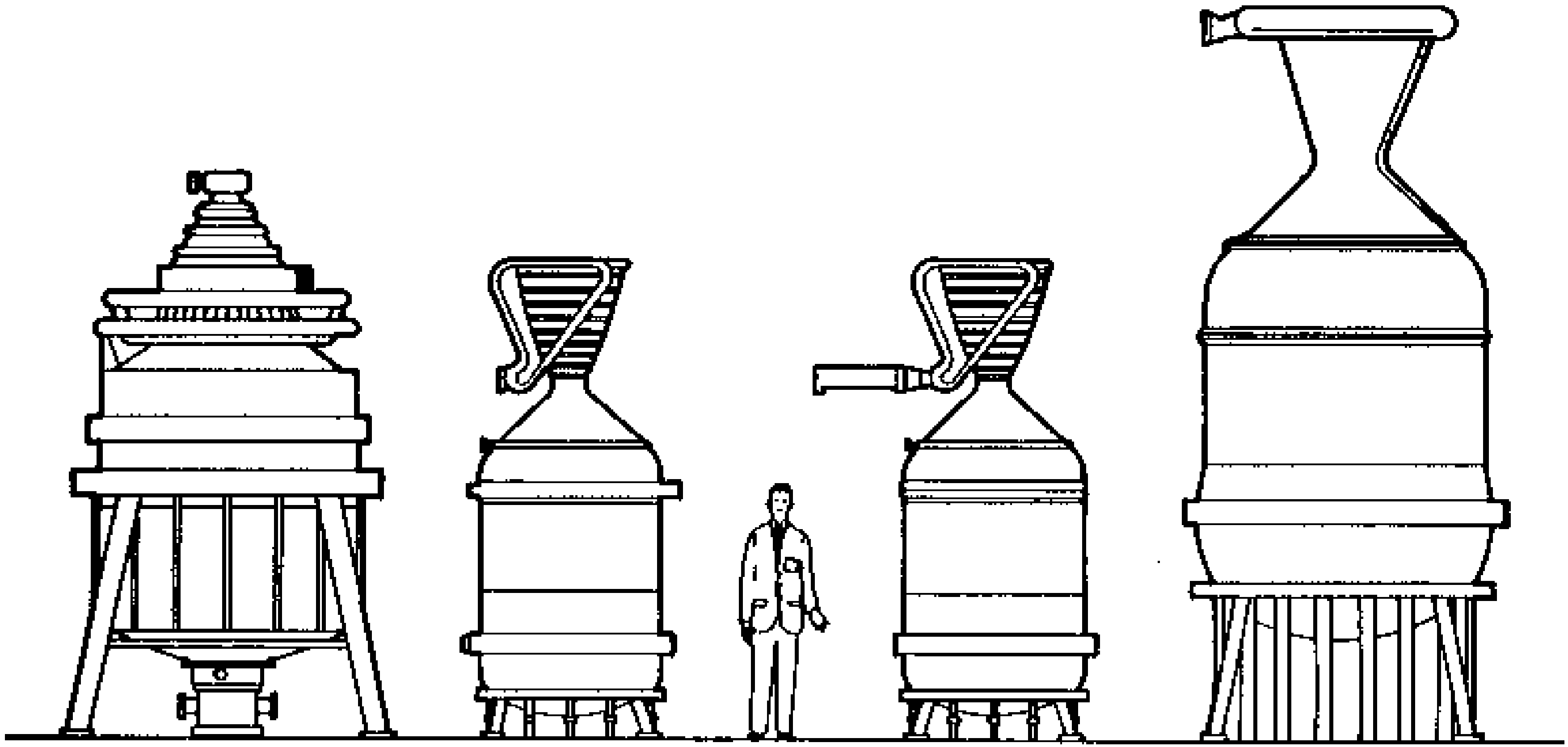
Video by Los Alamos National Laboratory Space, Energy, and Los Alamos National Laboratory

SEI Exhibit (1992 revision)

