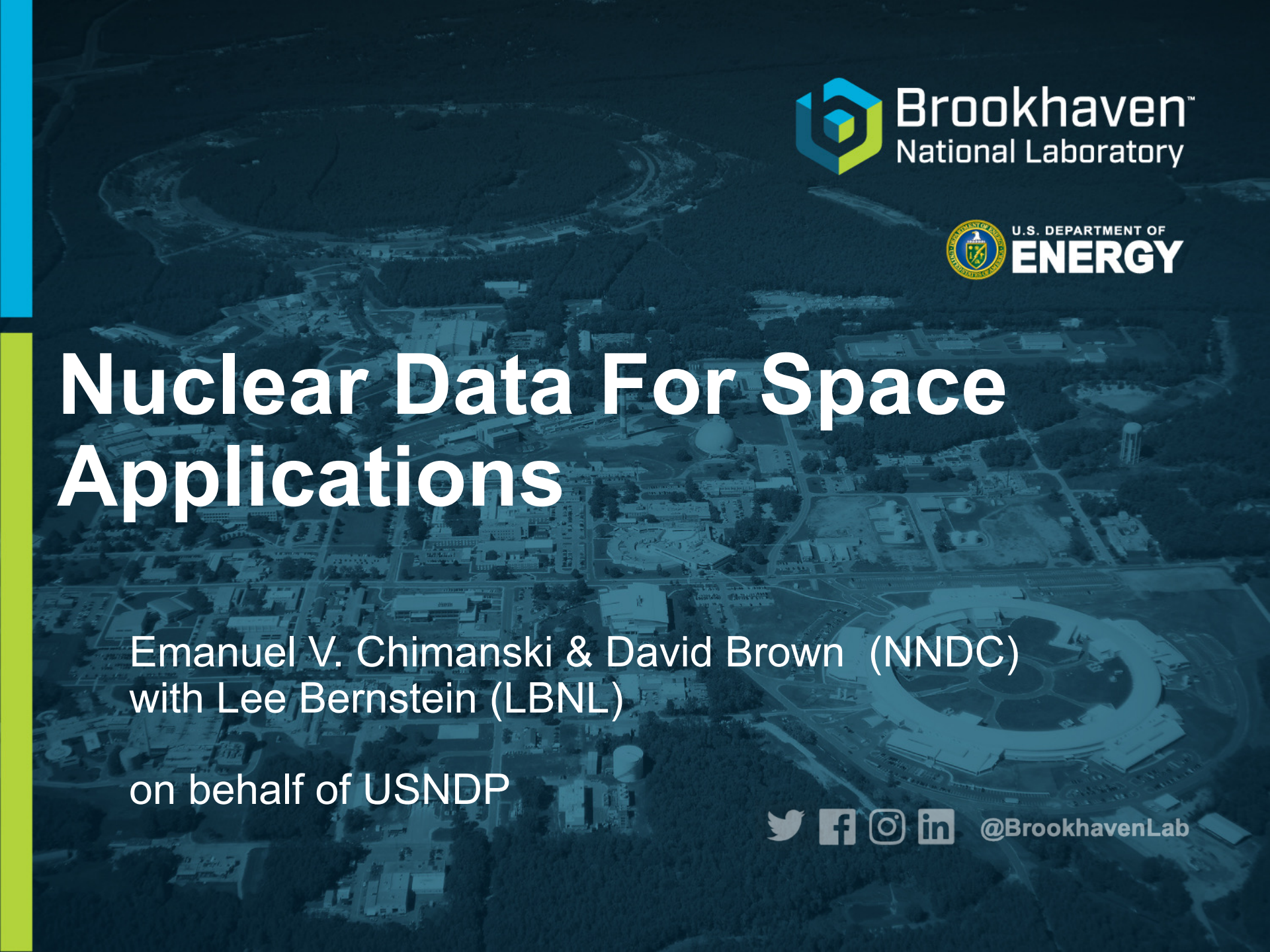
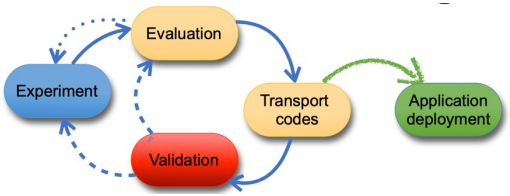

Brookhaven
National Laboratory
U.S. DEPARTMENT OF
ENERGY
Nuclear Data For Space Applications
Emanuel V. Chimanski & David Brown (NNDC)
with Lee Bernstein (LBNL)
on behalf of USNDP
@BrookhavenLab

