U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Space and Defense Power Systems Program Update

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Topics

- Update on Preparations for Mars 2020 Mission
- Plans and Current Status for Improvements to Existing Capabilities
- New Pu-238 Production Project Update
- Opportunity for Pu-238 production process improvements
- Advanced Power Conversion Technology R&D
- Summary

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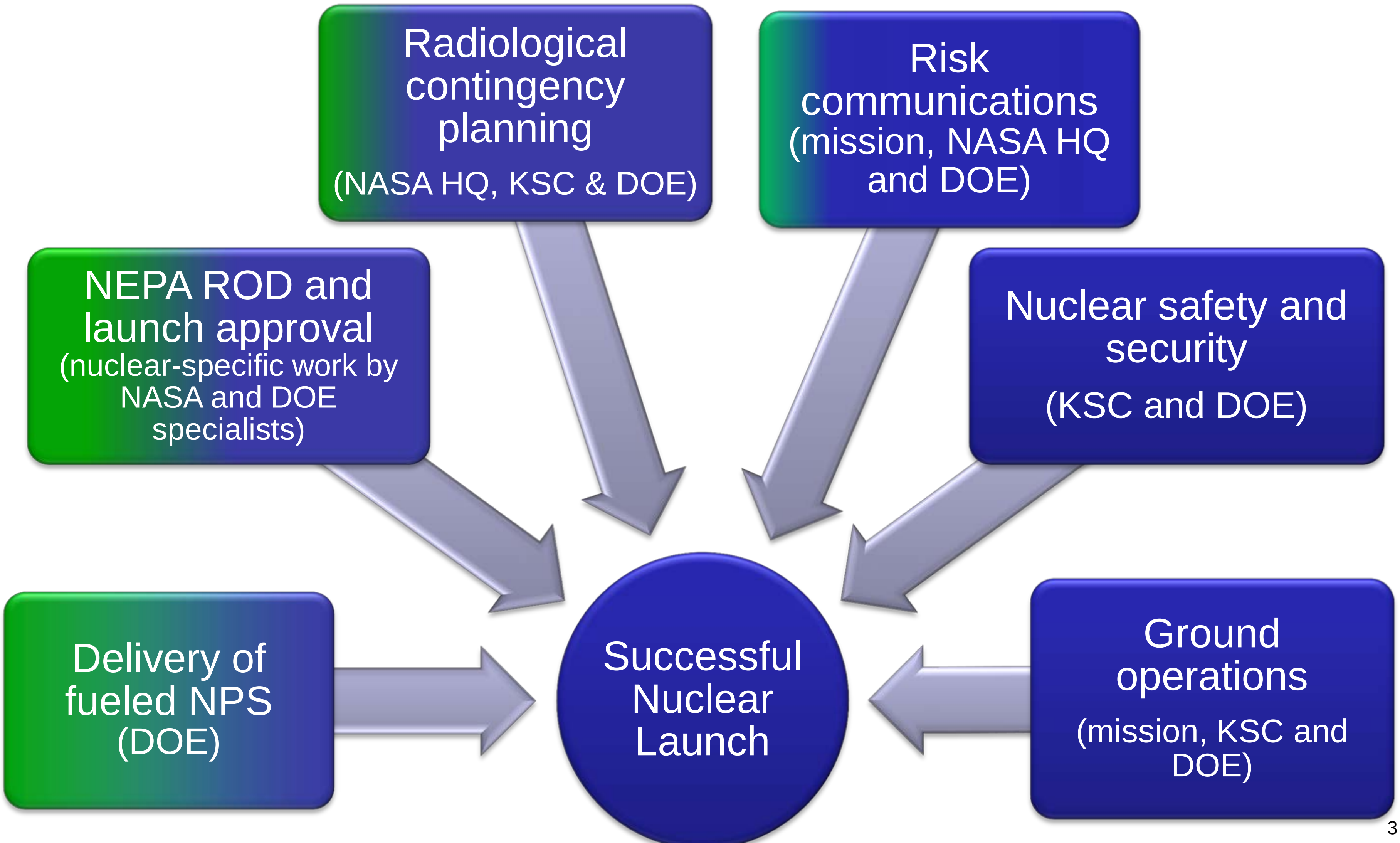
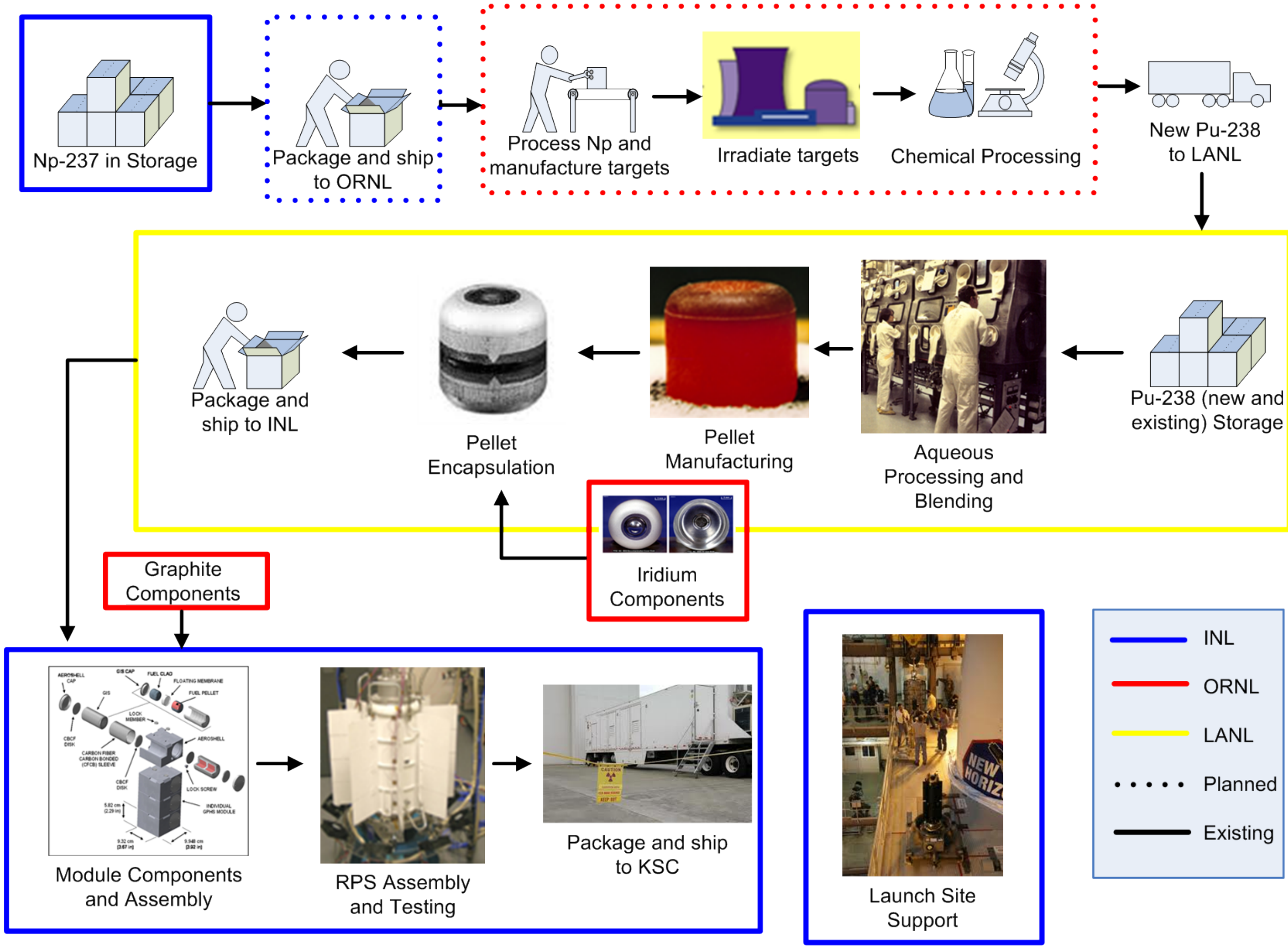
Elements of a Nuclear Launch – Mars 2020

(green = task progress)



Key Steps in RPS Production



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RPS Production Progress for Mars 2020

