Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Nuclear Data for Space Exploration

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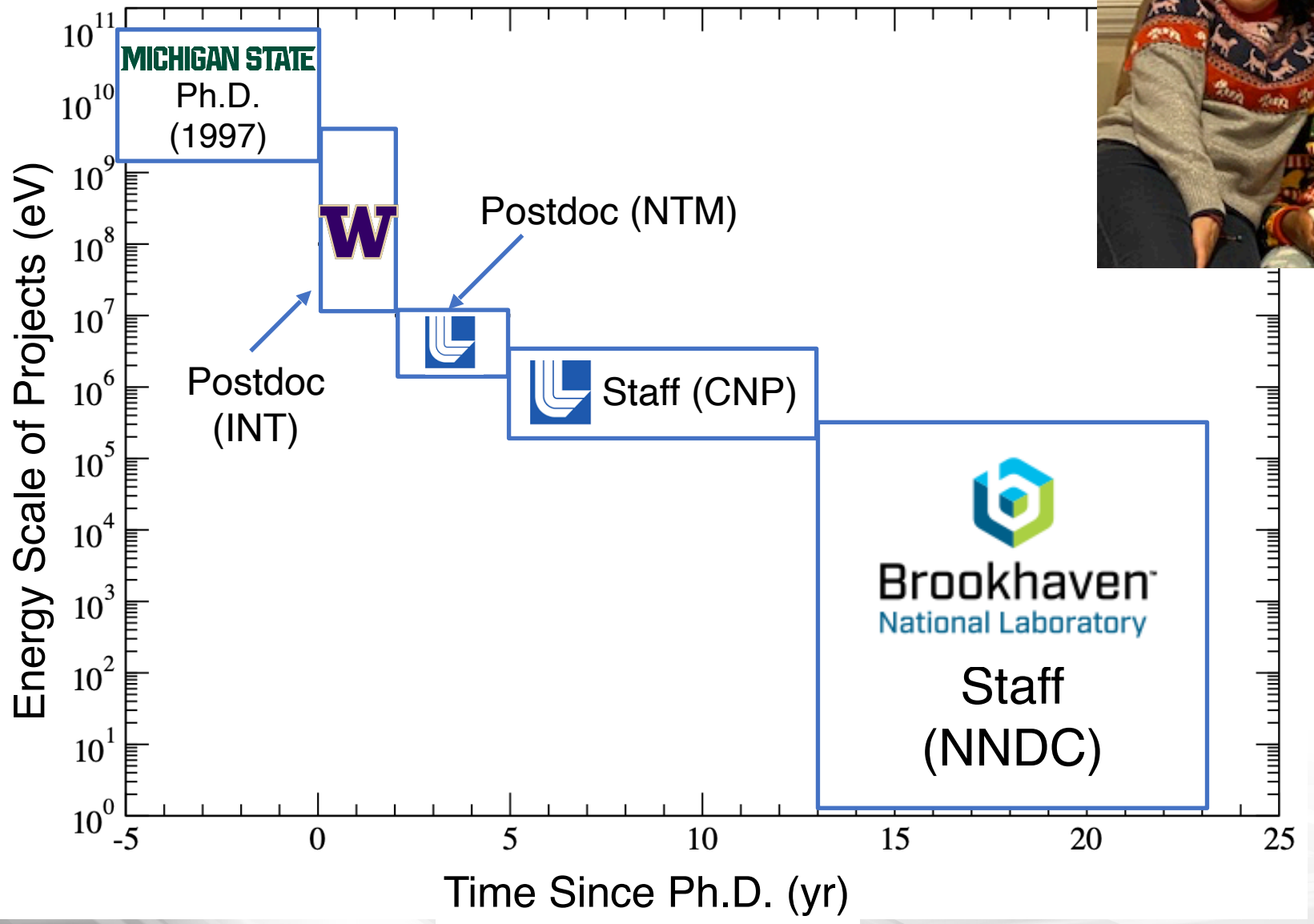
David Brown (NNDC, BNL),
Dan Cebra (UC Davis)

BNL Nuclear Physics Seminar,

17 August 2021

@BrookhavenLab

About me



Responsibilities

- NNDC Group Leader
- Chair USNDP & CSEWG
- Outgoing ENDF Library manager
- PI for NCSP, IF Venture, ^{238}U(n,n'g) projects
- Chair of Expert Group on GNDS

