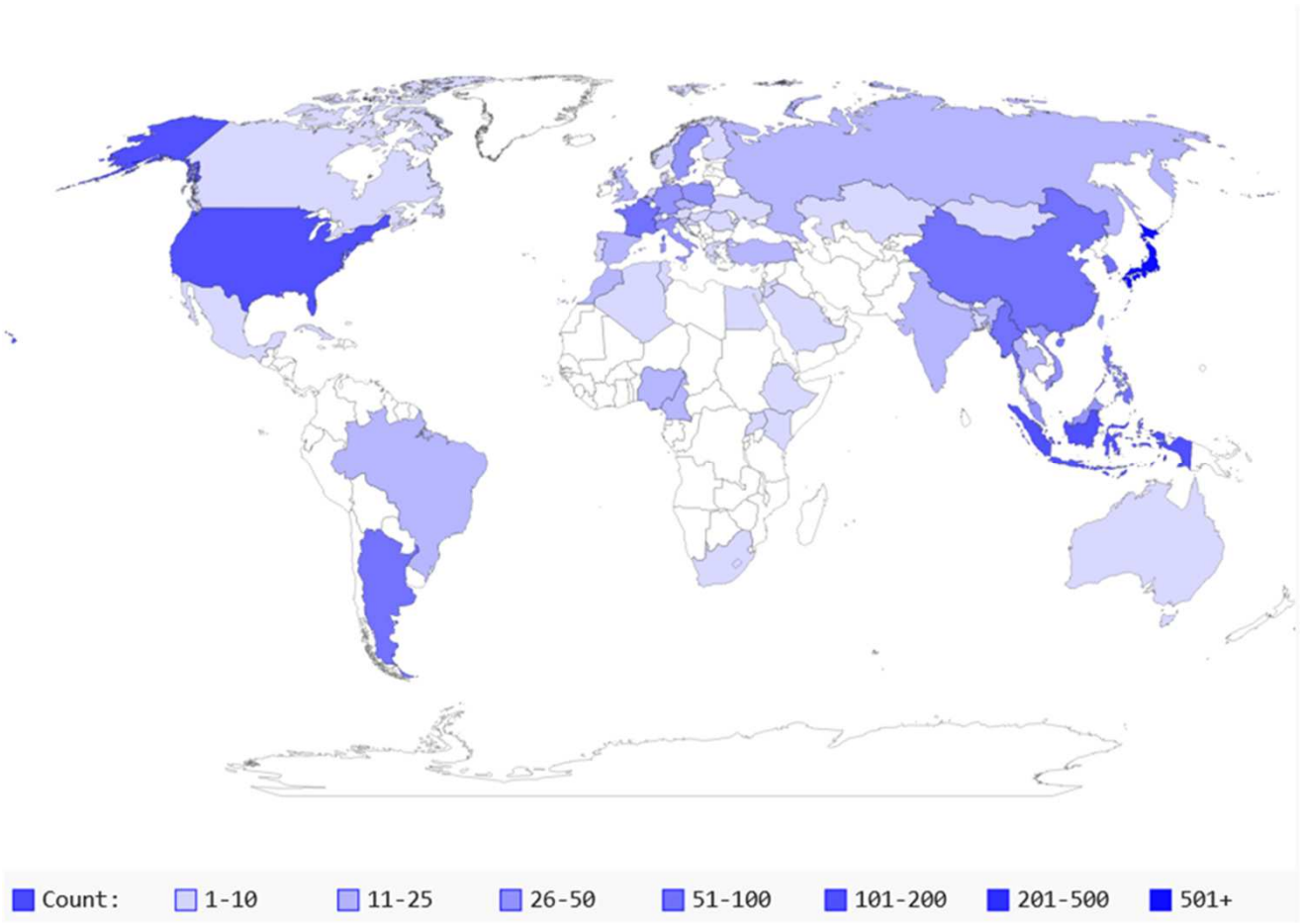
Features of PHITS3.27

PHITS development team, Mar. 2022

Number of PHITS users since 2019



Number of PHITS users in each country since 2019*

