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Benchmarking of SNAM with the ITER 3D model

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Abstract

The discrete ordinates particle transport codes (SN codes) are widely used in reactor design, radiation shielding, nuclear detection and other fields. SN automatic modeling system (SNAM) is an integrated interface program between CAD systems and SN codes, which makes full use of CAD technology to improve SN modeling and perform the conversion between CAD models and SN code input files. The modeling capability of SNAM has been tested by the International Thermonuclear Experimental Reactor (ITER) benchmark model in this paper. The benchmark process includes geometric model processing, material assignment, model normalizing, converting to SN code input file, calculating and analysis with SN code system VisualBUS. The neutron flux radial distribution of the inboard blanket modules is given and compared with the results calculated by MCNP.

Keywords: SN code; CAD; ITER; Benchmark; SNAM

1. Introduction

SN codes (e.g. TORT [1], THREEDANT [2] and VisualBUS [3]) are widely used in reactor design, radiation shielding, nuclear detection and other fields. Latest nuclear analysis in fusion field is urging for accurate simulations for large complex 3D devices like ITER. However, the SN modeling for such large-scale and complex systems is a time-consuming and error-prone task. A more efficient way is to shift the geometric modeling into a CAD system and to use an interface program to convert the CAD model into SN code input file.

SNAM is such an interface program between CAD systems and SN codes, which is developed by FDS Team in China. The SN modeling capability of SNAM is evaluated with the ITER 3D benchmark model that is created by the ITER neutronics work group to test and

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benchmark all kinds of the interface programs between CAD models and transport codes developed by the member counties.

The basic functions of SNAM and the ITER 3D model are described in Sections 2 and 3, respectively. The detailed benchmarking process is provided in Section 4, and the calculation and analysis is presented in Section 5 and the last section is the summary of this work.

2. Basic functions of SNAM

SNAM makes use of CAD technology to improve SN modeling accuracy and efficiency, which can automatically perform the conversion between CAD models and SN code input files. It allows access to full features of modern CAD systems, facilitating the geometric modeling. The basic functions of SNAM include geometry modeling, material modeling, conversion between CAD models and SN code input files.

The function of geometry modeling is to prepare suitable geometry model for SN modeling. It can create CAD model directly in SNAM, import/export CAD files as various formats (e.g. SAT, STEP and IGES, etc.), fix solids errors generated during the file formats conversion, check and remove the gaps and overlaps in the model.

Associating CAD model with physics properties can be performed in material modeling. With SNAM users can group the solids of model according to the material or zone number, assign/edit neutronics information, such as material name, density, zone number and other related physics properties.

The conversion of CAD models to SN code input files is the most important feature of SNAM. For the inherent limitation of SN method, most SN codes only support regular geometries, such as cylindrical (RΘZ), Cartesian (XYZ) or tetrahedral geometries, etc. SNAM can directly convert regular geometry models into SN code input files, which includes parsing neutronics physics properties, filling void solids, mesh grid generating and source modeling, etc. For the irregular geometry models not recognized by SN codes, the models should be first converted to the regular ones using model normalizing and uniting algorithms [4], and then into SN code input files.

The conversion of SN code input files to CAD models is another important function of SNAM, which can convert SN code file into CAD model with related physics properties. The model reverted by SNAM can be visualized and edited in SNAM or other CAD systems, which provides an effective way to check, verify and reuse the SN model.

3. ITER 3D model

The ITER 3D model (Fig. 1) is provided by ITER International Team (IT) to compare and evaluate various auto-modeling codes being developed by the ITER Participant Teams, which has a radius of 1680 cm and a height of 1670 cm. It is created in CATIA/V5, which has been chosen to the CAD system for ITER design, and saved in STEP file format. This CAD model includes all the important components with complex geometry of the 40° torus sector, as well as various complicated curved surfaces. It can fully test the SN modeling capability of interface programs between CAD systems and SN codes. The main components and material composition of model are listed in Table 1. Besides the description of geometry and the material, the CAD model of plasma source distribution is shown

