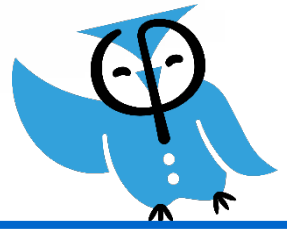


Features of PHITS3.35

PHITS development team, Apr. 2025

Recent Updates

2023 Sep. Register PHITS 3.33 to OECD/NEA Data bank

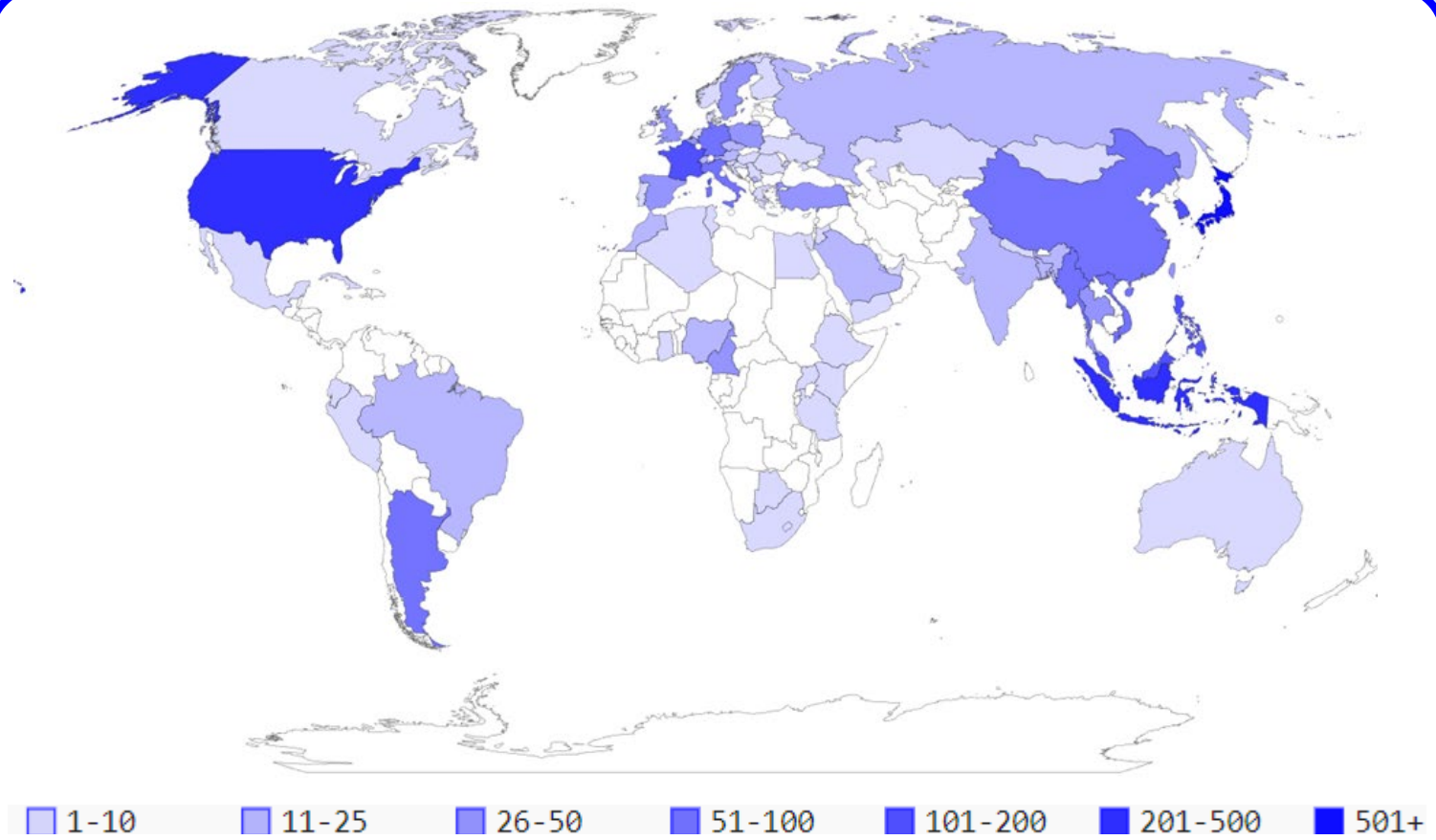
2023 Dec. Update PHITS official reference*

2024 Apr. Register PHITS 3.34 to OECD/NEA Data bank

2025 Apr. Register PHITS 3.35 to OECD/NEA Data bank

*T. Sato et al., Recent improvements of the Particle and Heavy Ion Transport code System - PHITS version 3.33, J. Nucl. Sci. Technol. 61, 127-135 (2024)