*@03/14/2022, based on the location of users' affiliation

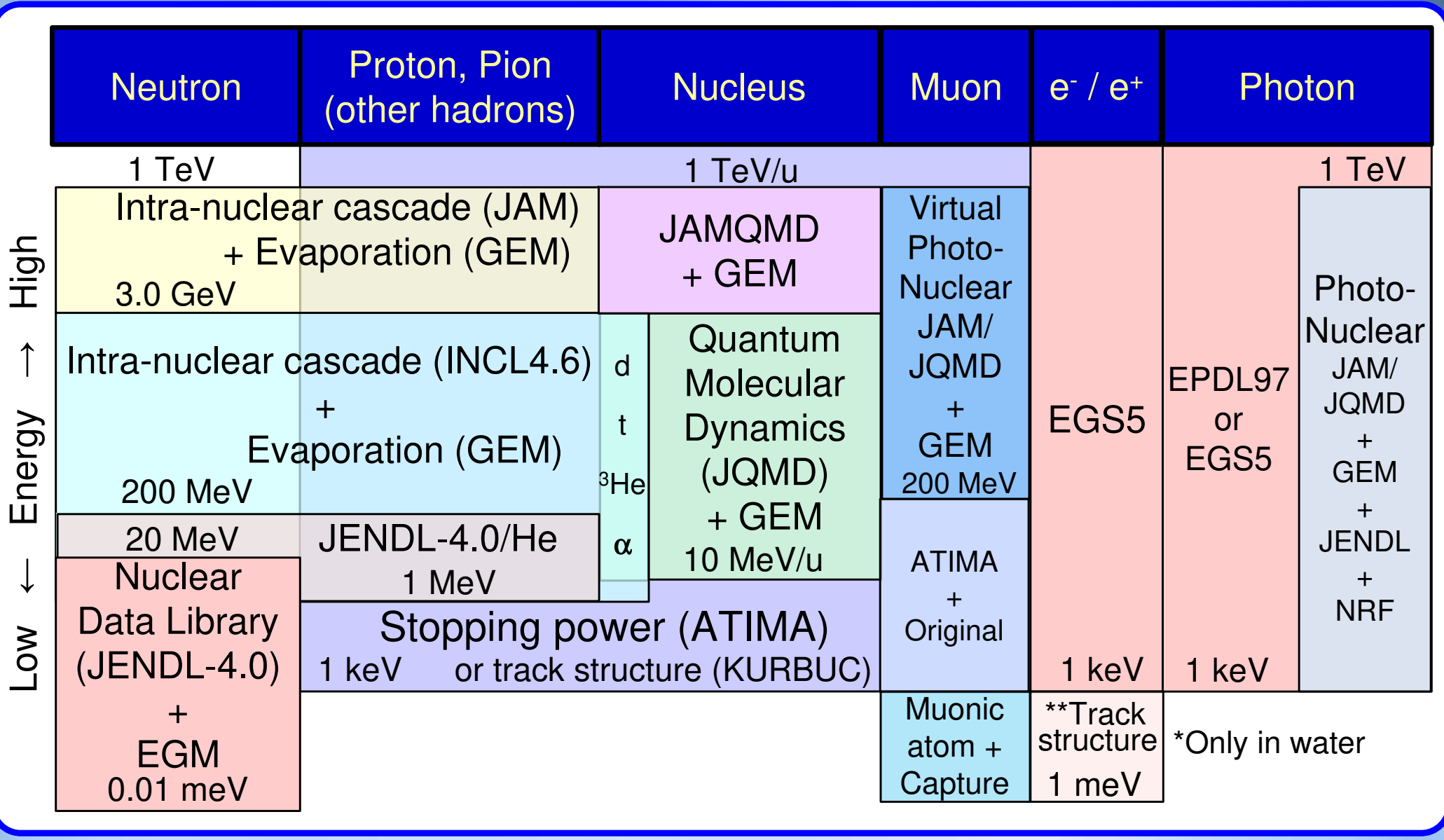
3,082 new users from 59 countries in three years!