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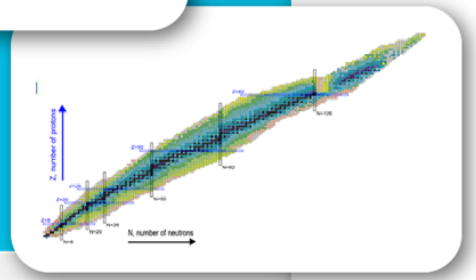
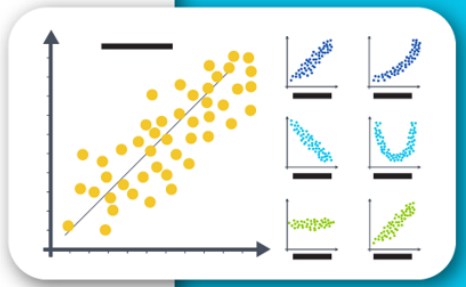
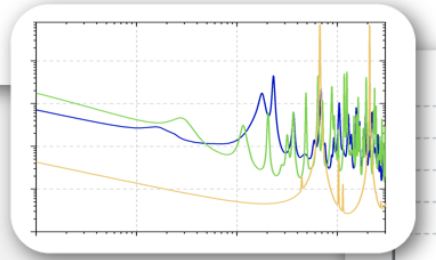
NATIONAL NUCLEAR DATA CENTER

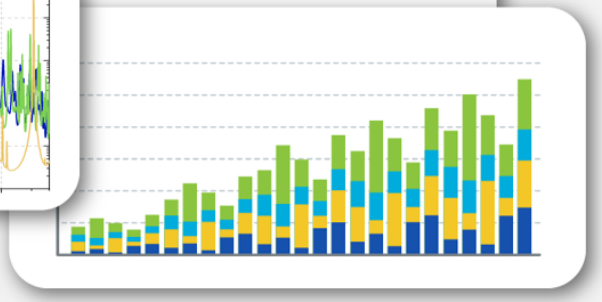
NNDC

Current, accurate, authoritative data in areas of nuclear science and engineering









PuRe Data Resources

Office of Science designated PuRe Data Resource | open data | data repositories, knowledgebases, analysis platforms

