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A COUPLED NEUTRONICS-THERMOHYDRAULICS MODELOF THE HOMOGENEOUS SLOWPOKE REACTORFOR APPLICATIONTO TRANSIENT STATES

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The primary application of the Homogeneous SLOWPOKE reactor, a design derived from the present heterogeneous SLOWPOKE-2 research reactor, is the production of radioisotopes for applications in industry and nuclear medicine, ^{99}Mo and ^{99m}Tc in particular. A network of about 15 Homogeneous SLOWPOKE reactors dispersed throughout North America can replace the NRU reactor which is nearing its service life for the production of these two radioisotopes, with the advantage of the proximity of the radioisotope production sites to the hospitals and radiopharmacies. The Homogeneous SLOWPOKE reactor is designed on a liquid fuel core that enables these isotopes to be extracted much more easily. The Homogeneous SLOWPOKE reactor has been designed also as a replacement for the heterogeneous SLOWPOKE-2 reactors at universities, allowing the continuation of their teaching and research missions in neutron activation analysis and neutron radiography.

The 20 kW Homogeneous SLOWPOKE reactor was modelled using both the deterministic WIMS-AECL and the probabilistic MCNP 5 reactor simulation codes. The homogeneous fuel mixture was a dilute aqueous solution of Uranyl Sulfate (UO_2SO_4) with a molality determined as 1.46 mol kg^{-1} for a Zircaloy-2 reactor vessel to maintain the fuel enrichment below 20%. Because this reactor is intended to replace the core of present SLOWPOKE-2 reactors, the diameter of the Homogeneous SLOWPOKE reactor core has to be equal to that of the present SLOWPOKE-2 reactor, resulting in a height about twice as tall for the Homogeneous SLOWPOKE reactor. The reactor could be controlled by mechanical absorber rods in the beryllium reflector, chemical control in the core, or a combination of both. The current design of the Homogeneous SLOWPOKE reactor uses five ganged control rods, all sliding in unison into vertical guide tubes located within the beryllium annular reflector. The control system is therefore comparable in complexity to that of the present SLOWPOKE-2 nuclear reactor which has a single control rod located at centre of the reactor core. Figure 1 below presents the main features of the reactor.

The simulation of the Homogeneous SLOWPOKE reactor by means of solving the neutronics equations revealed that the conditions necessary for achieving inherent

