Space and Defense Power Systems Program Update

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Office of Nuclear Energy

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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
Elements of a Nuclear Launch – Mars 2020
(green = task progress)

Successful Nuclear Launch

Radiological contingency planning
(NASA HQ, KSC & DOE)

Risk communications
(mission, NASA HQ and DOE)

NEPA ROD and launch approval
(nuclear-specific work by NASA and DOE specialists)

Nuclear safety and security
(KSC and DOE)

Delivery of fueled NPS
(DOE)

Ground operations
(mission, KSC and DOE)
Key Steps in RPS Production

1. Np-237 in Storage
2. Package and ship to ORNL
3. Process Np and manufacture targets
4. Irradiate targets
5. Chemical Processing
6. New Pu-238 to LANL
7. Pu-238 (new and existing) Storage
8. Aqueous Processing and Blending
9. Pellet Encapsulation
10. Pellet Manufacturing
11. Package and ship to KSC
12. Module Components and Assembly
13. RPS Assembly and Testing
14. Launch Site Support
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
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
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
Preliminary startup at reduced throughput still requires significant scale-up

<table>
<thead>
<tr>
<th></th>
<th>Desired Production Rate</th>
<th>Current R&amp;D Production Rate</th>
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<tbody>
<tr>
<td>Pu 238 (g/yr)</td>
<td>400</td>
<td>156</td>
</tr>
<tr>
<td>Np (g/yr)</td>
<td>4000</td>
<td>1560</td>
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<tr>
<td>Np (g/pellet)</td>
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<td>Pellets/yr</td>
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<tr>
<td>Pellets/target</td>
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<tr>
<td>Targets/yr</td>
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<td>50</td>
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<tr>
<td>Operational weeks/yr</td>
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<tr>
<td>Pellets/week</td>
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<td>65</td>
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<tr>
<td>Targets/week</td>
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<tr>
<td>Productive hrs/day</td>
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<tr>
<td>Pellets/min</td>
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<td>0.036</td>
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<tr>
<td>min/pellet</td>
<td>6.2</td>
<td>27.7</td>
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</tbody>
</table>

Need a throughput of ~ 1 pellet every 5 minutes
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
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

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.
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?