U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Space and Defense Power Systems Program Information Briefing

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Topics

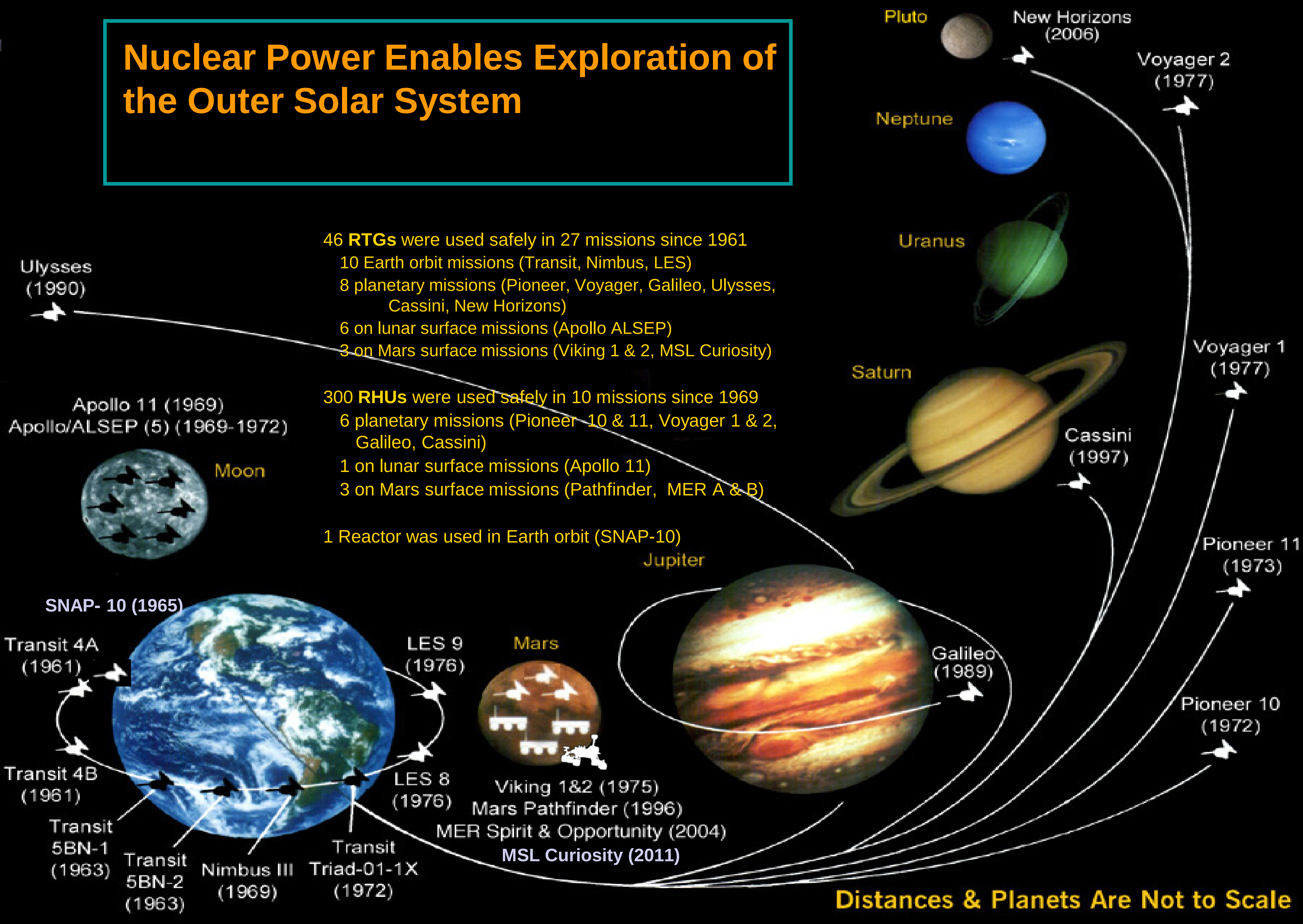
- **Overview of Space and Defense Power Systems mission**
- **DOE and NASA partnership roles supporting nuclear-enabled science missions**
- **DOE supporting capabilities**
  - Sustainment considerations
  - Budgets and Full Cost Recovery
- **Long Range Mission Planning Coordination**
- **Pu-238 supply**
- **Summary**

Nuclear Power Enables Exploration of the Outer Solar System

46 **RTGs** were used safely in 27 missions since 1961
- 10 Earth orbit missions (Transit, Nimbus, LES)
- 8 planetary missions (Pioneer, Voyager, Galileo, Ulysses, Cassini, New Horizons)
- 6 on lunar surface missions (Apollo ALSEP)
- 3 on Mars surface missions (Viking 1 & 2, MSL Curiosity)