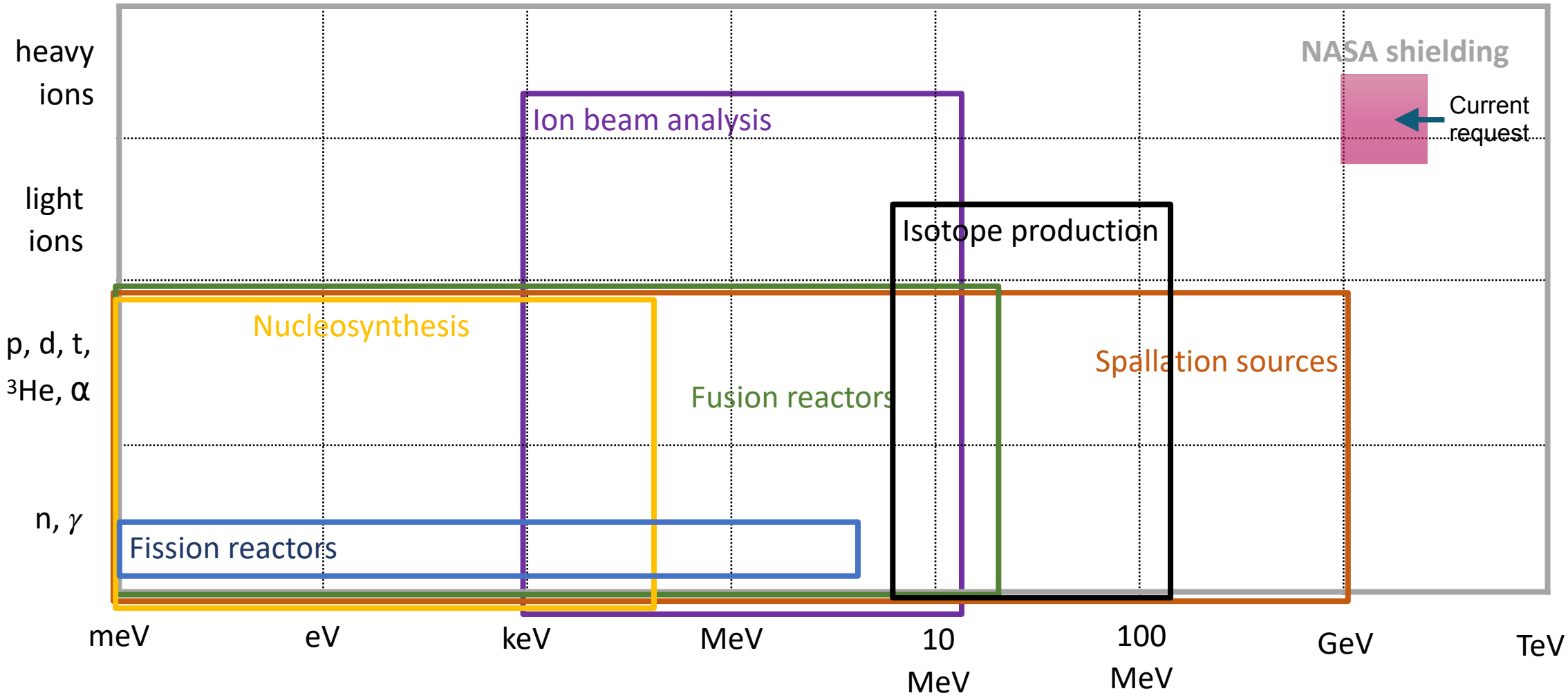
About the National Nuclear Data Center

- **Designated as PURE data resource May 2021**

  Public Reusable Research (PuRe) Data is a designation for key data repositories, knowledge bases, analysis platforms, and other activities that strive to make data publicly available to advance scientific or technical knowledge. Designation as a PuRe Data Resource does more than simply recognize the importance of these investments -- it carries the weight of SC stewardship. SC manages these resources under an oversight model with high standards for data management, resource operations, and scientific impact. The designated PuRe Data Resources go above and beyond the standard SC requirements for data management plans and act as community leaders in data stewardship.

- **Lead unit of the US Nuclear Data Program**
- **Maintains several unique & authoritative data resources:**
  - Nuclear Science References (NSR) - bibliographic resource for nuclear science
  - eXperimental Unevaluated Nuclear Data Library (XUNDL) - experimental nuclear structure data
  - Evaluated Nuclear Structure Data File (ENSDF) - world standard nuclear structure database
  - EXFOR (Area 1) - all nuclear reaction experimental data
- **Chairs CSEWG which produces the ENDF data library** (more on this soon)

NASA shielding applications cover wide swath of energies & projectiles



Transport codes for shielding applications

FLUKA	FLUKA	INFN (Italy)	http://www.fluka.org/fluka.php	Free reg.
PHITS	PHITS	JAEA (Japan)	https://phits.jaea.go.jp	Open Source
MCNP6	MCNP	LANL	https://mcnp.lanl.gov	EC, RSICC
GEANT4 A SIMULATION TOOLKIT	GEANT4	CERN	https://geant4.web.cern.ch	Open Source
NASA	HZETRN	NASA	https://software.nasa.gov/software/LAR-18803-1	EC, NASA, Free reg.