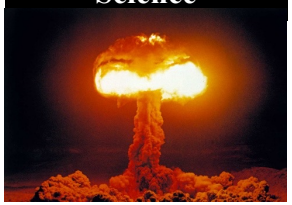
Nuclear Data and Space Applications

Applications rely on solid foundations

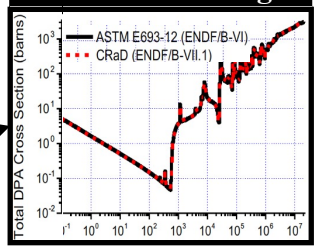
ENDF B-VIII.0



Stewardship Science



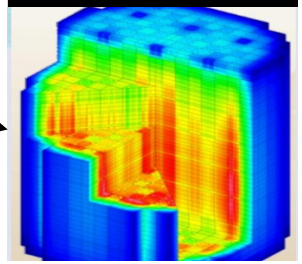
Materials Damage



Nuclear Data

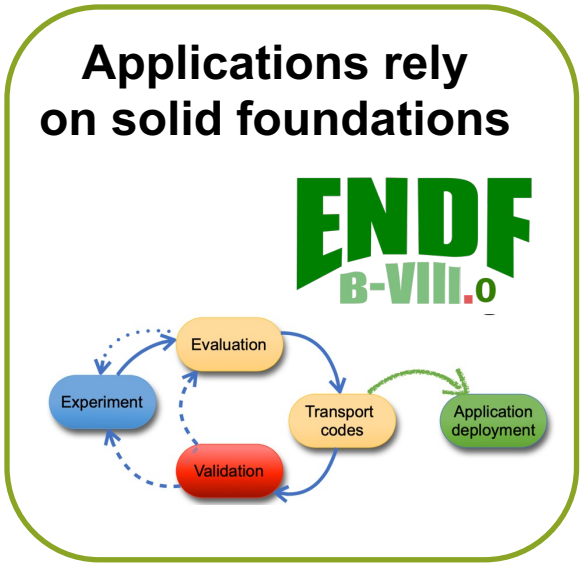
Medicine

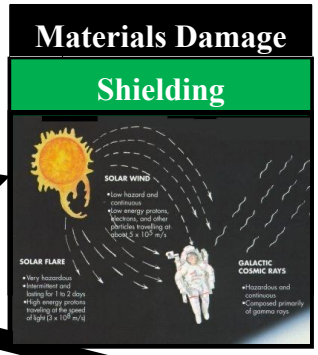
Energy

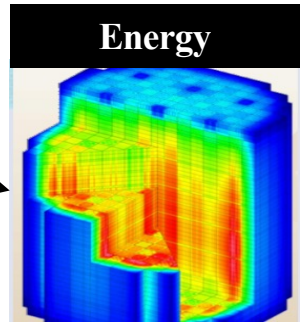


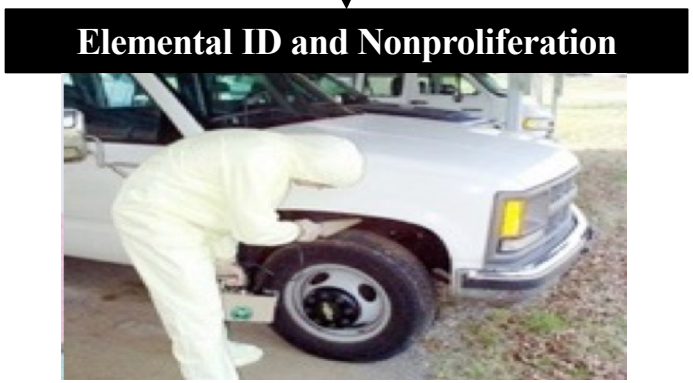
Elemental ID and Nonproliferation

Nuclear Data and Space Applications





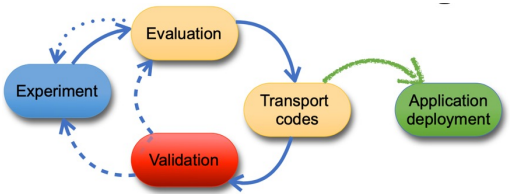




Nuclear Data and Space Applications

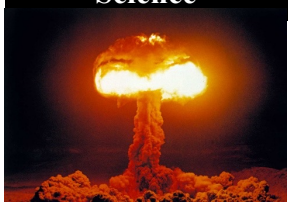
Applications rely on solid foundations

ENDF B-VIII.0



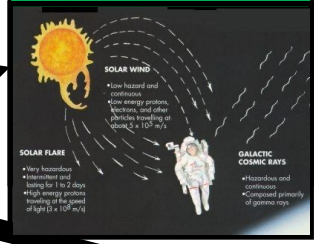
Nuclear Data

Stewardship Science



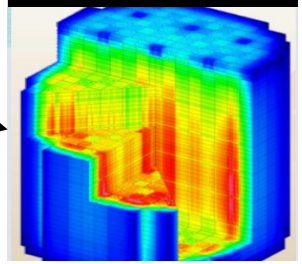
Materials Damage

Shielding



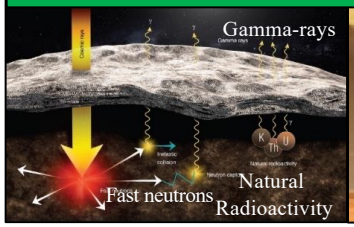
Medicine

Energy



Elemental ID and Nonproliferation

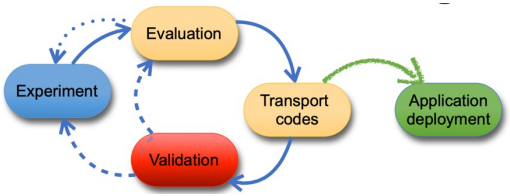
