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Title: Fabrication of Radioisotope Heat Sources at Los Alamos

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Fabrication of Radioisotope Heat Sources at Los Alamos

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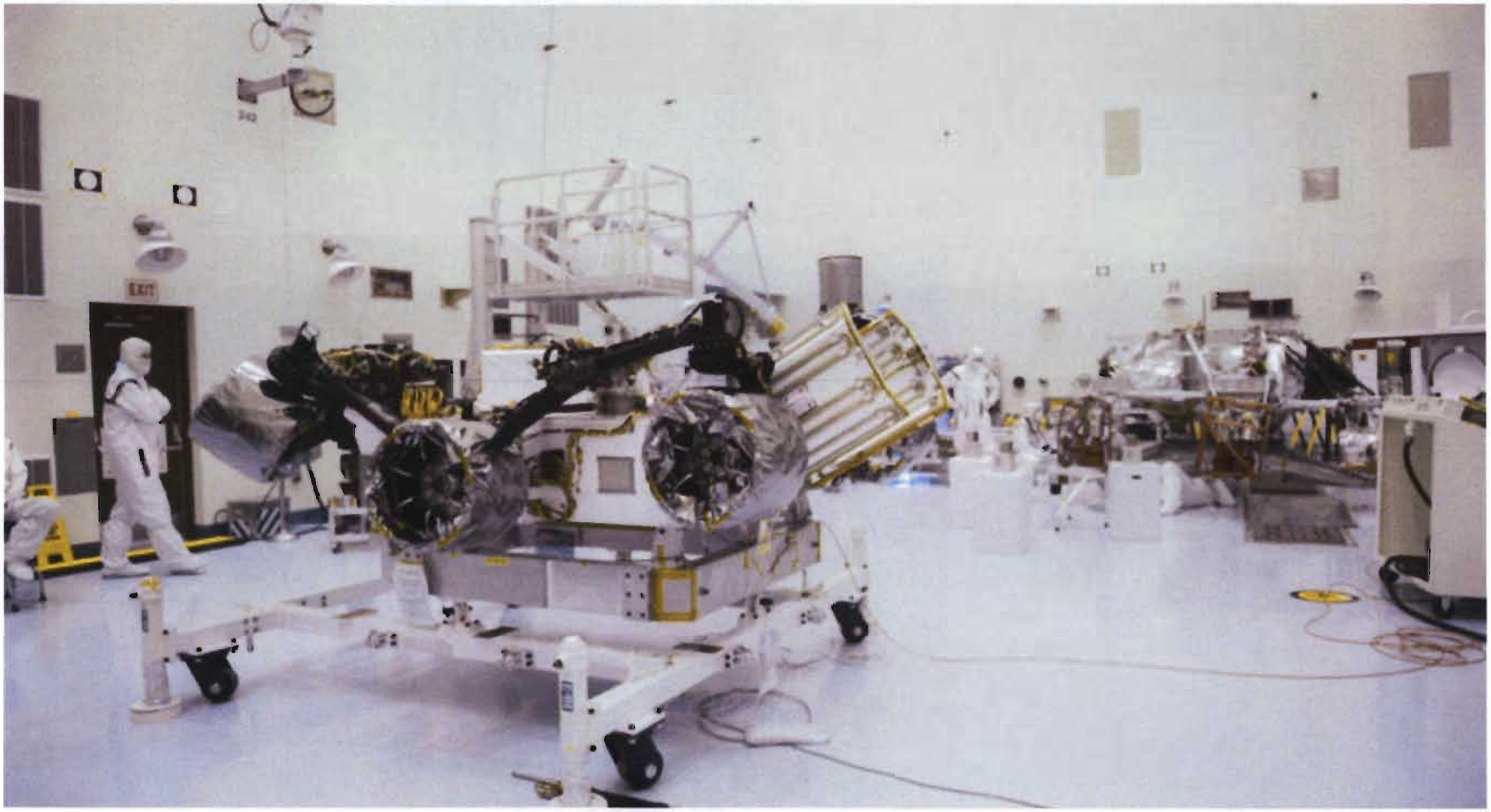
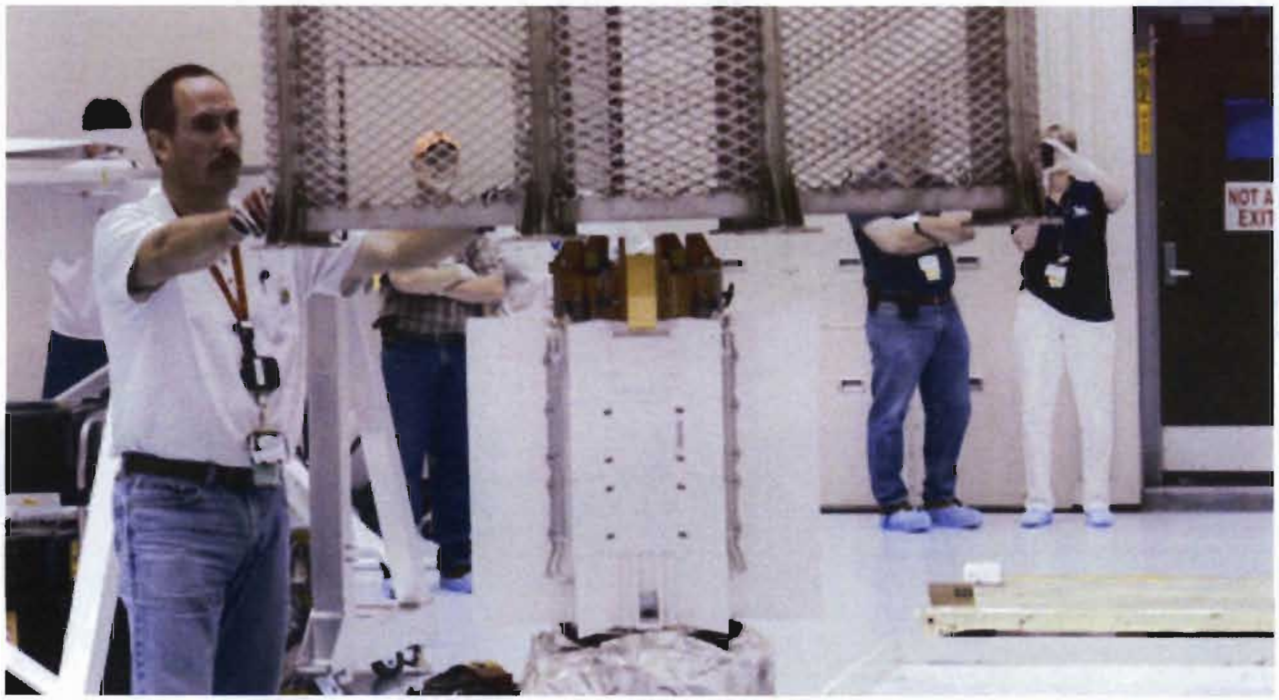
Curiosity Assembled in the PHSF



