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Technical note

Cold neutron source conceptual designing for Tehran Research Reactor

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ABSTRACT

A cold neutron source (CNS) conceptual designing for the Tehran Research Reactor (TRR) were carried out using MCNPX code. In this study, a horizontal beam tube of the core which has appropriate the highest thermal flux is selected and parametric analysis to choose the type and geometry of the moderator, and the required CNS dimensions for maximizing the cold neutron production was performed. In this design the moderator cell has a spherical annulus structure, and the cold neutron flux and its brightness are calculated together with the nuclear heat load of the CNS for a variety of materials including liquid hydrogen, liquid deuterium, and solid methane. Based on our study, liquid hydrogen with more ortho-concentration than para and solid methane are the best options.

1. Introduction

Cold neutron source (CNS) provides very low energy (low velocity) neutrons with long wavelengths for neutron scattering because the CNS cools the neutrons to 20 K, roughly 15 times lower in energy than the thermal neutrons. This reduction in temperature makes cold neutrons that are useful for studying superconductivity, magnetic, and other quantum effects that occur in materials at very low temperatures and due to this fact the installation of the CNS in research reactors increases the research capabilities in the field of physics and condensed matter. Many worldwide research reactors construct or aim to construct a CNS so that its energy is less than 10 meV. There are common design concepts for the construction of CNS, which have been summarized for instance by Kawai et al. (2003). The spherical and cylindrical annulus shape is the most common geometry of the CNS. The neutronic design of the CNS in several research reactors such as (Taiwan Research Reactor) TRR-II (Guung et al., 2002), (National Institute of Standards and Technology) NIST (Williams et al., 2003) and CARR (China Advanced Research Reactor) (Shen and Yuan, 2002) was done using the MCNP code. These research reactors use liquid hydrogen as a moderator. Other reactors such as (Forschungsreaktor München II) FRM-II (Gaubatz and Gobrecht, 2000) have been used liquid deuterium instead.

Tehran Research Reactor (TRR) is a 5 MW pool type with the order of magnitude maximum flux of 10^{13} n/cm^2 s, and it is designed to produce radio-isotopes for medical and industrial (Ghasempour et al., 2014; Lashkari et al., 2012). As shown in Fig. 1, TRR is facilitated with seven beam tubes and a thermal column. In this study, according to the available space and equipment, horizontal type of CNS is selected and it has been considered in the inside of *F* beam tube with an approximate diameter of 20 cm and length of 3 m which has the highest flux.

2. Conceptual design of CNS

The goal of the CNS conceptual design was to optimize the cold-neutron flux with wavelength longer than 2 A (and close to 20 K temperature) under the condition of suitable nuclear decay heating. Whatever the nuclear heat generated increases consequently the system need more cooling power and due to the operating temperature of the system (20 K), it leads to more design, construction and operation cost. In order to reduce the cost, it is necessary to maximize the cold-neutron flux while the nuclear heating should be minimized (Shen and Yuan, 2002).

There are two important selections that must be considered in details. Firstly, what kind of material should be used as a cold moderator among liquid hydrogen (H_2), liquid deuterium (D_2) and solid methane (CH_4) and secondly, what kind of geometry must be considered to make most flux as well as nuclear heat minimization.

In order to get conceptual information on the CNS, thermal shield, pre-moderator and reflector for the system and then five

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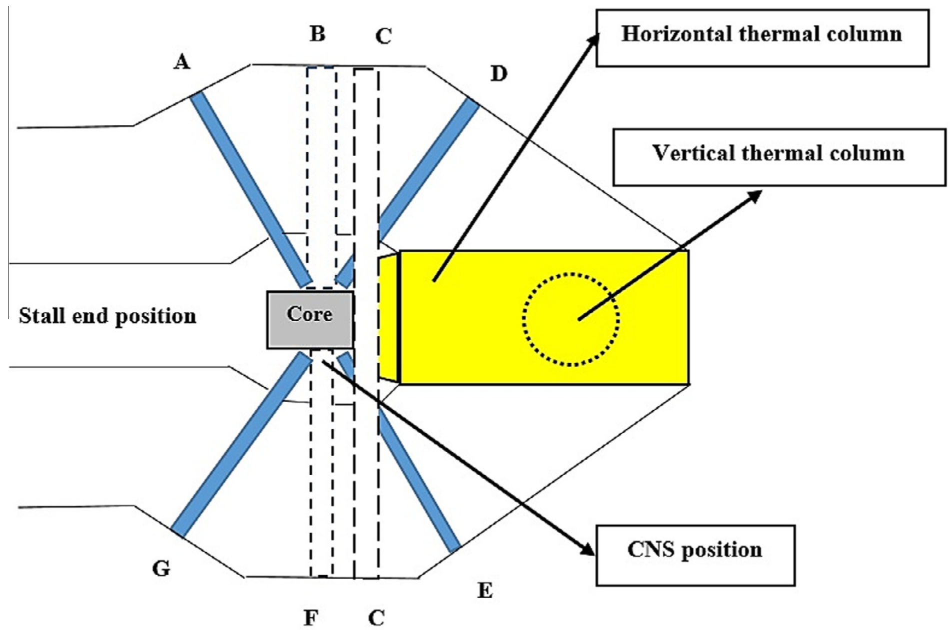