All codes have built in models that cover different physical regimes

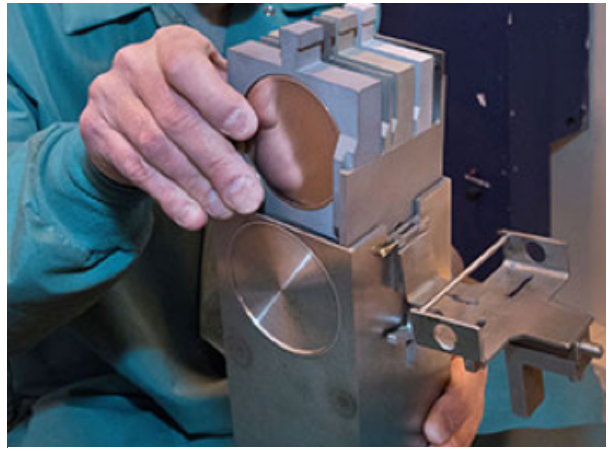
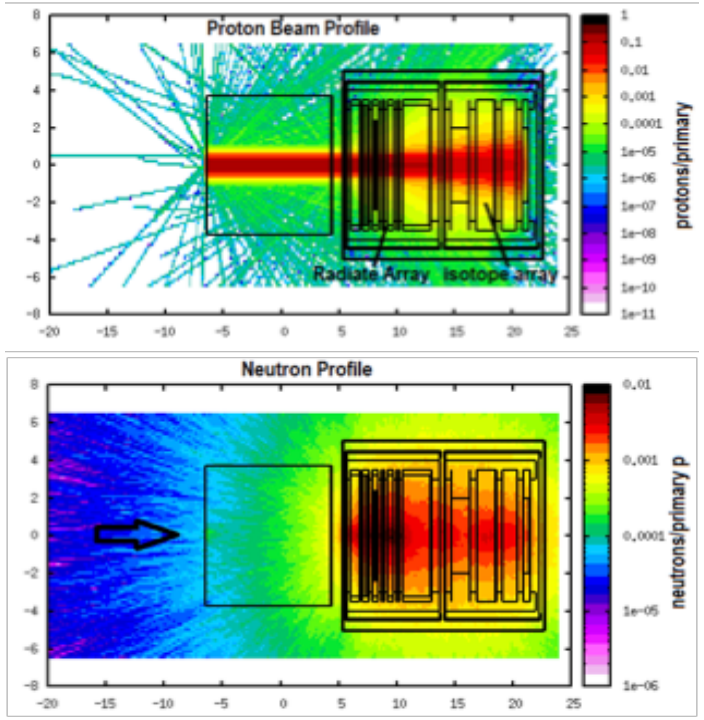
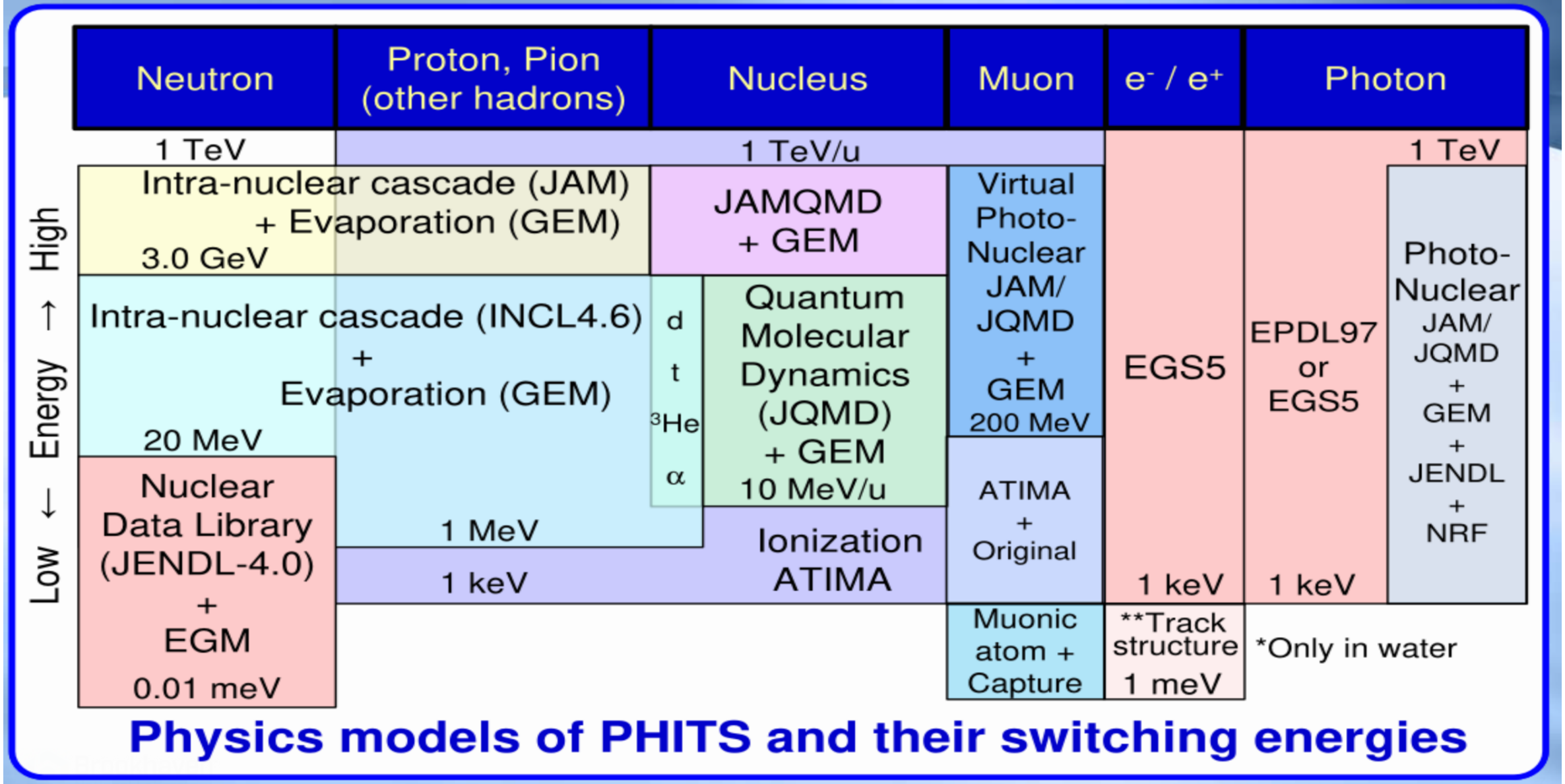