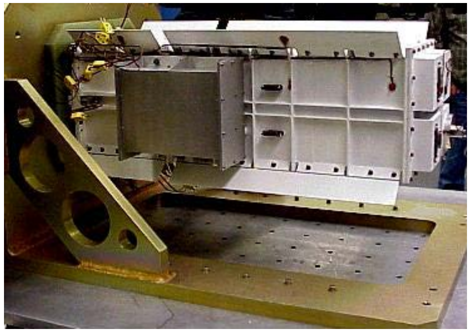
300 **RHUs** were used safely in 10 missions since 1969
- 6 planetary missions (Pioneer 10 & 11, Voyager 1 & 2, Galileo, Cassini)
- 1 on lunar surface missions (Apollo 11)
- 3 on Mars surface missions (Pathfinder, MER A & B)

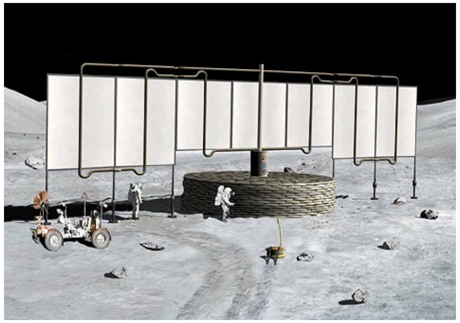
1 Reactor was used in Earth orbit (SNAP-10)



Space and Defense Power Systems

- **Develop, produce and deliver nuclear power systems (NPS) for space exploration and national security**
  - These include radioisotope power systems (RPS) and fission power systems (FPS)
  - Design, development, fabrication, evaluation, testing, and delivery to meet overall system requirements, specifications, schedules and interfaces as agreed to by users and DOE
  - Award, manage and direct system integration contracts; accept system on behalf of USG
  - Manage and direct national laboratory support
- **Maintain RPS production infrastructure to sustain capabilities between missions**
- **Manage Pu-238 and HEU supply for space and certain national security applications**
- **Support mission planning and technology trades**
- **Conduct nuclear risk assessments and safety analyses in support of NEPA reviews and nuclear launch approvals**
- **Keep technology current and available**





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DOE-NASA Partnership

DOE and NASA work as partner agencies to enable availability of radioisotope power systems for NASA missions

DOE

- Develop, produce, and deliver RPS
- Executes and manages work under DOE orders/directives
- Issues contractor direction
- Provides nuclear safety assurance
- Supports mission planning and technology trades
- Provides PAA indemnification for launches

DOE-NASA MOU

- Establishes agreed roles and responsibilities

Tiered Agreements

- Establishes specific agreed commitments
  - High level milestones
  - Funding profiles

← Requirements, specifications, schedules (as agreed)

→ Reporting for accountability to scope, schedule, financial commitments

NASA

- Provides overall planning priorities
- Provides requirements, specifications, schedules
- Provides funding resources