Active Interrogation



Nuclear Data and Space Applications

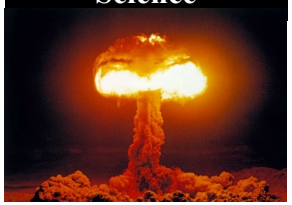
Applications rely on solid foundations

ENDF B-VIII.0



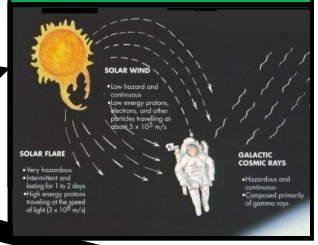
Nuclear Data

Stewardship Science



Materials Damage

Shielding

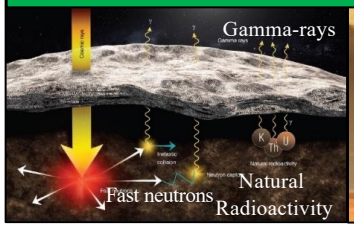


Medicine

Energy

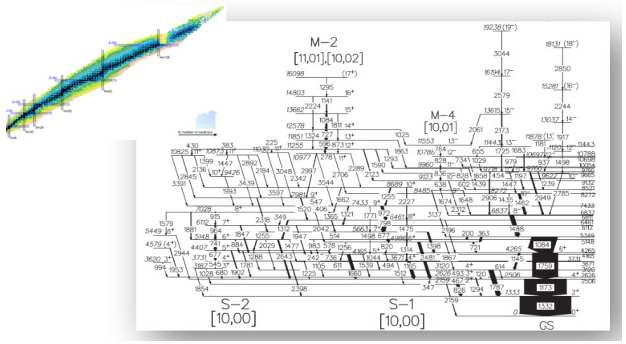
Elemental ID and Nonproliferation

Active Interrogation



Evaluated Nuclear Data

ENSDF
Evaluated Nuclear Structure Data File

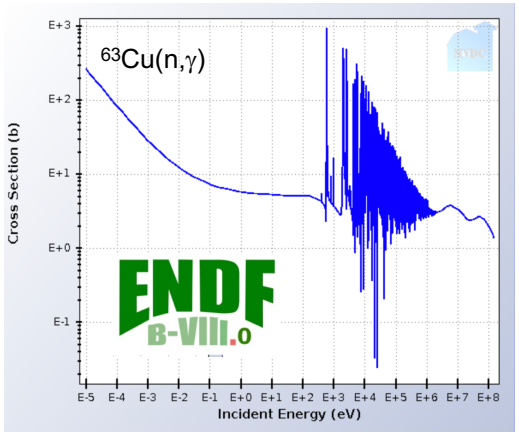


Measured data

- Structure and Decay Properties

If it was measured it is here

+



ENDF
Evaluated Nuclear Data File

Experimental supplemented with theoretical data

- Cross sections
- Particle spectra
- and much more…

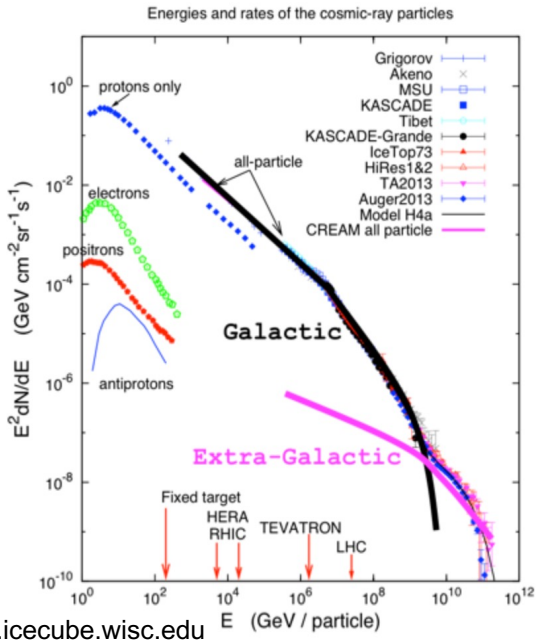
Shielding the Danger Hidden in Space

- Understand the **harmful** effects of **G**alactic **C**osmic **R**ays (GCRs) **requires a substantial amount of nuclear data**.
