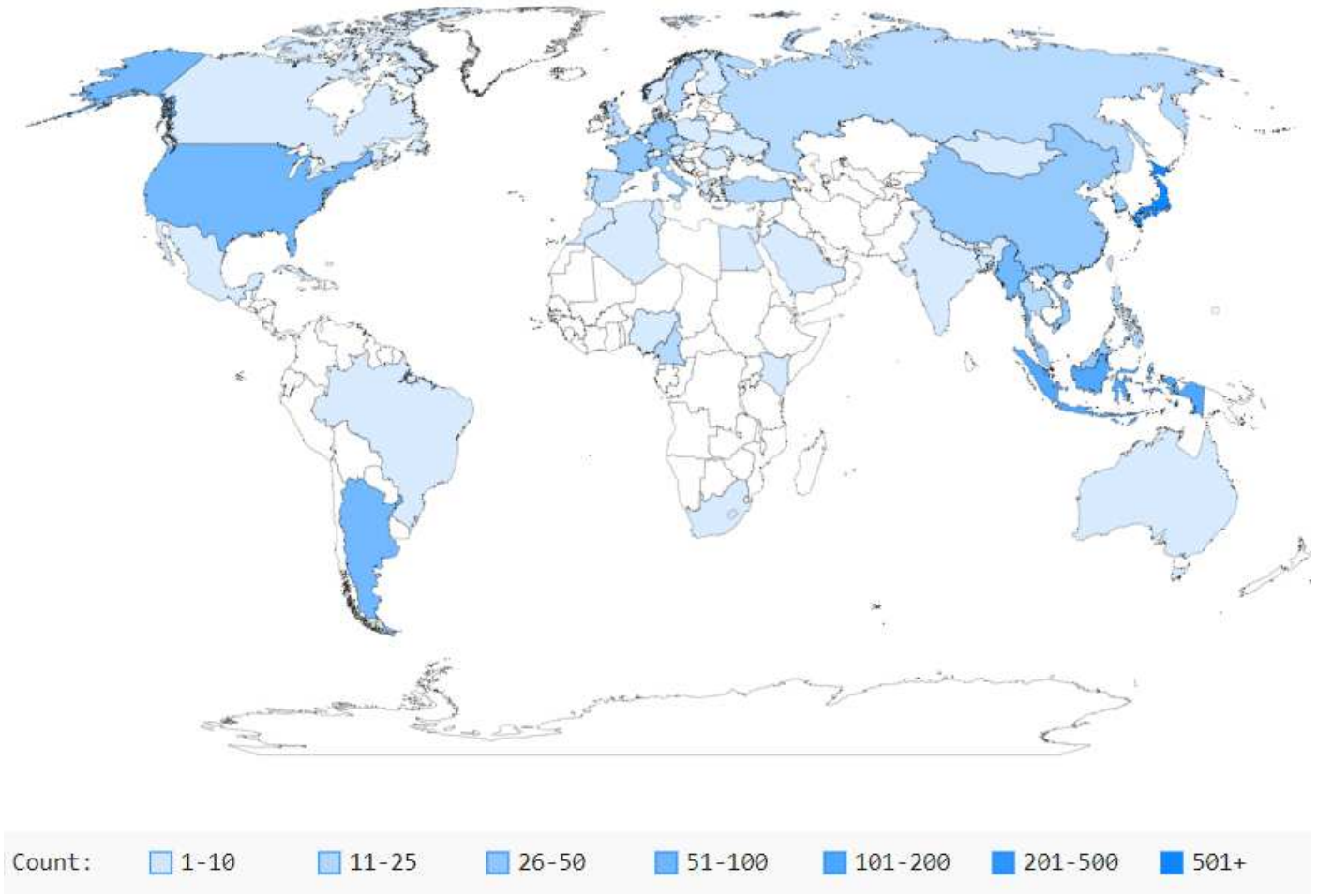
Features of PHITS3.24

PHITS development team, Mar. 2021

Number of PHITS users since 2019



Number of PHITS users in each country since 2019*

*@03/08/2021, based on the location of users' affiliation

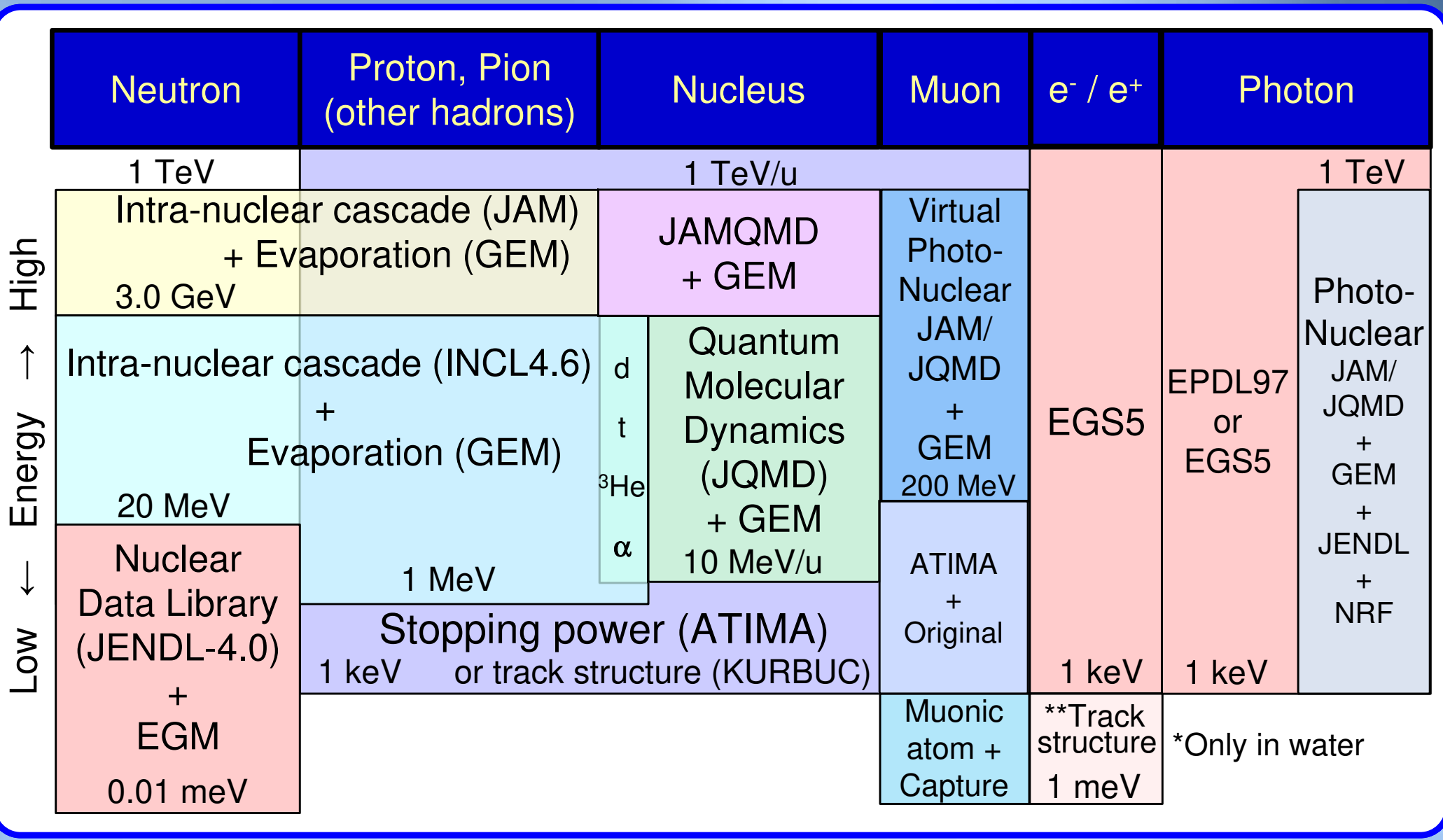
1,886 new users from 53 countries in two years!

Top 10 countries

Country	#users
Japan	1018
Indonesia	112
United States	88
Myanmar	79
Argentina	68
South Korea	46
France	43
Malaysia	39
Germany	32
Italy	31

https://phits.jaea.go.jp/usermap/PHITS_map_userbase.html

Map of Models Recommended to Use in PHITS



Nothing has been changed since the previous version (PHITS 3.20)

Major Upgraded Features in ver. 3.22

Distributed since Oct. 2020

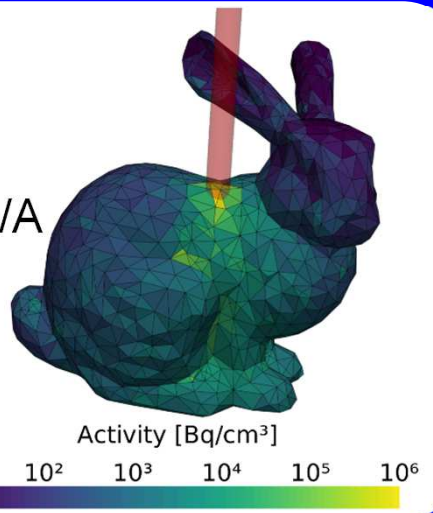
Upgraded Points from ver. 3.20

- ✓ [t-dchain] and DCHAIN-PHITS are improved in many aspects[*1)]
