Space Applications for Nuclear Data - Session Summary

WANDA 2021

Co-Chairs: Lawrence Heilbronn (UTK), Mary Burkey (LLNL), and Patrick Peplowski (JHU/APL)

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Session Scope

- The space radiation environment:
  - Space is filled with energetic ions.
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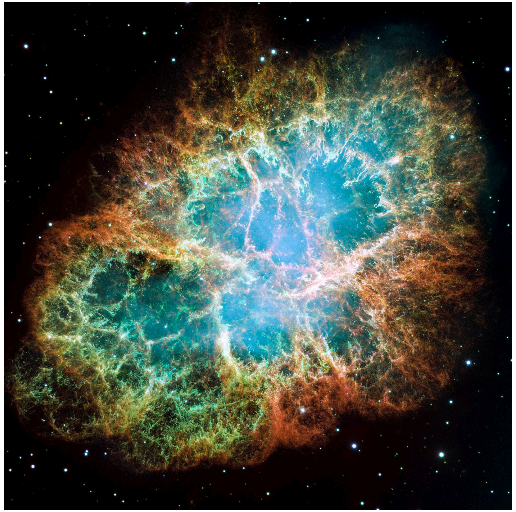

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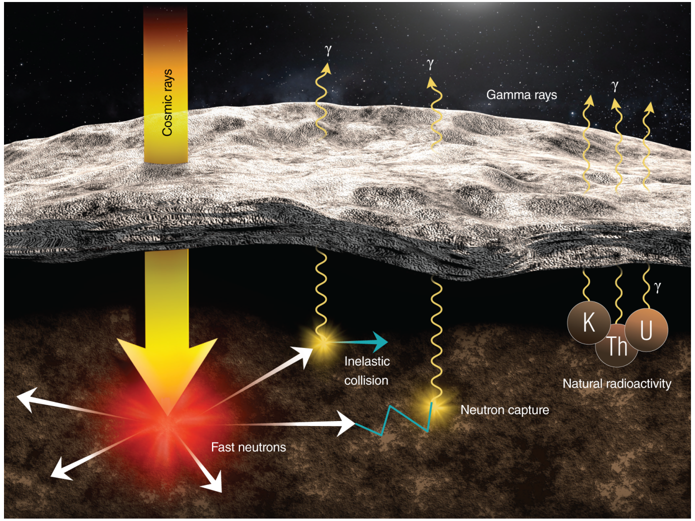