  - ➢ GCR charged particles interaction with spacecraft materials generates **secondary radiations** that, through energy deposition, can harm astronauts and electronic systems
- **Wide range of energies** (up to ~TeV) and **species** (*Z* ~1–28) (large overlap with nuclear science -- isotope production, ion beam analysis, fusion reactions, nucleosynthesis, fission reactors)

Nasa's Solar Dynamics Observatory
October 2, 2014.

Solar flares last 1-2 days
High energy protons!

Adapted image (L. Han/IAEA)

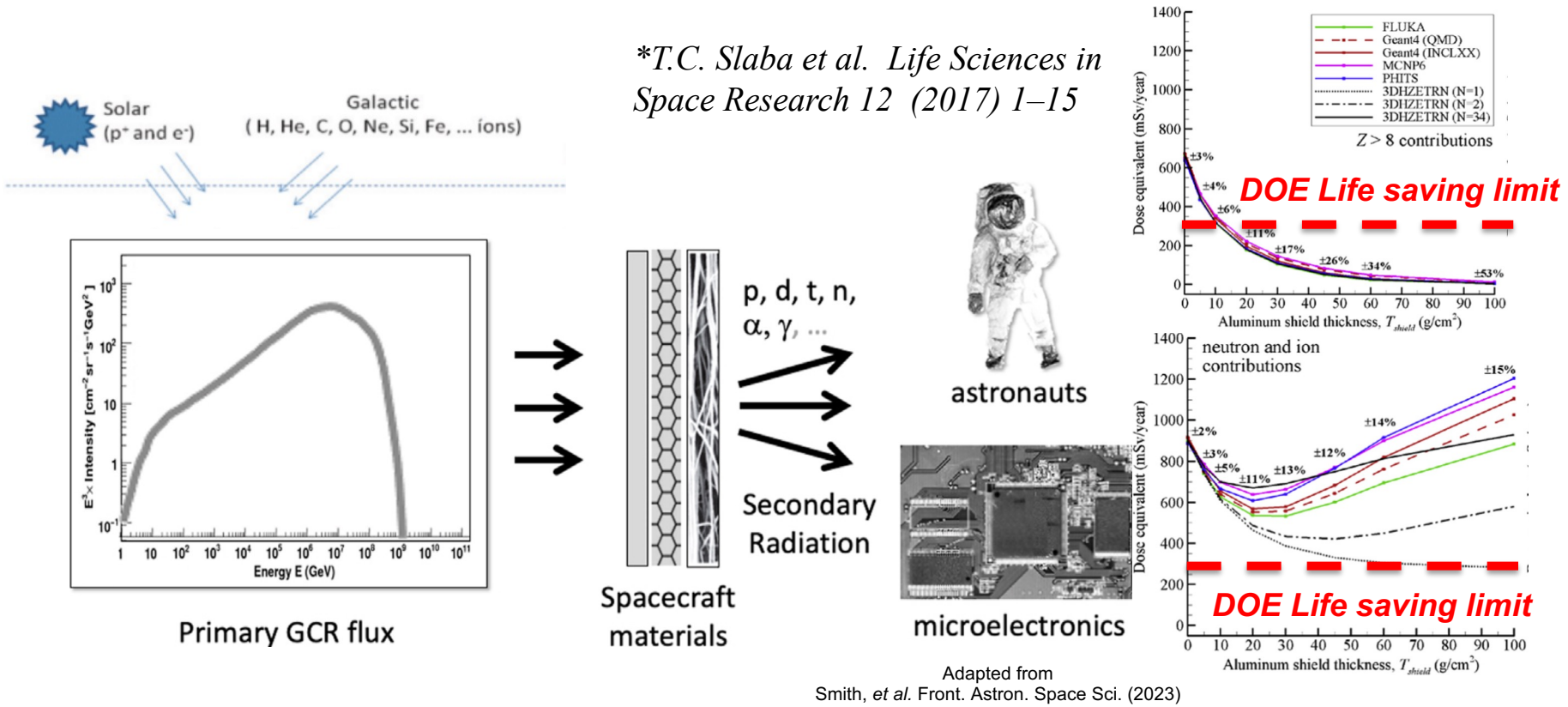


More in Smith, *et al.* Front. Astron. Space Sci. (2023)

masterclass.icecube.wisc.edu

Shielding the Danger Hidden in Space

*T.C. Slaba et al. *Life Sciences in Space Research 12 (2017) 1–15*



Adapted from
Smith, *et al.* Front. Astron. Space Sci. (2023)

- In space we don't have an atmosphere to provide a protective barrier

Above the Earth's atmosphere the GCRs provide a serious **impediment** to the **safety** and **viability** of space exploration.