Top 10 countries

Country	#users
Japan	1709
Indonesia	179
United States	162
Argentina	89
Myanmar	87
South Korea	84
France	73
Philippines	60
China	57
Germany/Italy	44

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

Map of Models Recommended to Use in PHITS



JENDL-4.0/HE is recommended to use for shielding design of accelerators*

*Nuclear reaction models are still recommended to use for the other cases

Major Upgraded Features in ver. 3.27

Upgraded Points from ver. 3.24

- ✓ The generalized track structure mode has been upgraded and renamed as ITSART
- ✓ Functions to read nuclear data libraires for deuteron, alpha particle, and photon in ACE format have been implemented*1)
- ✓ A function to automatically determine the maximum library energy of each nucleus from address file (xsdir) has been implemented*2)
- ✓ A conversion program from the cross sections contained in the EXFOR database to [frag data] has been developed*2)
- ✓ GUI of RT-PHITS has been developed
- ✓ The limitation of the number of particle types (part) specified in a tally was removed*2)
- ✓ A event generator mode using high-energy nuclear data library has been developed*2)
- ✓ Memory used in [t-yield] and [t-dchain] has been substantially reduced*2)

*1) Under support of ASTOM R&D and NAIS
*2) Under support of RIST

Major Upgraded Features in ver. 3.27

Upgraded Points from ver. 3.24

- ✓ The RI source function has been improved to generate all kinds of radiation emitted from decay when proj = all is set[*1)]
- ✓ The anatally function has become applicable to most tallies[*1)]
- ✓ Treatment of thermal scattering libraries has been improved, with support for continuous energy thermal scattering libraries, mixed elastic thermal scattering libraries and libraries containing SANS models[*2)]
- ✓ The Low-Earth Orbit (LEO) mode has been added to the cosmic-ray source mode