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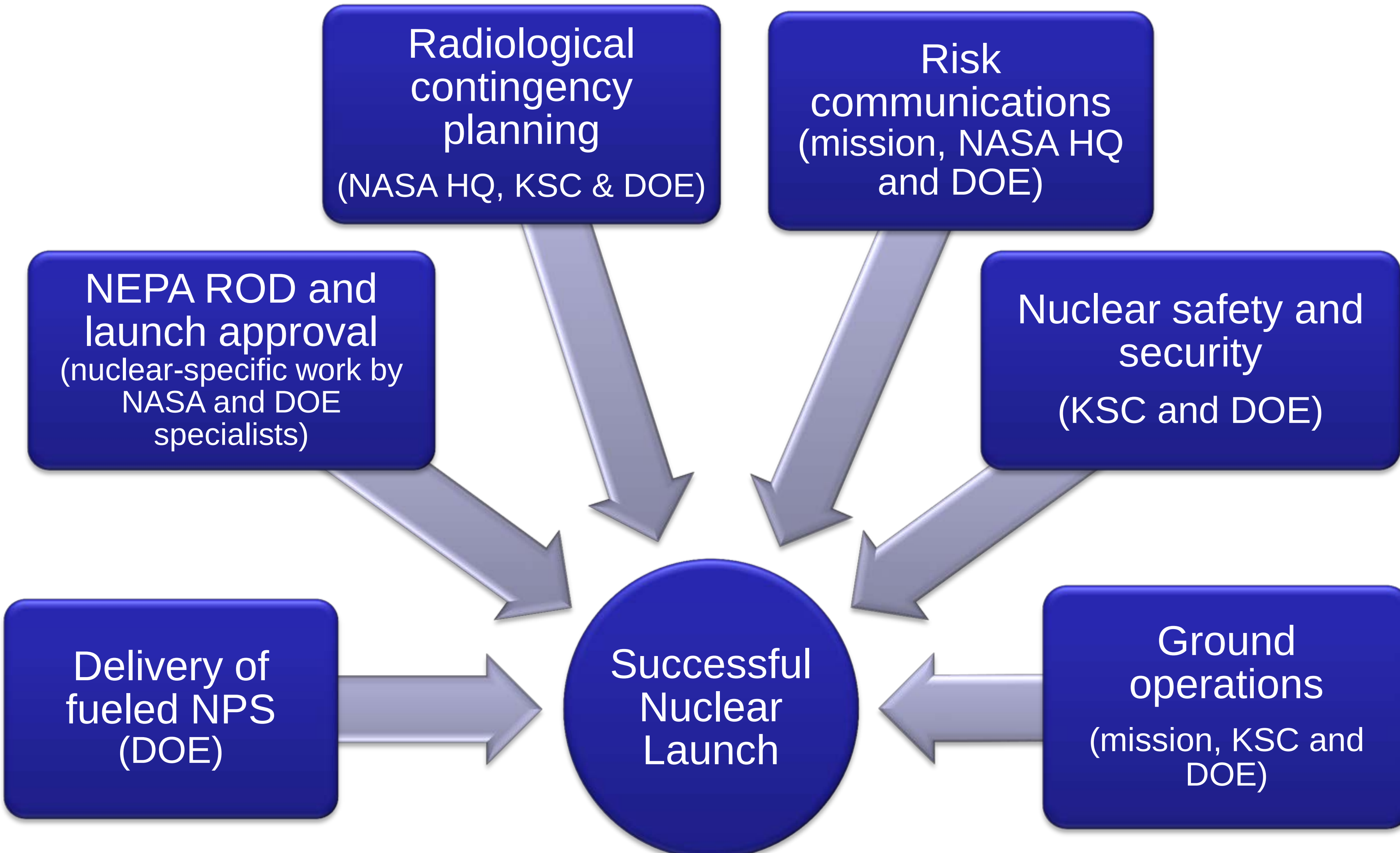
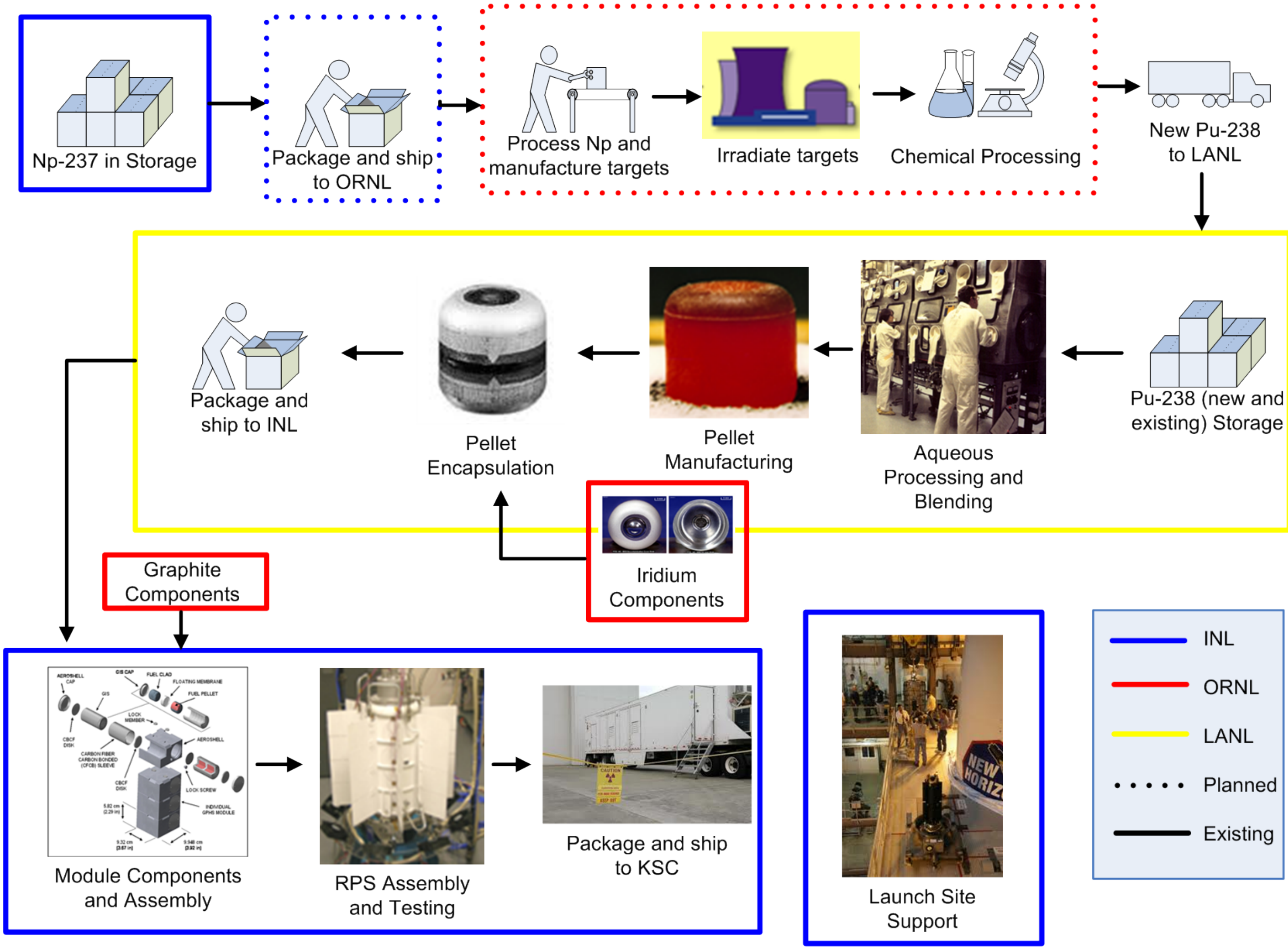
Elements and Interfaces of a Nuclear Launch