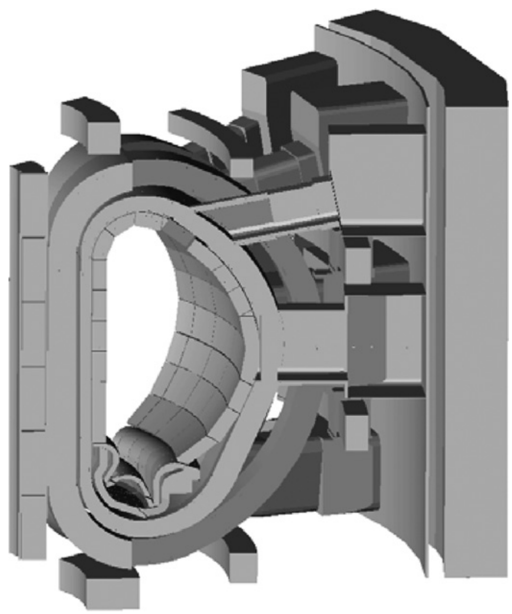

Fig. 1. ITER 3D model created in CATIA.

Table 1
Components and material composition

Components	Material Composition (homogenized with vol.%)
PFC stainless steel case, cryostat wall	SS304L-100%
Bioshield	Boron concrete-100%
PF4 and PF4 support structure, TFC stainless steel case, CS outer/inner tie plates	SS316LN-100%
Thermal shield	SS304L-100%
Vacuum vessel outer/inner shell, equatorial port and upper port	SS316L(N)-IG-100%
Vacuum vessel in wall shield	SS304B7-55%, water-45%
Blanket module first wall	SS316L(N)-IG-44%, water-16.3%, Be-14.3%, CuCrZr-IG-25.4%
Blanket module shield block, equatorial port and upper port dummy plugs	SS316L(N)-IG-70%, water-30%
Blanket module rear layer	SS316L(N)-IG-52.5%, water-21.5%
TFC winding pack	SS316LN-47.6%, SS316L-1.5%, He/liq.-12.9%, Nb3Sn-6.3%, *r*-epoxy-18%, Cu-13.7%
PFC winding pack	*r*-Epoxy-39%, SS316L-41%, He/liq.-9.1%, NbTi-1%, Cu-9.8%, Inconel-0.1%
Diverter body	SS316L(N)-IG-5%, water-35%
SS part of PFC	SS316L(N)-IG-55%, water-45%
PF cooling structure	SS316L(N)-IG-33%, water-7.1%, CuCrZr-IG-59.9%
PF units	Cu-20%, W-80%
PF units	CFC
CS winding pack	JK2 stainless steel-54.7%, SS316L-1.2%, Inconel-0.6%, He/liq.-11.2%, Cu-11%, Nb3Sn-5.5%, *r*-epoxy-15.8%

in Fig. 2. The neutron source is assumed to uniformly distribute in the plasma chamber with uniformly distributed energy from 13.5 to 15.0 MeV.

The normalized neutron flux radial distribution of the ITER 3D model should be calculated during the benchmark processing. For the ITER 3D model can be improved to be used as the data for nuclear analysis for its accuracy in shape and dimension to the real ITER device, this means the model is also valuable for ITER nuclear analysis.

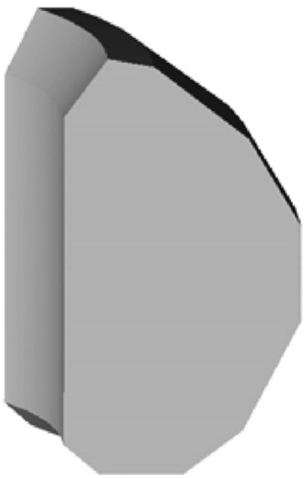

Fig. 2. Plasma source model created in CATIA.

4. Benchmark process

The processing of ITER benchmark model with SNAM is performed on Intel Pentium-4 2.0 GHz platform with 2 GB RAM. The whole benchmark process includes the following steps:

(1) The model saved in step file format is imported to SNAM. Solid errors generated in CAD file formats conversion are fixed. Gaps and overlaps in the model are checked and removed automatically.
(2) According to the material definition file given by ITER IT, group the solids of ITER 3D model and assign suitable physics properties, such as material, zone and other related auxiliary information. After the material modeling process, the ITER 3D model is converted to the neutronics model.