Number of PHITS users since 2019



Number of PHITS users in each country since 2019*

*@2025/03/26, based on the location of users' affiliation

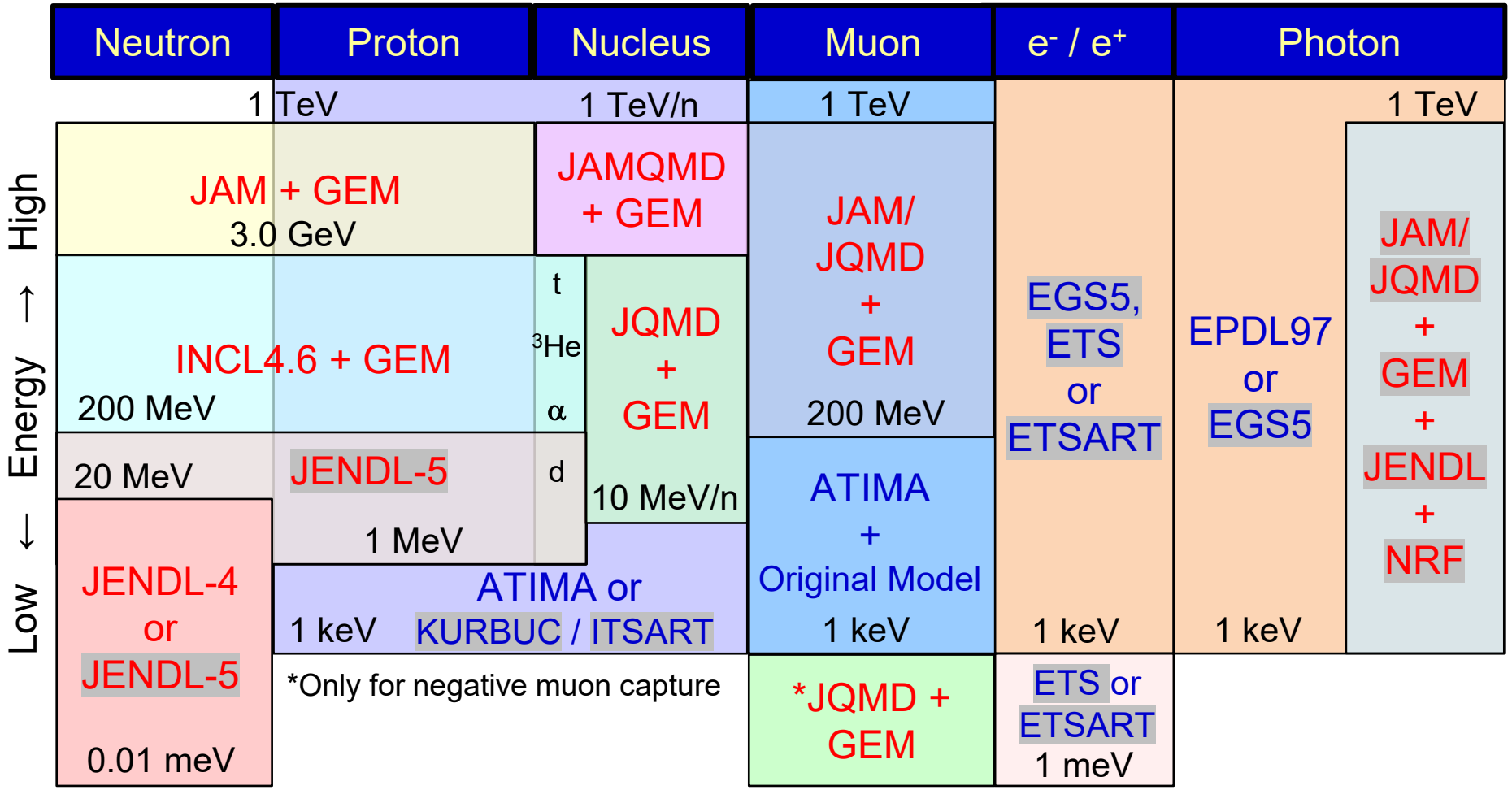
7,407 new users from 78 countries in six years!

Top 10 countries

Country	#users
Japan	3573
Indonesia	586
United States	426
South Korea	335
Philippines	266
China	197
France	183
Spain	157
Malaysia	153
Argentina	136

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

Map of Models Recommended to Use in PHITS



Red: Nuclear reaction model or library Blue: Atomic interaction model or library

Models and libraries highlighted in gray are not used in the default setting

No significant change since Version 3.34

Major Upgraded Features after ver. 3.34

- ✓ The JENDL-5 activation cross section has been converted into DCHAIN and ndata formats
- ✓ The weight-window generator [t-wwg] has been improved in various aspects
- ✓ The #all command has been added to [cell] for easy definition of the background region
- ✓ PHIG-3D has been improved to be capable of visualizing tally results
- ✓ The chemical code (PHITS-Chem) has been improved in various aspects
- ✓ Sample input files for reproducing neutron sources based on α-emitters has been added
- ✓ RT-PHITS has been improved in terms of nuclear-medicine dosimetry

Major Upgraded Features after ver. 3.34 (Cont.)

- ✓ The source code has been revised to be compatible with ifx
- ✓ A new function for calculating the statistical errors of “sum-over” values has been developed
- ✓ A function to automatically read the header information on dump source has been developed
- ✓ The angular-biasing function in Rutherford scattering has been implemented
- ✓ The mother parameter has been introduced in [t-deposit] and [t-dpa]
- ✓ The cosmic-ray source mode has applied to the plane sources (s-type = 1 & 2)
- ✓ The limitation of the maximum number of elements used in a material has been removed
- ✓ An interpolation method using the 4^{th}-order Lagrange polynomial has been introduced in [multiplier]
- ✓ A function to read tetrahedral geometry written in the HDF format has been developed
- ✓ The INC-ELF model has been updated
- ✓ A new format of [t-4dtrack] has been added
- ✓ Some libraries of DCHAIN have been updated to include (n,n’) cross section
- ✓ Several samples for user-defined particle and interaction have been provided to in phits/utility/UserDefinedModel