Shielding the Danger Hidden in Space

There are gaps in coverage: no heavy-ions, not enough high energy

Evaluated

(this is what goes in transport codes)

- PDG only elementary particle properties
- **ENDF only < 150 MeV + decay data**
- Three major data projects (JAEA, US, EU) have made forays into HE

Experimental data compilation

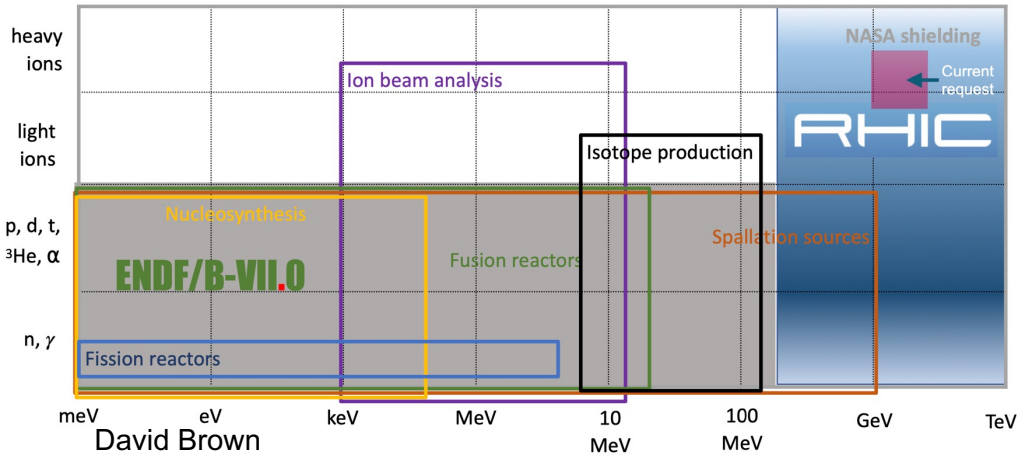
- EXFOR/NSR partial tabulation of data/references most comprehensive did not focus on High Energy

- Pilot project to compile RHIC/AGS data @NNDC but **data appears lost**

ROSSINI3 project (ESA-NASA-GSI *)

*https://www.gsi.de/work/forschung/biophysik/fragmentation, https://crosssection-db.herokuapp.com

USNDP libraries and RHIC/AGS/NRSL can cover



Theory

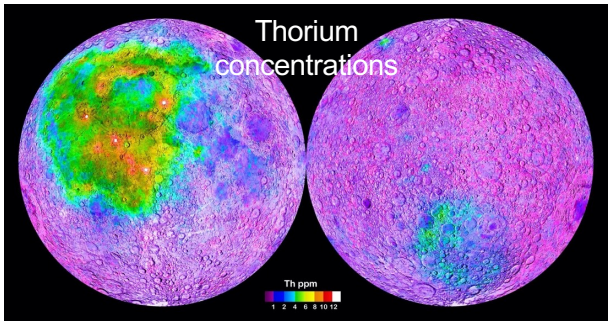
Complex cross over from **statistical** and **direct reaction** theory to **multifragmentation**

Good models but in need of tuning for extrapolation to all relevant systems

Opportunity to collaborate to meet data needs for emerging applications

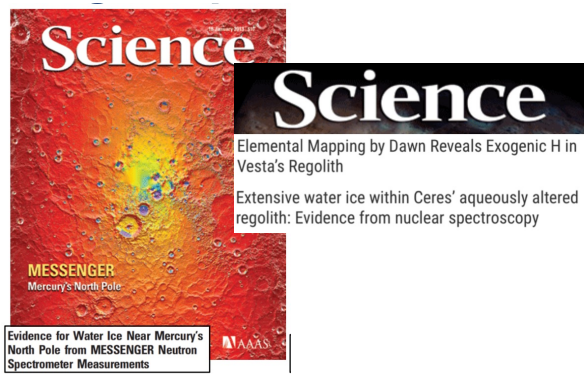
Planetary Nuclear Spectroscopy: Space exploration!