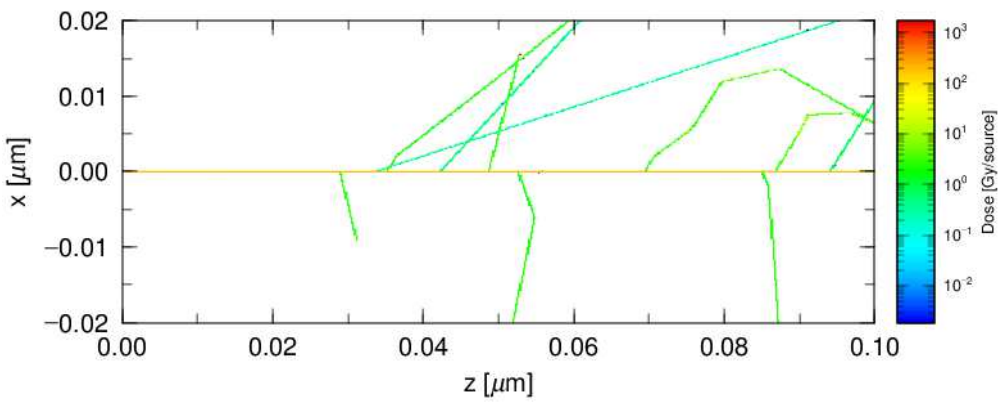
*1) Under support of CCSE of JAEA

*2) Under the support of Dr. JI Marquez Damian at European Spallation Source

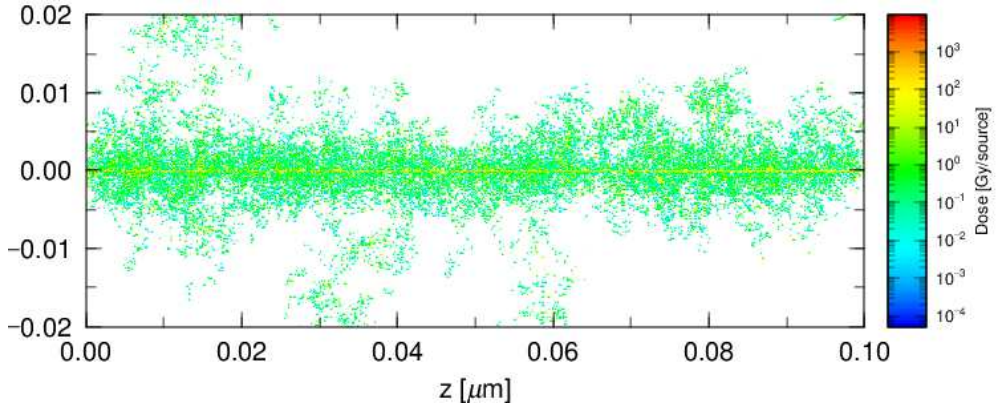
Generalized track structure mode ITSART

- ✓ Track structure mode for arbitrary ions and materials is implemented
