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SENSITIVITY ANALYSES OF THE USE OF DIFFERENT NEUTRON ABSORBERS ON THE MAIN SAFETY CORE PARAMETERS IN MTR TYPE RESEARCH REACTOR

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In this paper, three types of operational and industrial absorbers used at research reactors, including Ag-In-Cd alloy, B_4C, and Hf are selected for sensitivity analyses. Their integral effects on the main neutronic core parameters important to safety issues are investigated. These parameters are core excess reactivity, shutdown margin, total reactivity worth of control rods, thermal neutron flux, power density distribution, and Power Peaking Factor (PPF). The IAEA 10 MW benchmark core is selected as the case study to verify calculations. A two-dimensional, three-group diffusion model is selected for core calculations. The well-known WIMS-D4 and CITATION reactor codes are used to carry out these calculations. It is found that the largest shutdown margin is gained using the B_4C; also the lowest PPF is gained using the Ag-In-Cd alloy. The maximum point power densities belong to the inside fuel regions surrounding the central flux trap (irradiation position), surrounded by control fuel elements, and the peripheral fuel elements beside the graphite reflectors. The greatest and least fluctuation of the point power densities are gained by using B_4C and Ag-In-Cd alloy, respectively.

KEYWORDS : Research Reactors; Neutron Absorber; Safety; Shutdown Margin; Power Peaking Factor

1. INTRODUCTION

Research reactors are essential tools for nuclear energy development. Irradiation of materials, components, and developing power fuel elements carried out in research reactors must safely meet the needs of industry and utilities [1].

The core of a research reactor contains fuel assemblies, moderator, reflectors, reactivity control devices (neutron poisons), and experimental apparatus. In many cases, these components are modular and are placed in prescribed locations on a grid plate to achieve an operational core to meet the needs of the current experimental programs while fulfilling the requirements of the Operating Limits and Conditions, OLCs.

The research reactors are generally controlled by control rods (neutron absorbers). Control rods are an important technology for maintaining the desired state of fission reactions within a nuclear reactor. They constitute a real-time control of the fission process, which is crucial for both keeping the fission chain reaction active and preventing it from accelerating beyond control.

The state of a fission chain reaction can be concisely summarized by the effective multiplication factor, k, which indicates the change in total number of fission events during successive generations of the chain reaction [2]. It is defined as:

$$k = \frac{\text{total \# of fission events in a given generation}}{\text{total \# of fission events in the previous generation}}$$

A reactor that is in a steady state has $k = 1$, and the reactor is said to be critical. If $k < 1$, the reactor is subcritical and the chain reaction cannot be sustained. If $k > 1$, the reactor is supercritical and the reaction will grow exponentially.

The most important number for nuclear reactors is therefore 1, as any other value of the multiplication factor k implies a very useless or very dangerous reactor.

Maintaining precisely k = 1 is difficult, as this precise balance is influenced by a huge number of factors [2]. Some of these factors are inherent to the fissile fuel or reactor materials themselves, such as the number of neutrons produced in a fission event or the amount of neutron absorption due to fuel rod casings or moderators. However, even if engineered to perfect balance initially, the multiplication factor of a reactor will necessarily vary over time, as many by products of the fission reaction are neutron absorbers (referred to as poison) and will lower the overall neutron population as they accumulate.

Control rods thereby find their use as an effective method for combating these time-dependent changes in reactors. Control rods are essentially a highly effective neutron-absorbing mechanical structure, which can be actively inserted or withdrawn from the reactor core while the fission process is occurring.

By controlling the portion of the control rod that interacts with the fission reaction, the multiplication factor can be finely tuned to maintain reactor criticality .In addition, control rods can be used to intentionally make rapid changes to the reactor state (i.e. turning the reactor on and off), especially as an emergency shut off feature by fully inserting the rods [2].

Each control element has a reactivity worth, indicating the ability of the control element to absorb neutrons. The balance between excess reactivity worth of the reactor core and reactivity worths of the control elements should be estimated in such a way that the reactor can be operated safely. Most control rods contain materials which strongly absorb neutrons, so that insertion of a control rod produces significant flux changes throughout the reactor. These flux changes in turn alter the worths of other control rods present, so that the collective worth of the control rods may differ significantly from the sum of the individual worths [3]. This difference is thought to arise from interaction effects among the control rods, and determination of the magnitude of these interaction effects is essential to the proper control and safety of the reactor.

These reactivity changes and their effects should be predicted and compared with verified calculations or measured parameters to confirm that there is sufficient margin at all times to ensure that the reactor can be shut down safely and will remain shutdown following all normal operational processes, anticipated operational occurrences, and design basis accidents [4,5].

In the case of material irradiation special fuel tests, the total core excess reactivity, the reactivity worth of control rods, the shutdown margins, the power density distribution, the maximum linear power of the test sample, and the PPF must be estimated and verified in accordance with the Operating and Limit Conditions (OLCs) of the reactor.

Advanced irradiation, tests are typically performed at multipurpose research reactors, which have the flexibility to adjust sample power levels, sample average temperatures (in experimental devices), and the neutron flux spectrum and densities at the fuel samples locations, through adjustment of the neutron absorbers, core design, reflector layout, or the experimental device layout.

To determine core operating strategies that would permit maximum operating flexibility for reactor utilization while remaining within the OLCs, validated methods and codes should be utilized to determine core parameters.

In this paper, two-dimensional, three-group diffusion calculations are verified according to the IAEA 10 MW MTR reactor [6,7].The macroscopic cell and core calculations are performed using the well known reactor codes WIMS-D4 [8] and CITATION [9] respectively.

The reactivity worth effect of control rod movements and their shadow effect on the power distribution must be in accordance with the OLCs regarding a sufficient shutdown margin.

In this research, a sensitivity analysis of the use of different absorber materials on the main safety parameters is conducted. The related safety quantities and parameters are as follows: core excess reactivity, shutdown margin, the total reactivity worth of control rods, thermal neutron flux, power distribution and Power Peaking Factor (PPF).

To analyze the effect of different types of neutron absorber on these parameters, three industrial and operational types of absorber materials are selected : Ag-In-Cd alloy, B_4C, and Hf [6,7]. The main differences between them are the resonance neutron absorption spectrum, especially over the epi-thermal range, and thermal neutron absorption cross sections. In this research the integral effect of created spectrum is studied.

2. THE IAEA 10 MW BENCHMARK REACTOR

Computational models, numerical methods, and nuclear data should be verified, validated, and approved. The IAEA benchmark research reactor [6,7] is a pool type research reactor cooled and moderated by light water, which uses graphite as a reflector material. It can operate at a nominal power of 10 MW. It uses MTR fuel elements with low and high enriched U. In this study only the Low Enriched Uranium (LEU) fuel is considered. The defined reference core (Fig. 1) has a 5×6 grid filled by 21 Standard Fuel Elements (SFE), four Control Fuel Elements (CFE), and a central irradiation box composed of (H_2O+AL). All fuels are assumed to be fresh (i.e. without initial burn up) in this research.

The fuel elements consist of 23 fuel plates of SFE type and 17 fuel plates of CFE type. Two separate regions in CFE are dedicated for fork-type absorber blades. Fig. 2 and 3 show LEU SFE and CFE respectively. The reactor core is inserted in a light water pool, cooled by downward forced convection, and reflected by two opposite rows of graphite. Table 1 summarizes the main parameters of the reactor.