Important bug fixes after ver. 3.34

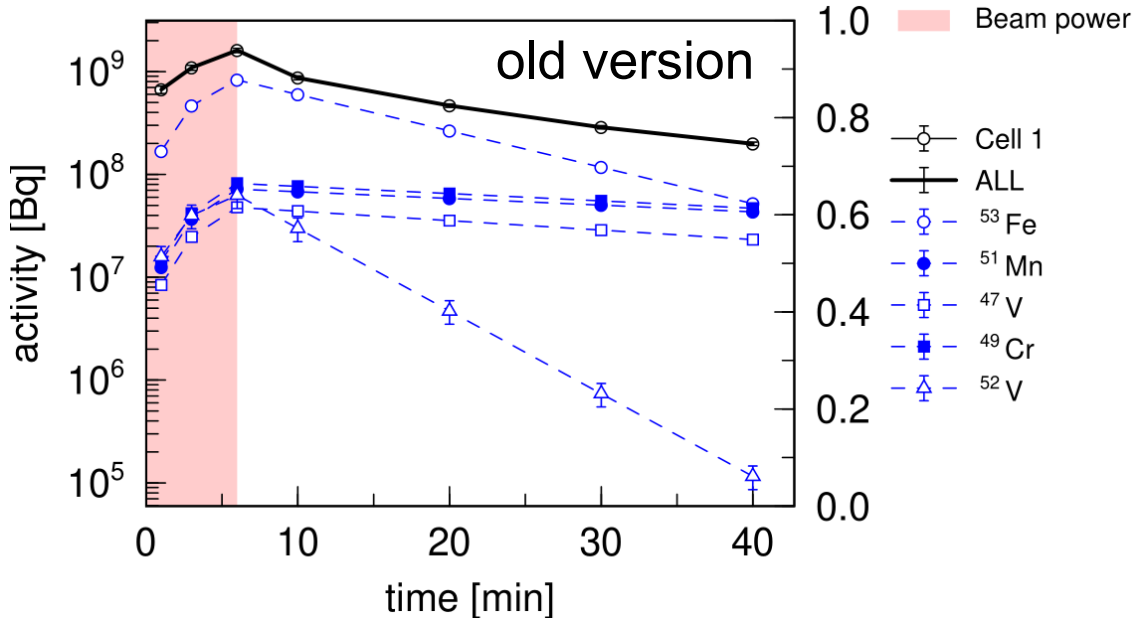
- ✓ Deposition energy calculated using kerma approximation for fissile nuclei
- ✓ Angular distribution in secondary particles produced from photonuclear data library
- ✓ Electron trajectory in electro-magnetic fields
- ✓ Angular distribution in ground-level muon fluxes for relatively small angle (1-45 deg)
- ✓ 2-D geometry drawing function (seldomly occurred only in version 3.341)
- ✓ [source] output function in the RI source format in DCHAIN
- ✓ Nuclear reaction induced by deuterons below 1 MeV/n
- ✓ Various bugs in track-structure modes
- ✓ Production in high-energy deuteron and alpha particle production above their dmax
- ✓ Restart calculation using [t-deposit] with unit = 5
- ✓ Angular distribution in s-type = 9 source
- ✓ Function to read nuclear data for meta-stable nuclides
- ✓ Event generator mode coupled with dir = -1 neutron source
- ✓ [t-cross] with samepage = z
- ✓ Several minor bugs in PHITS-Pad

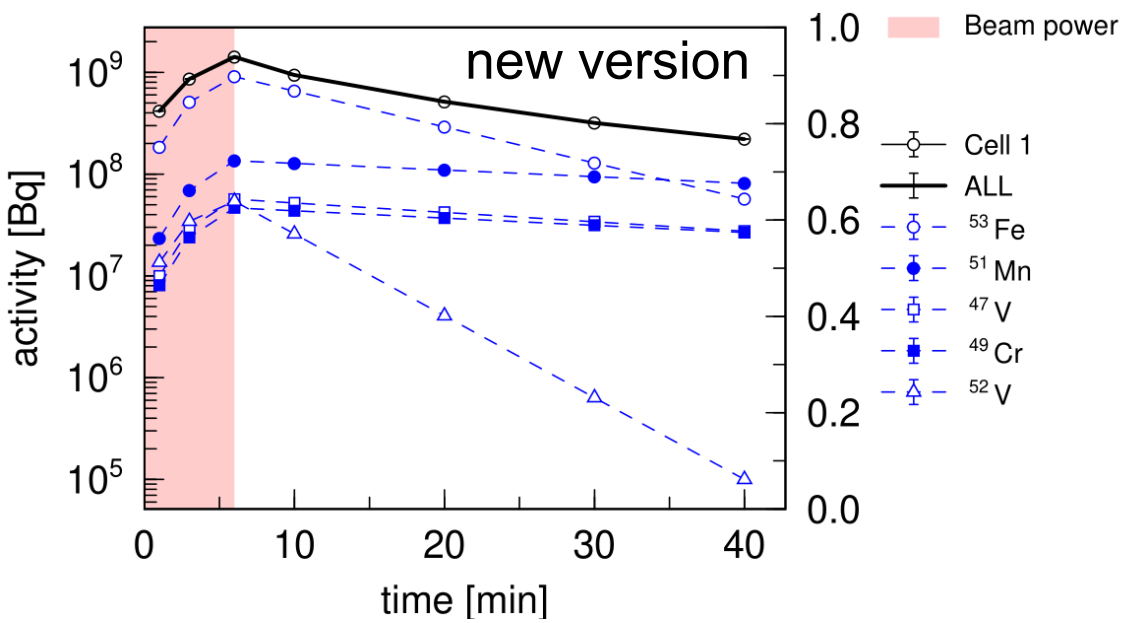
JENDL-5 activation cross section

Recommended nuclear yield calculation methods

Version	Neutrons below 20 MeV	Particles with JENDL-5*	Others
Before 3.34	JENDL/AD-2017 in DCHAIN format	Nuclear reaction models such as INCL and JQMD	
After 3.35	JENDL-5 in DCHAIN format	JENDL-5 in ndata format	Nuclear reaction models

*n (20 < E < 200 MeV), p (E < 200 MeV), d (E < 100 MeV/n), α (E < 3.75 MeV/n), γ (E < 150MeV)