- ✓ Every collision of protons/Ions is calculated not only in water

Trajectories of 1 MeV protons and secondary electrons in Si



Default : ATIMA+[Delta-ray]



Track structure mode ITSART

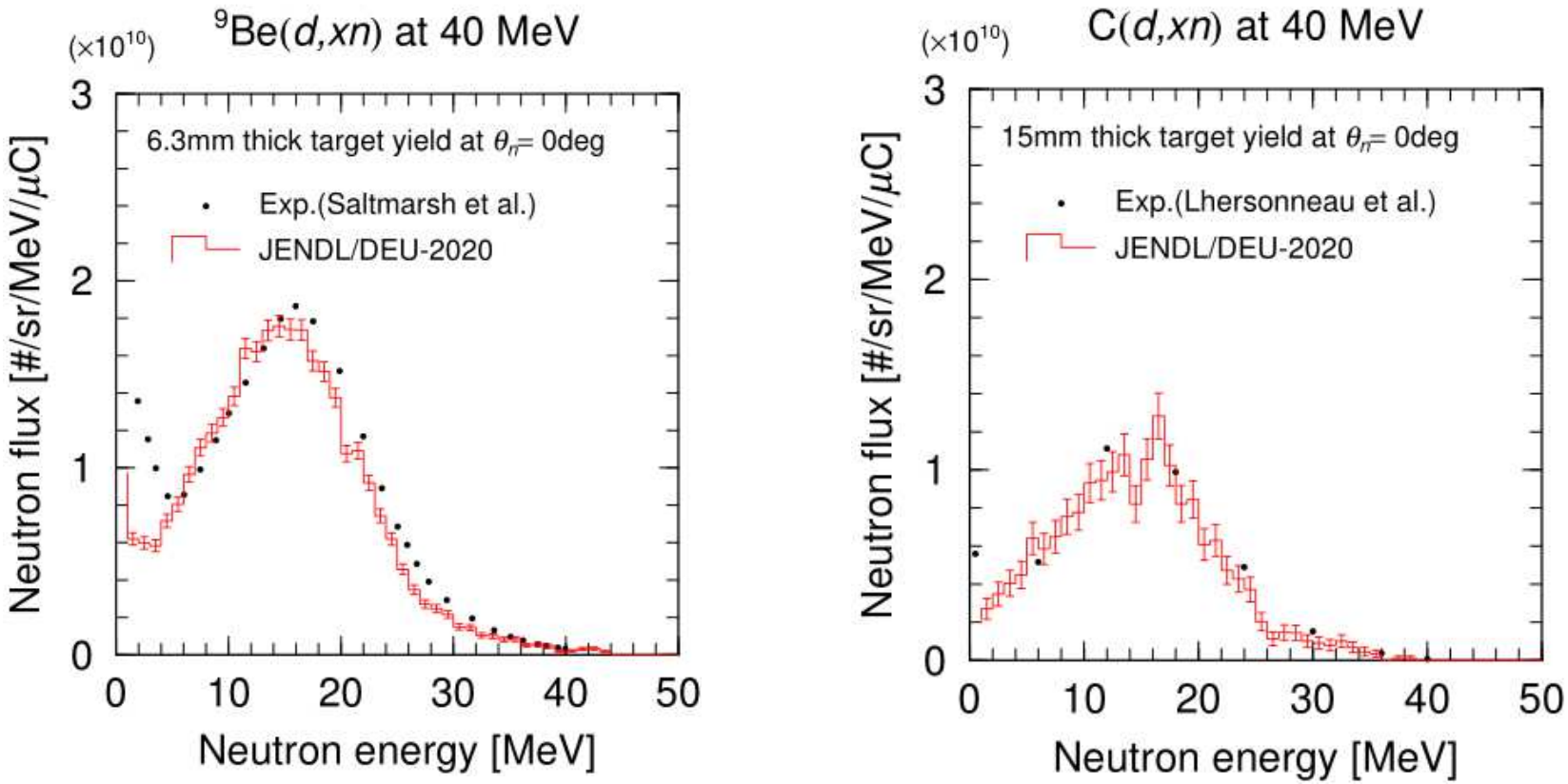
How to use?