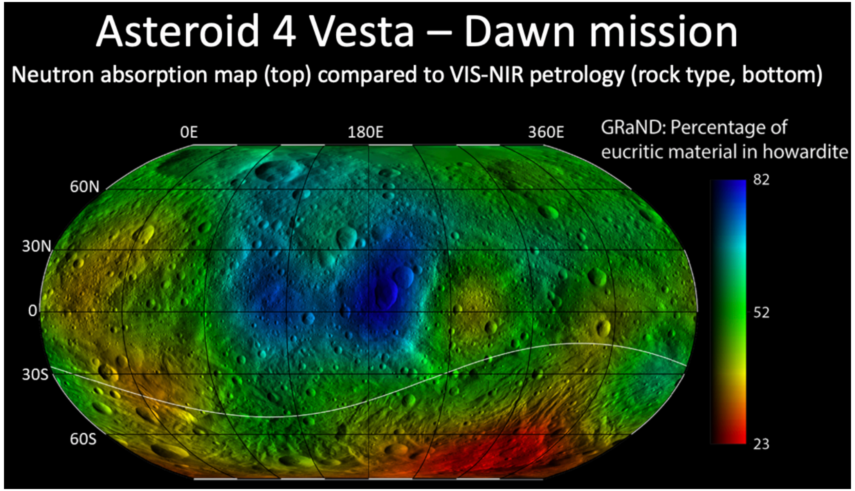

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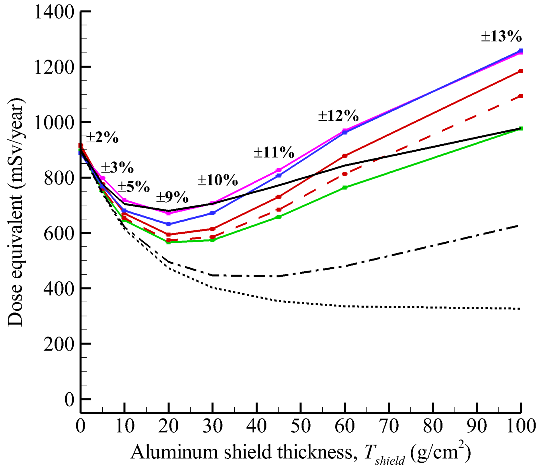
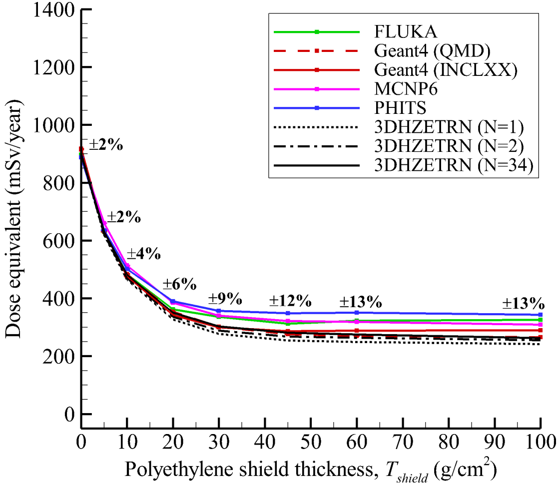
    - But they also pose a hazard to electronics and human explorers





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- Nuclear science as an enabling technology
  - Protecting the planet from asteroids
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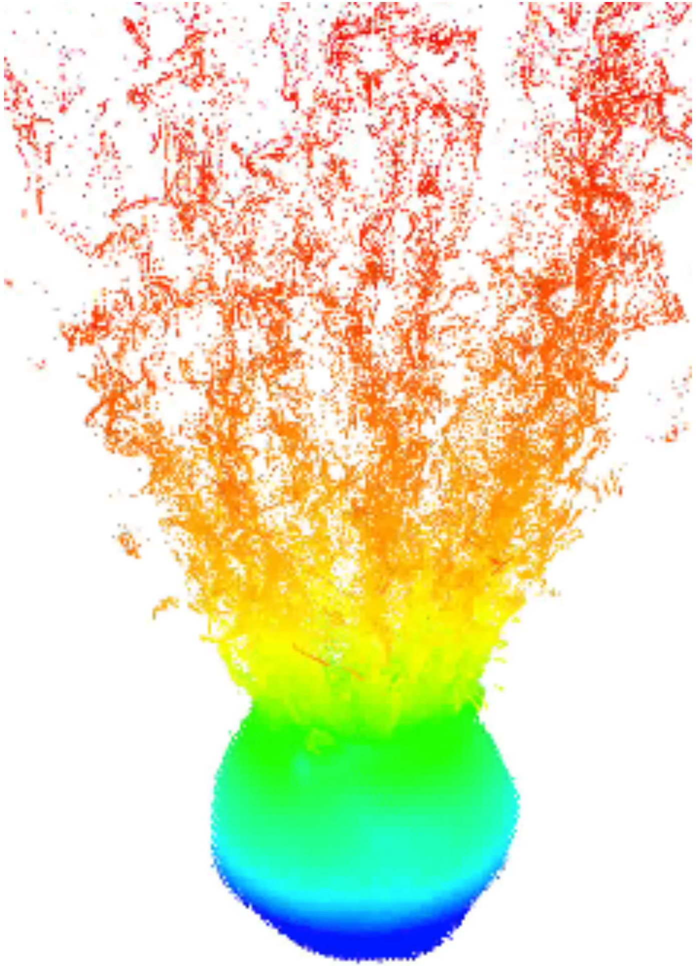