Time dependence of induced activities in Fe target irradiated by 150 MeV protons

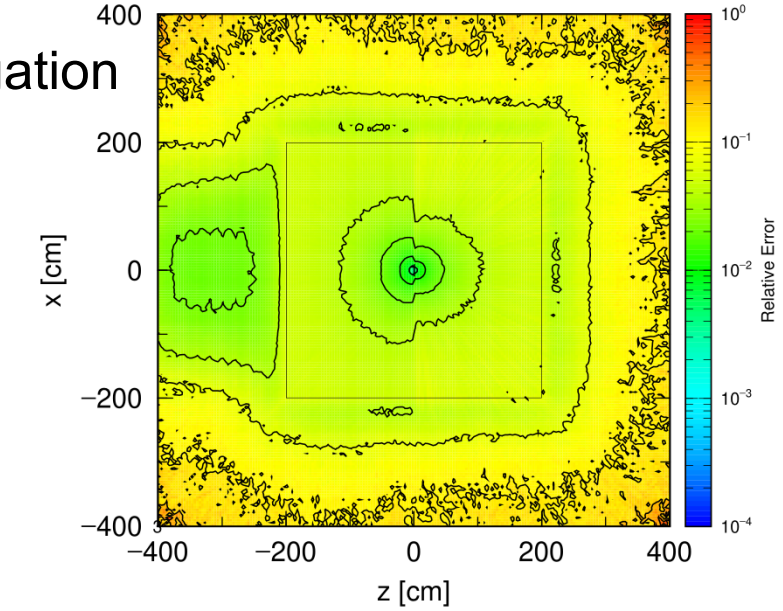
Results are not significantly changed in most cases, but more benchmarking is necessary

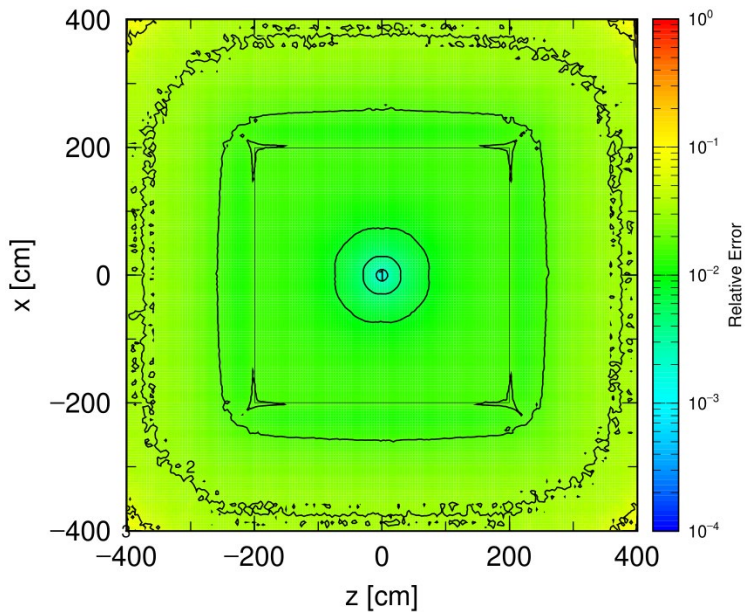
Improvement of Weight Window Generator

New features

- ✓ Particle navigation function using the history-counter method
- ✓ Low-energy unbiased method to enforce arising weight-window values for low-energy particles
- ✓ Introduction of the pedestal parameter to avoid too-low weight-window values at zero-flux regions

With navigation to left side





Without navigation

Relative error distributions with and without particle navigation function to the left side

*T. Sato et al. Nucl. Instr. Meth. B 557, 165535 (2024)

Lecture notes for variance reduction have been significantly revised (advanced/variance-reduction)

Introduction of #all in [cell]

What is #all?

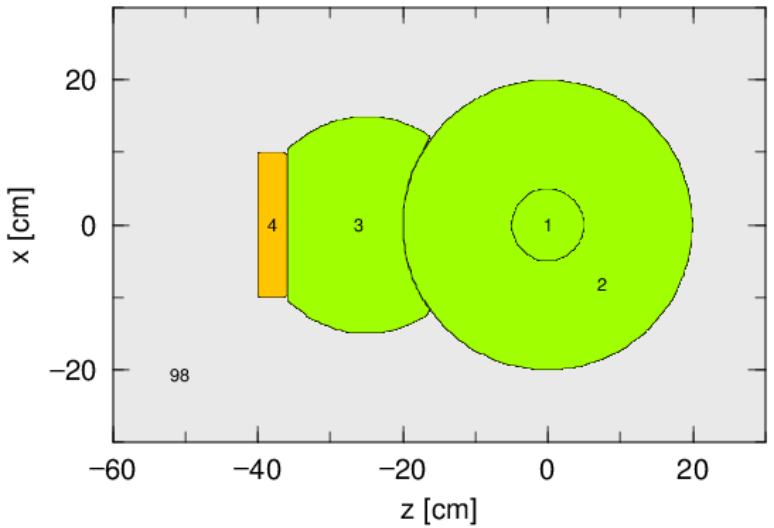
A new operator in [cell] to exclude all cells* from a single cell for simply defining air or void region