Key Steps in RPS Production



DOE RPS Sustaining Capabilities

Enabling capabilities include facilities and people – once established, both are sustained to avoid costly recapture

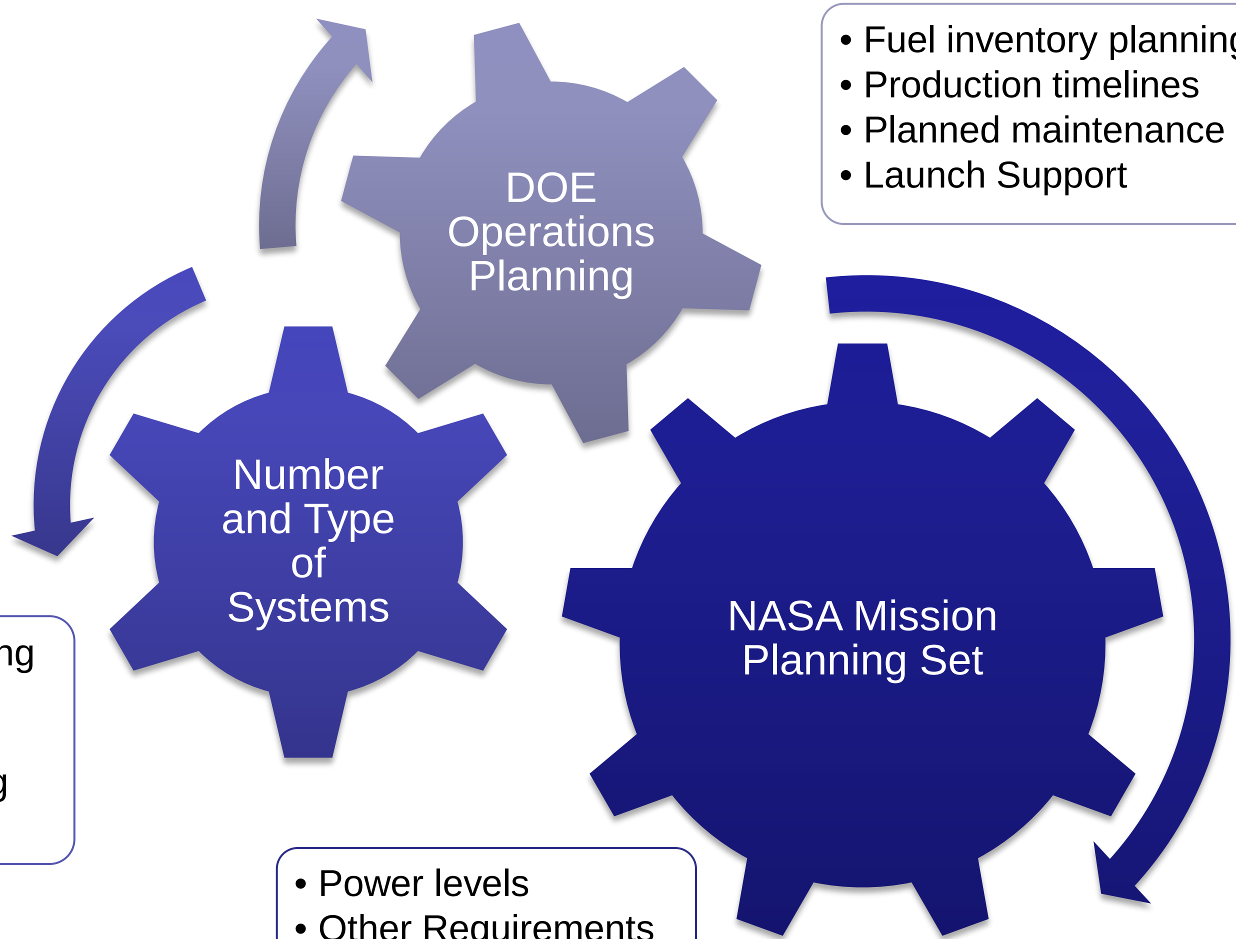
- **Physical infrastructure**
  - Material handling
  - Material storage
  - Safeguards and security
  - Safety
  - Waste management
- **Personnel skills**
  - Professionals and technicians
  - Corporate knowledge
  - Succession
- **Assemble, test and deliver power systems**
- **Analyze safety and risk of RPS deployment and operations**
- **Knowledge Bases**
  - Safety: in design, production and use for worker safety in production and public safety in application
  - Quality assurance: in production, assembly and testing to assure product quality
  - Program knowledge: the integration of all processes and participant organizations
- **Provide launch support and emergency response**
- **Manage nuclear materials supply**
- **Provide international leadership on safe use of space nuclear power systems**
- **Manage user funded RPS System Integration Contracts**