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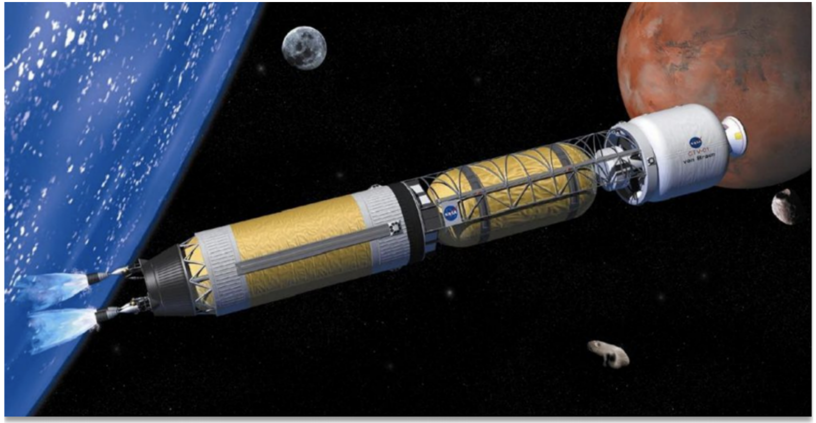

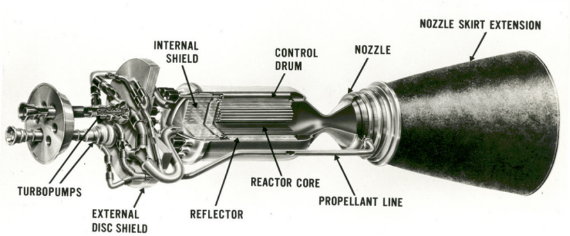

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  - Protecting the planet from asteroids
  - Powering space exploration
  - Monitoring human activities

This expansive range of applications informed our list of speakers & topics:

- **Space Radiation Transport**: Francesca Luoni (GSI)
- **Planetary Defense/Neutron Energy Deposition in Asteroids:** Lansing Horan (AFTAC)
- **Space-based Nuclear Detonation Detection**: David Gerts (LANL)
- **Planetary Nuclear Spectroscopy**: Thomas Prettyman (PSO)
- **Active Neutron Interrogation**: Marie-Laure Mauborgne (Schlumberger Inc.)
- **Space Nuclear Reactors, Advanced Thermionic Energy Conversion**: Austin Lo (UC Berkeley)
- **Space Reactors**: Brad Rearden (X-Energy)

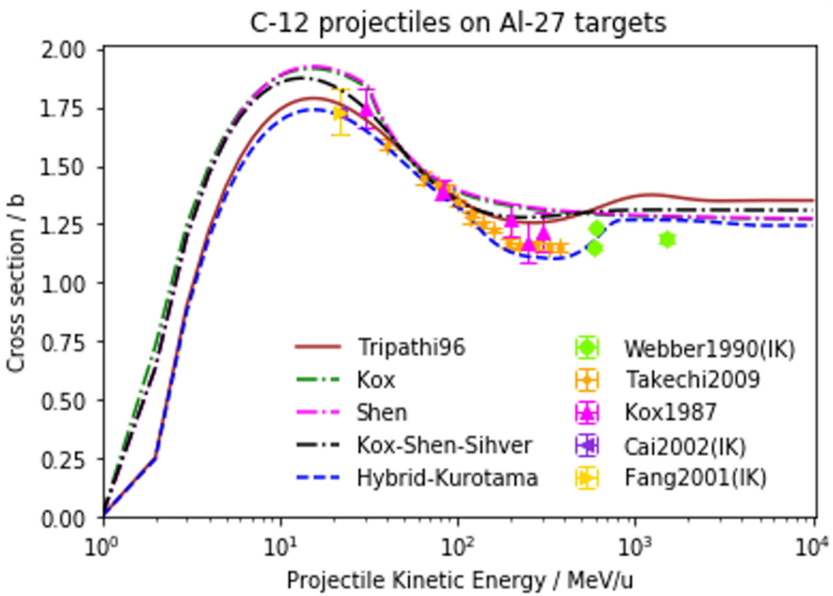
We encourage you to view the presentations, which are available on the WANDA 2021 Indico Site

Sponsor Highlights:

- Department of Energy (Keith Jankowski)
    - Engaged in outreach to NASA: planetary science, materials damage/radiation effects, nuclear energy.
    - More inter-agency collaboration is needed: build nuclear data documentation and identify needs with multiple interested partners.
    - The space data needs discussion should continue, potentially at another mini-workshop later this year.
- Johns Hopkins University Applied Physics Laboratory (David Lawrence)
    - NASA has many neutron and gamma-ray spectroscopy experiments already in space with more planned.
    - Data needs are (n,n'g) and (n,g) gamma-ray production cross sections on natural targets of major and minor elements (and incorporated into libraries for radiation transport codes)
    - cosmic induced and active induced neutrons are of interest.
- Defense Threat Reduction Agency (Joanna Ingraham)
    - Priorities are threat detection, weapons effects, survivability, protecting assets and the environment.
    - Want data on fission cross-sections and product yields with effects from μs to hours

Space Radiation Data Needs:

- **Context: Interactions between cosmic rays and spacecraft materials are of interest for electronics & human radiation exposure.**
- Critical need for helium-projectile, isotopic double-differential, cross sections for the production of neutrons and light ions (p, d, t, ^{3}He, ^{4}He)
- Additional need for same cross sections from heavy ions (C, O, Si, Fe)
  - Targets - H, C, O, Al, Fe
- Total reaction cross sections for some important models/systems for space radiation protection
- Total reaction cross sections for very high-energy ranges (> 1.5 GeV/u) for all models/systems



-Francesca Luoni (GSI)

Planetary Spectroscopy/Defense Data Needs:

- **Context: NASA has funded many instruments that use nuclear (neutron- and gamma-ray) spectroscopy to study planetary surface composition.**
- Nuclear spectroscopy models require:
  - Accurate nuclear data libraries for high-energy interactions (many GeV/nucleon)
    - Neutron transport and neutron-induced gamma-ray reactions, e.g. (n,n'g) and (n,g).
  - Experimental validation of models
  - Availability for MCNP and Geant4 (e.g. G4NDL, ENDF libraries)
    - Newer not always better, ENDF VI often better than ENDF VII and VIII.
    - Good group (chat) discussion of changes to ENDF that may explain this.
- New Experiments?
  - Perhaps a robust characterization of a single element, to benchmark less detailed measurement for a wider set of elements.

	Typical Gamma Rays (non-inclusive list)	Psyche GRS (Asteroid 16 Psyche)	MEGANE (Mars' Moon Phobos)	DraGNS (Saturn's Moon Titan)
H	(n,γ): 2223 keV		Y	Y
C	(n,n' γ): 4438 keV			Y
N	(n,n' γ): 2312 keV			Y
O	(n,n' γ): 6129 keV (n,n' $\alpha\gamma$): 4438 keV		Y	Y
Na	(n,n' γ): 440 keV		Y	Y
Mg	(n,n' γ): 1369 keV		Y	Y
Al	(n,n' γ): 843, 1014, 2211 keV	Y		
Si	(n,n' γ): 1778 keV (n,γ): 3539, 4934 keV	Y	Y	
P	(n,n' γ) 2233 keV			Y
S	(n,n' γ) 2232 keV	Y		Y
Cl	(n,γ) 1951, 1960, 6111 keV			Y
K	(n,n' γ) 2814 keV		Y	Y
Ca	(n,n' γ) 1940 keV (n,γ) 3736 keV	Y	Y	
Fe	(n,n' γ): 846, 1238, 1408, 1809 keV (n,γ): 7631, 7646, keV	Y	Y	
Ni	(n,n' γ): 1332, 1454 keV	Y		

Reactions of interest for upcoming NASA missions

- Thomas Prettyman (PSI), Marie-Laure Mauborgne (Schlumberger Inc), Lansing Horan (AFTAC)

