

◀ Detailed pin-cell geometry represented in full-core MONJU reactor calculation with PROTEUS.

PROTEUS

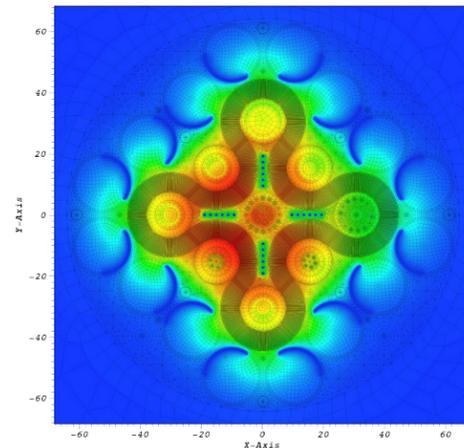
Argonne National Laboratory's
Simulation Toolset for
High-Fidelity Reactor
Physics Analysis

Using the PROTEUS Toolset

Argonne researchers maintain and develop the PROTEUS toolset as well as perform analysis with PROTEUS in collaboration with customers.

Users can request the MC²-3 code through the Radiation Safety Information Computational Center (RSICC) or Argonne National Laboratory. The Cross Section API, PROTEUS transport solvers and auxiliary meshing tools are available by contacting nera-software@anl.gov. Some government distribution restrictions apply.

Source code, manuals, and sample problems are included in the distribution. Training sessions and materials are available upon request.



◀ Thermal group flux distribution for Idaho National Laboratory's Advanced Test Reactor using SN2ND on the Argonne Leadership Computing Facility's Blue Gene/P.

Seventy years of leadership in nuclear science and technology

Argonne developed and/or built experiments, research reactors or prototypes of nearly every kind of commercial nuclear reactor in the world today, as well as many research and training reactors. An overview of this history can be found at

www.ne.anl.gov/About/ANL-Reactors.shtml

On the cover

Argonne's SN2ND code, part of the PROTEUS toolset, generates detailed pin-by-pin solutions for full core reactor problems.

Shown on the cover is the full core fast flux distribution for the Japanese MONJU reactor.

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The PROTEUS development team is led by scientists at the Nuclear Engineering Division of Argonne National Laboratory. Argonne is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.



Massively parallel neutronics calculations

enable high fidelity analysis. . . Argonne National Laboratory's powerful reactor physics toolset, PROTEUS, empowers users to study complex reactor designs reliably and accurately.

...Enabling multi-physics feedback and analysis of complex geometries.

The PROTEUS toolset performs cross section generation procedures, low and high fidelity radiation transport, and multi-physics modeling (within the SHARP Toolkit). PROTEUS' advanced modeling capabilities enable the nuclear reactor designer to explore detailed physics effects by modeling increased geometric complexity.

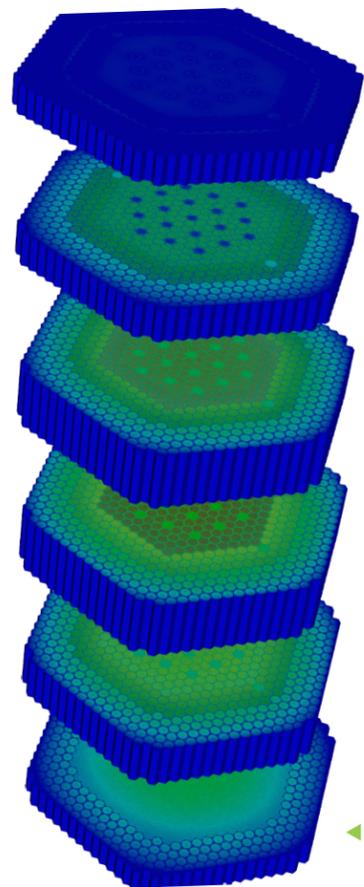
Advanced Modeling and Simulation for Reactor Physics Analysis

PROTEUS encompasses the set of advanced neutronics modeling and simulation tools developed at Argonne, including cross section generation codes, transport solvers, and mesh generation tools.

The MC²-3 code and the Cross Section API provide both thermal and fast reactor cross section processing capabilities. The high fidelity deterministic neutron transport solvers SN2ND (PROTEUS-SN), MOCEX (PROTEUS-MOC), and MOCFE (PROTEUS-MOCFE), provide different options for solving geometrically detailed and complex neutronics problems. Auxiliary tools are provided to automate finite element mesh creation.

The SN2ND solver within PROTEUS is part of a larger multi-physics design and analysis toolset (SHARP) that simulates neutronics, fluid dynamics and structural mechanics.

To date the PROTEUS toolset has been utilized for numerous calculations including heterogeneous fast reactors, thermal reactors, and test reactors (ATR, TREAT, ZPR/ZPPR).



◀ Slices from a full core SN2ND calculation showing the axial power distribution (log scale) in the MONJU reactor.