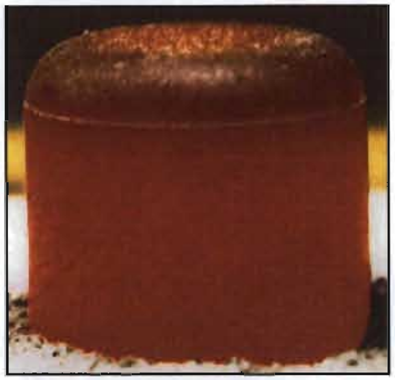
Curiosity's MMRTG

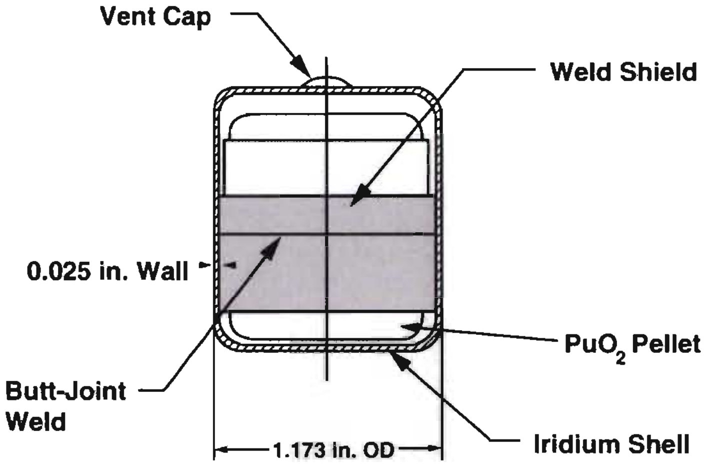


MMRTG attached to Curiosity

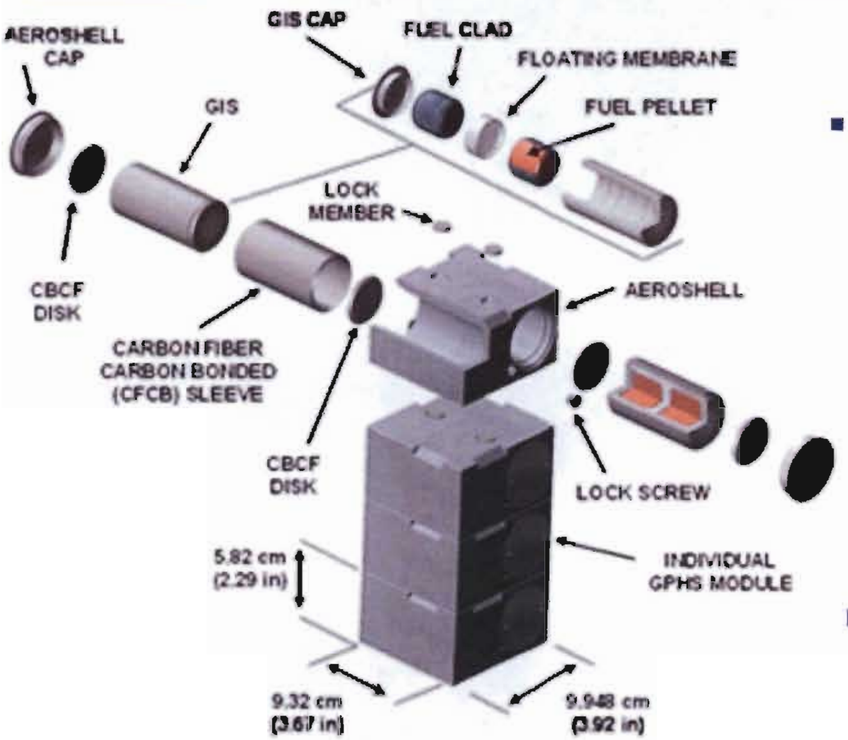
Los Alamos Heat Sources

- **General Purpose Heat Source (GPHS)**
  - ~150 g pellet of PuO_2 hot pressed into a right cylinder
    - Produces ~62 watts thermal power
  - Encapsulated in an iridium alloy (iridium – 0.3% tungsten)
  - Clad contains a sintered Ir frit to allow He release
  - Ir is compatible with PuO_2 at temperatures >1773 K
    - Ir melts at 2698 K