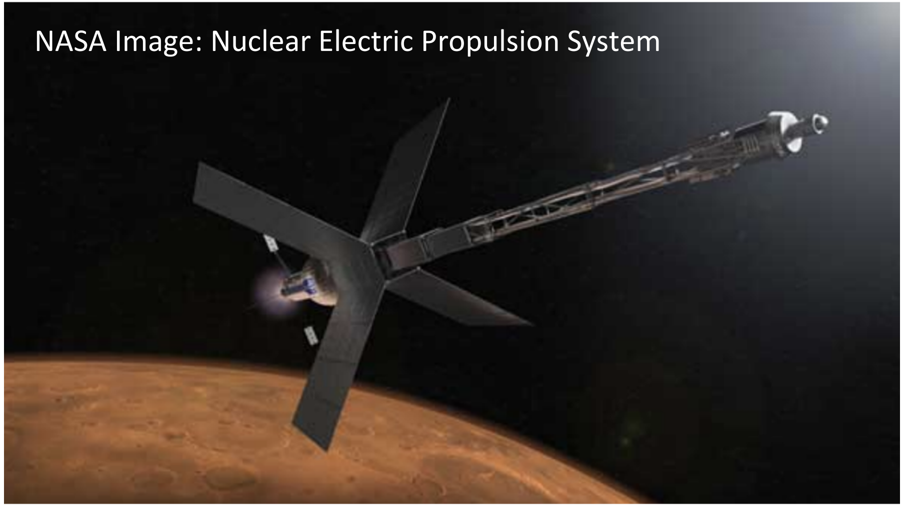
Space-Based Nuclear Threat Detection Data Needs:

- **Context: Space-based monitoring is an important asset for monitoring nuclear events.**
- More incident neutron energies
  - Forward modeling of source is limited by lack of smooth transition from asymmetric to symmetric fission
  - Predicting isotopic ratios is carries more uncertainty than simply using current accepted values
- Isotopic decay half-lives ~0.5 s can have significant uncertainties (for example: ± 0.5 s)
  - Can cause naive network decays schemes using linear solvers to become very stiff
  - Alternate methods have been developed: Integral, exponential moment, etc.
- Significant uncertainties in early time gamma ray emissions from fission fragments
  - 100 microsec to about 100 ms, short-lived isomeric decays, bounds on broad energy grouping, half-lives of isomeric isotopes, production estimates from U-235, U-238, Pu- 239
- Quantifying uncertainty is required for all reporting, but is an ongoing challenge
  - Currently building an approach to estimate uncertainty in delayed gamma rays using declared ENDF uncertainty

-David Gerts (LANL)

Space Reactor Data Needs (1/2):

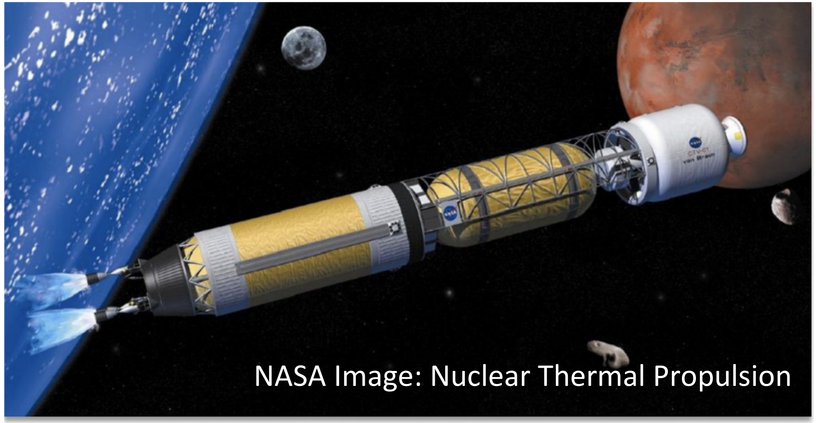
- **Context: NASA is currently studying a wide range of options for nuclear power to enable human exploration.**
- Small and precise reactors require optimized power and lifetime predictions:
  - Power distribution, reactivity control and shutdown margin, fission product inventories
  - Fission product yields are also important for thermonic energy conversions
- Precise source term and shielding data:
  - Prompt neutrons and gammas from fission, gamma emissions from fission product decay, neutron capture data, material activation and decay, neutron and gamma attenuation



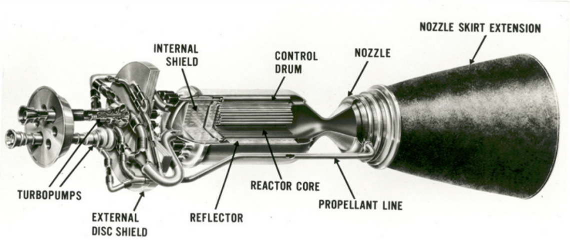
NASA Image: Nuclear Electric Propulsion System