Budget Approach

- **Sustained funding level is required to maintain infrastructure in a “ready” condition**
  - This is the ~$50 million per year that was formerly funded by DOE appropriations, but was transitioned to a full cost recovery model as part of the FY 2014 federal budget; NASA has also provided additional funding to refurbish critical equipment at LANL
  - DOE independently manages the operation of its nuclear facilities in order to ensure nuclear safety and security and to allocate resources across organizations to meet mission needs and synergies with DOE programs
- **Project to re-establish Pu-238 Production Capability**
  - This has always been funded by NASA, since it began in FY 2012
  - Total estimated cost range was $85-$125 million over 9 years, but this is likely to increase as the available funding has not supported this pace.
  - FY15 funding is $17M, and total received to date is $54.8M (~14M/yr avg)
- **Users continue to pay incremental costs of supporting missions**
  - For example, mission-specific hardware, safety analysis, launch support

DOE long-range resource planning

- Fuel inventory planning
- Production timelines
- Planned maintenance
- Launch Support



- Acquisition Planning
- Technology development
- Production, testing and delivery

- Power levels
- Other Requirements
- Launch Dates
- Acquisition Approach

Planned Maintenance Example: LANL Hot Press & Furnaces

- LANL currently has 2 hot presses, of 1950's vintage
  - Hot press #1 (HP1) is fully operable
  - Hot press #2 (HP2) partially operable
- Repair of HP2 and installation of HP4 will allow LANL to increase manufacturing reliability and pellet throughput
- Addition of 2 new oxide conversion furnaces in adjacent glovebox will reduce reliance on the aging Line 7
- Completed D&D of equipment space and initiated contracts
- Work to be complete by 2017

Pu-238 Supply

- DOE NE Pu-238 inventory supports NASA and national security applications
  - Other DOE programs maintain program specific inventories
- Current Pu-238 inventory comprises two types:
  - Domestically produced – production ceased in late 1980s; most does not meet thermal specifications for current space system designs
  - Procured from Russia – higher thermal power than US domestic; meets or exceeds thermal specifications

Pu-238 Allocation for Civil Space

- Separate allocations for civil space and national security applications established July 2013
  - Allows transparent planning basis for NASA missions while protecting information related to national security
- Total 35 kg Pu-238 isotope available for civil space; of that approximately 17 kg meets specifications and balance available for blending
- At the end of FY 2022, with the fabrication of 3 MMRTGs (2020 and notional 2024 missions), available remaining inventory would be reduced to approximately 21 kg with only 4 kg of material within the enrichment specification
  - This (4 kg) may be enough for 1 more MMRTG at the 1952 Wth level (minimum current spec level) but with no margin and would not provide flexibility to balance power among subsequent missions.
- Enrichment and total amount of inventory will continue to decrease