Lunar Prospector (1998) - gamma rays



- **Planetary gamma-ray spectroscopy** via **A**ctive **I**nterrogation (AI) is an established technique for characterizing the surface composition of planets from orbit
  - ➢ The success of **AI** depends on quality of **evaluated nuclear data**: Uncertainties vary from ~5 to ~25% for these cross sections. >10% drives the systematic uncertainties of planetary measurements.
- NASA currently has numerous active and upcoming investigations valued at >$100M.

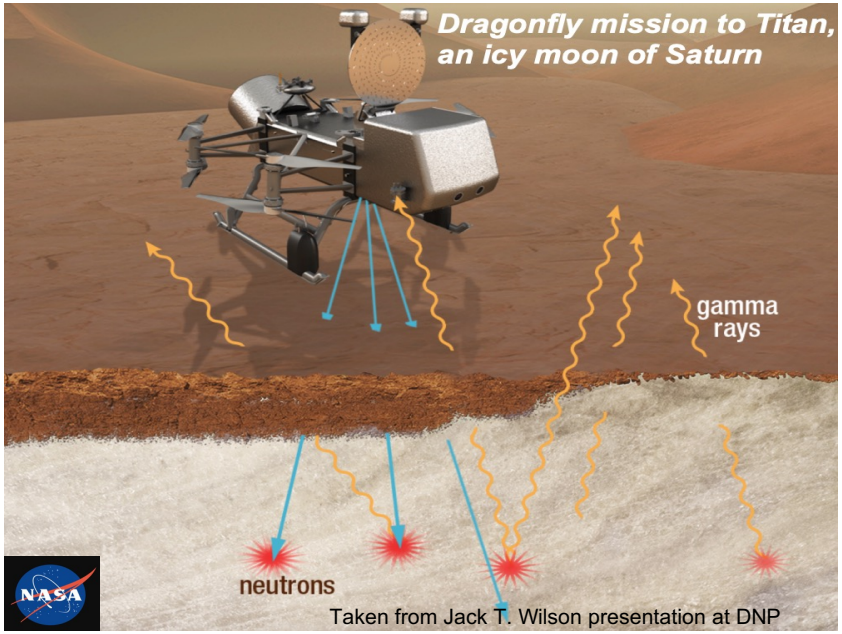
High Impact Science!!



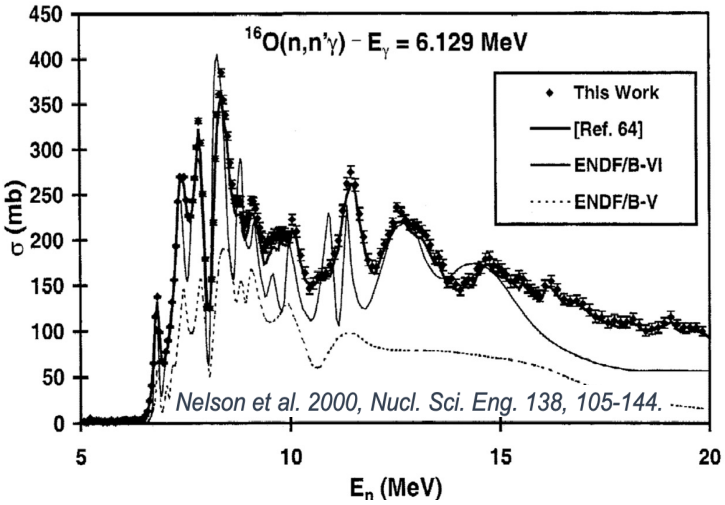
Neutron Interrogation for Material Characterization is strongly dependent on gamma ray production libraries

Planetary Nuclear Spectroscopy: Space exploration!

- **Active Interrogation with fast neutron beams**
  En = 14 MeV
- **Capture, Inelastic and Decay Gammas**
  Nuclear fingerprints
- **Subject to**
  - Thorough experimental knowledge;
  - Precise models and evaluations;
  - Incorporation of data into evaluated files;



Taken from Jack T. Wilson presentation at DNP



- **Missions**:
- LunaH Map (2022+)
- Psyche (2023),VIPER (2023)
- MMX (2024)
- **Dragonfly (2026)**
- Commercial Lunar Payload Services (multiple payloads/missions, 2022+)