Nuclear Rocket Operation

Catalog 90-106

Nuclear Rockets Were Developed to a High State of Readiness in the 1960's



KIWI A
1958–60
100 MEGAWATTS
5000 lb THRUST

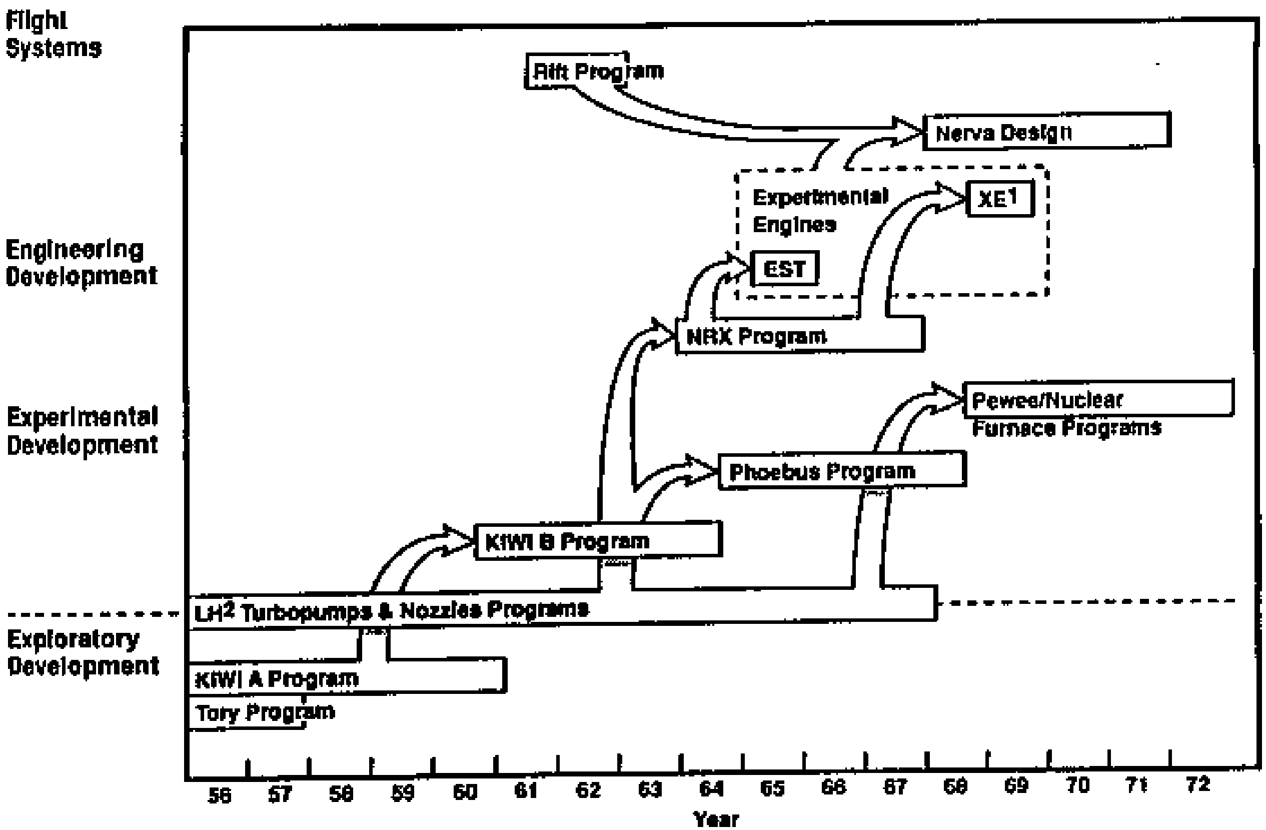
KIWI B
1961–64
1000 MEGAWATTS
50,000 lb THRUST