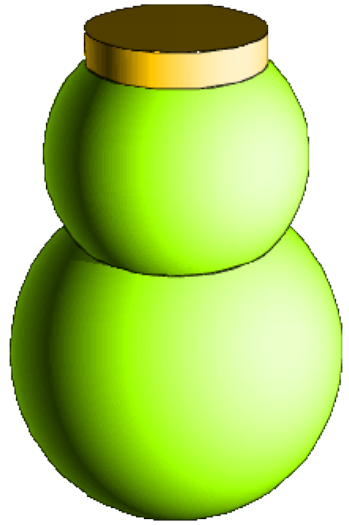
*except for cells in other universes and the outer void regions

```
[ C e l l ]
 1   1 -1.0  -1          $ Target
 2   1 -1.0  -2  1       $ Big ball
 3   1 -1.0  -3  2   #4  $ Small ball
 4   2 -2.7  -11 21 -22  $ Al plate
98   0   #1 #2 #3 #4  -999  $ Void
99  -1              999  $ Outer region
```

```
[ C e l l ]
 1   1 -1.0  -1          $ Target
 2   1 -1.0  -2  1       $ Big ball
 3   1 -1.0  -3  2   #4  $ Small ball
 4   2 -2.7  -11 21 -22  $ Al plate
98   0       #all  -999  $ Void
99  -1              999  $ Outer region
```