- ✓ A new function for calculating the response function of organic scintillator based on SCINFUL-QMD is developed[*2)]
- ✓ A function to output cross sections and kerma factors used in PHITS is developed as a part of icntl=1
- ✓ An algorithm for adjoint Monte Carlo simulation is implemented for efficiently estimating the photon fluences[*3)]
- ✓ A function to use the stopping power of liquid water, graphite, and dry air given in ICRU90 is developed[*4)]
- ✓ A new option is introduced in the phase-space source based on accelerator emittance (s-type=11)[*5)]
- ✓ An option to select share/non-share of tally variables for OpenMP shared-memory parallel computing is implemented

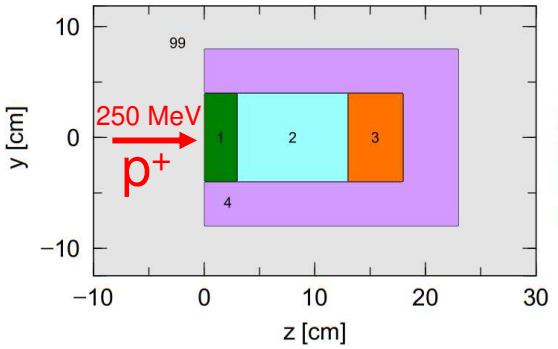
Under support of *1) CCSE of JAEA, *2) Dr. D. Satoh of JAEA, *3) Dr. A. Malins of JAEA, *4) Dr. M. Shimizu of AIST and Dr. Y. Namito of KEK, and *5) CCSE of JAEA