PHOEBUS 1/NRX
1965–66
1000 and 1500 MEGAWATTS
50,000 lb THRUST

PHOEBUS 2
1967
5000 MEGAWATTS
250,000 lb THRUST

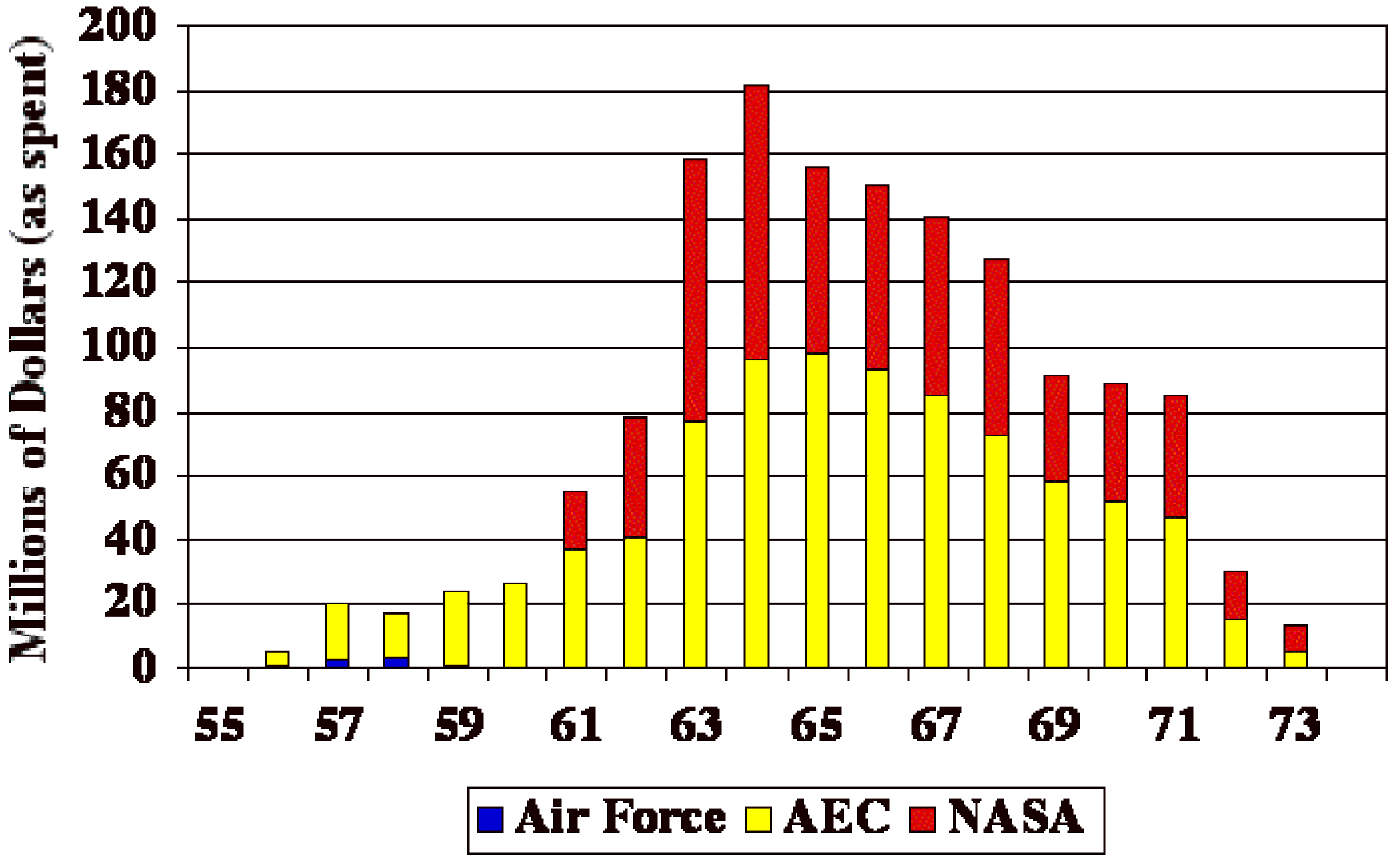
Source: S. V. Gunn, (1989) "Development of Nuclear Rocket Technology", AIAA paper 89-2386

The Nuclear Rocket Program Constructed Over 20 Nuclear Cores in 16 Years



Source: S. V. Gunn, (1989) "Development of Nuclear Rocket Technology", AIAA paper 89-2386

