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Development and Preliminary Verification of Reactor Shielding Design Code cosSHIELD of COSINE Code Package

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Abstract

COre and System INtegrated Engine for design and analysis (COSINE), is an integrated nuclear engineering code package, which is developed by State Nuclear Power Software Development Center (SNPSDC) in China. Reactor radiation shielding is an indispensable part of nuclear power plant design. According to relevant regulations and guidance, and based on the discrete ordinate method, the reactor shielding design code cosSHIELD was developed and verified preliminary using TEKEDA and Kobayashi benchmark. The results show that cosSHIELD can solve the critical and stationary source problem very well, in addition mitigate the ray effects efficiently.

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Keywords: Radiation Shielding; COSINE; cosSHIELD; S_N

1. Introduction

COre and System INtegrated Engine for design and analysis (COSINE), an integrated nuclear engineering code package, is being developed by State Nuclear Power Software Development Center (SNPSDC) in China [1]. Reactor physics codes, thermal hydraulics codes, severe accident analysis codes, probability safety analysis software, etc., are

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included in COSINE. The reactor physics codes contain the lattice physics code (LATC), the core simulator analysis code (CORE), the kinetics code (KIND) and reactor shielding design code (cosSHIELD), etc. [2].

In full power operation, because of the fission and decay of the fuel and neutron capture by the structure material, reactor will release a large amount of radioactive particles. After shutdown, gamma from the fission and activation products becomes one of the most important radiation source, which do harm to biological tissue and produce thermal deposition and irradiation damage in equipment and devices. Thus before the design of a plant, it should be made a calculation and analysis by using software. Recently, there are many famous code over the world such a DOORS [3], Denovo [4], which developed by ORNL, DANTSYS [5], PARTISN [6], which developed by LANL. As a result, it is necessary and valuable to develop a self-reliance radiation shielding code.

This paper provides an overview of the development and preliminary verification of the reactor shielding design code cosSHIELD, which is mainly used to ensure the security and conservatism of important devices such as pressure vessel, concrete shielding and auxiliary building.

Nomenclature

S_N	discrete ordinates method
P_N	spherical harmonics method
k_{eff}	effective multiplication factor
Σ_t	total cross section
Σ_s	scattering cross section

2. Basic Methodologies

The program is a multi-dimensional discrete ordinates particle transport code which solves multi-group transport equation.

2.1. Discretization of transport equation

According to conservation, the transport equation in a given energy/time unit is as follow [7]:

$$\frac{1}{v}\frac{\partial\Phi(\vec{r},\vec{\Omega},E,t)}{\partial t}+\vec{\Omega}.\nabla\Phi(\vec{r},\vec{\Omega},E,t)+\Sigma_t\Phi(\vec{r},\vec{\Omega},E,t)= \int_0^\infty dE^{'}\int_{\vec{\Omega}}\Sigma_s(\vec{r},E^{'})f(\vec{r},E^{'}\to E,\vec{\Omega}^{'}\to\vec{\Omega})\Phi(\vec{r},E^{'},\vec{\Omega}^{'})d\vec{\Omega}^{'}+Q_f(\vec{r},\vec{\Omega},E,t)+q(\vec{r},\vec{\Omega},E) \quad (1)$$

where: $\frac{1}{v}\frac{\partial\Phi(\vec{r},\vec{\Omega},E,t)}{\partial t}$ is the change rate of neutron flux.

In steady state, equation (1) can be described as:

$$\vec{\Omega}.\nabla\Phi(\vec{r},\vec{\Omega},E)+\Sigma_t\Phi(\vec{r},\vec{\Omega},E)= \int_0^\infty dE^{'}\int_{\vec{\Omega}}\Sigma_s(\vec{r},E^{'})f(\vec{r},E^{'}\to E,\vec{\Omega}^{'}\to\vec{\Omega})\Phi(\vec{r},E^{'},\vec{\Omega}^{'})d\vec{\Omega}^{'}+Q_f(\vec{r},\vec{\Omega},E,t)+q(\vec{r},\vec{\Omega},E) \quad (2)$$

where the $\vec{\Omega}.\nabla\Phi(\vec{r},\vec{\Omega},E)$ is the leakage term, the $\Sigma_t\Phi(\vec{r},\vec{\Omega},E)$ is the removal term, the $\int_0^\infty dE^{'}\int_{\vec{\Omega}}\Sigma_s(\vec{r},E^{'})f(\vec{r},E^{'}\to E,\vec{\Omega}^{'}\to\vec{\Omega})\Phi(\vec{r},E^{'},\vec{\Omega}^{'})d\vec{\Omega}^{'}$ is the scatter source, the $Q_f(\vec{r},\vec{\Omega},E,t)$ is the fission source, and the $q(\vec{r},\vec{\Omega},E)$ is the external source.