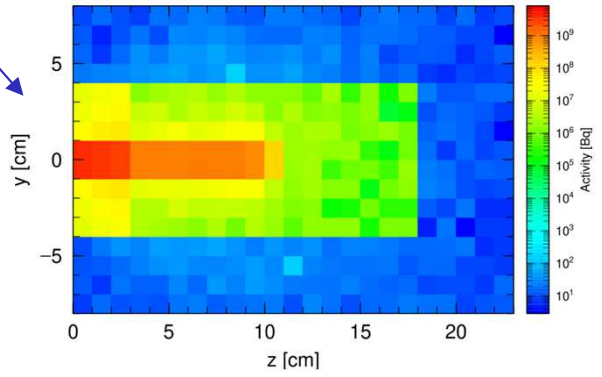
Improvements to DCHAIN-PHITS

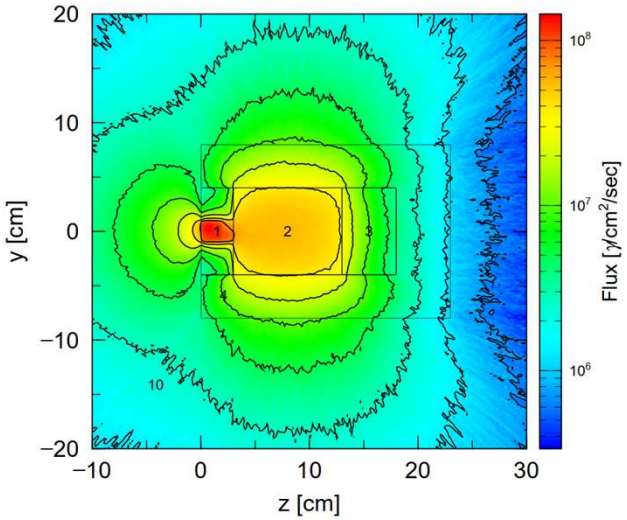
- ✓ All statistical uncertainties now propagated to results
- ✓ Hybrid activation cross section libraries now available
  →Various combinations of JENDL/AD, JENDL, ENDF, JEFF & FENDL/A
- ✓ New γ dose coefficients from ICRP 116 and ICRP 74
- ✓ Output plots show beam power and can track nuclides
- ✓ Support added for **mesh=tet** tetrahedral geometries



- ✓ For **mesh=xyz**, [Source] from *.pht output now usable as a **multi-source** in PHITS, *.pht files can be split by time step, and new automatic **2D activity plots** can be written





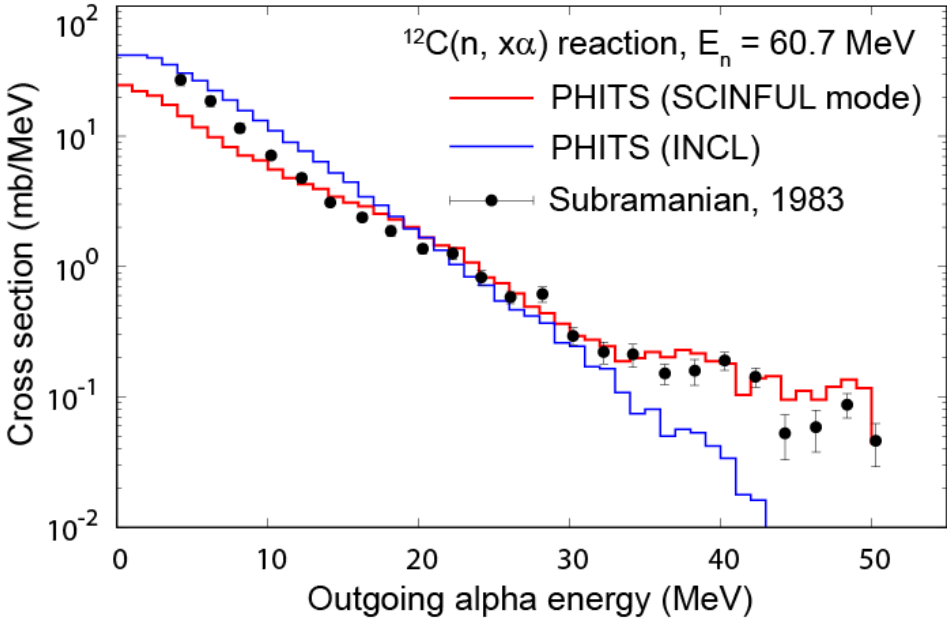


PHITS simulation → DCHAIN activity distribution → PHITS decay γ flux

H.N. Ratliff et al., Nucl. Instrum. Methods Phys. Res. B, 484, 29-41 (2020)