Project Rover/NERVA Was Funded for 18 years, 1956-73



Source:J. A. Dewar, To the End of the Solar System, Univ Press of Kentucky, 2004

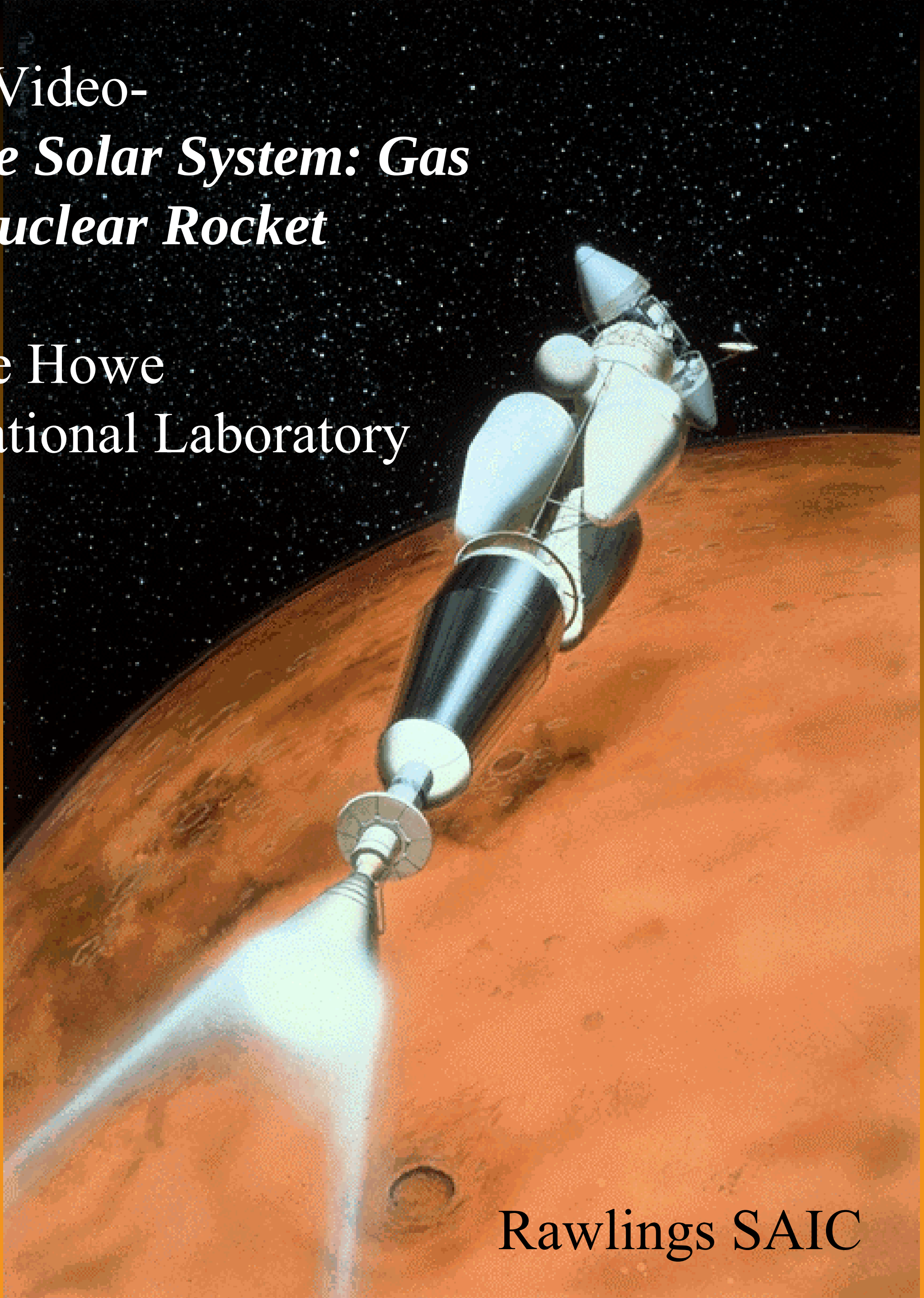
Achievements of the ROVER/NERVA Program

- Biggest-Phoebus 2 (4,100 MW_t)
- Highest Thrust-Phoebus 2A (930 kN)
- Highest H_2 Flow Rate-Phoebus 2A (120 kg/s)
- Highest Specific Impulse-Pewee (838 seconds)
- Minimum Specific Mass-Phoebus 2A (2.3 kg/MW)
- Smallest-Nuclear Furnace (44 MW)
- Hottest-Pewee (2,550 °K exit gas, 2,750 °K fuel)
- Longest Run-Nuclear Furnace (109 minutes)
- Highest Power Density-Pewee (5,200 MW/m^3 fuel)
- Greatest Number of Restarts-XE (28)

Video-

Gateway to the Solar System: Gas Core Nuclear Rocket

Producer: Steve Howe
Los Alamos National Laboratory



Rawlings SAIC


Video
Bimodal Nuclear Thermal Rocket Propulsion:
Artificial Gravity Mars Mission
Glenn Research Center
Stan Borowski
Len Dudzinski
Rawlings-SAIC

