

# PHITS Tools and DCHAIN Tools: Python modules for parsing and processing output from the PHITS radiation transport and DCHAIN activation codes

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## Summary

Various areas within the nuclear sciences—such as nuclear facility design, medical physics, experimental nuclear physics, and radiation protection—rely on complex codes employing nuclear data and a large variety of physics models to simulate the transport (and interactions) of radiation through matter to answer important questions, in both research and applied contexts. For example: How should a shielding wall be designed to comply with radiation safety regulations? What is the expected dose an individual may receive in a particular exposure scenario? After how long will an irradiated radioactive sample decay enough to become safe to handle? How should an experiment be designed to make the most of limited time at an accelerator facility?

While simplified “rule of thumb” calculations and lookup tables can provide crude answers in some very basic scenarios, often it is preferred or necessary (especially for higher-energy radiation) to fully model a radiation scenario to obtain a much more precise answer. PHITS (Sato et al., 2024) (Particle and Heavy Ion Transport code System) is one such general purpose Monte Carlo particle transport simulation code, presently with over 6000 users worldwide. Though PHITS can simulate a large variety of complex nuclear physics, it can only do so on the extremely short time scales of nuclear reactions. To calculate the activation, buildup, burnup, and decay of nuclides with time on any scale (seconds to centuries), distributed with and coupled to PHITS is the DCHAIN (Ratliff et al., 2020) (or DCHAIN-PHITS) code.

Within PHITS (and other similar codes) are “tallies” which score various physical quantities such as the number of particles passing through a region in space, the number of particles crossing a surface, the frequency and products of nuclear interactions of various types, deposition of energy, timing of interactions, displacements per atom (DPA), and more. Users provide the desired binning for the tally histograms to be created (such as specifying a range of energies of interest and how many bins the tally should have within that energy range), and the code will simulate the histories, or “lives”, of many particles, outputting the aggregate distributions for the quantities being tallied, which should be converged to the “true” or “real” distributions provided a statistically sufficient number of histories were simulated (often on the order of millions or more). For a few tallies, PHITS provides the option to output “dump” files where, in addition to the histograms, detailed raw history-by-history event data are recorded to an ASCII or binary file for every history satisfying the tally’s criteria and being scored by it, allowing users to, in post, create even more complex tallies and analyses than possible with the stock tallies in PHITS.

The DCHAIN code coupled to PHITS specializes in calculating nuclide inventories and derived quantities (such as activity, decay heat, decay gamma-ray emission spectra, and more) as a function of time for any arbitrary irradiation schedule from any radiation source.

## Statement of need

PHITS Tools and DCHAIN Tools serve as an interface between the plaintext (and binary) outputs of the PHITS and DCHAIN codes and Python, greatly expediting further programatic analysis, comparisons, and visualization in Python and providing some extra analysis tools. The outputs of the PHITS code are, aside from the special binary “dump” files, plaintext files formatted for processing by a custom closed-source visualization code (generating Encapsulated PostScript files) shipped with and automatically ran by PHITS, and those of the DCHAIN code are formatted in a variety of tabular, human-readable structures. Historically, programatic extraction and organization of numerical results (and metadata) from both codes often required writing a bespoke processing script for most individual simulations, possibly preceeded by manual data extraction/isolation too. PHITS Tools and DCHAIN Tools provide universal output parsers for the PHITS and DCHAIN codes, capable of processing all of the relevant output files produced by each code and outputting the numerical results and metadata in a consistent, standardized output format.

The substantial number of combinations within PHITS of geometry specification, scoring axes (spatial, energy, time, angle, LET, etc.), tally types (scoring volumetric and surface crossing particle fluxes, energy deposition, nuclide production, interactions, DPA, and more), potential particle species, and fair amount of “exceptions” or “edge cases” related to specific tallies and/or their settings highlight the utility of such a universal processing code for PHITS. When parsing standard PHITS tally output, PHITS Tools will return a metadata dictionary, a 10-dimensional NumPy array universally accomodating of all possible PHITS tally output containing all numerical results (structured as shown in the table below), and a Pandas DataFrame containing the same numerical information, which may be more user-friendly to those accustomed to working in Pandas.

axis	name	description
0	ir	Geometry mesh: reg / x / r / tet *
1	iy	Geometry mesh: 1 / y / 1
2	iz	Geometry mesh: 1 / z / z *
3	ie	Energy mesh: eng ([T-Deposit2] eng1)
4	it	Time mesh
5	ia	Angle mesh
6	il	LET mesh
7	ip	Particle type / group (part =)
8	ic	Special: [T-Deposit2] eng2; [T-Yield] mass, charge, chart; [T-Interact] act
9	ierr	= 0/1/2, Value / relative uncertainty / absolute uncertainty *
*exceptional behavior with [T-Cross] tally when enclos = 0 is set; see full docs		

PHITS Tools is also capable of parsing the “dump” output files (both binary and ASCII formats) that are available for some tallies, and it can also automatically detect, parse, and process all PHITS output files within a provided directory, very convenient for PHITS simulations employing multiple tallies (each with its own output file) whose output are to be studied in Python. The PHITS Tools module can be used either by (1) importing it as a Python module in a script and calling its functions, (2) running it in the command line via its CLI with a provided PHITS output file (or directory of files) and settings flags/options, or (3) running it without any arguments to launch a GUI stepping the user through the various output processing options and settings within PHITS Tools.

When used as an imported module, PHITS Tools provides a number of supplemental functions aiding with further analyses, such as tools for constructing one’s own tally over the history-by-history output of the “dump” files, rebinning histogrammed results to a different desired binning

79 structure, applying effective dose conversion coefficients from ICRP 116 (Petoussi-Henss et al.,  
80 2010) to tallied particle fluences, or retrieving a PHITS-input-formatted [Material] section entry  
81 (including its corresponding density) from a large database of over 300 materials (primarily  
82 consisting of the selection of materials within the PNNL Compendium of Material Composition  
83 Data for Radiation Transport Modeling (McConn et al., 2011)), among other useful side  
84 functions.

85 DCHAIN Tools is a separate Python module for handling the outputs of the DCHAIN code  
86 and is included as a submodule within the PHITS Tools repository. Its primary function  
87 parses all of the various output files of the DCHAIN code and compiles the metadata and  
88 numeric results—the confluence of the specified regions, output time steps, all nuclides and  
89 their inventories (and derived quantities), and complex decay chain schemes illustrating the  
90 production/destruction mechanisms for all nuclides—into a single unified dictionary object.  
91 The DCHAIN Tools module includes some additional useful functions such as retrieving neutron  
92 activation cross sections from DCHAIN's built-in nuclear data libraries, calculating flux-weighted  
93 single-group activation cross sections, and visualizing and summarizing the most significant  
94 nuclides (in terms of activity, decay heat, or gamma-ray dose) as a function of time.

95 In all, the PHITS Tools and DCHAIN Tools modules make the results produced by the PHITS  
96 and DCHAIN codes far more accessible for further use, analyses, comparisons, and visualizations  
97 in Python, removing the initial hurdle of parsing and organizing the raw output from these  
98 codes, and provides some additional tools for easing further analyses and drawing conclusions  
99 from the PHITS and DCHAIN results.

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