



### US Nuclear Data Program databases

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# Transport codes for shielding applications

FUKA	FLUKA	INFN (Italy)	<u>http://www.fluka.org/</u> <u>fluka.php</u>	Free reg.	
<b>PHITS</b>	PHITS	JAEA (Japan)	https://phits.jaea.go.jp	Open Source	
MC P6	MCNP	LANL	https://mcnp.lanl.gov	EC, RSICC	
GEANT4	GEANT4	CERN	<u>https://</u> geant4.web.cern.ch	Open Source	
+ NASA + +	HZETRN	NASA	<u>https://</u> <u>software.nasa.gov/</u> <u>software/</u> <u>LAR-18803-1</u>	EC, NASA, Free reg.	



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))



All codes have built in models that cover different physical regimes

### **Map of Models Recommended to Use in PHITS**

	Neutron	Proton, Pion (other hadrons)		Nucleus	Muon	e- / e+	Photon	
	1 TeV		1 TeV/u					1 TeV
High	Intra-nuclea + Ev 3.0 GeV	ar cascade (JAM) aporation (GEM)		JAMQMD + GEM	Virtual Photo- Nuclear			Photo-
rgy →	Intra-nuclear c Eva	ascade (INCL4.6) + aporation (GEM)	d t	Quantum Molecular Dynamics	JAM/ JQMD + GEM	EGS5	EPDL97 or EGS5	Nuclear JAM/ JQMD
ne	20 MeV	1	зНе	(JQMD)	200 MeV			GEM
ш ↓	Nuclear		α	+ GEM 10 MeV/u	ΑΤΙΜΑ			JENDL +
>	Data Library	1 MeV		lonization	+ Original			NRF
8	(JENDL-4.0)	1 keV		ATIMA	ongina	1 keV	1 keV	
_	EGM					**Track structure	*Only in water	
	0.01 meV				Capture	1 meV		

#### Physics models of PHITS and their switching energies

Switching energies can be changed in input file of PHITS

### **Map of Models Recommended to Use in PHITS**



Switching energies can be changed in input file of PHITS

## Space shielding applications cover wide swath of energies & projectiles



### Evaluated data libraries cover a large range of what is needed, but not all of it!



# 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,  ${}^{3}\text{He}, \alpha$ ) 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

Recommended values combining theory, experiment w/ ML glue



(In development, planned Feb. 2024)



A Journal Devend no Complications and Evaluations of Experimental and Theoretical Results in Nuclear Physics E.A. McCitchan, Editor National Nuclear Data Center, Brookhave National Laboratory, Upton, NY 11973-5000, U www.matchall.got

Special Issue on Nuclear Reaction Data Special Issue Editor: Pavel Obložinský Special Issue Assistant Editor: Boris Pritychenko

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



# 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



### Improved modeling above 1 GeV/A?

Punch through ~ 800 MeV/u

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 (a) and from spallation (a).

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!



# 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!



### There are gaps in coverage: no heavyions, not enough high energy

#### **Evaluated (this is what goes in transport codes):**

- PDG only elementary particle properties
- CSEWG's ENDF only < 150 MeV + decay data
- 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 <u>https://www.gsi.de/work/</u> forschung/biophysik/fragmentation, <u>https://crosssection-db.herokuapp.com</u>)
- Pilot project to compile RHIC/AGS data @NNDC circa 2000, but data appears lost

#### **Opportunity to collaborate to meet data needs for space physics**