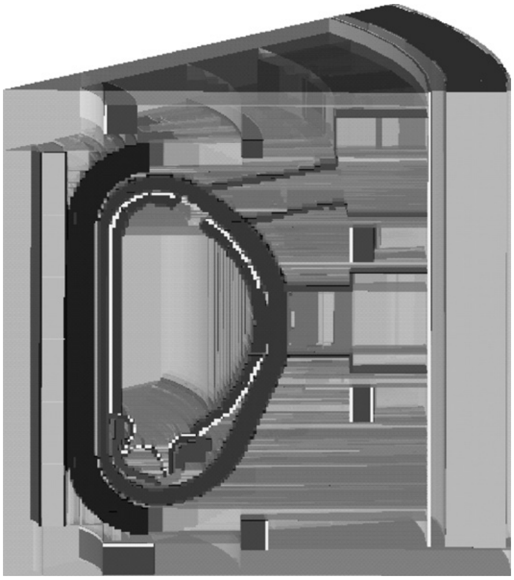

Fig. 3. Reverted neutronics model by SNAM.

(3) The ITER 3D model consists of regular geometry solids which are not recognized by SN code. SNAM first converts the ITER 3D model to the normalized one which only includes regular solids, and then converts the normalized model into SN code input file automatically, which includes 5,416 bodies and dimension of mesh grids are $520 \times 4 \times 967$.
(4) In order to check and verify SN code input file generated by SNAM, the input file is reversely converted to the CAD model with SNAM and the model is shown in Fig. 3. Analyze the models geometry, material, zone and other physics properties, which are consistent with the model description of SN code input file.

5. Calculation and analysis

Using the input file generated by SNAM, the neutron transport calculation was carried out by SN code VisualBUS with data library MATXS10 (30 neutron groups + 12 gamma groups) [5]. The Legendre expansion of the scattering kernel is P_1 and the angular quadrature set used by VisualBUS is S4. The normalized neutron flux radial distribution of the ITER 3D model is calculated by VisualBUS. The neutron flux

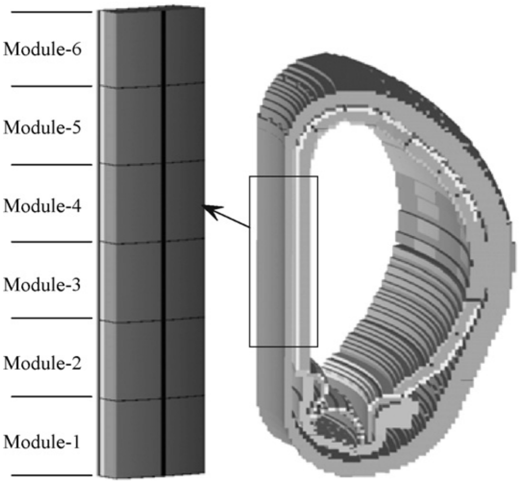

Fig. 4. Inboard blanket modules of ITER 3D model.

distribution of the inboard blanket modules (Fig. 4) is compared with those calculated by MCNP/4C [6] with data library FENDL-2.1 [7] and the statistical errors of the results are less than 1%, the MCNP input file having been converted from the ITER 3D model by Monte Carlo Automatic Modeling System (MCAM) [8–10]. The normalized neutron flux distribution in Module 4 calculated by VisualBUS and MCNP is shown in Table 2.

As shown in Table 2, the calculation results by VisualBUS match well with those calculated by MCNP and the peak difference is 15%. This difference may lie in the different data libraries used by VisualBUS and MCNP, as well as the different methods of considering the neutron stream effect in the gap for VisualBUS and MCNP. It can demonstrate that SNAM can correctly convert large-scale complex CAD model to SN code input file. The more detailed calculations and analysis will be discussed in later articles.

Table 2
Normalized neutron flux distribution in Module 4 ($53.3 < Z < 153.8$ cm, $10° < \theta < 20°$)

Radial range	Normalized neutron flux	
	VisualBUS (1/[cm^2 sn])	MCNP (1/[cm^2 sn])
359–370.35	1.2415E−07	1.4723E−07
370.35–381.5	4.2341E−07	4.8686E−07
381.5–393	1.7082E−06	1.8709E−06
393–397.35	4.0623E−06	4.2451E−06
397.35–404.5	7.0708E−06	7.1998E−06

6. Summary

The SN modeling capability of SNAM is benchmarked by the ITER 3D model, and the SN code input file is automatically generated by SNAM. The input file generated by SNAM has been calculated by VisualBUS, and the results are good agreements with those calculated by MCNP. It can be concluded that SNAM has the ability to process large-scale and complex CAD models correctly for SN modeling. This also means SNAM has successfully passed the benchmark and it will be an efficient and potential SN modeling tool for complex fusion device models.

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