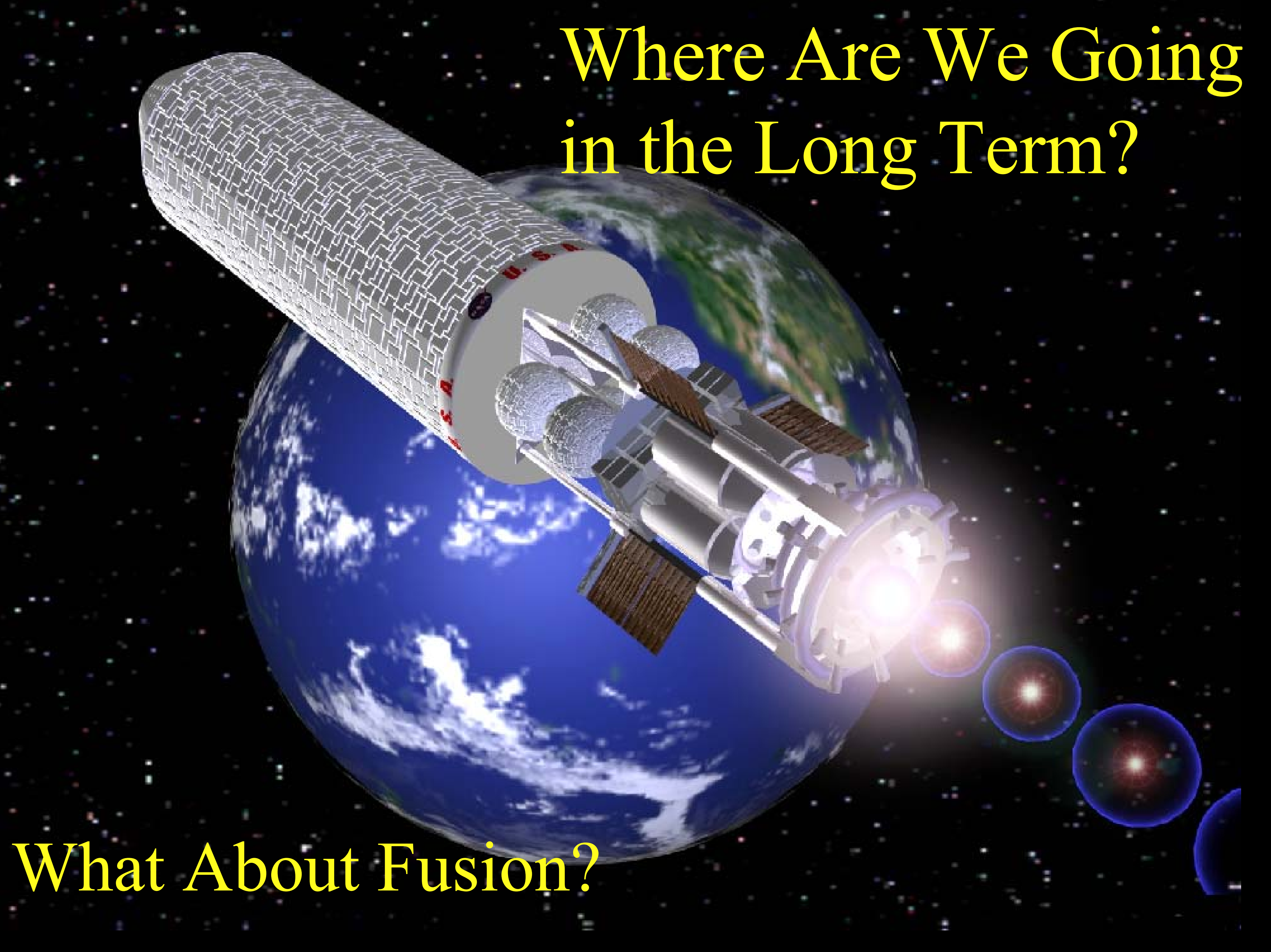
Video

Rockets into Space-
Splitting the Atom in Space

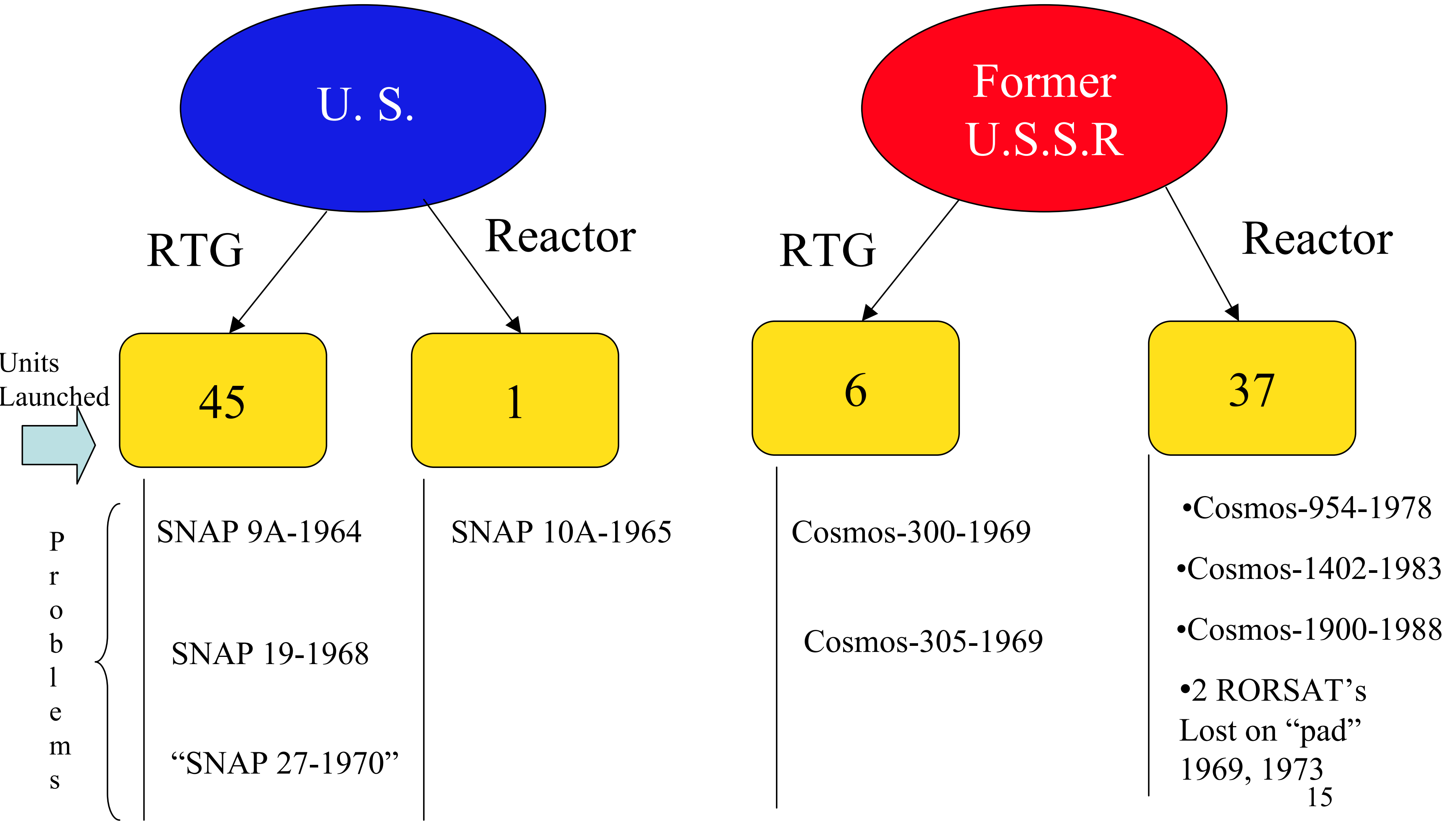
Wingspan Network

Produced by Lianishan Films, L.I.C.

1997


Where Are We Going
in the Long Term?
What About Fusion?
U.S.A.

Space Nuclear Power Satellite Malfunctions



There Have Been 11 Known Cases Where Satellites Carrying Nuclear Power Systems Have Malfunctioned

- Former Soviet Union
  - Cosmos-300 (1969)
  - Cosmos-305 (1969)
  - Two RORSAT's on the "Pad" (1969, 73)
  - Cosmos-954 (1978)
  - Cosmos-1402 (1983)
  - Cosmos-1900 (1988)
- United States
  - TRANSIT 5BN-3 (SNAP-9A) (1964)
  - SNAP-10A (1965)
  - NIMBUS B-1 (SNAP-19) (1968)
  - Apollo-13 (SNAP-27) (1970)

Cosmos-300, 305, Soviet RTG's

- Cosmos-300 launched Sept. 23, 1969 and reentered Sept. 27, 1969.
- Cosmos-305 launched Oct. 22, 1969 and reentered Oct. 24, 1969.
- One or both of these payloads may have been a Lunokhod and carrying a ^{210}Po heat source.
- Upper stage malfunction prevented payloads from leaving Earth orbit.