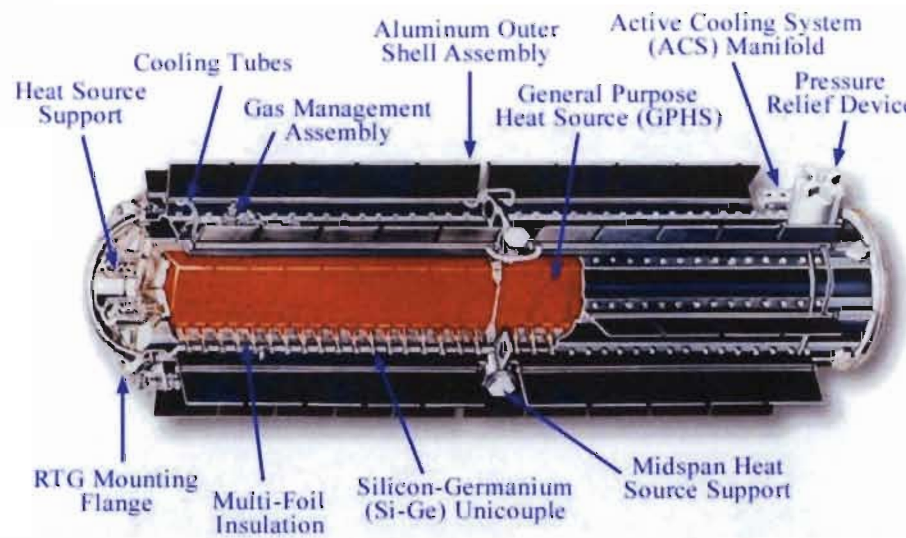




Radioisotope Thermoelectric Generator (RTG)



- **General Purpose Heat Source RTG (GPHS)**
  - Mass of ~54 kg
  - Contains 72 Fueled Clads
  - Silicon/germanium thermoelectric couples
  - Designed to provide 285 watts of electrical power at BOM



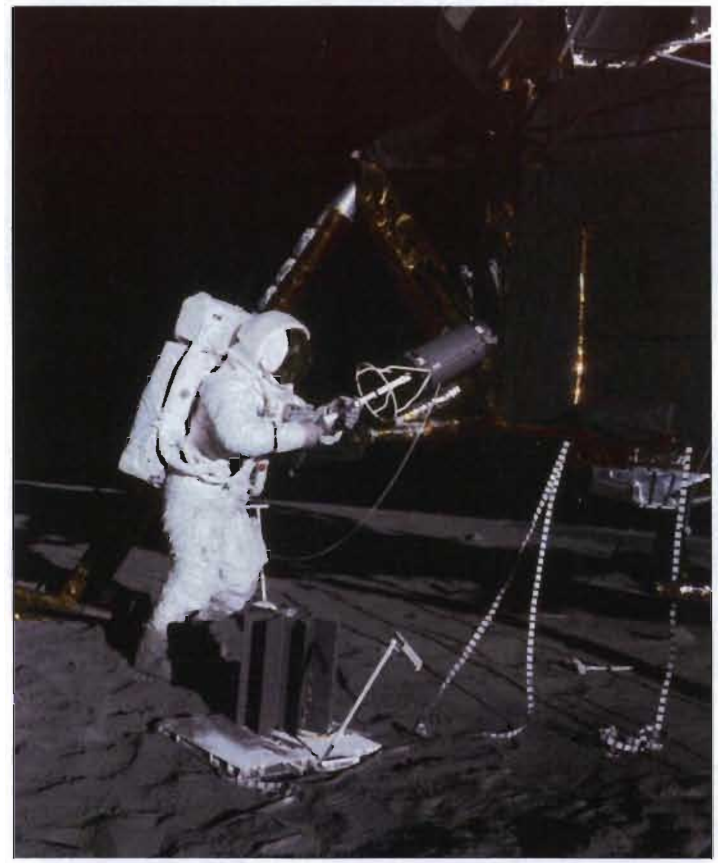
- **Multi-Mission RTG (MMRTG)**
  - Mass of ~45 kg
  - Contains 32 Fueled Clads
  - Pb Te / TAGS thermoelectric couples
  - Modular design to provide 120 watts electrical BOM

Additional Los Alamos Heat Sources

- **Light Weight Radioisotope Heating Unit (LWRHU)**
  - ~2.7 g pellet of PuO_2 hot pressed into a right cylinder
    - Produces ~1 watt thermal power
  - Encapsulated in an platinum alloy (platinum – 30% rhodium)
  - Clad contains a sintered Pt frit to allow He release
  - Areoshell is Fine Weave Pierced Fabric (FWPF) and serves as primary heat shield and impact shell
    - Pyrolytic graphite sleeve serve as a thermal shield to keep the clad from melting upon accidental reentry

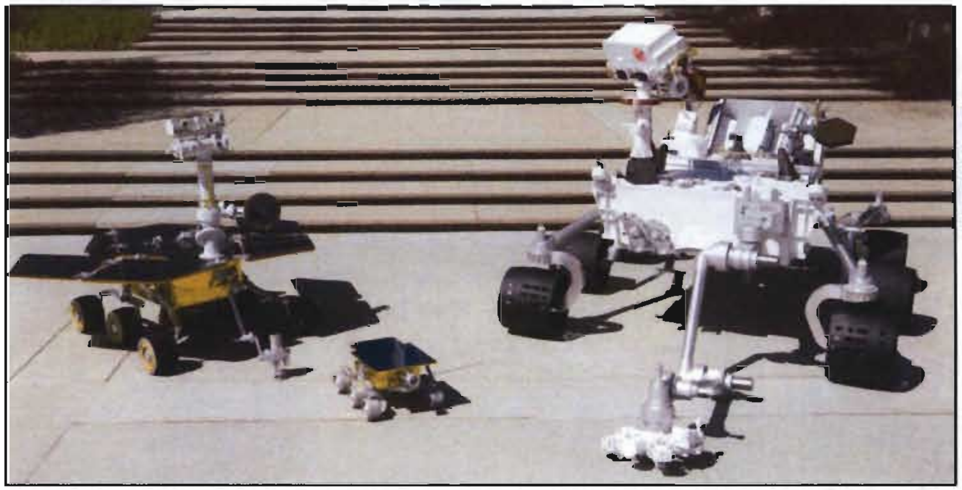
RTG Heat Source Manufacturing History at LANL

