Research and Virtual Reactor Design at UIUC, invited

John Griffith, Jianwei Hu, Nick Karancevic, Federico E. Teruel, Yizhou Yan, James Stubbins, and Rizwan-uddin

Department of Nuclear, Plasma and Radiological Engineering
University of Illinois, 103 S. Goodwin Ave.,Urbana, IL 61801 USA
Phone: 217 244-4944; Fax: 217 333 2906; rizwan@uiuc.edu

INTRODUCTION

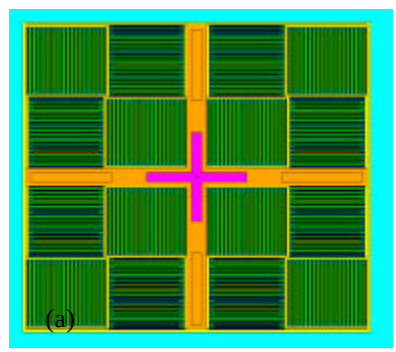
In the Big-10 INIE consortium, University of Illinois at Urbana-Champaign is taking the lead in developing computational tools, analyzing existing research reactors, and developing and testing concepts for new research reactor designs, as well as developing a "virtual" research reactor. Significant progress has been made in each of these areas since last ANS winter meeting [1]. A more detailed review of earlier work is in Ref. [2]. A brief summary of some recent efforts and accomplishments is presented here. [Work related to computational tool development for neutronics and thermal hydraulics analyses of reactors is not covered in this summary [3, 4].)

DESCRIPTION

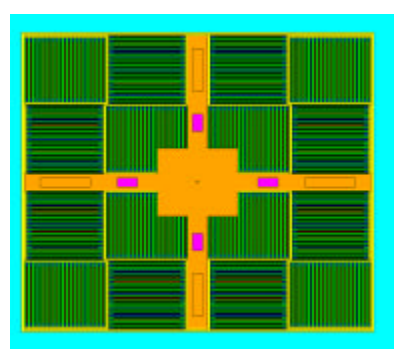
Building on our earlier beam line optimization studies carried out for the UI Triga design [5], recent focus has been on the development of new reactor designs. As the industry moves toward the goal of using Monte Carlo techniques for whole core calculations of power reactors, the current set of tools in this work for research reactor analysis are MCNP and ORIGEN2; along with MONTEBURNS. Small size core of research reactors allow fairly detailed analyses of core design as well as burnup calculations.

First reactor design considered is a variation of the German FRM-II design (HEU, 20 MW). The design specs were changed to LEU fuel and 10 MW of power while keeping the same maximum thermal flux per MW (MTF/MW) requirement as in the FRM-II. An asymmetric design with LEU fuel, in which half of the annular core is of different thickness than the other half, achieves the same MTF/MW as in FRM-II, still yielding a reasonably acceptable core life of over 40 days [6]. The design produces a high thermal neutron flux zone (3.9E14 $n \cdot cm^{-2} s^{-1}$), a moderate thermal neutron flux zone (2.4E14 $n \cdot cm^{-2} s^{-1}$), and a low thermal flux zone (1.0E14 $n \cdot cm^{-2} s^{-1}$) in the outer reflector. Moreover, an inner-irradiation area of at least 154 cm^2 is available. This region may be useful to irradiate material with harder spectrum than in the outer reflector without perturbing the neutron fluxes there. All these features make the design an interesting candidate for the next generation of research reactor.

The second design considered is the Australian Replacement Research Reactor. Since the original specs did not require access to fast neutrons for material irradiation studies, our goal was to modify the design without much disturbing the other design features, and provide access to high fast neutron flux for material irradiation. In the proposed design variation [7], a square cavity is introduced in the center of the core, replacing the cross-shaped control blade. Control blades are moved to the narrow slits between the quadrants of the core. Heterogeneous core is modeled with full details including the Cadmium wire at the edges of the fuel plates. Results show that compared to the fast flux available at the edge of the core in the original RRR design, the fast flux available for material irradiation in the center cavity in the modified design is about an order of magnitude higher; without significantly impacting the thermal flux levels in the reflector. Figure 1a and 1b respectively show the original RRR core design and the modified version with the center cavity.



(a)



(b)

Figure 1. (a) Core of the original RRR design, (b) Modified core with a central cavity.