Gamma Rays Induced by Neutrons
The GRIN team

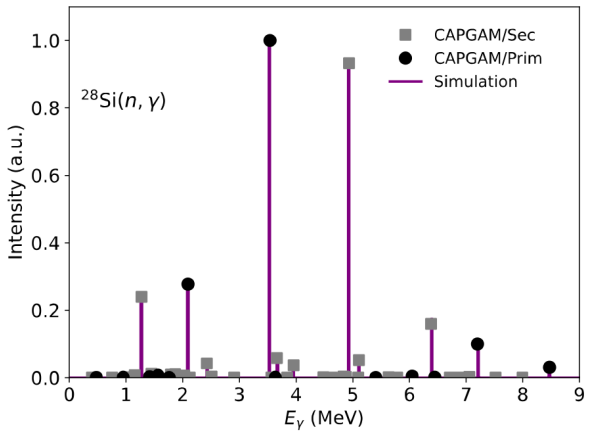
- **BNL:**
  - E. Chimanski;
  - D. Brown, G. Nobre
  - S. Ota, E. McCutchan, C. Morse
- **LLNL:**
  - B. Beck, G. Gert, C. Matton, J. Verbeke
- **UCB/LBNL:**
  - A. Hurst, L. Bernstein
- **IAEA:**
  - R. Capote
- **JSI:**
  - A. Trkov

Gamma Rays Induced by Neutrons (GRIN)

We are identifying and fixing problems related to the ENDF/B capture and inelastic gamma-ray evaluated data[1]

The Need

- The applications
- Inelastic and Capture gammas
- Modeling needs



The Issues

- Bad ENDF gamma data
- ENSDF!=ENDF
  - **ENDF structure data must be synced to ENSDF**
- Need more physics!

(capture is HARD) requires significant effort from evaluator

We can now fix gamma data for (n,n'), (n,p), (n,a), … data,

not just (n,n')

[1] E. V. Chimanski, *et al.* The current status of inelastic and capture gamma-ray production evaluations in translated endf-viii.0 gnds files and recommended remediation actions, Tech. Rep. BNL-224447-2023-INRE (2023)

We can go further than just capture and Inelastic

The GRIN project is making tools that can later be employed in fixing other reaction channels also important for applications

For example, the different reaction channels important for A.I.

$^{16}O(n,n'\gamma)^{16}O$	6128.6	2^{nd} (3-) → G.S. (0+)	100% E3
$^{16}O(n,p)^{16}N$	6128.6	2^{nd} (3-) → G.S. (0+)	100% E3
$^{16}O(n,n'p\gamma)^{15}N$	5269.2	1^{st} (5/2+) → G.S. (1/2-)	100% (M2 + E3)
$^{16}O(n,n'\alpha\gamma)^{12}C$	4438.0	1^{st} (2+) → G.S. (0+)	100% E2

and more…

But often we find ourselves with lack or old evaluated data…

^{16}O ENSDF evaluation is 30 years old
Updating ENDF is complicated without data

Workshop for Applied Nuclear Data Activities (WANDA)

- We have been going to WANDA to echo and highlight the space applications needs;

The Berkeley Atlas: A database of absolute cross sections for inelastic, gamma-ray production with 14 MeV neutrons

in response to

Nuclear Data InterAgency Working Group (NDIAWG) Research Program
FOA DE-FOA-0002952

Approved!

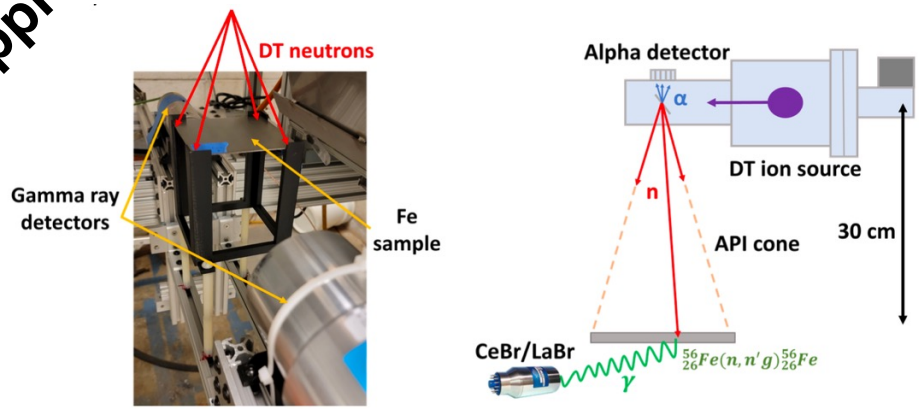


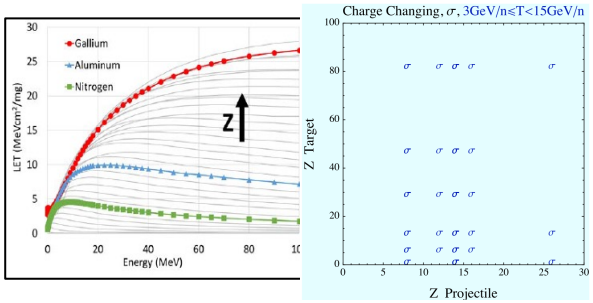
Figure 8: Actual (left) and schematic (right) Experimental setup showing the placement of both an iron sample relative to the neutron source and the gamma-ray detectors.