Figure 1: Photograph of a BLIP target stack ready for proton bombardment. (courtesy of C. Cutler)



FLUKA simulation of the BLIP target stack showing the primary proton beam and secondary neutron production (N. Simos (2016))

Map of Models Recommended to Use in PHITS

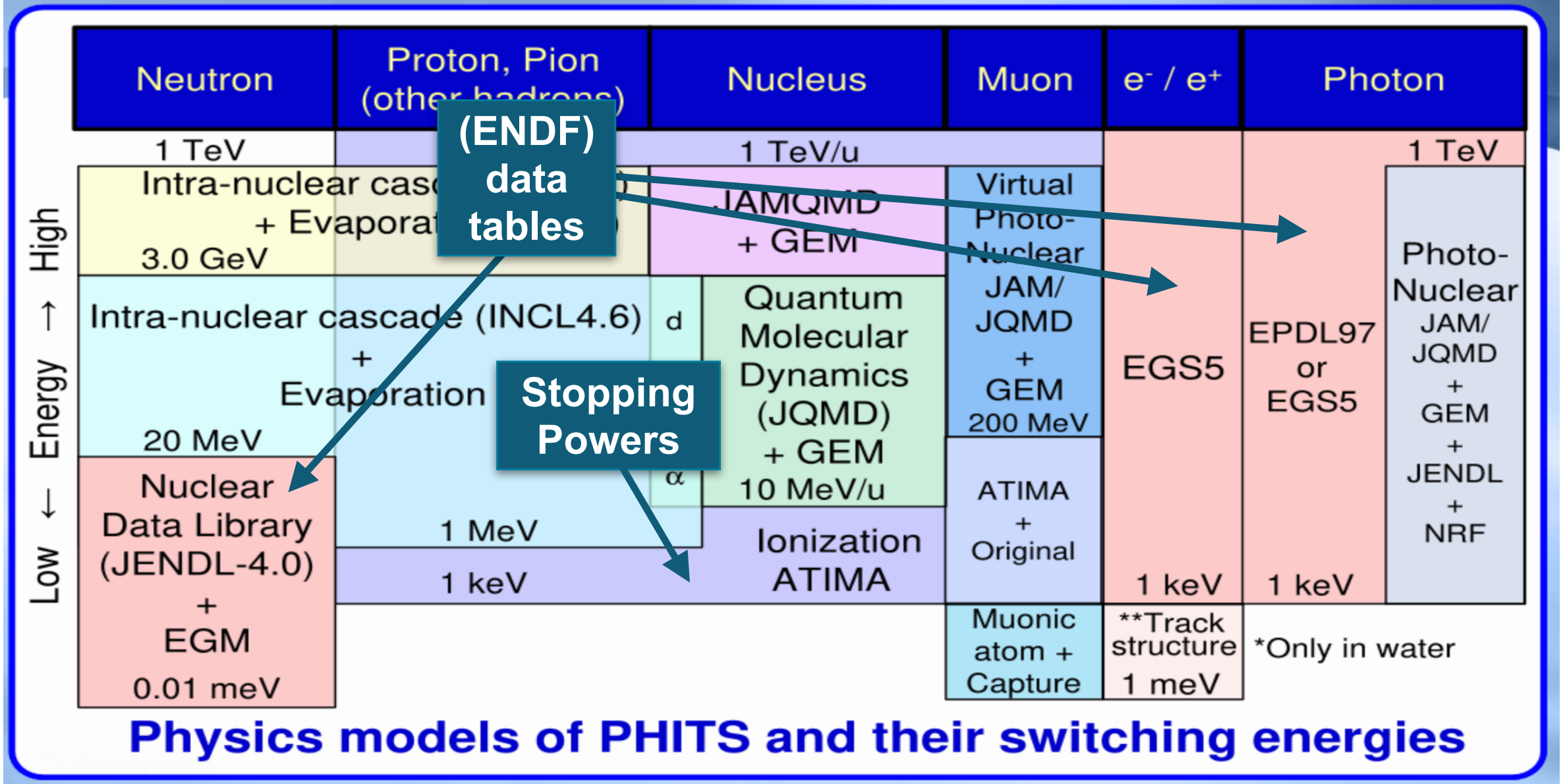


Physics models of PHITS and their switching energies

Switching energies can be changed in input file of PHITS

https://phits.jaea.go.jp/lec/phits-introduction-en.pdf

Map of Models Recommended to Use in PHITS



Physics models of PHITS and their switching energies

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https://phits.jaea.go.jp/lec/phits-introduction-en.pdf