- Brad Rearden (X-Energy), Austin Lo (UC Berkeley)

Space Reactor Data Needs (2/2):



NASA Image: Nuclear Thermal Propulsion



1960s Nuclear Engine for Rocket Vehicle Application (NERVA)

- Thermal scattering law data:
  - Advanced moderators/reflectors are needed for small HA-LEU cores, YHx is of interest for lower temperature applications, NTP systems approach 3000 K for fuel and structural materials with H_2 as internal propellant
  - Will doppler-shifting the data to account for temperature work with crystalline structures?
- Irradiation damage assessment is needed for wide range of materials: Damage cross sections should be included in ENDF libraries:
- Data relevant to space radiation (GCR and SPE) interacting with reactor materials.

- Brad Rearden (X-Energy), Austin Lo (UC Berkeley)

So what do we (space application community) need in terms of improved nuclear data? (chat responses)

Correlated neutron-gamma ray production for fast -> slow neutrons. Epithermal neutron capture gamma-ray spectra (Bernstein)

Double-differential alpha-induced reaction cross sections on light nuclei for improved shielding modeling and materials damage studies (Francesca's talk, Bernstein)

- Correlations between outgoing particles: particle detection
- Angular correlations between emitted gammas: particle detection and modeling damage metrics
- Secondary gamma production for more than capture reactions: material survivability
- Improved attention on the recoil atom energy spectra: support for nSEE studies and equivalence of proton sources used to simulate the LET spectrum from neutron interactions. (Patrick Griffin)

Neutron-induced gamma ray production cross sections on light elements particularly at 14 MeV incident neutron energy (but others as well) (Unzueta)

Match of the secondary gamma ray energy between ENDF and ENSDF and the Baghdad atlas (or any better inelastic gamma ray reference) (Mauborgne)

high energy He induced double differential cross sections on light ions (p, d, t, 3He, neutrons) - also of interest to medical physics (radiotherapy), and isotope production (Heilbronn, Luoni)

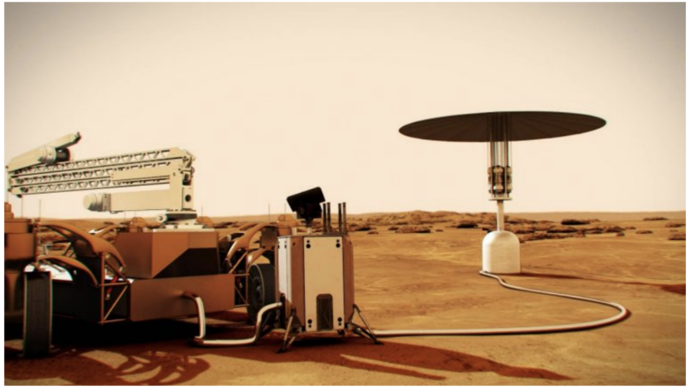
Neutron inelastic and capture gamma ray cross sections; useful for planetary nuclear spectroscopy, isotope production, active interrogation (oil field work and homeland security) (Peplowski)

Accurate neutron captures for creating secondary gammas (exothermic) and also other secondary particles (for Si/O, endothermic), in a well-validated Monte Carlo code (Horan +other nuclei, Bernstein)

What's next for the space applications community?

- Finish the WANDA 2021 effort:
  - Identify cross-discipline needs.
    - Many issues discussed here are also of interest to isotope production, reactor/accelerator shielding, and national security and non-proliferation communities.
    - This should be included in the WANDA 2021 PRR paper.
  - Engage the nuclear evaluation community to identify immediate needs:
    - Improve cross section libraries for our reactions of interest
    - Identify an element of interest for the community (Al, Mn?) to measure cross sections from 1 MeV to 3+ GeV for model development and benchmarking.

- Post-WANDA 2021
  - Follow-on summer workshop on space-based nuclear data needs?
    - Similar participation as this WANDA session, more targeted discussions.
    - Find and engage a relevant NASA PM.



Feedback is welcome from everyone as we pull together the summary report!

Please contact any session co-chair if you have something to contribute.