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# Nuclear-thermal-coupled optimization code for the fusion breeding blanket conceptual design

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## HIGHLIGHTS

- A nuclear-thermal-coupled predesign code has been developed for optimizing the radial build arrangement of fusion breeding blanket.
- Coupling module aims at speeding up the efficiency of design progress by coupling the neutronics calculation code with the thermal-hydraulic analysis code.
- Radial build optimization algorithm aims at optimal arrangement of breeding blanket considering one or multiple specified objectives subject to the design criteria such as material temperature limit and available TBR.

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## ABSTRACT

Fusion breeding blanket as one of the key in-vessel components performs the functions of breeding the tritium, removing the nuclear heat and heat flux from plasma chamber as well as acting as part of shielding system. The radial build design which determines the arrangement of function zones and material properties on the radial direction is the basis of the detailed design of fusion breeding blanket. For facilitating the radial build design, this study aims for developing a pre-design code to optimize the radial build of blanket with considering the performance of nuclear and thermal-hydraulic simultaneously. Two main features of this code are: (1) Coupling of the neutronics analysis with the thermal-hydraulic analysis to speed up the analysis progress; (2) preliminary optimization algorithm using one or multiple specified objectives subject to the design criteria in the form of constrains imposed on design variables and performance parameters within the possible engineering ranges. This pre-design code has been applied to the conceptual design of water-cooled ceramic breeding blanket in project of China fusion engineering testing reactor (CFETR).



## 1. Introduction

Development and optimization of design of blanket is a logical progression based on initial results obtained with one and two dimensional scoping and parametric analyses followed by detailed 3D design and analyses. A set of critical parameters such as functional zones arrangement, composition of materials and coolant parameters (pressure, temperature and velocity) were expected to change and expanded as the evaluations and studies proceeded and as they provided feedback into the iterative design process [1]. Multi-disciplines are involved in the blanket design progress such as neutronics, thermal-hydraulics and mechanical load analysis those are depended on the different analysis codes as well as the individual parameter format [2]. It is time/force consuming progress for the blanket design.

Therefore a comprehensive design tool is needed to be capable of considering all these variables to define the optimum blanket design and satisfying all the design constraints for the adopted figure of merit and the blanket design criteria. Be different from the existing blanket design tools [3–5], this contribution aimed at optimizing the radial build design including optimization materials components, arrangement of cooling plates and breeder/multiplier zones those are parallel to first wall. The optimizing objective is to achieve the best nuclear and thermal-hydraulic performance for the breeding blanket. A Nuclear-thermal-coupled Optimization Code (NTOC) has been developed and been applied to the conceptual design of a kind of water cooling solid blanket whose radial

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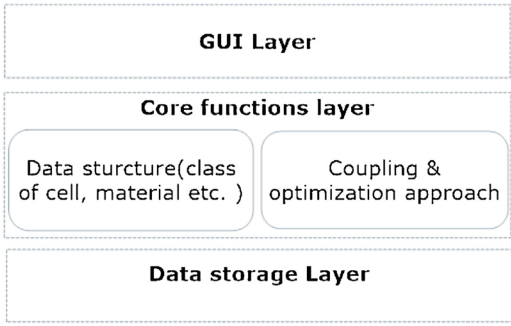


**Fig. 1.** Framework of NTOC.

build arrangement is parallel to the first wall. This paper discusses in details on the coupling, optimization approaches and implementations of this code.

## 2. Design principle of NTOC

### 2.1. Framework and GUI of NTOC

NTOC adopts the object-oriented and modularization design pattern which is benefit to improve the robustness and extendibility of code. The code has been developed on the Visual Studio 2010 platform. Fig. 1 shows the layering framework of NTOC consisting of graphical user interface (GUI) layer, core functions layer and data stored layer. User-friendly GUI aimed at making blanket design progress easier and more efficient. Fig. 2 (left) shows the main GUI which contains the radial build list view, functional buttons and option setting. Fig. 2 (right) shows the function of configuration which provides the blanket parameters setting and option of normalization factor which is the important parameter to estimate the nuclear response variations such as neutron flux and nuclear heating. Two options neutron wall load (NWL) and fusion power have been provided as normalization factor. Core functions layer includes the reasonable data structure and the approach of coupling and optimization. For the radial build optimization problem, each blanket function zone is designed as a cell class consisting of geometry data, materials and thermal parameters etc. Material as property of a cell class, it is also an independent class which encapsulated not only compositions and density of material but also operations of material such as adding and removing a composition from a material. Various cells are organized as a list array from which