- ✓ In [Track structure], if mID of the cell is -1, ITSART is used.
- ✓ In [Track structure], even if mID of the cell is 1, ITSART is used outside the energy/particle range of ETS and KURBUC
- ✓ Chemical forms can be considered by specifying, for example, chem = H2O 1.0 N2 2.0 in [Material] section.

*T. Ogawa, Y.Hirata, Y.Matsuya, T.Kai, Scientific Reports, 24401 (2021)

Functions to read d, α & photo-nuclear libraries

- ✓ Data should be in ACE format (the same as neutron and proton libraries)
- ✓ Deuteron data library JENDL/DEU-2020* is contained in XS folder
- ✓ α & photon-nuclear data libraries should be downloaded from elsewhere



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

[frag data] format is replaced by ACE format since version 3.27

*S. Nakayama et al., J. Nucl. Sci. Technol. 58(7), 805-821 (2021)

Automatic determination of [data max]

[parameters] setting

- ✓ Proton library: dmax(1)>0
- ✓ HE neutron library: dmax(2) > 20
- ✓ deuteron library: dmax(15) > 0
- ✓ α-particle library: dmax(18) > 0
- ✓ Photonuclear library: dpnmax > 0 & ipnint = 1

Yes

Automatically search the library with extension specified by "lib" parameter in xsdir for each nucleus

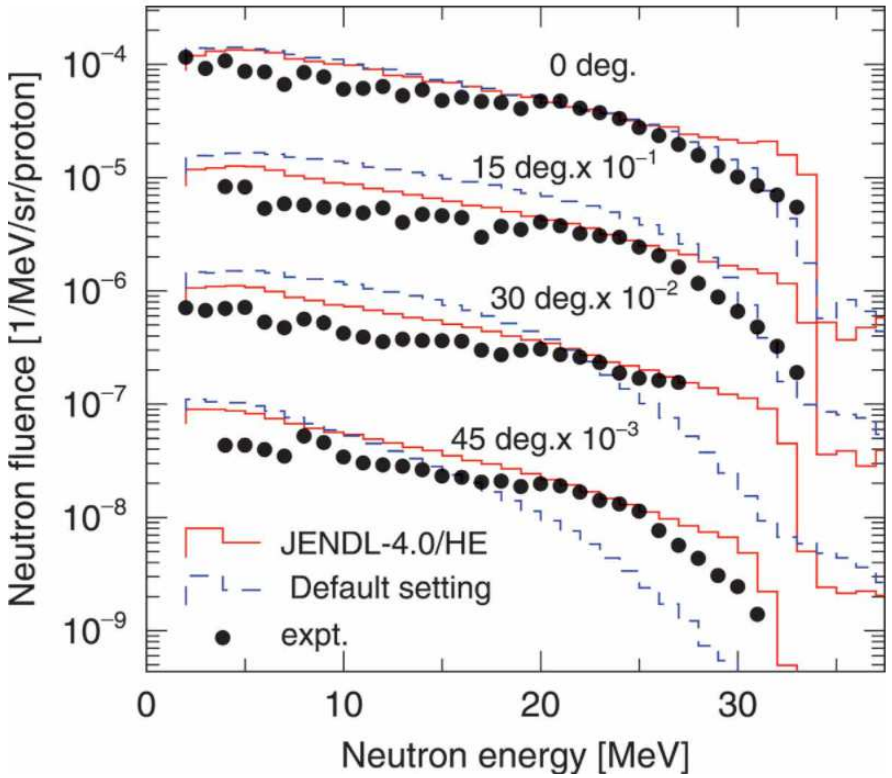
Yes

Use the library

No

- ✓ Conventional library (neutron)
- ✓ Nuclear reaction model (others)