Implementation of SCINFUL-QMD Algorithm

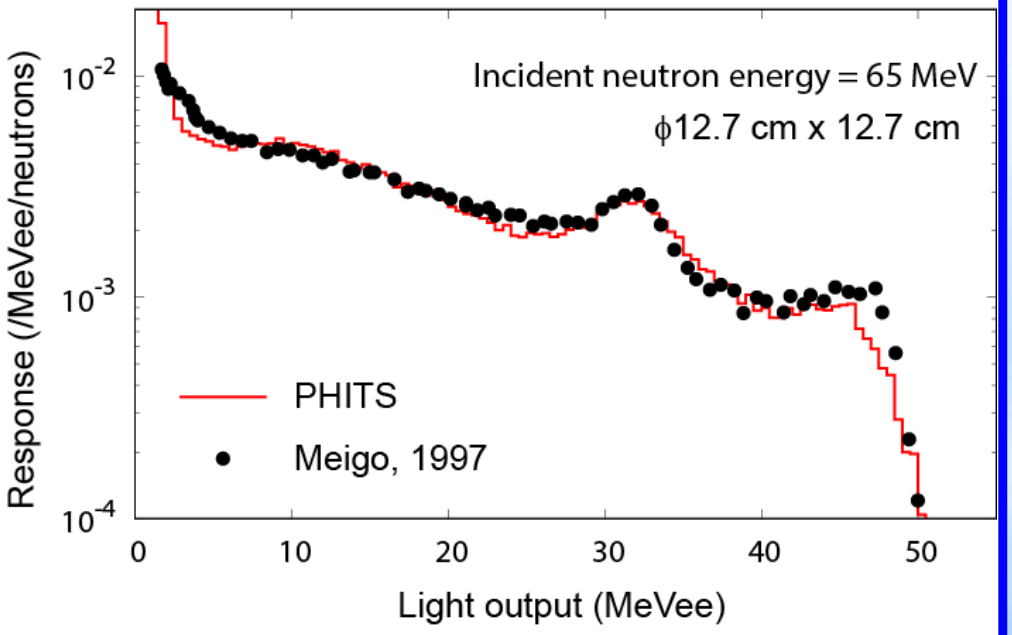
✓ Activate (n,C) cross section database in SCINFUL-QMD by setting iscinful=1 in [parameters]



α-production cross sections of ^{12}C bombarded by neutrons

Ref.) T. S. Subramanian et al., Phys. Rev. C, **28**, 521 (1983).

✓ Light-outputs from an organic scintillator can be estimated



Response function of a liquid organic scintillator for neutrons

Ref.) S. Meigo, Nucl. Instr. Meth. A, **401**, 365 (1997).

Neutron responses and detection efficiencies of an organic scintillator can be reproduced well on this mode

Major Upgraded Features in ver. 3.24

PHITS 3.24 was released in Mar. 2021

Upgraded Points from ver. 3.22

- ✓ RT-PHITS is developed by extending the function of DICOM2PHITS[*1)]
- ✓ A new calculation method for DPA is introduced
- ✓ PHITS Interactive Geometry viewer in 3D (PHIG-3D) is developed[*2)]
- ✓ Cosmic-ray source mode has been implemented
- ✓ User-defined anatally function is developed
- ✓ The concept of “history-counter” has been introduced[*3)]
- ✓ JENDL/DEU-2020 [frag data] File has been implemented[*4)]
- ✓ Functions for independently controlling source generations and summarizing tally results of each batch are implemented
- ✓ A function to output the line number subroutine & file names where error or warning message is written in the source program is implemented[*5)]

Under support of *1) Dr. Y.Koba, Dr. S.Yonai, Dr. S.Matsumoto, Dr. W.Chang of QST and Dr. T.Watabe and Mr. H.Sasaki of Osaka University, *2) Dr. S.Ohnishi of NMRI, *3) Dr. N.Furutachi of RIST, *4) Dr. S.Nakayama of JAEA , and *5) Mr. T.Imaki of JAEA

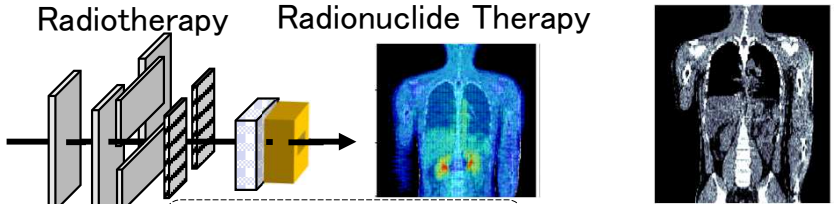
Extension from DICOM2PHITS to RT-PHITS

RadioTherapy package based on PHITS

DICOM data (RT-Plan, PET-Image, CT-Image, RT-Structure, RT-Dose)

Radiotherapy

Radionuclide Therapy



or

RT-PHITS (Plan2PHITS, PET2PHITS, CT2PHITS, PHITS2DICOM)

Under development

or

Intermediate files (Beam geom., Source info, Patient geom., Tally setting)