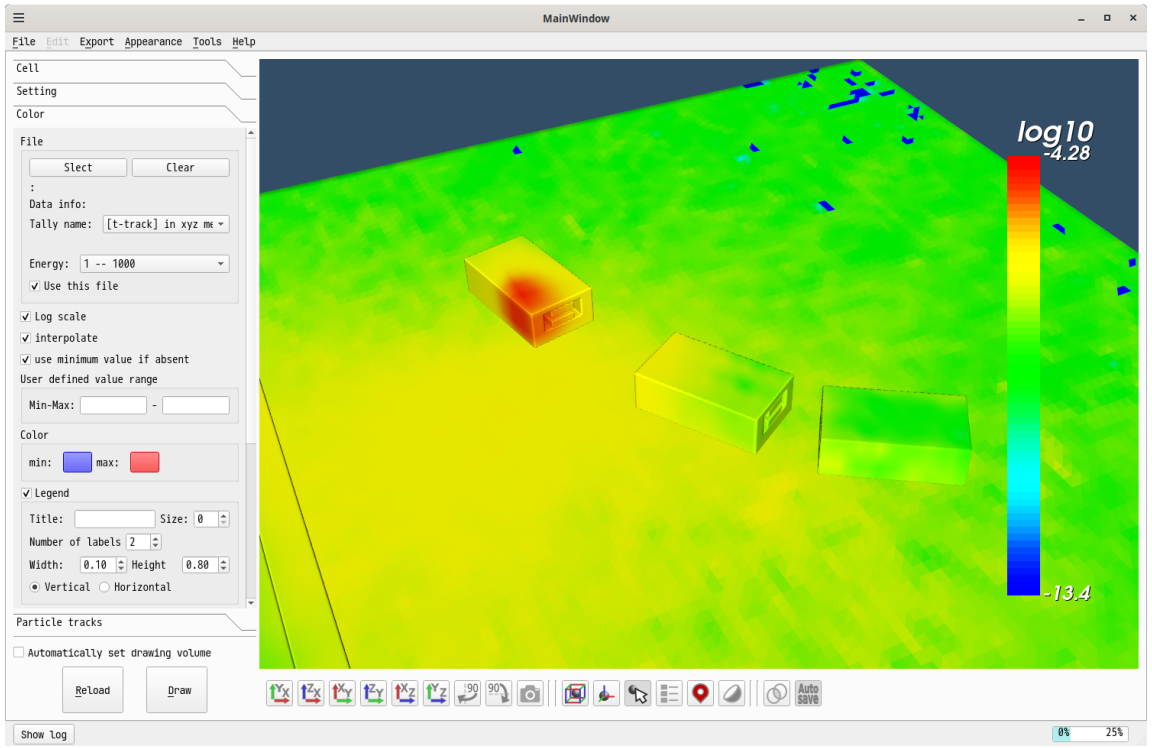
snowman.inp

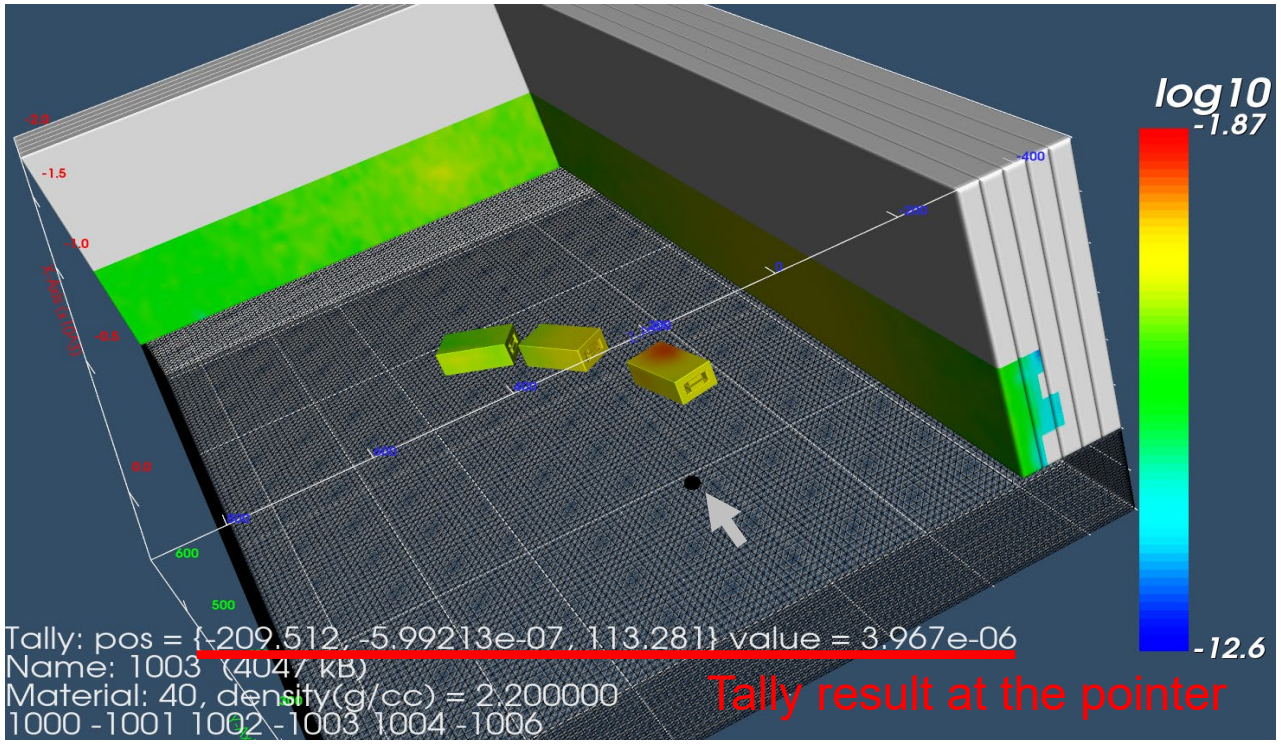




- ✓ **Useful for beginners but be careful in the case of very complicated geometry!**
- ✓ **Too much # may result in longer computational time (or insufficient memory)**

Improvement of PHIG-3D





Visualization of tally outputs from phits/recommendation/shielding

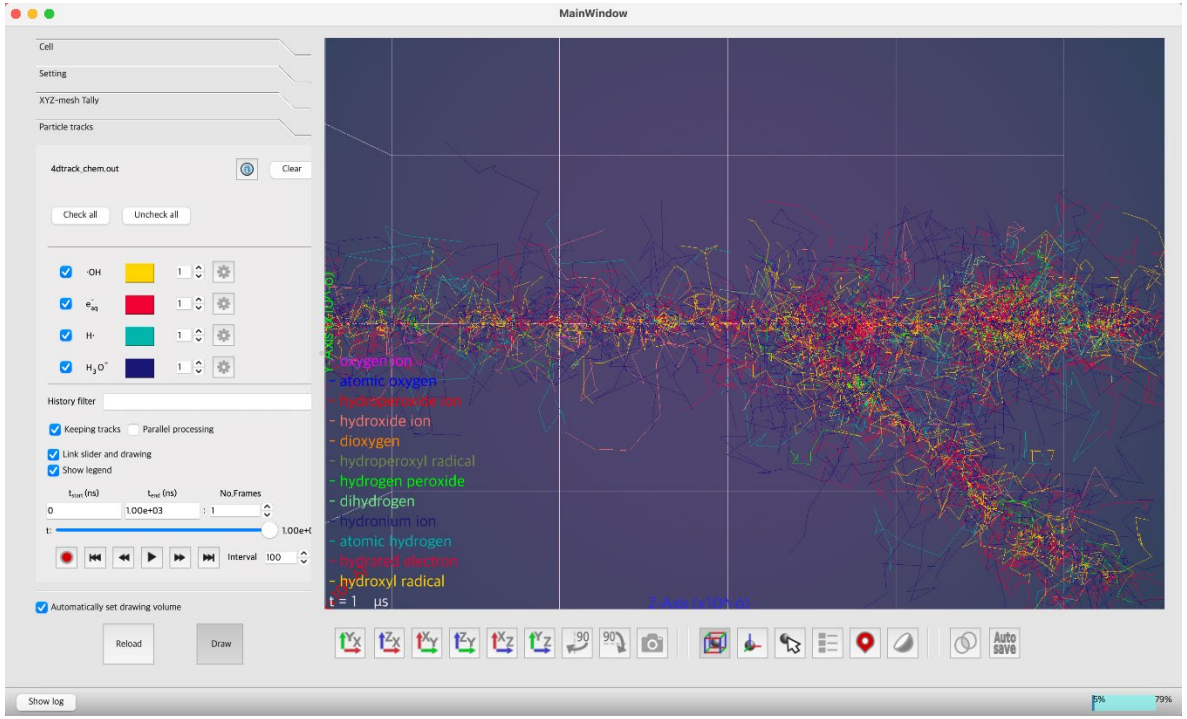
- ✓ Tally results with xyz mesh can be visualized on the material surfaces and a certain plane
- ✓ The numerical value of the tally result at the mouse pointer can be extracted
- ✓ Polygon Boolean method has been implemented to reduce the memory consumption

This improvement was performed under the support of Dr. S. Ohnishi of National Maritime Research Institute (NMRI)

Improvement of PHITS-Chem

New features

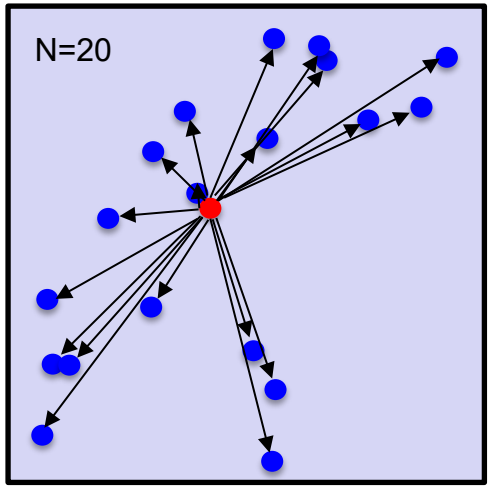
- ✓ Improvement of the chemical code to simulate radicals for ion track-structure models (PHITS-KURBUC and ITSART)
- ✓ Development of a function to display 3D animation of radical dynamics using PHIG-3D
- ✓ Introduction of the space partitioning method to reduce calculation time (e.g., approx. 28 times faster for 1-MeV e^-)



Application to ion tracks! & 3D animation with PHIG-3D!