- **RTGs are used in a variety of remote and harsh environments to provide electrical power**
  - Enabling component is the radioactive fuel material
    - Commonly used isotopes include Am-241, Cm-244, Po-210, Pu-238, and Sr-90
      - Am-241; $t_{1/2}$ 432 years; 3 Ci/g; α decay to Np-237
      - Cm-244; $t_{1/2}$ 18 years; 82 Ci/g; α decay to Pu-240
      - Po-210; $t_{1/2}$ ~140 days; 4500 Ci/g; α decay to Pb-206
      - Pu-238; $t_{1/2}$ 87.7 years; 17 Ci/g; α decay to U-234
      - Sr-90; $t_{1/2}$ 29 years; 150 Ci/g; β^- decay to Y-90
    - Pu-238 has a long half life and minimal shielding requirements
  - The United States have used RTGs to provide electrical power to spacecraft since 1961
    - All RTGs that have been launched by the U.S. have used Pu-238
  - Los Alamos began fabricating heat sources in the late 1970s
    - Previous processing was completed at Mound



RTG Heat Source Manufacturing History at LANL, *(con't)*

- **NASA Missions**
  - LANL-manufactured heat sources have flown on numerous spacecraft, including:
    - Historical missions:
      - Galileo – 2 GPHS modules
        - ~22 kg PuO_2
    - Current missions:
      - Cassini – 3 GPHS modules
        - ~33 kg PuO_2
      - Pluto / New Horizons – 1 GPHS module
        - ~11 kg PuO_2
      - Mars Exploration Rovers – 8 LWRHUs
        - ~10g PuO_2 per rover
      - Mars Science Lab – 1 MMRTG module
        - ~5 kg PuO_2



Brief Introduction to ^{238}Pu

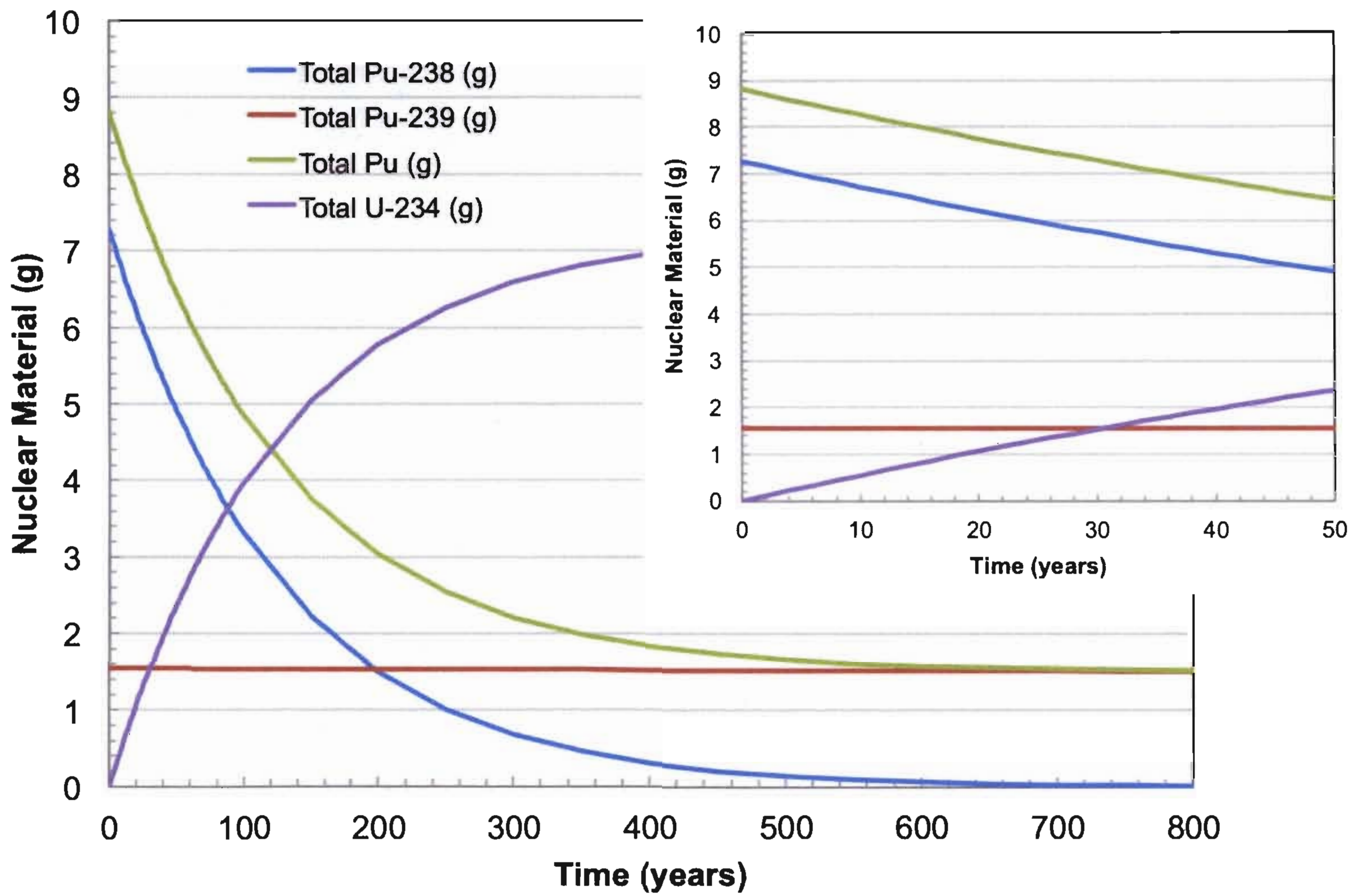
- ^{238}Pu **decays predominately (>99.9%) via α-decay**

$$^{238}_{94}Pu \longrightarrow ^{234}_{92}U + ^{4}_{2}He$$

- **1g ^{238}Pu produces 6.335 x 10^{11} α/sec**
- **1g ^{238}Pu generates 0.74 cm^3 (STP) of helium per year**
- **1g ^{238}Pu produces ~2000 neutrons/sec from spontaneous fission**
- **Typical Pu-238 enrichment of heat source fuel is 80 – 85%**
  - 10g fuel nominally enriched at 82.5% contains (at t = 0):
    - 8.8g Total Plutonium
      - 7.3g Pu-238
      - 1.5g Pu-239
      - 0g U-234