Computational fluid dynamics and commercial codes are being explored to perform thermal hydraulics and safety analyses of these core designs [8]. Commercial CFD code, FLUENT, is used to simulate natural convection in the RRR core and pool using a porous media approximation for the core region. Parameters for the porous media model are determined from a detailed assembly level simulation of a single fuel assembly. Results show that a water temperature rise of about 43 C is expected across the core during the transient after a pump failure.

Development of virtual reactor, virtual control rooms, and other virtual components has also progressed very well. INIE program at UIUC now has access to three operational VR (virtual reality) facilities on campus: a six walled CUBE; a four walled CAVE; and a dedicated single wall VISBOX system. Summaries and details of earlier work can be found in Refs. 9-11. Recent focus has been on two fronts: developing models in standard 3D CAD formats and then importing them into the virtual environment; and development of models using game engines. The latter provides fast development of simple models and exploits the efficiency and speed of the gaming engine products.

While standard VR allows navigation in the virtual environment, introducing interactivity with objects such as control panels and touch screen monitors in such environment is currently being implemented. For this purpose, among other products we have used the front end of the BWR simulator [12] and displayed it in the virtual environment of a reactor control room. Figure 2 shows a virtual control room [13] with the front end of the BWR simulator "pasted" on a control panel of the virtual model.

NOTE

John Griffith and Nick Karancevic worked on virtual reactor development. Jianwei Hu worked on the neutronics analysis of the RRR reactor design. Federico Teruel worked on the asymmetric reactor core design, and Yizhou Yan worked on the CFD analysis of the RRR.

ACKNOWLEDGEMENT

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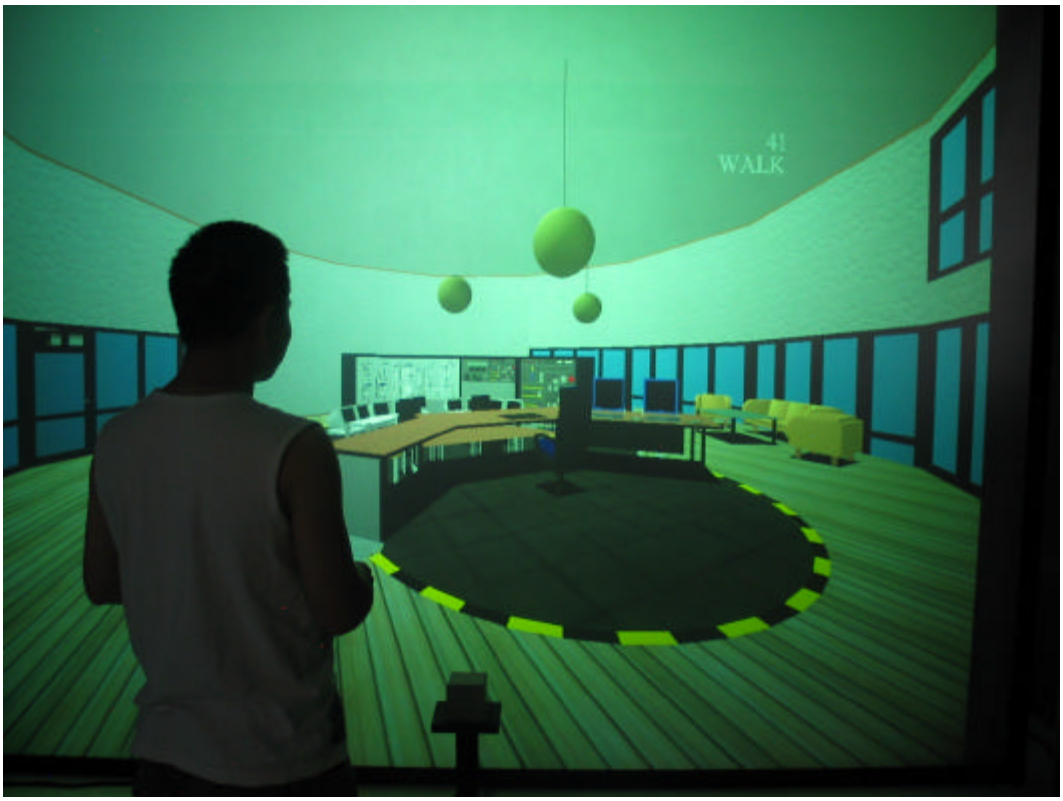

Figure 2. Pictures of the VISBOX (NPRE, UIUC) showing a model of a virtual control room [13]. Broad view (top); close up of the front end of the BWR simulator panel (bottom) [12]