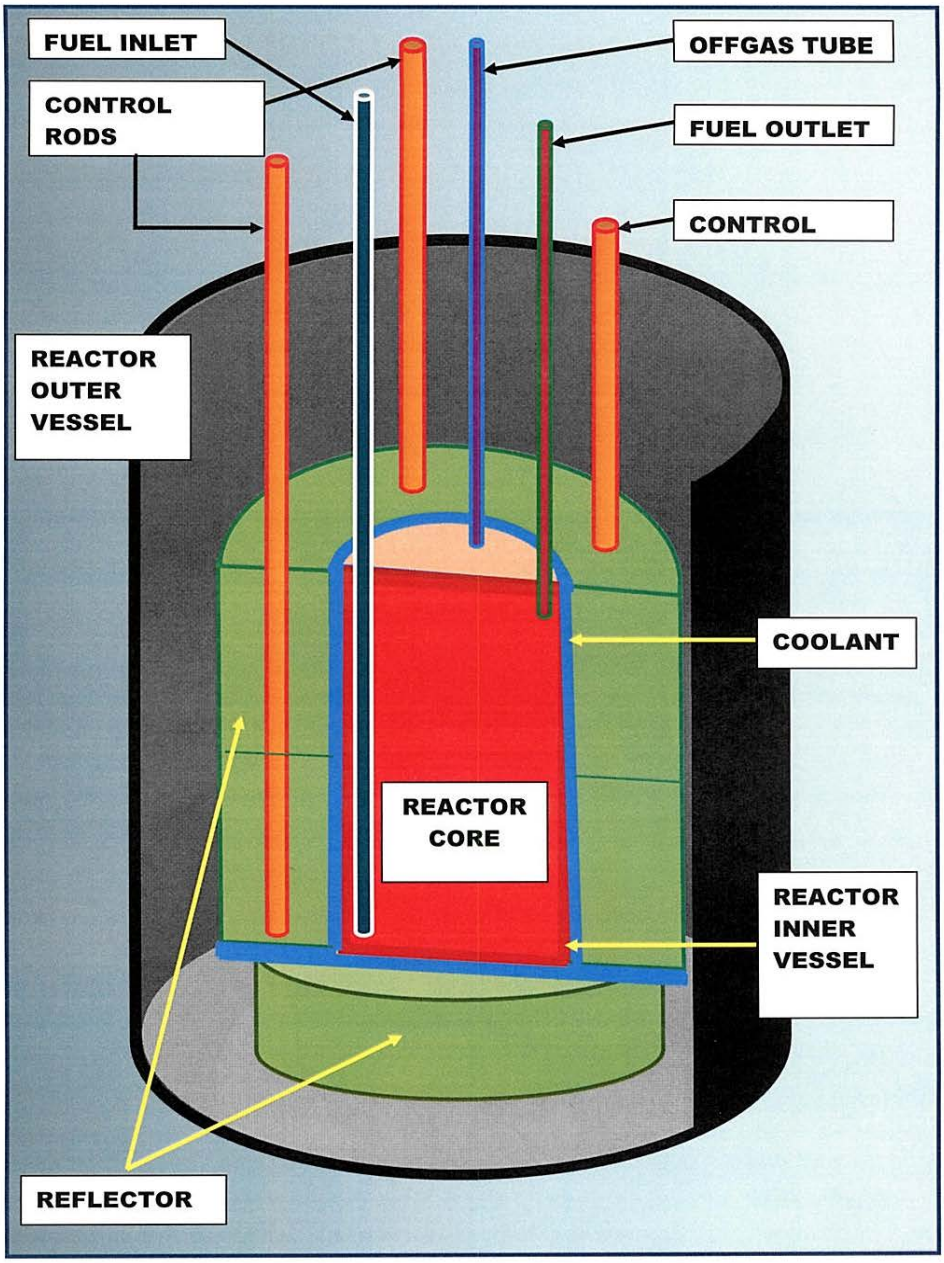


Figure 1: Simplified Diagram of the Homogeneous SLOWPOKE Nuclear Reactor

safety were predicted, such as negative reactivity coefficients due to reactor temperature, negative reactivity coefficient due to moderator-coolant density and negative reactivity coefficients due to voiding. These conditions alone are not sufficient to declare the reactor as inherently safe. Further studies were performed on the

HomogeneousSLOWPOKE reactor for a variety of transient states under several start-up and shut-down conditions, as well as abnormal situations. Thermohydraulics calculations were performed using COMSOL Multiphysics. The results showed that natural convection was sufficient to ensure adequate reactor cooling in all situations. The most severe transient simulated resulted from a 5.87 mk step positive reactivity insertion to the reactor in operation at critical and at steady state. Peak temperature and power were determined as 83°C and 546 kW, respectively, reached after 5.1 s after the reactivity insertion. However, the power fell rapidly to values below 20 kW some 35 s after the peak and remained below that value thereafter. Both the temperature and void coefficients are significantly more negative than the corresponding coefficients in SLOWPOKE-2. The simulations of the reactor in transient states showed that the temperature and power levels attained never compromised the integrity of the reactor. Figure 2 below illustrates typical behaviours of the reactor following several perturbations, and allows one to conclude that hazardous operating conditions are not attained by the reactor.