	^{238}Pu	^{239}Pu	^{234}U
$t_{1/2}$	87.74 yrs	24,119 yrs	245,500 yrs
Specific Activity	17.12 Ci/g	0.057 Ci/g	0.006 Ci/g
Specific Power	0.568 W/g	0.00193 W/g	-

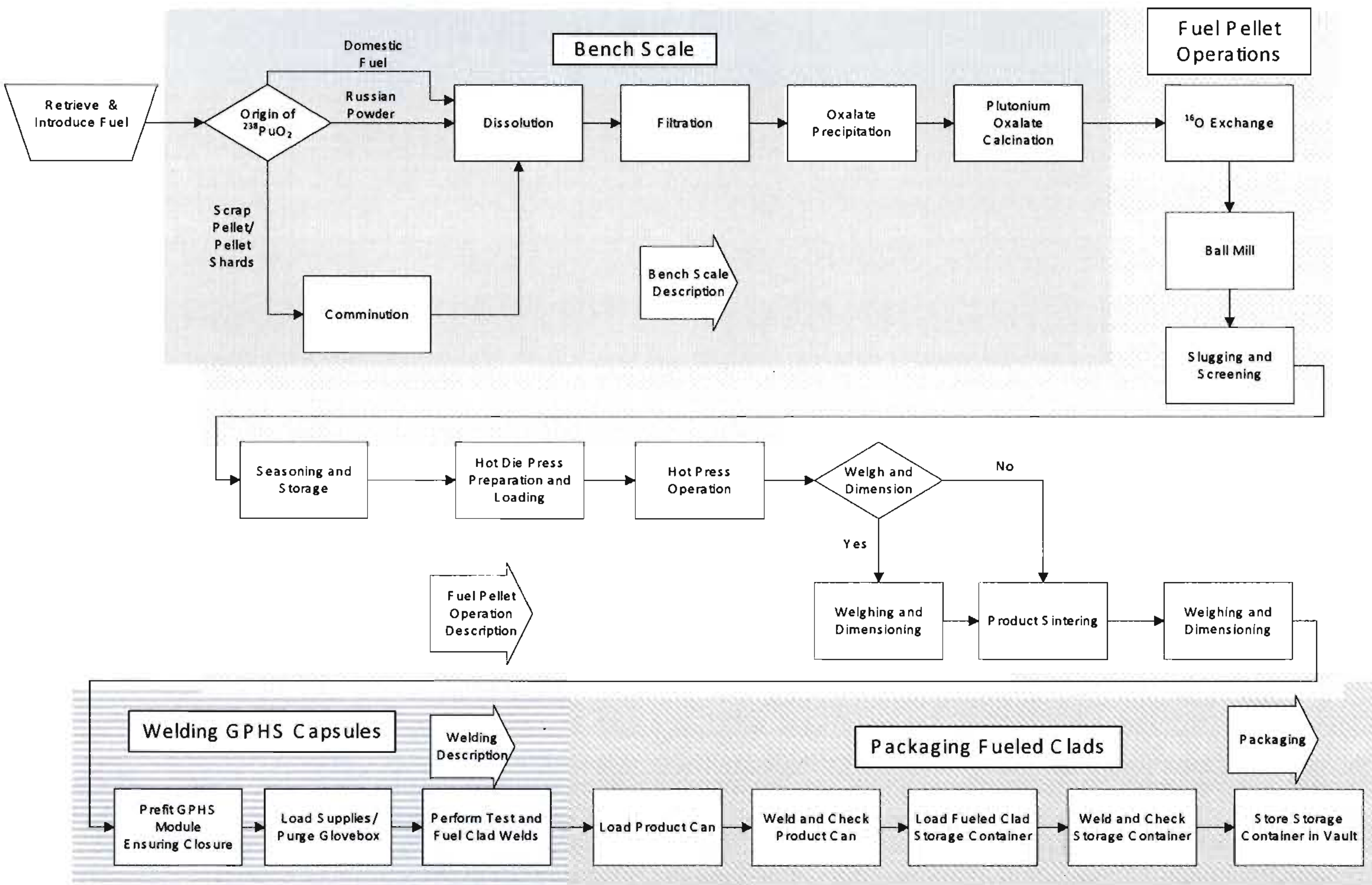
Brief Introduction to ^{238}Pu, *(con't)*



Radiation Characteristics of ^{238}Pu

- **1g ^{238}Pu produces ~2000 neutrons/sec from spontaneous fission**
  - Atoms of low atomic number (^{17}O, ^{18}O, F, Be, etc.) produce neutrons when bombarded by α-particles
    - ~20,000 neutrons/sec are produced from the (α,n) interaction with naturally occurring abundance oxygen
  - Atmospheric O_2 isotopic composition is:
    - ~99.8% ^{16}O, 3.8×10^{-4} % ^{17}O, 2.1×10^{-3} % ^{18}O
    - Fuel processing exchange ^{17}O and ^{18}O with ^{16}O during granule seasoning
      - Dry argon is flowed through $H_2{}^{16}O$ which passes over the PuO_2
      - The ^{16}O exchange occurs at temperatures >500°C
      - This operation accounts for the major reduction in neutron emission rates
  - The (α,n) reaction is the major source of neutron dose and worker exposure