Comprehensive benchmark of PHITS+JENDL-4.0/HE for shielding



Neutron fluence from p(52MeV) on C

Y. Iwamoto et al., J. Nucl. Sci. Technol., DOI:10.1080/00223131.2021.1993372

- ✓ High energy nuclear data library can be easily used in PHITS
- ✓ JENDL-4.0/HE is adopted in the recommendation setting for shielding etc.

Exfor data converter: Exfor2frag

What is Exfor2frag?

- ✓ Convert the experimental cross section data contained in the EXFOR database* to [frag data] file
- ✓ Exactly reproduce the experimental data in the PHITS simulation

* https://www-nds.iaea.org/exfor/

```
REACTION    (8-O-16(P,X)1-H-1,,DA/DE)
EN-SEC      ANG is polar angle (lab.) between beam and proton
            (E,P)
SAMPLE      - Target is natural.
            - Chemical-form of target: Al2O3
            - Target-thickness is 1.34 mg/cm**2.
STATUS      (TABLE) Plotted in Fig.4 of J,PR/C,82,034604,2010
HISTORY     (20100927R) Received by e-mail from Y.Uozumi
ENDBIB                 8
COMMON                 1          3
EN
MEV
 300.
ENDCOMMON              3
DATA                   4        143
E           ANG          DATA       ERR-S
MEV         ADEG         MB/SR/MEV  MB/SR/MEV
   4.00E+01         30.    2.87E-01   5.46E-02
   4.00E+01         50.    3.27E-01   2.35E-02
   4.00E+01         75.    3.44E-01   4.64E-03
   4.00E+01         90.    1.54E-01   1.68E-02
   4.00E+01        105.    9.22E-02   6.34E-03
   5.00E+01         30.    3.54E-01   5.27E-02
```

Convert

```
proton
160
           1
 2.5000E+02  3.0000E+02
 0.0000E+00  0.0000E+00
         100
 1.5500E+00  1.6500E+00  1.7500E+00  1.8500E+00  1.9500E+00  2.1000E+00  2.3
 4.1000E+00  4.3000E+00  4.5000E+00  4.7000E+00  4.9000E+00  5.2500E+00  5.7
 1.0750E+01  1.1500E+01  1.2500E+01  1.3500E+01  1.4500E+01  1.5500E+01  1.6
 3.1000E+01  3.3000E+01  3.5000E+01  3.7000E+01  3.9000E+01  4.0000E+01  4.1
 6.2500E+01  6.7500E+01  7.0000E+01  7.2500E+01  7.7500E+01  8.0000E+01  8.2
 1.2000E+02  1.2500E+02  1.3000E+02  1.3500E+02  1.4000E+02  1.4500E+02  1.5
 2.1000E+02  2.2000E+02  2.3000E+02  2.4000E+02  2.5000E+02  2.6000E+02  2.7
           9
 7.5000E+00  3.0000E+01  4.0000E+01  5.0000E+01  6.0000E+01  7.5000E+01  9.0
           2
proton  neutron
 0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0
 0.0000E+00  6.4931E-02  9.3349E-02  8.2338E-02  2.6057E-03  3.8370E-03  4.3
 0.0000E+00  6.5605E-02  9.3899E-02  8.2976E-02  3.4814E-03  4.7240E-03  8.3
 0.0000E+00  6.6058E-02  9.4448E-02  8.3614E-02  4.3571E-03  5.6110E-03  1.2
 0.0000E+00  6.6511E-02  9.4998E-02  8.4252E-02  5.2327E-03  6.4980E-03  1.6
 0.0000E+00  6.7154E-02  9.5822E-02  8.5209E-02  6.5463E-03  7.8285E-03  2.2
 0.0000E+00  6.8023E-02  9.6921E-02  8.6485E-02  8.2976E-03  9.6025E-03  3.0
 0.0000E+00  6.8929E-02  9.8020E-02  8.7761E-02  1.0049E-02  1.1376E-02  3.8
 0.0000E+00  6.9835E-02  9.9118E-02  8.9037E-02  1.1800E-02  1.3150E-02  4.6
 0.0000E+00  7.0740E-02  1.0022E-01  9.0313E-02  1.3552E-02  1.4924E-02  5.4
 0.0000E+00  7.1646E-02  1.0132E-01  9.1589E-02  1.5303E-02  1.6698E-02  6.2
 0.0000E+00  7.2551E-02  1.0242E-01  9.2864E-02  1.7055E-02  1.8472E-02  7.0
 0.0000E+00  7.3457E-02  1.0351E-01  9.4140E-02  1.8806E-02  2.0246E-02  7.8
 0.0000E+00  7.4362E-02  1.0461E-01  9.5416E-02  2.0557E-02  2.2020E-02  8.6
 0.0000E+00  7.5268E-02  1.0571E-01  9.6692E-02  2.2309E-02  2.3794E-02  9.4
```