What data do these codes need to produce meaningful results?

Cross sections: Only total cross section and elastic/reaction cross section needed to first approximation

Particle multiplicities

Outgoing particle distributions: $dN/dE'd\Omega$

"Fancy things"- flow, femtoscopy, jets , etc. are unimportant

There is an opportunity to provide modeling support for shielding applications!

Improved modeling above 1 GeV/A?

Punch through achieved!

Nuclei are obliterated!

Only total, elastic and reaction cross sections, multiplicities and energy-angle distributions needed

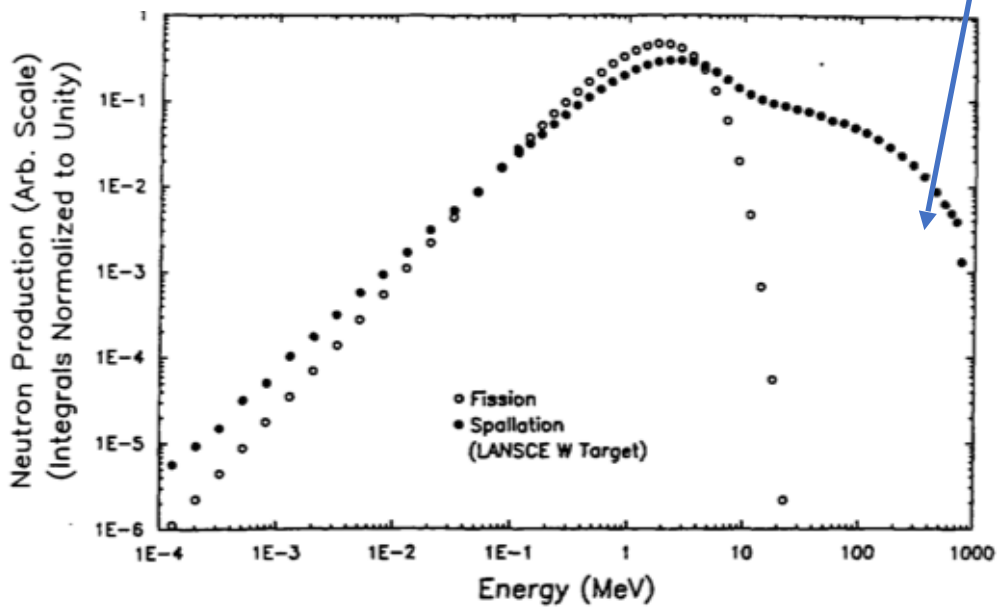


Figure 6. Neutron production from fission (○) and from spallation (●).