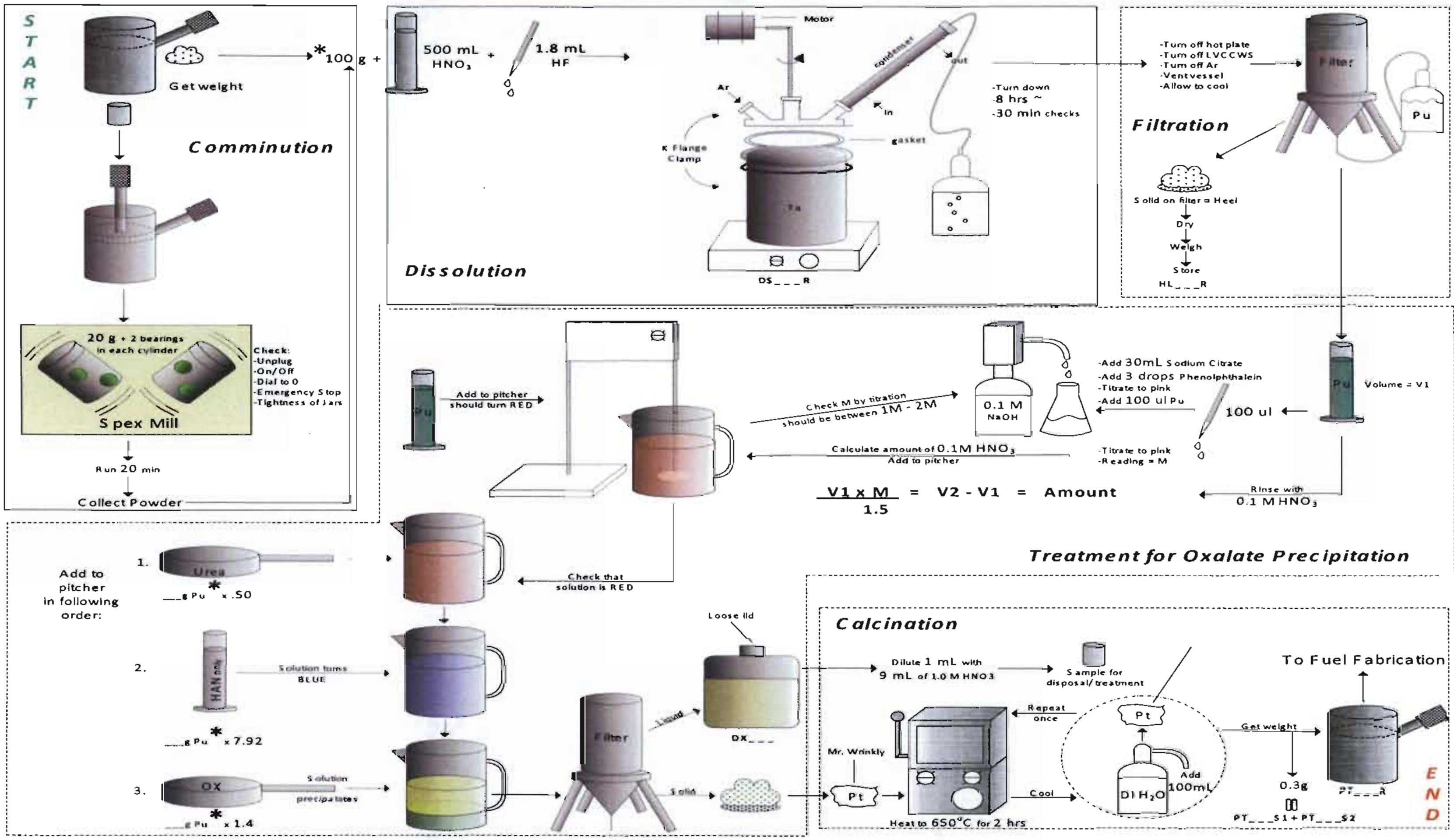
Pu-238 Processing Activities



PuO_2 Aqueous Processing (1 of 2)

- **Purpose**
  - To remove impurities and "standardize" the material for subsequent processing
    - Major impurity is U-234
    - Russian fuel is processed with a Pu(IV) intermediate while domestic production uses a Pu(III) intermediate
- **Major Steps**
  - Dissolution
    - Concentrated HNO_3 with HF added to catalyze dissolution
  - Oxidation state adjustment
    - Hydroxlyamine nitrate (HAN) reduces Pu(IV) to Pu(III)
  - Precipitation
    - Addition of oxalic acid selectively precipitates $Pu_2(C_2O_4)_3$ (s)
  - Filtration
  - Calcination
    - Heat $Pu_2(C_2O_4)_3$ at 650°C for two hours to form PuO_2

PuO_2 Aqueous Recovery (2 of 2)