EXFOR file (left) for $^{16}O(p,x)^{1}H$ is converted into [frag data] file (right)

- ✓ In [frag data] section, set a generated fragdata.dat file with opt=5

See phits/utility/exfor2frag in more detail

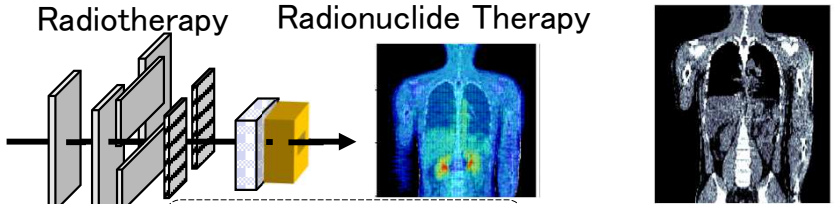
Extension from DICOM2PHITS to RT-PHITS

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

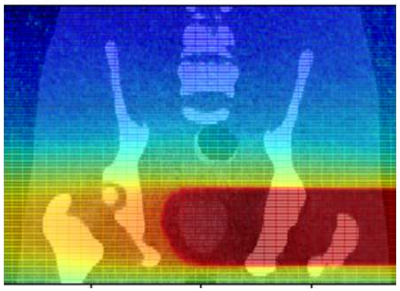
PHITS input

Phase Space File

PHITS

Dose distribution

General DICOM software



Detailed analysis

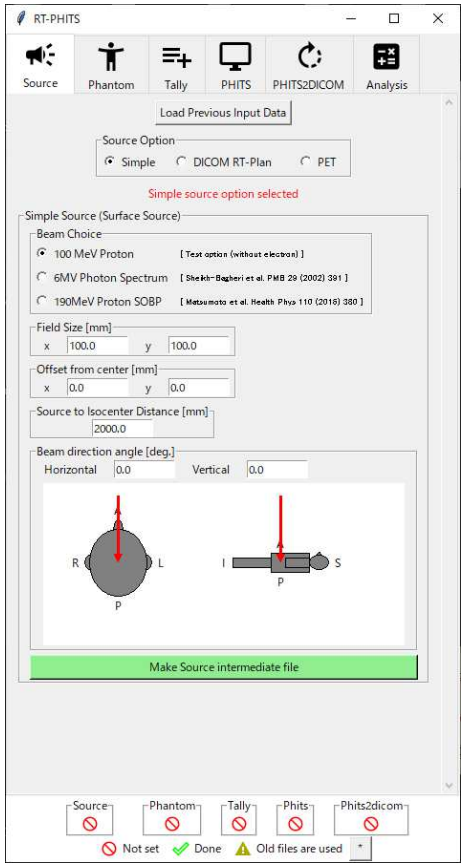
- 3D view
- DVH analysis

phits/utility/RT-phits

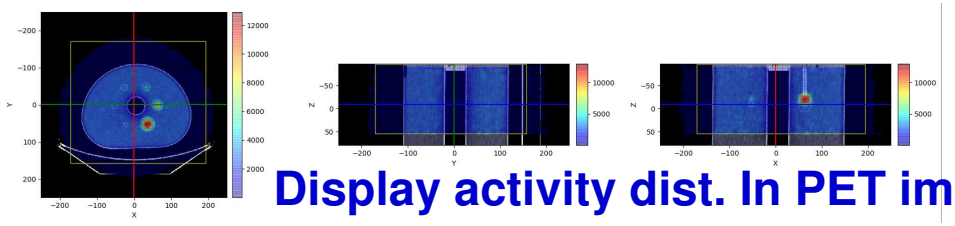
Development of RT-PHITS GUI (β ver.)

RadioTherapy package based on PHITS

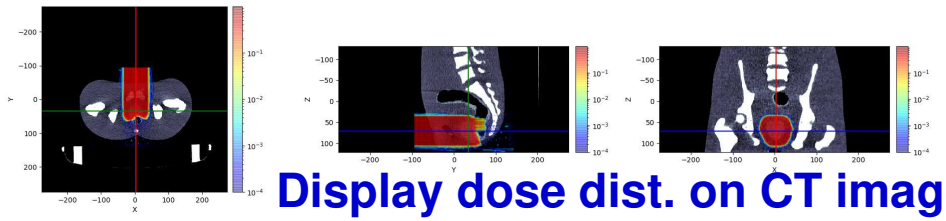
- ✓ User support function for RT-PHITS by a Python tkinter GUI
- ✓ It allows distribution analysis by interactive interface



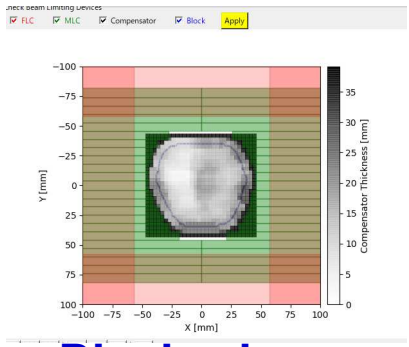
Interactive setting



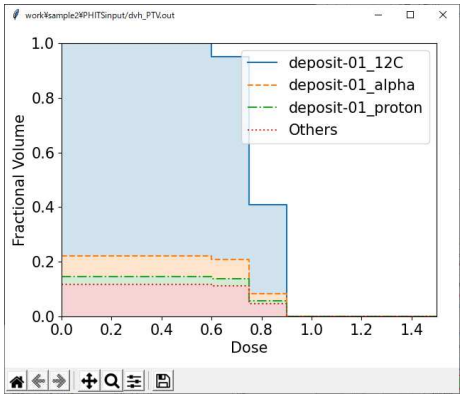
Display activity dist. In PET images



Display dose dist. on CT images



Display beam device geometry (under development)



DVH analysis

See phits/utility/RT-phits/RTphitsGUI.pptx for more details

Upcoming Futures

We are planning to …

➢ Improve the track structure mode

- ✓ Extension of the precise mode applicable to other elements/compounds
- ✓ Improvement of ITSART to be capable of handling excitation
- ✓ Development of coupling modules connecting to material & life sciences

➢ Improve affinity to nuclear data library

- ✓ Inclusion of JENDL-5.0 and photonuclear data libraries

➢ Develop user support functions

- ✓ Special editor for making PHITS input file
- ✓ Improvement of RT-PHITS

➢ Improve accuracy and nuclear reaction model

- ✓ Improvement of JQMD ver. 2.0 to be faster and more accurate
- ✓ Improvement in the evaluation methods for both statistical & systematic uncertainty
- ✓ Comprehensive V&V