Neutron Production from LANSCE Tungsten Split–Target
Bombarded by 800–MeV Protons

G. Russel, "Spallation Physics – An Overview", ICANS-XI International Collaboration on Advanced Neutron Sources KEK. Tsukuba. October 22-26,1990

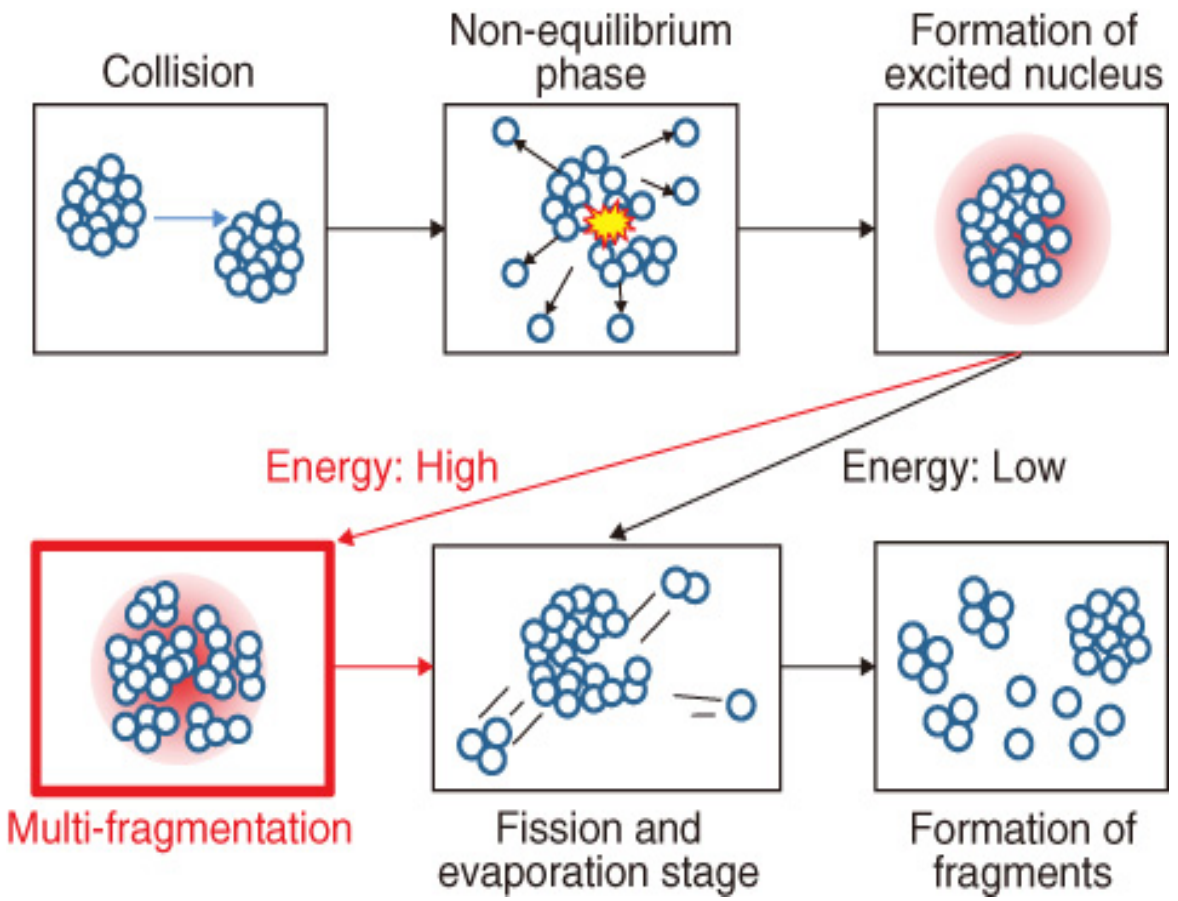
BlastWave, Therminator, etc. level modeling may be enough!