InputCreater4PHITS

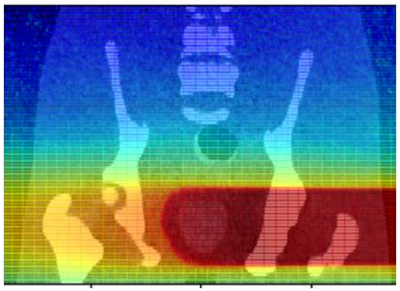
PHITS input

Phase Space File

PHITS

Dose distribution

General DICOM software



Detailed analysis

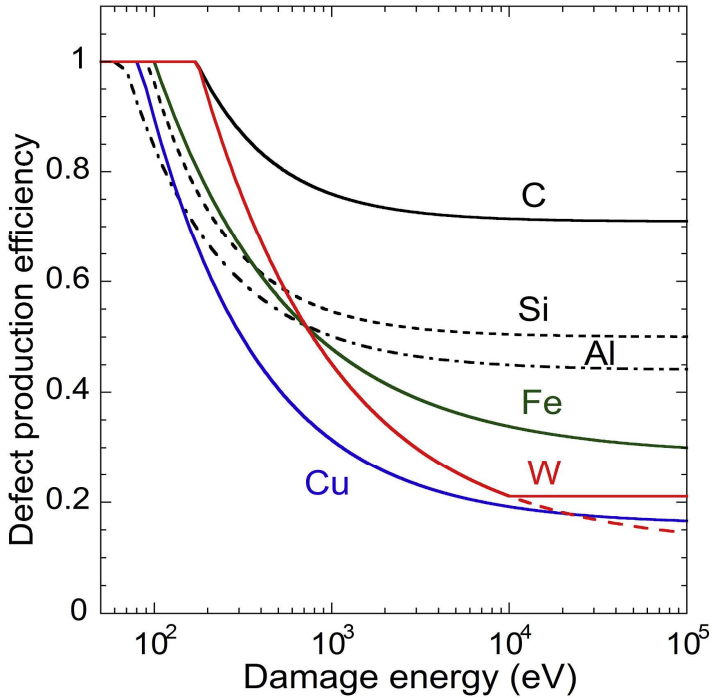
- 3D view
- DVH analysis

phits/utility/RT-phits

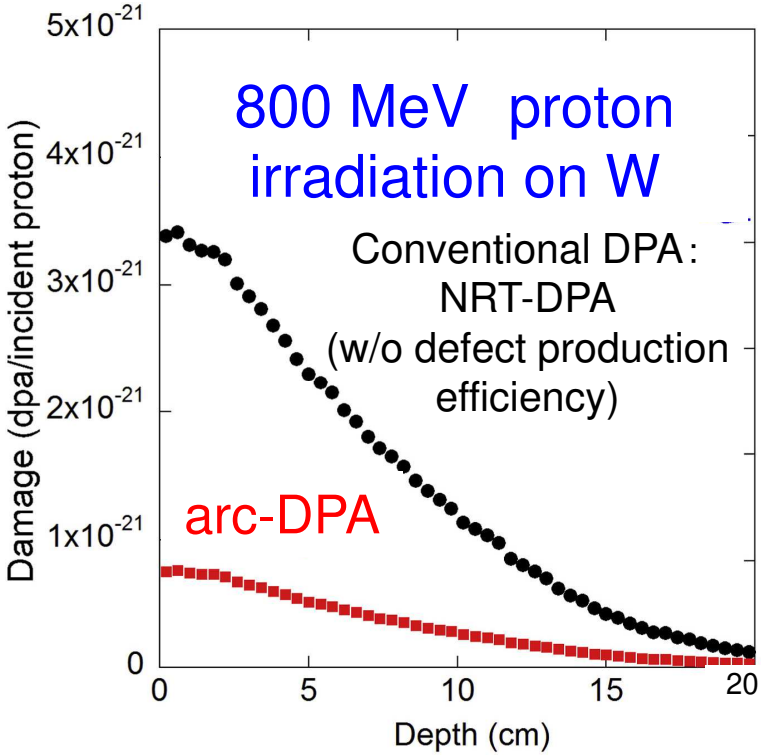
New calculation method for DPA

- ✓ DPA : Average number of displaced atoms per atom of a material
  → Index of radiation damage
- ✓ PHITS can calculate new index (*arc-DPA) with defect production efficiency

*arc-DPA: athermal-recombination-corrected DPA



Examples of defect production efficiencies



DPA depth distribution in tungsten

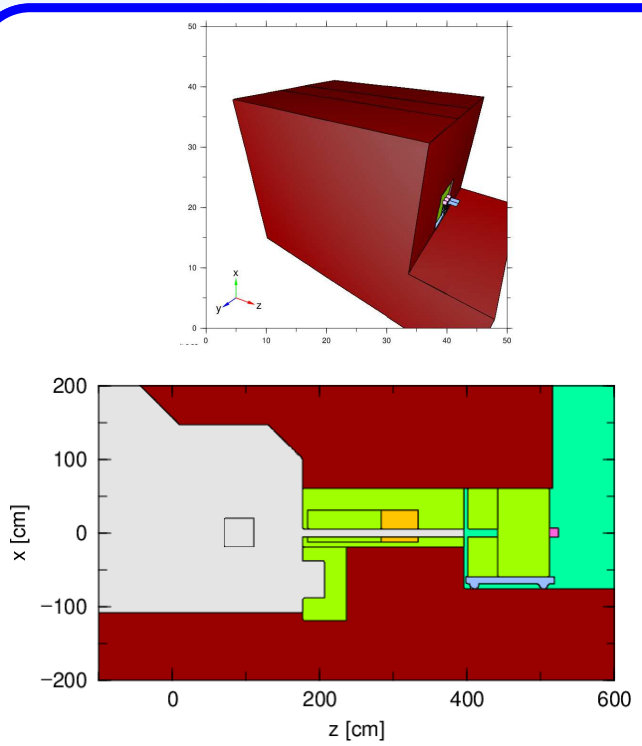
arc-DPA is generally lower than NRT-DPA

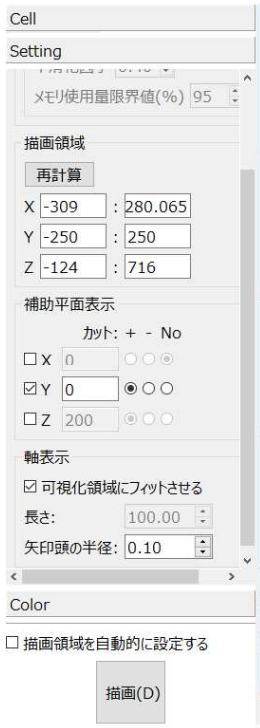
Y. Iwamoto et al., Journal of Nuclear Materials, 538 (2020) 152261