Matching Pu-238 Supply to missions

Multiple Inventory Types

- Newly produced material
- Existing, currently in-spec material
- Older, below-spec material (age and quality vary)

Losses

- Continuous decay
- In-spec material can age to fall below spec
- In-process losses

Option space for missions

- Timing – Early fuel manufacturing reduces risk, but lowers power
- Power levels –balance current and future missions
- Funding/Cost – schedules can be adjusted for mission constraints

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Pu-238 Supply Project

Project to restart domestic production underway

- Initiated in FY2012 with NASA funds
- Existing reactors and facilities will be used
- Plan has been to reach full production capacity (1.5 kg/yr oxide) by 2021, with a total cost of $85-$125M
- Available funding does not support this pace, but DOE is studying the feasibility of a phased in production approach to meet mission needs
- Assay (Pu-238 relative to other Pu isotopes) will be optimized as part of operations
- Higher assay product can be blended with older domestic fuel to yield more net usable material for missions

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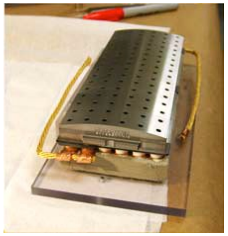
Potential for Higher Efficiency Systems

- **Higher efficiency thermoelectrics – eMMRTG**
  - Goal is to insert new technology into a flight proven system
  - Upgraded thermoelectric materials developed and demonstrated at JPL
  - Other minor design changes to increase operating temperature
  - With minimal risk to existing MMRTG design, eMMRTG could provide:
    - 21 to 24% BOM power boost over MMRTG
    - EOM improvements are also expected (>50%)
- **Stirling technology – higher system efficiencies (>25%) but with added complexity**
  - Goal is system that is simple, robust, and reliable
  - Next steps are to develop high level requirements and evaluate current Stirling industry and technologies
    - Applicability of ASRG technologies will be assessed

Skutterudite (SKD) materials



Advanced SKD MMRTG modules

Summary

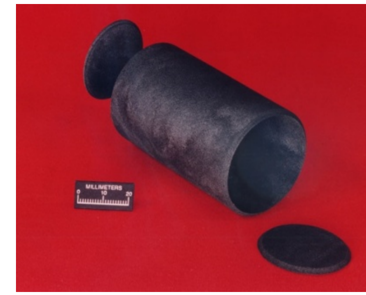
- DOE is a ready partner for RPS powered missions
- DOE is proud of its highly successful track record of RPS in space exploration
- Pu-238 supply is progressing as funding allows, and studying the best approach to supporting future missions
- DOE has tools in place to support integrated mission planning

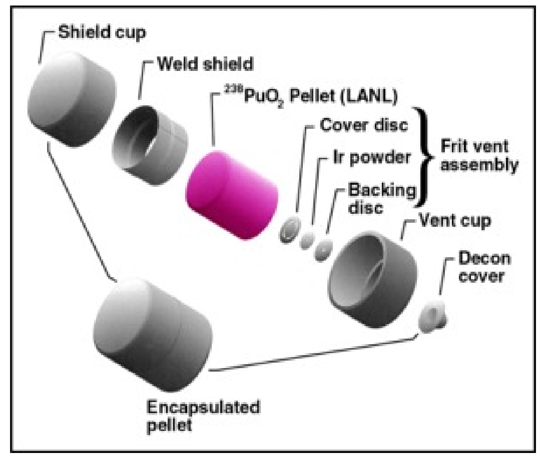
Questions?

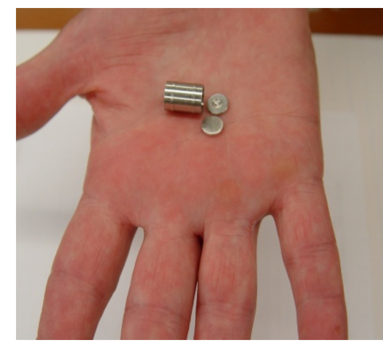
Background

Iridium Hardware and Material Testing Oak Ridge National Laboratory

- **Oak Ridge National Laboratory is the lead materials development laboratory**
- **Specific capabilities:**
  - Iridium alloy encapsulation hardware production
  - Manufacture of Carbon Bonded Carbon Fiber (CBCF) insulation
  - Unique materials testing capabilities
  - Manufacture Light Weight Radioisotope Heater Unit (LWRHU) components
- **ORNL also leads project to reestablish domestic supply of Pu-238**