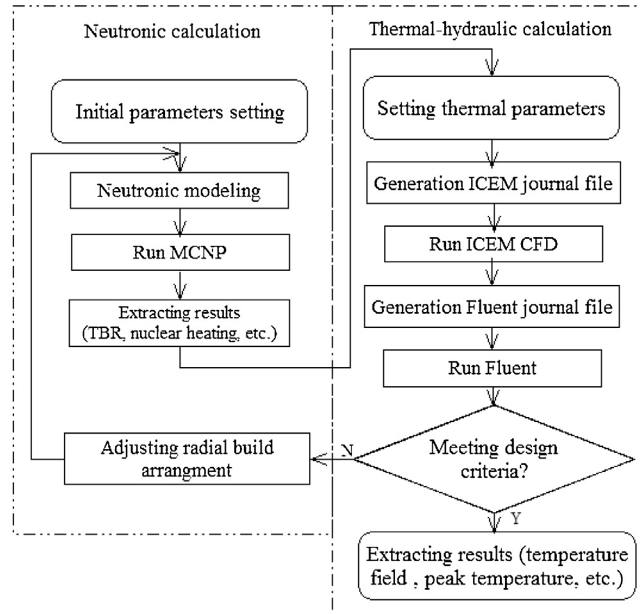


**Fig. 3.** Flowchart of coupling module of NTOC.

is convenient to insert and remove an instance of cell class. The approach of coupling and optimization calculation is introduced in detail in Section 2.2. For the data storage layer, it is data base for the default configuration parameters and material compositions.

### 2.2. Approach of coupling and optimization

The design objective of NTOC is to achieve the best/proper nuclear-thermal performance by optimizing the radial build of blanket. To fulfill this objective, under the specific optimization strategy, the iterative optimizing progress would be carried out automatically by the coupling calculation interface. Fig. 3 shows the workflow chart of the coupling module. The key issue for coupling approach is to ensure that geometry dimension and properties of calculation models are consistent between neutronics calculation and thermal-hydraulic calculation. For this radial build optimization problem, one dimensional cylinder neutronics model and two-dimensional thermal calculation model have been developed respectively and they share the identical geome-

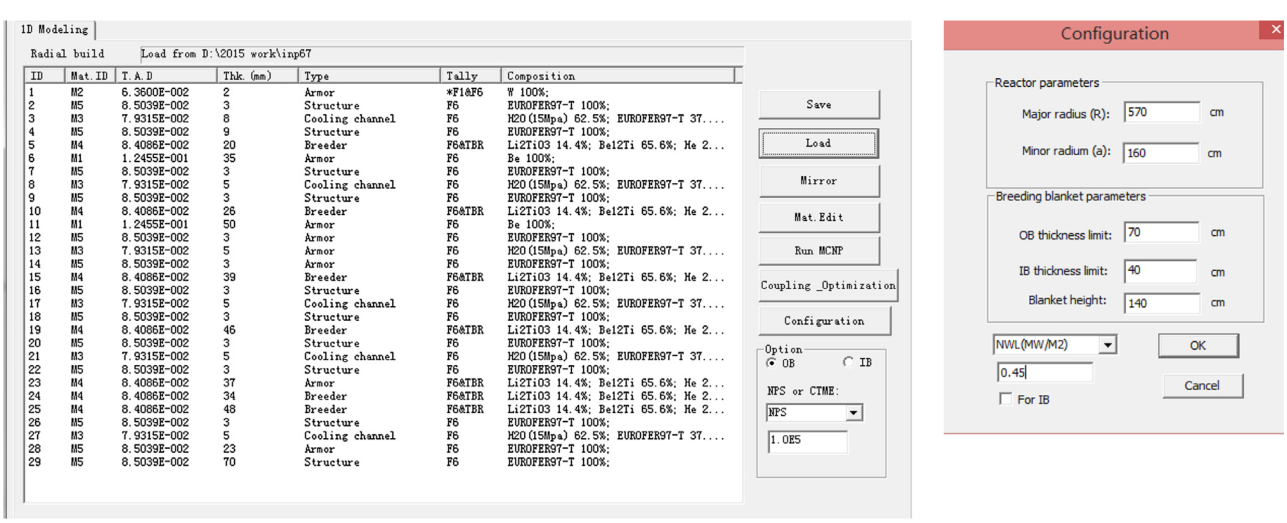


**Fig. 2.** Main window (left) and Configuration window (right) of NTOC.