Conventional algorithms

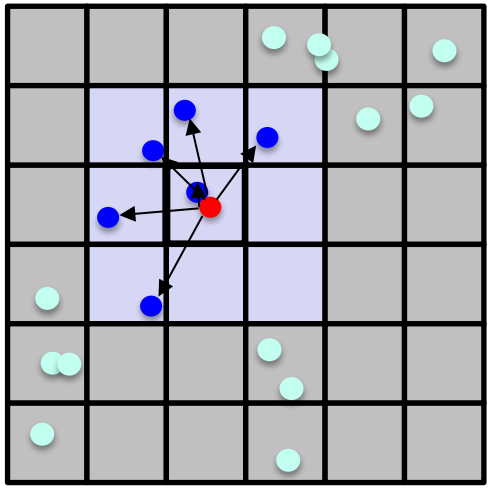
Cal. target: all radicals



: Region of cal. target

Space partitioning method

Cal. target: Nearby radicals only



: Out of region of cal. target

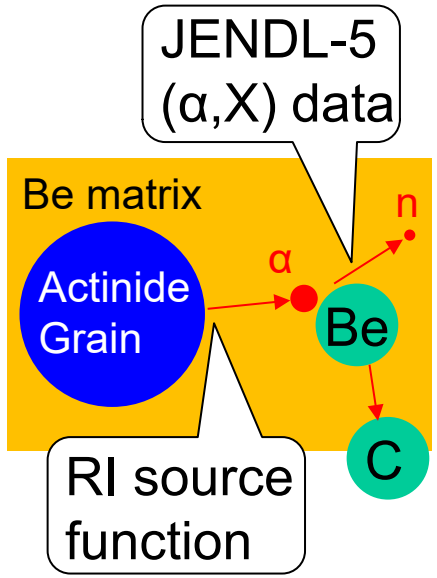
Efficiently analyse only the needed chemical reactions!

See phits/utility/usrtally/ChemCode & Y. Matsuya et al. Phys. Chem. Chem. Phys. (2025) DOI: 10.1039/d4cp04216f

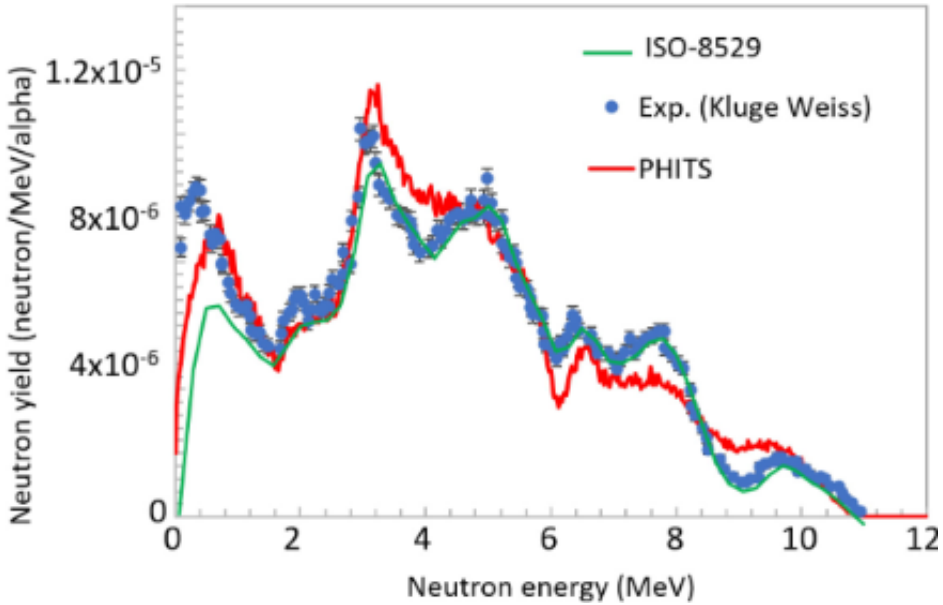
This improvement was performed under the support of Dr. Yuji Yoshii (Hokkaido University of Science)

Composite neutron source inputs (e.g. Am-Be)

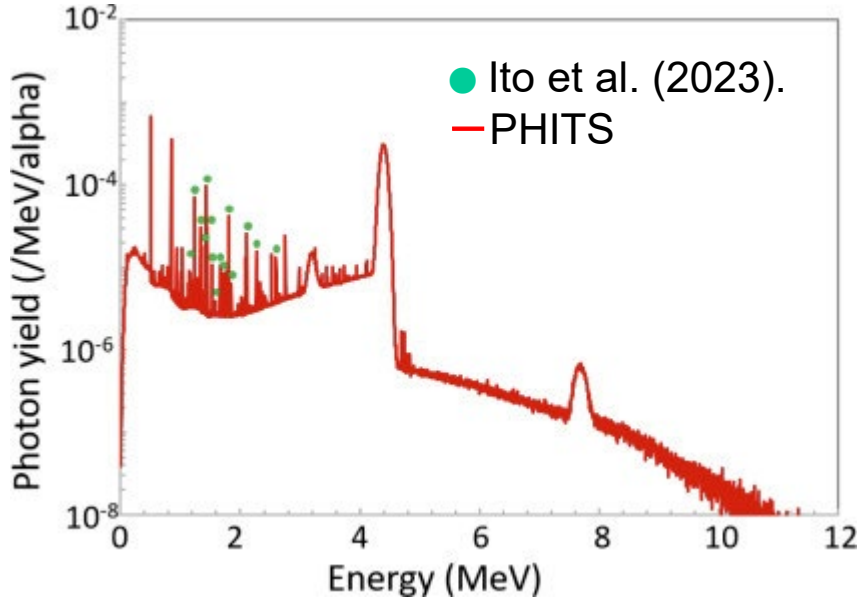
1. Composite neutron source sample inputs are available in ¥phits¥sample¥source¥NeutronSource¥Precise-model
2. Unlike ¥phits¥sample¥source¥NeutronSource¥AmBe, source parameters (length, grain size, actinide species, etc) are all adjustable and observables (e.g. gamm-ray emission) are calculated .
3. Installation of JENDL-5 alpha-particle sublibrary is required.