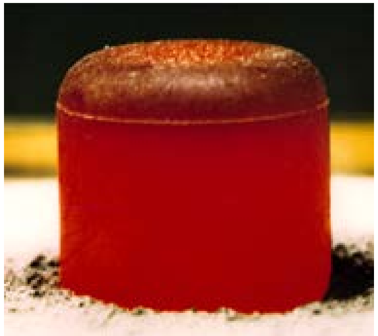




Heat Source Production
Los Alamos National Laboratory

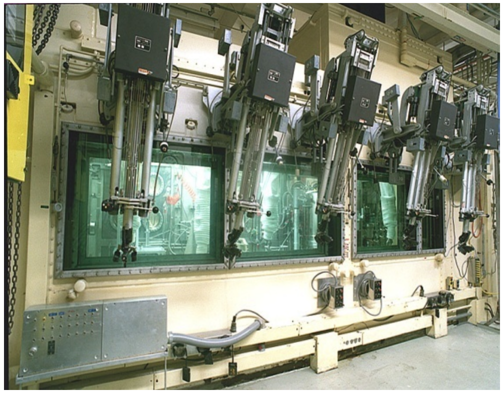
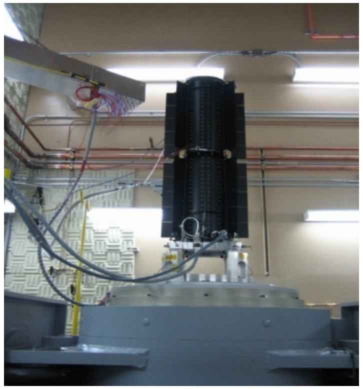
- **LANL maintains capability for Pu-238 oxide processing and fueled clad fabrication**

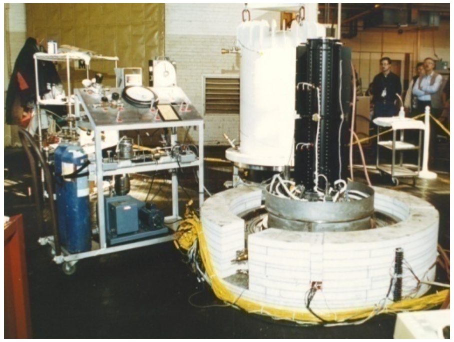
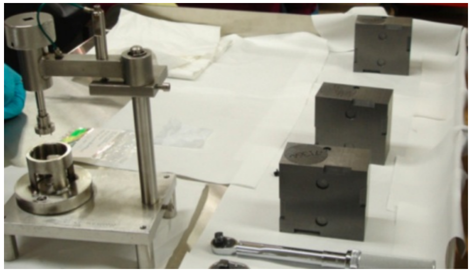
- **Specific Capabilities:**
  - Purification of Pu-238 (scrap recovery)
  - Pelletization of purified Pu-238
  - Encapsulation of Pu-238 pellet
  - Impact testing for safety verfication
  - Metallography
  - Chemical analysis
  - Nuclear material storage and security
  - Waste handling and disposal



Power System Assembly, Testing and Delivery – Idaho National Laboratory

- **INL maintains capability for RPS assembly, testing, storage, and delivery of radioisotope power systems for NASA and national security applications**
- **Specific capabilities:**
  - Material procurement and component fabrication
  - Heat source module assembly
  - RPS assembly
  - RPS acceptance testing
  - Specialized transportation systems
  - Delivery of RPS to customers
  - Ground support at customer site, including standing up temporary DOE nuclear facilities
- **INL serves as the Technical Integration Office and Lead Laboratory for quality acceptance**