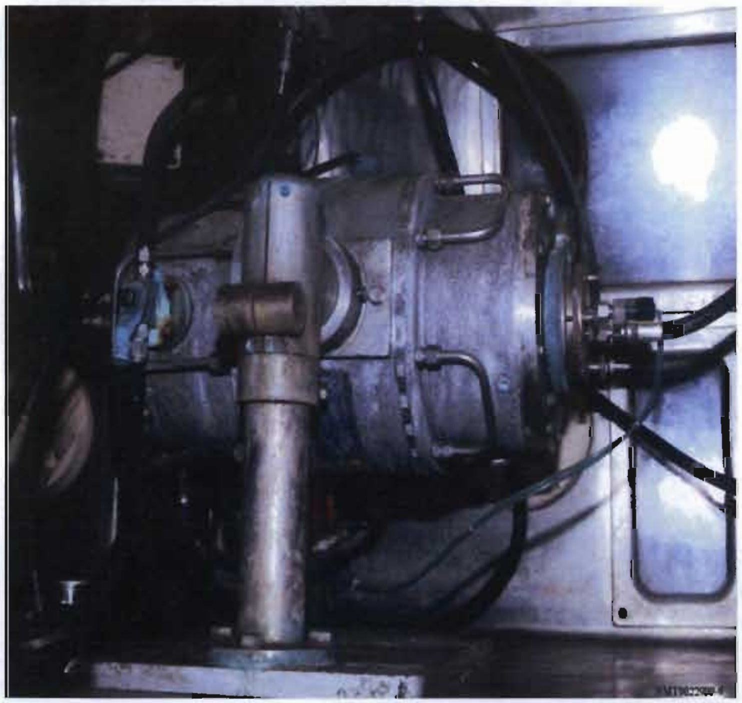


PuO_2 Fuel Processing (1 of 3)

- **Purpose**
  - To form a sintered pellet of PuO_2
- **Major Steps**
  - Feed standardization
    - Ensure a consistent size of feed material
      - Takes feed material to the sub-micro particle size
  - Granule formation
    - Build the feed material to a consistent size
      - 50 – 250 micron
  - Heat treatment
    - Begin thermal stabilization of granules
  - Pellet formation and sintering
    - Form final ceramic pellet

PuO_2 Fuel Processing (2 of 3)

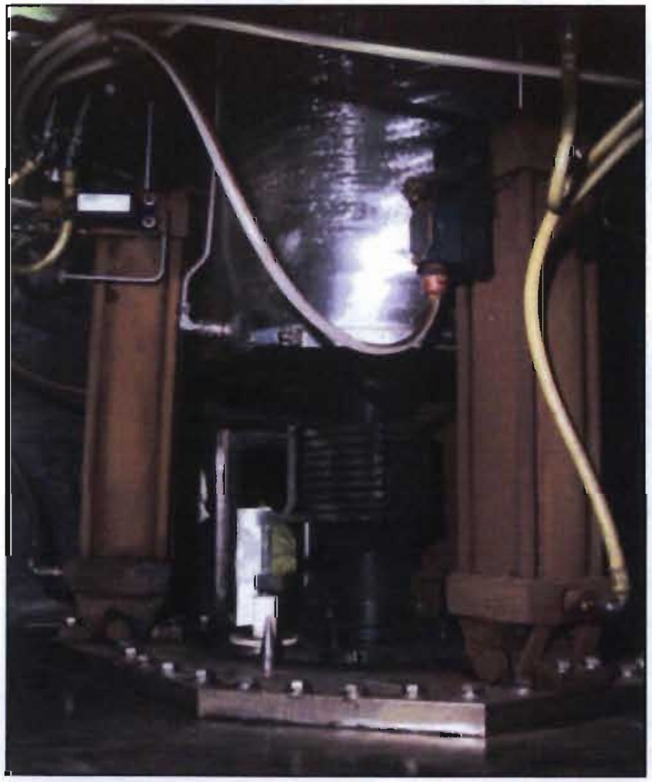
- **Furnaces Operations**
  - 3 Astro furnaces capable of 1600°C
  - 2 Centorr furnaces 1100°C
  - Can hold 60 – 100g PuO_2 per furnace run



- **Granule Seasoning**
  - Low-Fired – 1100°C for 6 hours
    - Physically reactive (mortar)
  - High-Fired – 1600°C for 6 hours
    - Physically un-reactive (brick)

PuO_2 Fuel Processing (3 of 3)

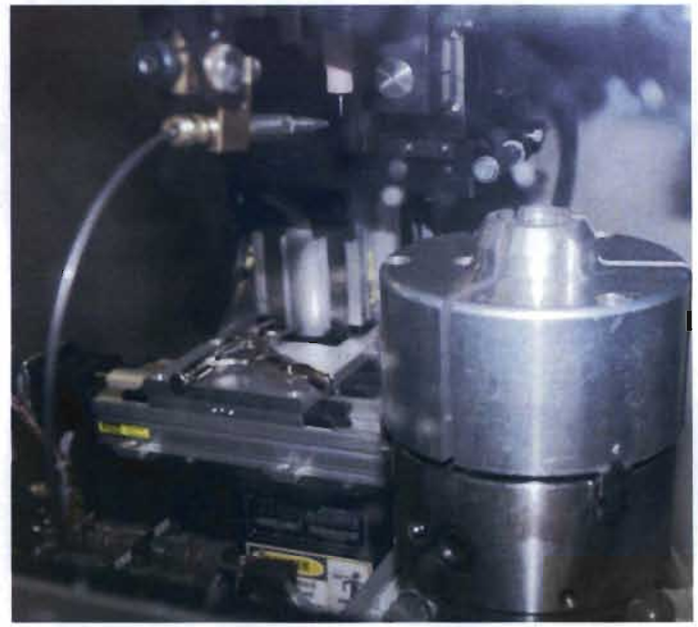
- **Hot Press Die Loading ➔**
  - Blend 60% Low-fired and 40% High-fired
    - Total of 151g PuO_2



- **🡐 Hot Presses**
  - Hydraulic press with induction heating system
  - 1 GPHS or 16 LWRHU pellets pressed in one operation
  - Ramp temperature to 1500°C and 2800 lb
  - Pellets sintered at 1527°C for 6 hours after removal from hot press die

PuO_2 Welding Operations

- **Welding Systems**
  - Two separate fixtures – Primary and Secondary cladding
  - Glovebox atmosphere controlled with dri-train



- **Clad Decontamination**
  - Remove external contamination by washing parts in a HNO_3 – HF bath
    - Contamination levels must be below 100 dpm/cm^2 to remove from the line