- **New Pu-238 Production (ORNL) – online later this decade; existing inventory is being used**
- **Iridium and graphite components (ORNL) – existing inventory being used**
- **Heat Source Manufacturing (LANL) – started in FY 2015**
  - 20 fueled clads needed by 2018 for in-specification power
  - Minimum mission “go/no-go” is 8 fueled clads
  - Difficulties with aging hot presses could slow manufacturing, but margin was planned in
- **Balance of generator (Aerojet Rocketdyne, Teledyne)**
  - F2 & F3 in storage require cooling tube installation and optical coating
- **Fueling and testing operations (INL)**
  - Procedures, tooling, facilities remain in place since MSL
  - Additional needed staffing will be brought on board in 2016

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FY15 progress on reliability improvements (not related to Pu-238 production)

Los Alamos National Laboratory

- New furnaces, hot press (continues through 2017)
- Welder upgrade (into FY16)
- Window replacements

Idaho National Laboratory

- Thermal vac chamber controller
- Graphite furnace
- Magnetics table

Oak Ridge National Laboratory

- Carbonization furnace
- E-beam welder upgrade

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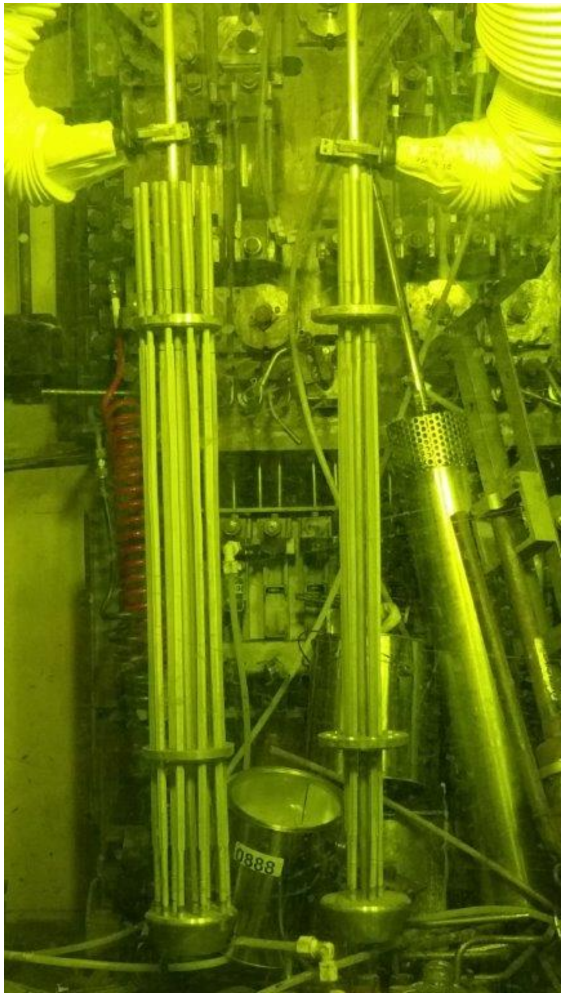
Pu-238 Supply Project Update

- **Neptunium shipping glovebox ready to operate at INL**
  - First Np shipment to ORNL expected early FY 2016
- **First end-to-end production demonstration in progress**
  - Twenty targets irradiated for two cycles - ~ 50 gm ^{238}Pu
  - Two targets have been dissolved; 18 more in FY15
- **First sample shipment to LANL 2nd Quarter FY 2016 (a few grams for analytical verification)**
- **42 more targets made for second demo**
- **Planning ramp-up to full rate continues in parallel**



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Preliminary startup at reduced throughput still requires significant scale-up

	Desired Production Rate	Current R&D Production Rate
Pu 238 (g/yr)	400	156
Np (g/yr)	4000	1560
Np (g/pellet)	0.6	0.6
Pellets/yr	6667	2600
Pellets/target	52	52
Targets/yr	128	50
Operational weeks/yr	23	40
Pellets/week	290	65
Targets/week	6	1.25
Productive hrs/day	6	6
Pellets/min	0.2	0.036
min/pellet	6.2	27.7