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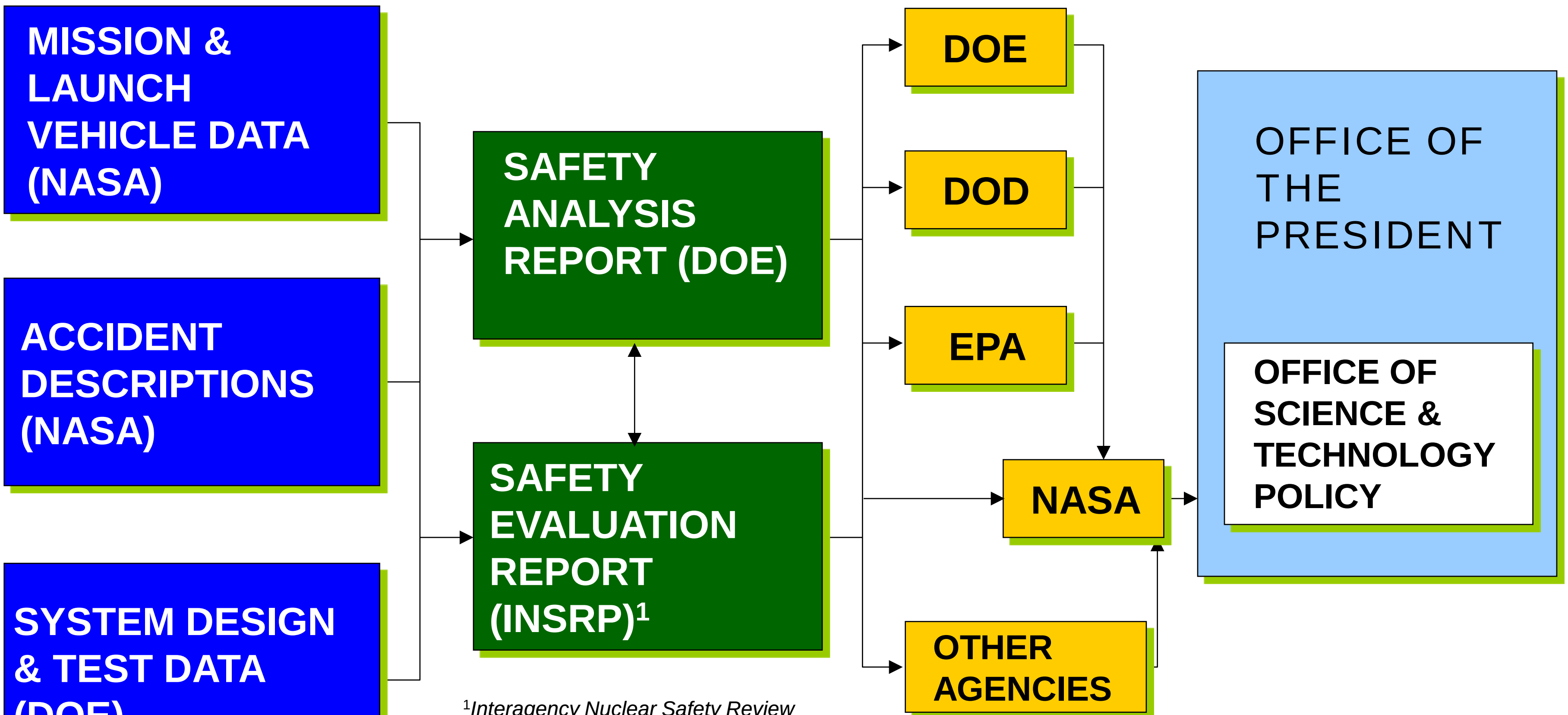
Transportation

- **Maintain fleet of Type B shipping containers for very specialized transport of ~$100M RPS**
  - Specialized active cooling and monitoring
  - SARP addendums prepared for each payload
- **Arrange for transport to KSC using Office of Secure Transportation (OST)**
- **Maintain two specially equipped trailers to provide cooling and system health checks during secure transport**

9904 Type B Shipping Package

Nuclear Safety Review and Launch Approval Process



[1] *Interagency Nuclear Safety Review Panel*

DOE prepares a nuclear risk assessment which will be used by the Office of President to make a decision to authorize a launch using nuclear materials.

Risk Communications

- **Public Affairs, Education and Outreach, and Risk Communications is an important element of every nuclear launch**
- **DOE reviews fact sheets, talking points, videos, press releases etc. that discuss the power system and nuclear safety to insure information is presented factually and accurately**
  - Pre-approved language and materials are used wherever possible to ensure a consistent and correct message
- **DOE provides spokesperson for the power system and nuclear safety for the mission**
  - Public meetings
  - Briefings to local officials, site workers
  - Media events, including print and television
- **DOE provides risk communication and technical experts in the interagency Joint Information Center during launch operations**
  - Provides informational releases to the media, public and other governments on the status of the radiological monitoring and assessment actions and conditions post-accident

Nuclear Safety and Security at the Launch Site

- **Stand up temporary nuclear facilities under DOE jurisdiction per 10CFR830**
- **DOE indemnifies launch of a nuclear payload**
- **Prepare Documented Safety Analysis (DSA) for KSC facilities**
  - DSA covers operations between arrival at KSC and positioning of the RPS on upper deck of building housing rocket
- **Review/Approval by DOE**
- **Conduct operations of DSA through USQ process involving work in DOE-KSC nuclear facilities**
- **The Safety Analysis Report for launch covers operations from final integration with spacecraft onward**

KSC Ground/Launch Support

- Wellness check of RPS unit
- Hot fit check with spacecraft / rover
- Final dry run at Vertical Integration Facility (VIF)
- Integrate with spacecraft at VIF