Development of PHIG-3D

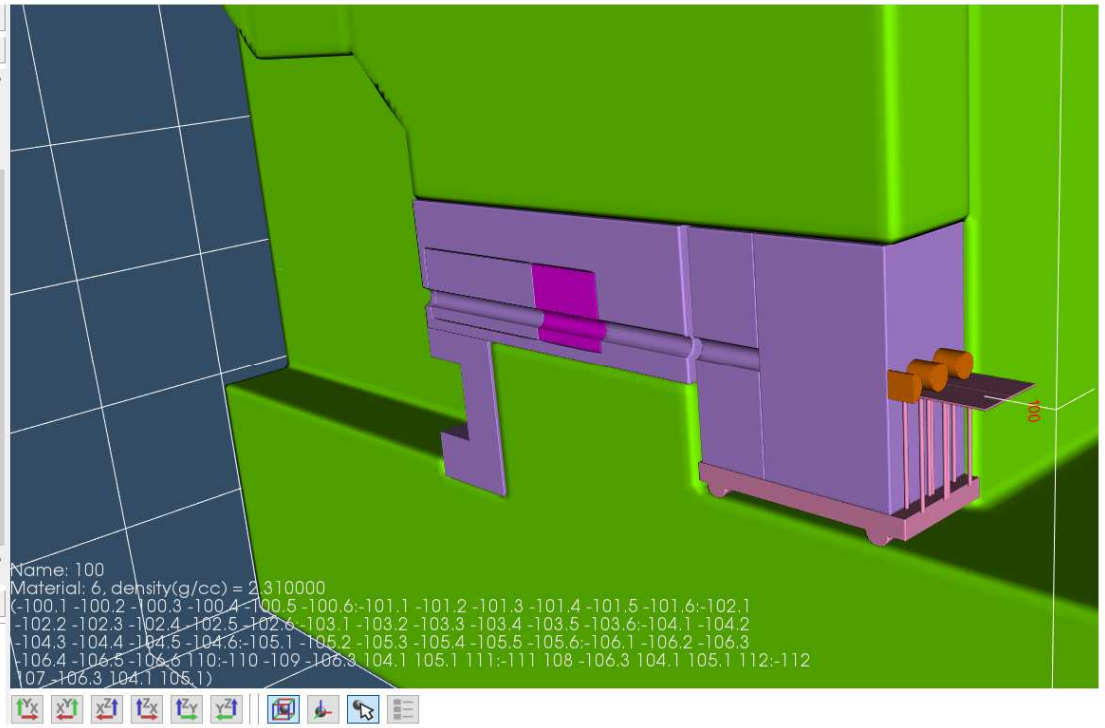
What is PHIG-3D?

- ✓PHIG-3D represent PHITS Interactive Geometry viewer in 3D
- ✓GUI software for visualizing geometry in 3D by reading PHITS input file
- ✓Interactively enlarge, reduce, and rotate geometry by mouse operation





[t-3dshow] & [t-track]



3D cross-sectional view by PHIG-3D

- ✓ Lattice or tetrahedral geometry with large meshes may not be drawn due to lack of memory
- ✓ PHIG-3D works only in 64-bit computers

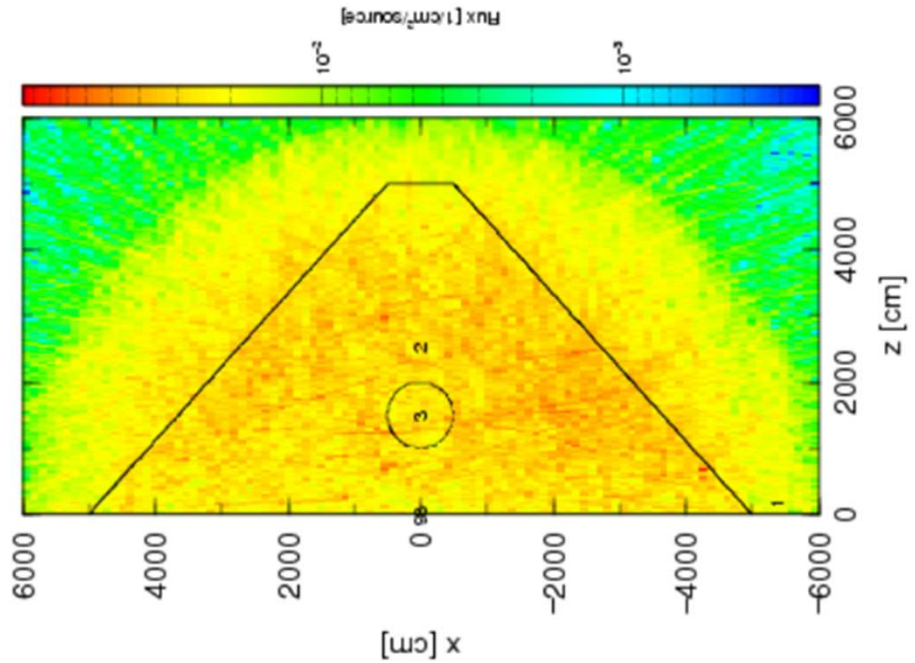
Cosmic-ray source mode

Features of cosmic-ray source mode in PHITS

- ✓ Precisely reproducing energy and angular differential fluxes of galactic cosmic-rays in space and in the atmosphere using the PARMA model*
- ✓ Simple input parameters such as altitude, latitude, longitude, & date of interest
- ✓ Applicable to large solar particle events using the Band function**

Example of [source]

```
e-type = 26     $ cosmic-ray source
icenv = 1       $ terrestrial GCR mode
alti=1.0        $ altitude in km
glat = 35.0     $ latitude in degree
glong = 142.0 $ longitude in degree
icyear = 2020 $ year
icmonth = 1     $ month
icday = 5       $ day
```



Sample simulation for muon radiography

*T.Sato PLOS ONE 11: e0160390 (2016)

**A.J.Tylka, 31st ICRC (2009)

User-defined anatally function

What is user-defined anatally?