PROTEUS' advanced methodology enables reactor designers to analyze complex configurations

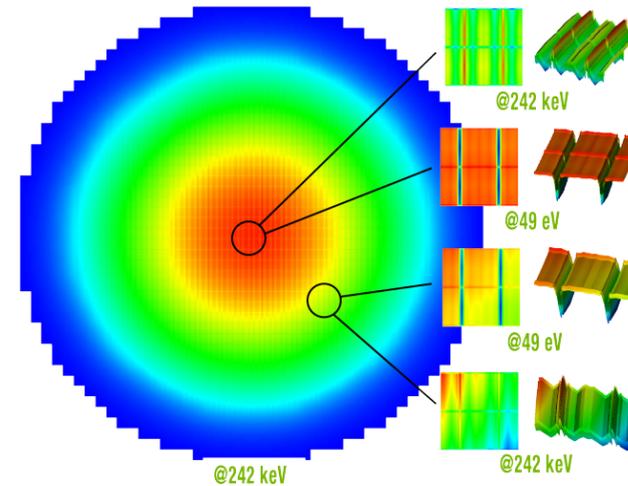
Argonne's PROTEUS toolset contains advanced tools ranging from cross section generation codes to transport solvers. PROTEUS uses modern programming structures and easy-to-read keyword format input. Finite element meshes can be flexibly generated on-the-fly with no prior experience or additional packages.

Multi-group Fast Reactor Cross Section Processing: MC²-3

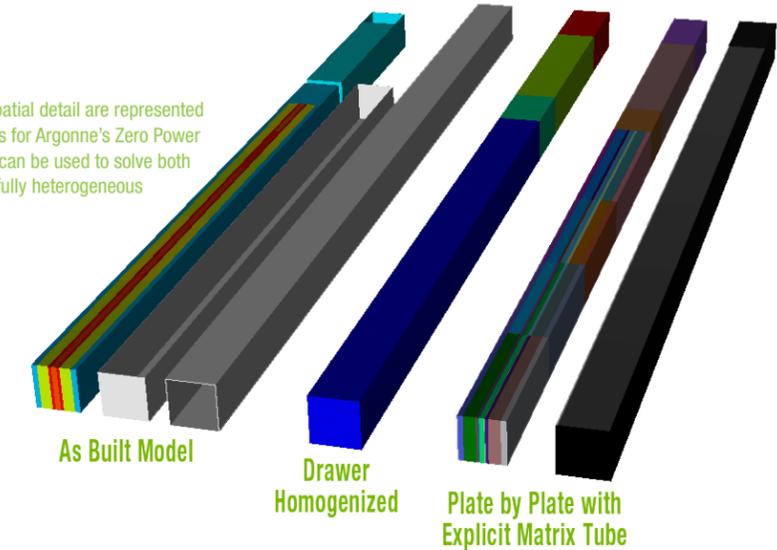
MC²-3 generates broad-group, cell-average microscopic cross sections from ENDF/B nuclear data. MC²-3 handles the complicated resonance self shielding in fast spectrum systems by directly accounting for the resonance interactions in detail and performing ultrafine-group 3D MOC (the same methodology as MOCEX) calculations on fuel cells, drawers, or assemblies. The resulting microscopic cross sections are used for fast reactor design and analysis calculation. A thermal cross section capability recently added is under verification.

Cross Section Application Programming Interface (API)

The Cross Section API allows PROTEUS' transport solvers to generate self-shielded multi-group cross sections on-the-fly – accounting for the effects of heterogeneous geometry as well as temperature and composition. The cross section library is generated using MC²-3 and NJOY for the reactor spectrum type of interest. The cross section API is developed as a functional module such that it can be easily adapted to other transport codes if they provide a fixed source transport solver to the cross section API.



Varying levels of spatial detail are represented in geometry models for Argonne's Zero Power Reactor. PROTEUS can be used to solve both homogenized and fully heterogeneous plate geometries.



SN2ND: Even Parity Discrete Ordinates Code

The SN2ND code (also called PROTEUS-SN) is a massively parallel neutronics solver for large scale simulations based on an unstructured finite element, multigroup, discrete ordinates formulation of the even-parity transport equation. SN2ND's higher fidelity representations permit the gradual phasing-out of existing modeling simplifications, allowing users to solve more complicated problems in finer detail. Using SN2ND's parallel computing capabilities, researchers were able to reduce the error on predicted Zero Power Reactor (ZPR) reaction rates from ~15% to within the experimental measurement error (<3%). SN2ND was recently extended to solve both fast and thermal reactor types by incorporating the cross section API.

MOCEX (2D/3D) and MOCFE (3D): Method of Characteristics Codes

PROTEUS includes two MOC solver options to efficiently solve heterogeneous geometry problems. MOCFE is based on a full 3D formulation

while MOCEX combines the 2D MOC method with the discontinuous Galerkin finite element method for the axially extruded geometry problem. Due to significant increase of memory, MOCFE is recommended for 2D or small 3D problems. MOCEX is a promising tool to solve axially complex geometry problems including void, without the limitations of the 2D/1D approach (e.g., DeCART).

Auxiliary Meshing and Visualization Tools

PROTEUS includes an extensive set of mesh processing tools to assist users with the creation of finite element meshes in PROTEUS format.

PROTEUS generates conventional Cartesian or hexagonal lattice finite element meshes, including pin and assembly duct details, using the UFMESH tool. For more complex geometries, a conversion utility is available to convert externally-generated EXODUS II meshes into PROTEUS format. PROTEUS reads MOAB (.h5m) meshes directly when linked to the open source MOAB package.

PROTEUS transport solver results are visualized using the VisIt software package.

Finalist for GORDON BELL PRIZE in Supercomputing

SN2ND, part of the PROTEUS toolset, is capable of handling larger, more detailed problems than most, if not all, transport codes. SN2ND scales on massively parallel machines such as Argonne's IBM BG/Q Leadership Computing Facility, allowing researchers to solve more complicated problems in finer detail with fewer approximations. SN2ND was nominated for the prestigious Gordon Bell Prize in Supercomputing for its efficient and scalable algorithms.