Fig. 1. A schematic view of the TRR pools and its irradiation facilities, (A, D, G, E) 6″ diameter beam tubes, (C) 6″ diameter through tube, (B) 12″ × 12″ beam tube, (F) 8″ diameter beam tube (Atomic Energy Organization Of Iran, 2006).

Table 1
TRR core specification (Lashkari et al., 2012).

Meat material/enrichment	U_3O_8-AL/20%
Number of fuel plates in SFE/CFE	19/14
Maximum grid plate capacity	6 × 9 fuel element
Fuel meat thickness	0.07 cm
Cladding thickness	0.04 cm
Water channel thickness	0.27 cm
Fuel meat width	6.00 cm
Total plate width	6.70 cm
Fuel meat length	61.50 cm
Inner distance between side wall	6.70 cm
Fuel element dimensions	8.1 × 7.7 × 61.5 cm
Fuel plate cladding and side wall material	AL6061
Absorber type	Fork
Absorber material for shim safety rods	Ag-In-Cd
Absorber material for fine regulating rod	AISI-316/L stainless steel
Uranium per fuel plate	15.26 g
Maximum inlet design temperature	37.8 °C
Maximum outlet design temperature	46 °C

cases to evaluate nuclear heat load, cold-neutron flux and brightness as well as gain factor have been investigated.

3. Modeling the core and CNS

In order to design a cold neutron source, it is necessary to simulate the core and its irradiation facilities with a detailed simulation of the reactor and then by selecting one of the horizontal beam tubes around the core, a cold neutron source design and optimization of parameters will be performed. All neutronic calculations were performed using MCNPX2.6 (Pelowitz, 2008), which is a general-purpose Monte Carlo code coupled with neutron and gamma rays, developed at the Los Alamos National Laboratory (LANL). This code has cross-sections as a function of continuous energy and thermal scattering kernels for various materials used in a CNS and are capable some new features which are not our aims in the current study. ENDF/B-VI cross section library, which are developed by LANL, is used (MacFarland, 1994) in the present study. Typically, the first 20 cycles were skipped for better conversion and a total of 20,000,000 histories were run to get statistical accuracy less than 5%. We mention here that MCNPX2.6 simulations of TRR have been carefully benchmarked against experimental measurements.

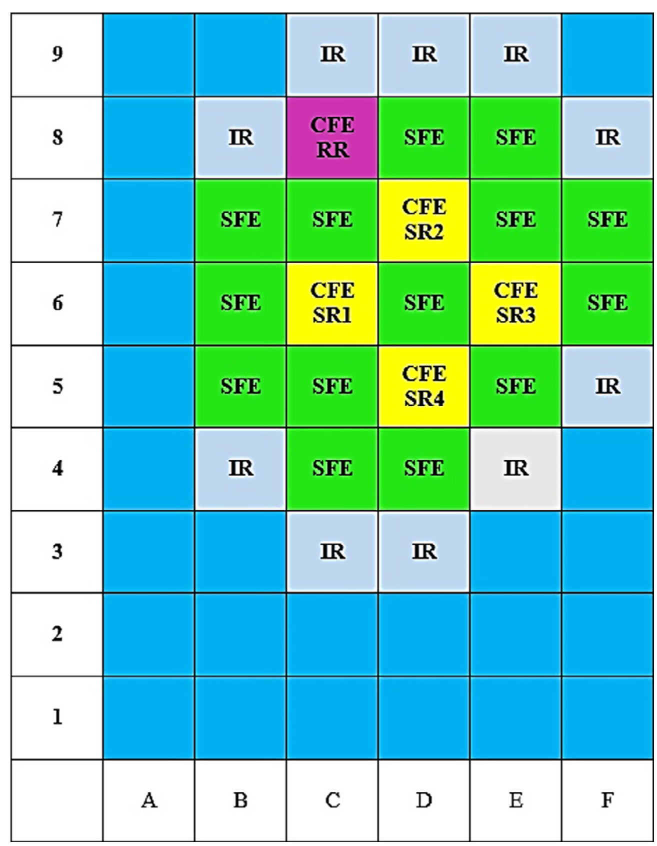

Fig. 2. Configuration of the TRR first core includes, SFE: Standard Fuel Element, CFE: Control Fuel Element, IR-BOX: Irradiation Box, SR: Shim Safety Rod, RR: Regulating Rod.