- ✓ User-defined program for analyzing multiple tally results at once and generating a new tally result
- ✓ Sample programs for calculating dose-mean LET, and equi-effective doses based on the SMK model* are included in the PHITS package

*T.Sato & Y.Furusawa, Radiat. Res. 178, 341-356 (2012)

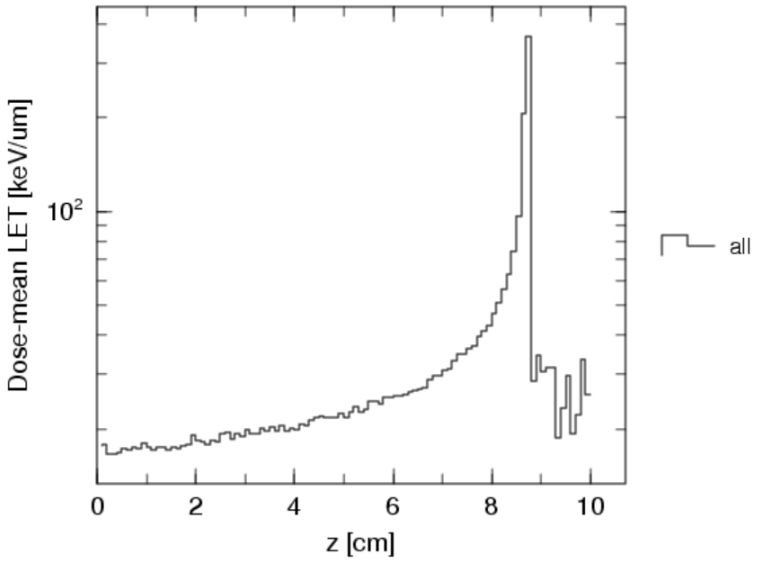
Procedure for calculating dose-mean LET using sample user-defined anatally

Particle transport simulation (icntl = 0)

Tally 1	Tally 2
∫ deposit energy	∫ deposit energy x LET

Anatally calculation (icntl = 17)

$$\frac{\text{Tally 2}}{\text{Tally 1}} = \text{Anatally Dose-mean LET}$$



Calculated dose-mean LET for C ion

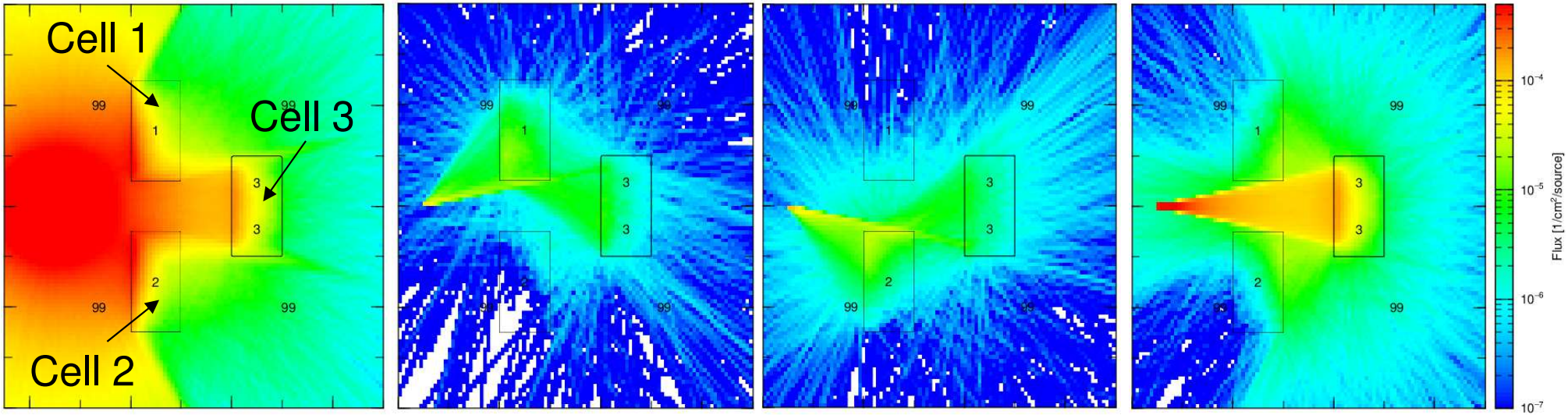
See phits/utility/usranatal in more detail

History-counter function

What is history-counter?

- ✓ The maximum counter value of all particles generated in one history
- ✓ By defining a constraint using history-counter, you can tally your interested events selectively by tracing back to the generation of their sources.