Non-Destructive Testing Capabilities

- **Calorimetry Systems**
  - Capable of measuring thermal output ranging from <1W to 250W
  - Used for product qualification and material control and accountability

- **HYTEC Radiography Unit**
  - 225 keV system
  - Digital imaging

Isotope Facility Impact Tester (IFIT) Capability

- **Experimental Parameters**
  - Temperature Range: 25°C to ~1200°C
  - Velocity Range: 30 to 150 m/s
  - Payload Weight: 100 to 1400 grams
  - Physical Projectile Dimensions: 7" dia. x 12"
- **Containment Parameters**
  - Catch Tube Design and Size
    - Multi Hundred Watt (MHW),
    - Milli-Watt (mW)
    - Radio Isotope Heater Unit (RHU)
    - General Purpose Heat Source (GPHS)
    - Outer and Inner Catch Tubes (OCTs and ICTs)
- **Operational Safety**
  - Over 380 shots fired
  - ~30 years of safe operation

Overall Instrument

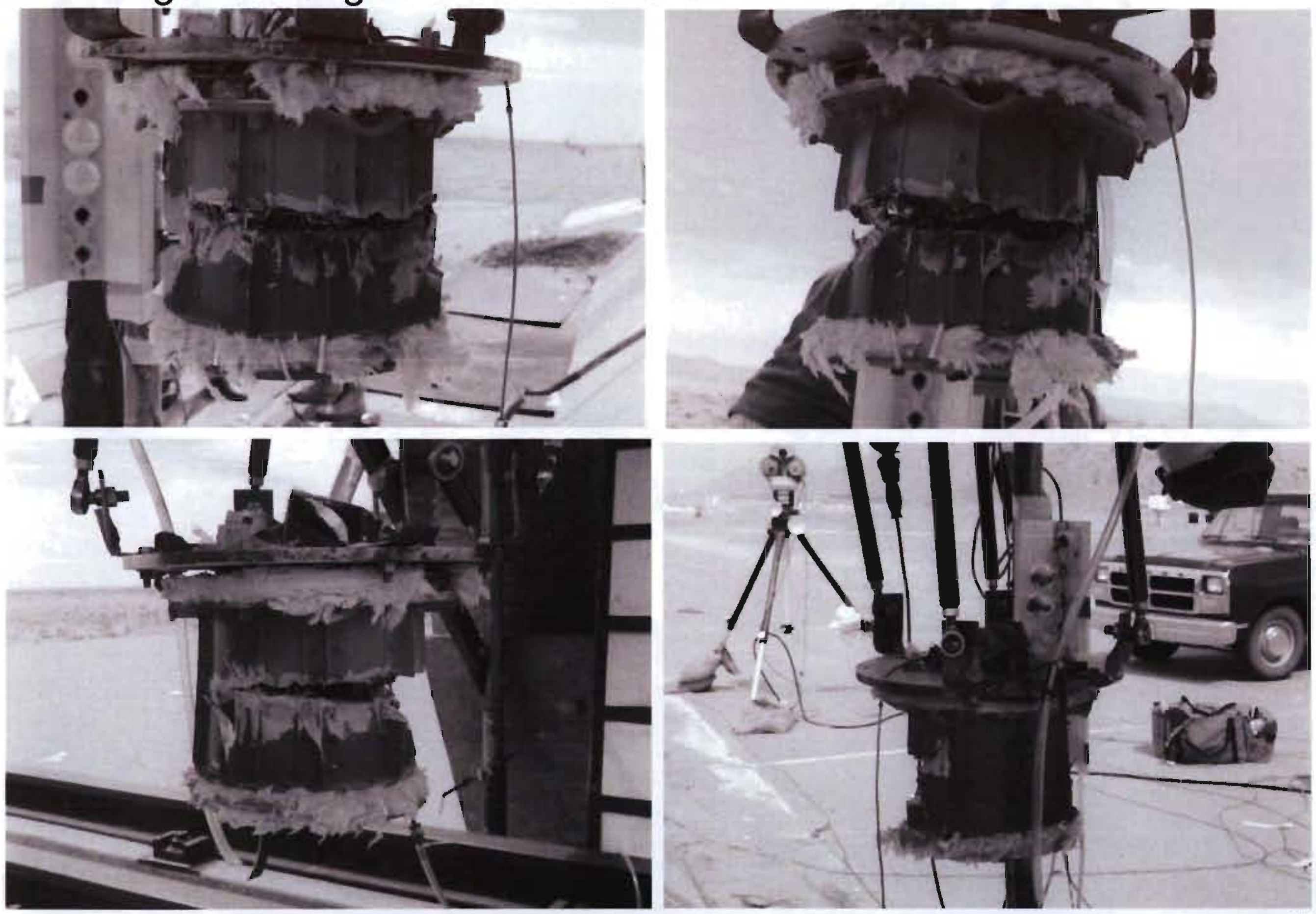
Muzzle End

Safety Testing: RTG Impact Tests for Cassini

- **Two End-On Impact Tests – Half RTG**
  - RTG-1
    - 57.2 m/sec (terminal velocity)
    - 5 of 9 modules contained simulant-fueled GPHS clads
    - There were no clad breaches identified
  - RTG-2
    - 77.1 m/sec (accelerated impact)
    - 6 of 9 modules contained simulant-fueled GPHS clads
    - Three clads breached

Safety Testing: RTG Impact Tests for Cassini

- **Thin Fragment Impact Tests – RTG Section**
  - Fragment velocity was 306 m/sec
  - Significant damage resulting in one clad failure



Proposed NASA Deliverables

- **NASA requires the following heat sources based on current planning**
  - Total of 172 FCs and 250 LWRHUs
    - Assuming 20% "failure" rate, ~32kg PuO_2 required