- **Johns Hopkins University Applied Physics Laboratory (Lead Institution)**
  - P. Peplowski (P.I)
  - J. Wilson (Co-P.I)
- **Lawrence Berkeley National Laboratory**
  - A. Persaud (Co-P.I)
  - L. Bernstein (Collab)
- **NASA/Catholic University of America**
  - M. Ayllon-Unzueta (Co-P.I)
- **Brookhaven National Laboratory/NNDC**
  - E. Chimanski (Co-P.I)
  - D. Brown (Co-P.I)
- **Schlumberger Inc. (SLB)**
  - Marie-Laure Mauborgne (Unf. Coll.)

Nuclear Data and Space Applications

Shielding and Space Radiation

Stopping Powers for Secondary Particles[2]



Cross Section & Stopping Power data is needed to model Linear Energy Transfer for Event Effects and Fission Fragment Energy Deposition

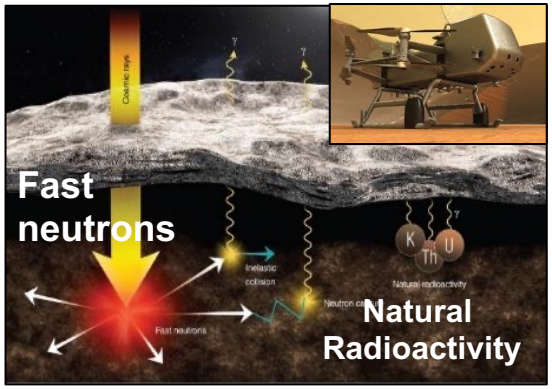
Interplanetary Astronaut Dose Considerations[1]

~ 100 MeV/n - 10 GeV/n
- Projectile **fragmentation partial** and **total cross-sections**.

[1]J. Norbury et al., Rad. Meas. (2012) + numerous
[2]J. Osheroff *et al.,* IEEE Trans. (2021)

Active Interrogation

Fast neutrons (14 MeV) (DT) generators



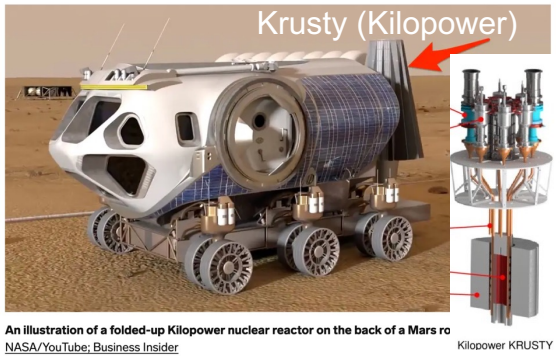
Inelastic, Capture and Decay Gammas (nuclear fingerprints)

- For basically all elements < Cu
- Precise models and evaluations
- Incorporation of data into evaluated files

C. Romano *et al.,* WANDA 2020 Final Report. ORNL/TM-2020/1617 (2020).
P. Peplowski numerous

Nuclear Propulsion/Power

Fission-powered rockets



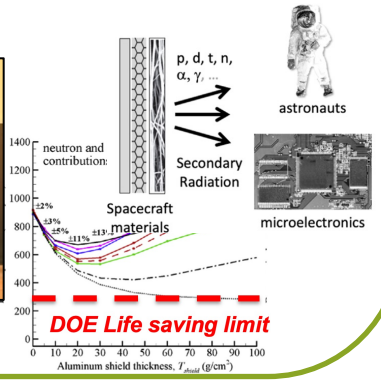
Cross Section data already needed for powerplants

New: Spin Polarization for **Fusion** Propulsion[1]
- Larger cross-section (facilitates fusion ignition). Provides direction for reaction products (better trust, reduces weight)

[1]L. Baylor *et al Nucl. Fusion (2023)*

A joint effort to support Space Applications
Experiment + Evaluations + Validation

- Space exploration requires efforts in the **"nuclear data pipeline"**
  - Experimental measurements
  - Compilation
  - Evaluation
  - Databases and dissemination (modernization)
  - Reaction modeling and uncertainty quantification.



We're organizing a
Satellite Meeting (@DNP2023)

Announcement of the Satellite Meeting at the 2023 Fall Meeting of the Division of Nuclear Physics of the American Physical Society and the Physical Society of Japan:

Topic: Nuclear Data for Space Applications
Date: October 7, 2023
Location: Hyatt Regency Maui Resort and Spa, Hawaii

- 6 invited + contributed talks

- Theory
- Transport codes
- Radiation Damage
- Evaluations
- Measurements
- Data needs

On hold due to the catastrophic fires in Maui moving to 11/26 or 12/2 (Waikoloa)

Thank you!

chimanski@bnl.gov