Possible Launch Failure of Soviet RORSAT's

- Unnamed system launched Jan. 25, 1969 and failed on "Pad".
- Unnamed system launched April 25, 1973 and failed on "Pad".

Cosmos-954 Nuclear Reactor

- Launched 9/18/77
- RORSAT-marine radar
- 100 kW thermal power
- ≈ <5 kWe
- Reactor designed to separate from satellite, boost core into higher orbit
- Re-entered over Pacific 1/24/78
- Glowing object detected by telescope over Hawaii
- After 12 min. & 5500 km impacted over Canada
- USSR said it was designed to burn up, but several glowing objects observed over Canada
- "Operation Morning" Light conducted in -40°C
- Radioactivity spread over 600 km path, 124,000 km^2
- >50 objects recovered (steel plates, Be, fuel, etc.) --65 kg.
- Radiation levels 0.6 to 200 Rad/hr
- Some enriched ^{235}U detected in the atmosphere

Cosmos-1402 Nuclear Reactor

- Launched 8/30/82
- In Dec-82, malfunction caused satellite to intentionally split into 3 parts, A, B, C
- Part B (probably radar antenna) entered atmosphere on Dec. 30, 1982
- Part A fell into Indian Ocean, Jan. 23, 1983
- Part C (probably the reactor) entered Feb. 7, 1983, fell into the ocean 1,600 km east of Brazil
- If part C had entered 20 minutes earlier, it would have impacted over central Europe

Cosmos-1900, Nuclear Reactor

- USSR reported on May 13, 1988 that it had lost contact with Cosmos-1900 in April
- They could not send the reactor into a higher orbit
- Probably the same system as Cosmos-954
- 37 cyl. fuel rods with some Be rods, plus 6 Be cylinders (3.6 kg ea)
- On Sept. 30, 1988 they did get the Nuclear Power Unit separated and sent it into a 720 km orbit
- Rest came in over the Indian ocean

TRANSIT 5BN-3, SNAP-9A RTG

- Launched April 21, 1964 and failed to reach orbit
- Contained 17,000 Ci of ^{238}Pu.
- Reentered at 120 km altitude and burned up (as designed) over West Indian ocean.
- Aug-64, ^{238}Pu detected in stratosphere (32 km) in southern hemisphere.
- May-65, radioactive dust detected at aircraft levels. Four times more ^{238}Pu in So. Hemisphere compared to N. Hemisphere.
- By Nov-70, only 5% of original Pu left in atmosphere; detected on all continents and at all latitudes. Removal half-life ≈ 14 months.
- Amount ^{239}Pu from nuclear atmospheric tests is 180,000 Ci.
- Amount of 238Pu from atm. Tests is 8,000 Ci(≈ half that of SNAP-9A)

SNAP-10A, U. S. Nuclear Reactor

- Launched April 3, 1965
- Reactor started after satellite reached designed orbit
- Reactor operated for 43 days.
- A voltage regulator failed on the satellite and ground operator sent the wrong signal to the reactor
- Core was inadvertently ejected into higher orbit

NIMBUS B-1, SNAP-19 RTG

- Launched May 21, 1968 from Vandenberg, CA
- Contained 34,000 Ci of ^{238}Pu in form of oxide
- Destroyed by Range Safety Officer at altitude of 30 km
- Fell into Santa Barbara Channel off the coast of CA
- Recovered from 100 m depth, no leakage, reused the fuel.

Apollo-13, SNAP-27 RTG

- Launched April 11, 1970 to the Moon
- Contained 44,500 Ci of ^{238}Pu in form of oxide
- Oxygen tank explosion, had to come back to Earth
- Purposely jettisoned the RTG over the South pacific ocean.
- No radioactivity ever detected
- Now resides in > 6,000 m of water, TONGA trench.

Conclusions

- Of the 51 RTG's and 38 nuclear reactors launched on rockets, there have been 11 malfunctions of the satellites.
- All of the malfunctions were due to a problem with the vehicle or human error on the ground.
- In 8 of the cases, all or parts of the nuclear system reentered the Earth's atmosphere.
- There have been no known health effects due to any accidents with nuclear reactors in space.