Need a throughput of ~ 1 pellet every 5 minutes

Pu-238 Production Process Improvement

- **Baseline process design is based on fastest/lowest cost path to assured supply**
  - High TRL
  - High confidence of attaining full rate
  - Decades of experience with similar processes
- **Parallel piece of project scope has always been to study future improvement potential**
  - How could production capacity be increased?
  - Can life cycle cost and/or cost/kg be reduced?
  - How do we design now to ensure such options remain open?
- **Effort has identified a target design modification with near-term potential**

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Alternate Target Design May Increase Yield/Reduce Cost

- **The idea is a change to the pellet and cladding materials**
  - Based on similar manufacturing methods/materials used for nuclear reactor fuels in commercial reactors
- **Would not require significant equipment rework, or redesigning chemical processes**
- **Concept has been analyzed and independently checked, but not tested**
- **Could reduce the number of targets by 65-75% for 1.5 kg/yr rate**
- **“Assay” of Pu-238 in the oxide would increase (more Pu-238 in the same 1.5 kg total oxide)**
- **Capacity could increase beyond 1.5 kg/yr without major capital investments**

Not a "sure thing" but shows Promise

Pros

- **High Pu-238 assay (ratio of Pu-238 to total Pu in the oxide)**
  - Increases heat density in fuel, increases shelf life, extends usability of the existing inventory
- **Higher yield per reactor unit volume**
  - Reduces cost and increases production capacity
- **Decreased waste**
  - Reduces cost and has environmental benefits
- **Reduce target fabrication requirements**
  - Reduces cost and increases production capacity

Cons

- **Additional development work (time and $)**

Low risk, low cost, high potential payoff.
Does not risk near-term production on baseline path.

Pu-238 Supply Status

- **Total 35 kg Pu-238 isotope available for civil space; approximately 17 kg meets specifications and balance available for blending**
- **Number of MMRTGs that could be fabricated using this material depends on decisions about individual missions**
  - Mars 2020 – Plan is to build generator with specified thermal power
  - For later missions, DOE-reported estimates have varied based on the scenario being discussed:
    - Scenario details matter for remaining inventory usage: assumptions about processing efficiency/losses, processing dates, launch dates, etc.
    - Scenario Approach: Maximizing power for a certain mission? Trying to extend the supply as long as possible?
- **Currently envision at least 3 more MMRTGs after Mars 2020, but below specified power**
  - May be adjusted as Pu-238 supply project proceeds (could make fewer with higher power if future supply is assured)

R&D to Improve System Efficiency

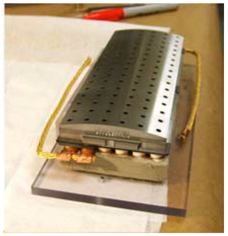
Higher efficiency thermoelectrics – eMMRTG

- 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
  - EODL improvements are also expected (>50%)
- PSD's Radioisotope Power System Program funding technology maturation and risk reduction task, including tech transfer to industry
  - Gate reviews to verify technology readiness prior to flight system development effort

Skutterudite (SKD) materials

Status

- First gate review will assess:
  - Performance, properties and manufacturing readiness of SKD materials,
  - Transfer of technology to industry
  - Status of element and couple design
  - review is to demonstrate that the SKD Technology Maturation task should proceed to Phase B demonstration of module performance.



Advanced SKD MMRTG modules

R&D to Improve System Efficiency (cont'd)

- **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
- **NASA-DOE assessment of current state of Stirling industry technologies and capabilities**
  - Request for Information issued June 3, 2015 to seek input on
    - Technology design features and constraints
    - Performance parameters, reliability and scalability
    - Operating experience and manufacturing history
    - Measures to reduce cost, schedule and technology development risks
  - Responses from industry received and evaluations are underway
  - Results to inform future Stirling development efforts

Summary

- DOE continues to improve the reliability of its existing capabilities while supporting NASA missions
- Project to reestablish domestic Pu-238 production capability is producing excellent results
  - Limited production later this decade
  - Full rate as funds allow, mid-2020s
- Ongoing process improvement studies have revealed significant opportunities
  - Increased capacity, reduced cost, reduced waste
  - ~ 2 years for preliminary tests – stay tuned
- DOE and NASA are making good progress on technologies to increase system efficiency

Questions?