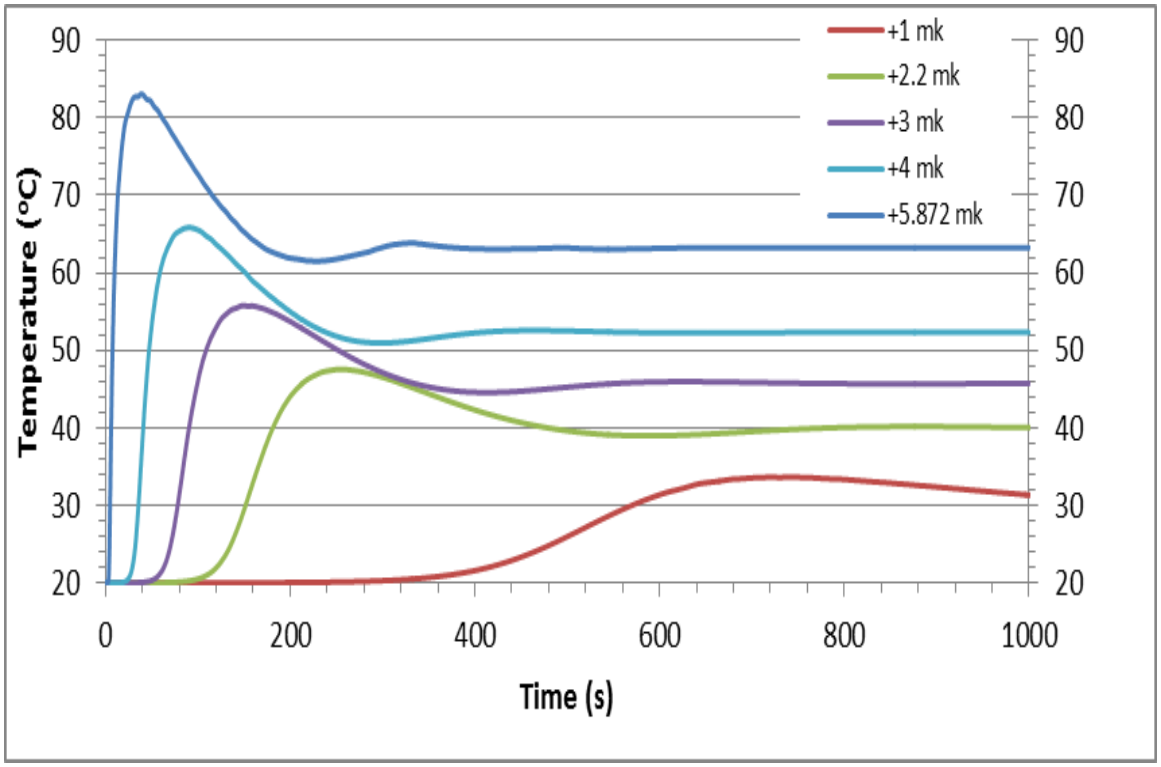


Figure 2: Transient Analysis: Evolution of the Reactor Temperature following Sudden Positive Reactivity Insertions.

The transient analyses carried out so far were based on thermohydraulics calculations using COMSOL coupled with a point kinetics model for the neutronics

component of the model. A weakness in this approach comes from the assumption that the neutronics response of the reactor core is uniform throughout the core volume. Such an assumption results in a good model for a heterogeneous core configuration, but for a homogeneous reactor, the core content is fluid and the fuel density may well not be uniform in the volume at a given time in addition to varying with time, resulting in possible important power peaking which may be of concern with respect to safety.

The on-going research is now focussing on the development of an accurate computer model which dynamically simulates the interacting neutronics and thermohydraulics effects within the liquid core. This component of the development of the Homogeneous SLOWPOKE reactor is needed to address safety-related issues arising from the non-rigid core configuration. The proposed model uses the probabilistic code MCNP 6 for the neutronics calculations and COMSOL Multiphysics for the thermohydraulics computations. By using a mesh geometry that would be common in the two programs, and by writing programs to import, export, and format data, MCNP 6 and COMSOL may be coupled to iteratively determine accurate temperature, heat source, density, and neutron flux distributions within the core to be used in further safety analysis and refinement of the design. The codes will be used in an alternating fashion for each time step, creating a model that accounts for the actual configuration of the core as time progresses.

The production of medical radioisotopes such as ^{99}Mo and ^{99m}Tc from a Homogeneous SLOWPOKE reactor requires a radioisotope extraction facility. Because of the intense activity of the irradiated fuel, the extraction has to be performed in hot cells with remote handling, comparable to the extraction process done with the NRU-based radioisotope production. No new technologies would need to be implemented as radiation protection and health physics issues are already addressed in this process. Compared with the NRU-based process for which it is needed to dissolve irradiated solid highly enriched uranium targets, the extraction process based on the Homogeneous SLOWPOKE reactor is simplified, as the fuel is already in the liquid form.Consequently, by alternating two core tanks on a weekly schedule, ^{99}Mo could be produced 24/7 with a one hour shutdown. The consumption of LEU fuel would be approximately 0.8%, and there would be no need to remove fission products for at least a year. The 20 kW LEU homogeneous Argus reactor at the Kurchatov Institute has demonstrated that radiopharmaceutical ^{99}Mo can be produced on a laboratory scale. It is worth noting that, to put safety issues in the right perspective, the volume of each core tanks is only 15.3 L of radioactive liquid material. The radioprotection issues would be here reasonably straightforward to address without the need of developing advanced systems. As an example, the concern of possible leakage in the piping system can be solved with double or even triple-wall conduits, at a reasonable cost since the whole facility would be compact in size.