[Counter] Cell 1: in→ +10, cell 2: in→ +100, cell 3: in→ +1000 & out→ -2000



No constraint	chmin(1) = 1005 chmax(1) = 1015	chmin(1) = 1095 chmax(1) = 1105	chmin(1) = 995 chmax(1) = 1005
All particles	**via cell 1 to 3**	**via cell 2 to 3**	**Directly into cell 3**

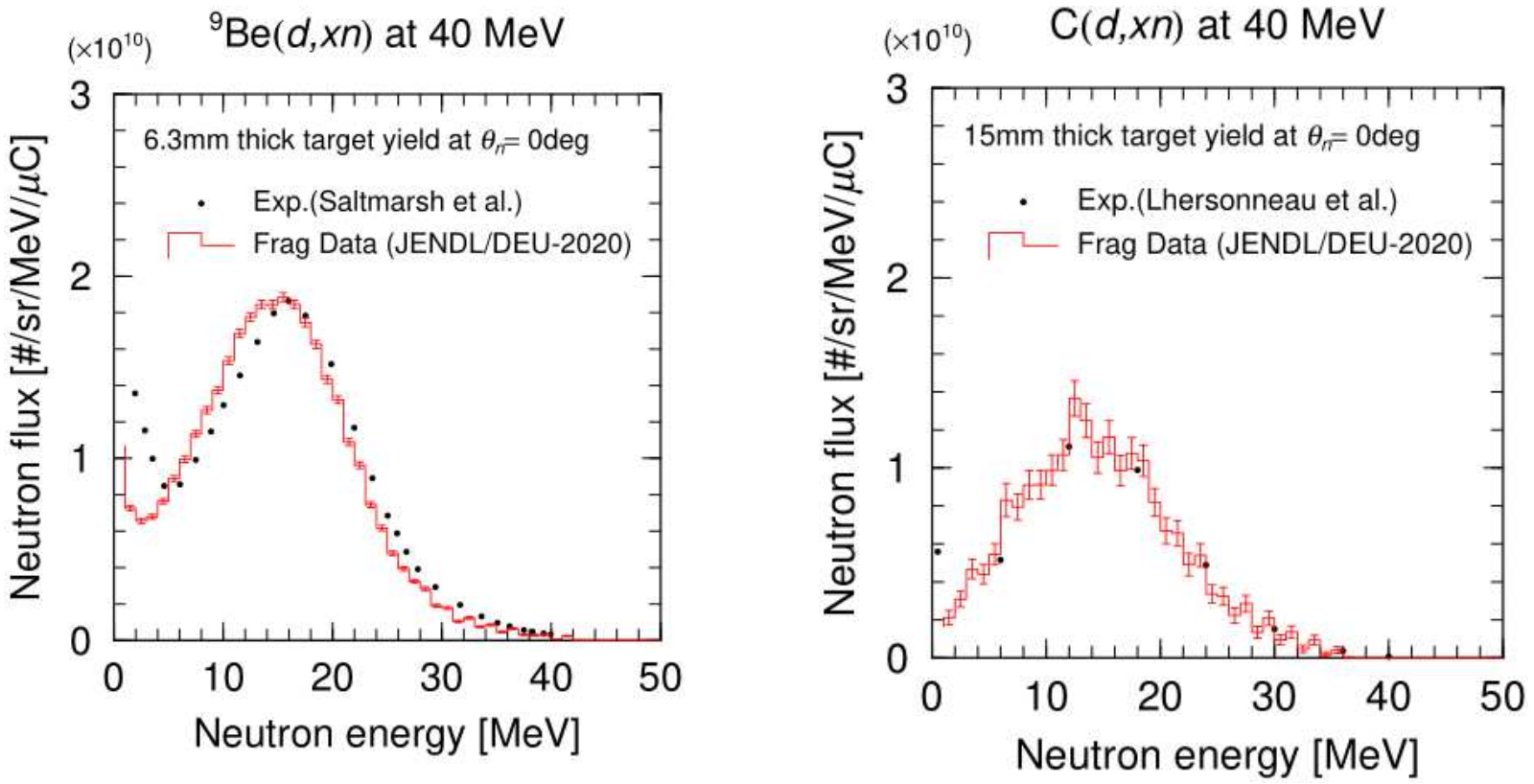
Distinguished by particle pathway before entering the region of interest

See phits/sample/misc/history_counter in more detail

JENDL/DEU-2020 [frag data] File

- ✓ Implementation of [frag data] of JENDL Deuteron Reaction Data File 2020*
- ✓ Accelerator-based neutron sources using ^{6,7}Li, ^{9}Be, ^{12,13}C(*d*,*xn*) reactions

*S. Nakayama et al., J. Nucl. Sci. Technol., DOI:10.1080/00223131.2020.1870010



Neutron energy spectra on ^{9}Be(left) and C(right) thick target

- ✓ In [frag data] section, set opt=5 and specify each target file in phits/XS/fragdata/

See phits/recommendation/NeutronSource in more detail

Upcoming Futures

We are planning to …

➢ Improve affinity to nuclear data library

- ✓ Full set of JENDL-4.0/HE
- ✓ Adoption to nuclear data libraries for d, t, ^{3}He, α, γ

➢ Implement new functions

- ✓ Extension of track-structure mode to various ions & material
- ✓ Estimation of systematic uncertainties

➢ Develop user support functions

- ✓ Special editor for making PHITS input file
- ✓ DICOM viewer for RT-PHITS

➢ Improve accuracy and nuclear reaction model

- ✓ Improvement of Fission & intra-nuclear cascade models
- ✓ Benchmark using shielding database SINBAD