Improved modeling in the 100 MeV/A-1 GeV/A region

Cross over from Hauser-Feshbach & multistep direct/ compound theory to multifragmentation

Corresponds to liquid-gas phase transition in heavy-ions

Theory well developed, but needs tuning to extrapolate to all relevant systems



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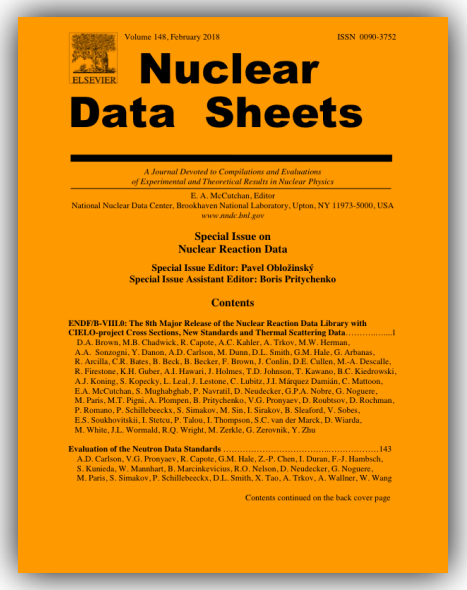
Data tables from ENDF libraries power the low energy portion of these simulations

- Neutrons up to 30-150 MeV (depending on nucleus)
- Light charged particles (p, d, t, ^{3}He, α) up to 30 MeV (150 MeV for p's)
- Electrons up to 1 GeV (atomic)
- Photons
  - up to 1 GeV (atomic)
  - 100 MeV photonuclear
- Decay data

ENDF/B VIII.1

(In development, planned Feb. 2023)

Recommended values combining theory, experiment w/ ML glue



2018 special issue detailing ENDF/B-VIII.0. 755 citations (Google Scholar)

The Cross Section Evaluation Working Group produces ENDF/B library

Formed 1966 & Chaired by BNL

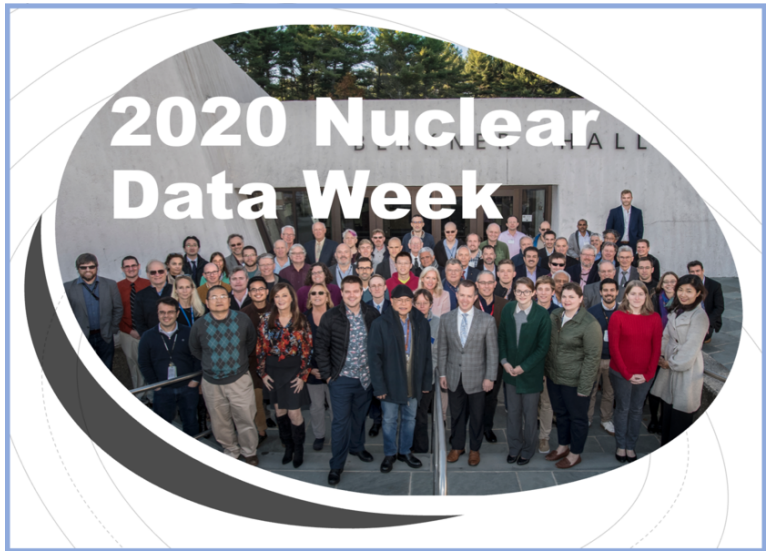
Collaboration of many US programs, industry and international partners

- If you see something in the library, at some point a sponsor somewhere wanted it

All steps of nuclear data pipeline coordinated through CSEWG

Depending on what needs done, getting required data in library can be major effort

We are always open to new users and collaborators



The December 2020 Nuclear Data Week at BNL was virtual. The picture was from the 2019 meeting and reminds us of better days.

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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
- CSEWG's ENDF only < 150 MeV
- Three major regional data projects (JAEA, US, EU) have made forays into HE

Experimental data compilation:

- EXFOR/NSR partial tabulation of data/references most comprehensive but poor HE coverage
- Smaller scale projects with basic science focus: HEPdata, nn-online, GWU DAC
- 3 year ROSSINI3 project (ESA-NASA-GSI) (see https://www.gsi.de/work/forschung/biophysik/fragmentation, https://crosssection-db.herokuapp.com)
- Pilot project to compile RHIC/AGS data @NNDC circa 2000, but data appears lost

Opportunity to collaborate to meet NASA data needs

USNDP libraries and RHIC/AGS/NSRL can cover much of this phase space