Calculated mechanism



Neutron

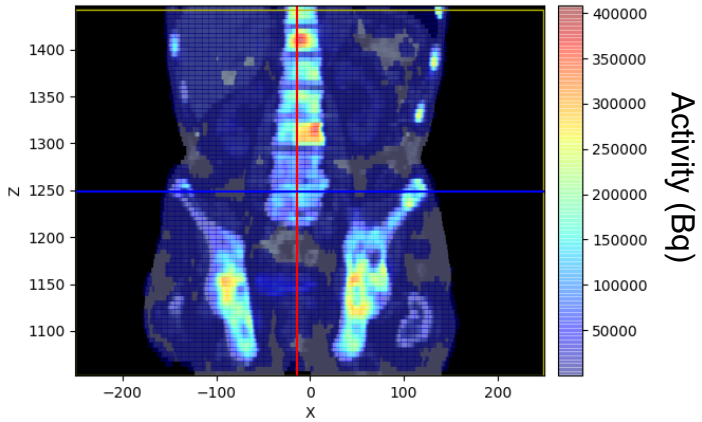


Gamma

Calculated and measured spectra of ^{241}Am-Be source.

For further details, see T. Ogawa, *Annals of Nuclear Energy*, 216, 111256, (2025)

Improvement of RT-PHITS for Nuclear Medicine



SPECT/CT image

CT2PHITS
PET2PHITS

Dose rate map

PHITS2DICOM
ROI2PHITS

Organ/Tumor dose rate

ExPORT-PHITS ver. 1.01

"Excel-based Program for time integration of Organ dose rates calculated by RT-PHITS" developed by T. Sato

Input conditions in blue columns			Scanning Date	Scanning Time	Copy & paste these columns for increasing ROI: Organ name: Whole body; Dose Rate (Gy/s) β & γ-rays	Dose Rate (Gy/s) α-ray	Time integral Dose (Gy) β & γ-rays	Time integral Dose (Gy) α-ray
Injected RI	Lu-177							
Half-life (s)	574300.8	1	2018/11/15	13:06	8.51E-07	0.00E+00	1.153E-02	0.000E+00
Physical decay constant (/s)	1.20694E-06	2	2018/11/16	13:05	5.67E-07	0.00E+00	6.040E-02	0.000E+00
Injected activity (MBq)	7210	3	2018/11/19	16:27	3.54E-07	0.00E+00	1.227E-01	0.000E+00
Injected date	2018/11/15	4	2018/11/20	13:21	3.28E-07	0.00E+00	2.567E-02	0.000E+00
Injected time	9:22	5					1.493E-01	0.000E+00
Number of images	4	6					0.000E+00	0.000E+00
RBE of α-ray	5	7					0.000E+00	0.000E+00
Biodecay after the last image	Mean	8					0.000E+00	0.000E+00
Biological decay constant (/s)	0.00E+00	9					0.000E+00	0.000E+00
		10					0.000E+00	0.000E+00
					Each radiation dose (Gy)		3.697E-01	0.000E+00
					Total absorbed dose (Gy)		3.697E-01	
					Dose per activitiy (Gy/MBq)		5.127E-05	
					RBE-weighted dose (Gy.Eq)		3.697E-01	
					EQDX (Gy)		2.565E-01	

		Time after injection (s)			λ bio,i (/s)		Integral time	
Input EQDX parameters in blue columns		0						
Cell line	HSG	13440	0	0.155555556	0	0	13440	13440
Type of model	TE-based SMK	99780	1	0.154861111	3.49424E-06	1E-20	86340	86340
X for EQDX (Gy)	2	371100	4	0.295138889	5.28595E-07	1E-20	271320	271320
α_0 (Gy^{-1})	0.156	446340	5	0.165972222	-2.05666E-07	1E-20	75240	75240
β (Gy^{-2})	0.0607	0	0	0	9.92462E-07	0	0	0
μ (hr^{-1})	1.5	0	0	0	0	0	0	0
$z^*_{d,1D,ref}$ (Gy)	1.96	0	0	0	0	0	0	0
$z^*_{d,1D,\alpha}$ (Gy)	47.5	0	0	0	0	0	0	0
$z_{d,1D,\alpha}$ (Gy)	94.8	0	0	0	0	0	0	0

Patient1-Tc99m | data

ExPORT-PHITS
(Excel-based Program for Integration of Organ dose rates calculated by RT-PHITS)

Organ/Tumor dose and their biological effect (EQDX) can be easily derived from SPECT/CT image

See phits/RT-PHITS/ExPORT-PHITS.xlsx & T. Sato et al. *EJNMMI Phys.* (2025) DOI: 10.1186/s40658-025-00743-6

Upcoming Futures

We are planning to …

➢ Improve the track structure mode

- ✓ Extension of the precise mode applicable to other elements/compounds
- ✓ Improvement of coupling modules connecting to material & life sciences

➢ Improve affinity to nuclear data library

- ✓ Feasibility of dose calculation using JENDL-5.0 up to 200 MeV

➢ Develop user support functions

- ✓ Improvement of PHITS-Pad (help function)
- ✓ Coupling with deterministic codes via tetrahedral mesh in the HDF format

➢ Improve accuracy and nuclear reaction model

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