* Common introduction for whole report
* Exercise chapter:

– Exercise-specific introduction.

– Exercise-specific theory and methods.

– Exercise-specific results and discussion.

– Exercise-specific conclusion.

* References

**Introduction:**

Nuclear power plant (NPP) staff, research reactor (RR) operators, and students of physics, nuclear engineering, and related subjects often use research nuclear reactors for teaching and training.

Since not all countries or educational institutions have direct access to research reactors, students can do exercises in other countries or use simulators. Micro SimTech created the first PC-based TRIGA research reactor simulator. Using the six-group point kinetics equation with feedback, the research reactor simulator (RRS) mimics the time behavior of reactor power, fuel temperature, and reactivity. Temperature feedback mechanisms and xenon poisoning are included. Using graphics acceleration to generate simulation results and a basic integration approach with a short simulation step to send physics enables low latency between user input and simulation result display, which is critical for research reactors capable of performing quick transients. The simulator is designed for TRIGA-type reactors; however, any physical parameters can be changed in real time. As a result, the simulator is easily adaptable to model other reactors.

Furthermore, it is meant for instruction on the principles of delayed neutron effect, multiplication factor, criticality, reactivity control by rods, and boron concentration. Although the simulator includes boron concentration fluctuations, it is vital to note that in all real TRIGA-type reactors, reactivity is controlled using control rods and demineralized water as a coolant and moderator. It is also employed to research feedback on fuel (Doppler) and moderator temperatures, as well as xenon and samarium toxicity.

The simulator is used to investigate the following exercise sets:

* supercritical, critical, and subcritical reactor behaviour
* reactor stability during oscillatory reactivity insertion
* fuel temperature feedback and Xe poisoning feedback

**Exercise 1: Reactor behavior at supercritical, critical, and subcritical conditions**

Any reactor's subcritical and supercritical states are only transitory. The reactor neutron population (and power) increases exponentially in a supercritical condition. When a reactor is being started and is being brought up to the desired power output, it is in this condition.

In a critical state, the neutron population is perfectly balanced, causing one fission to trigger another, and the power is steady. This is the typical operational condition. The neutron population (and power) are decreasing in a subcritical state. Reactors are placed in this state to switch them off. After a lengthy period of subcritical operation, the reactor achieves a low equilibrium power, which is supported by fission chains started by environmental neutrons.

These situations could be summarized in terms of multiplication factor, :

* When the fission chain reaction is stable, equals one, and the system is critical. (The reactor power stays constant over time.)
* When the fission chain reaction (and thus the power) grows across successive generations (time), > 1 and the system is supercritical.
* When the fission chain reaction (and thus the power) decays across successive generations (time), < 1 and the system is said to be subcritical.

Sometimes source neutrons must be artificially introduced into the system. An external neutron source consists of a material that emits neutrons and cladding that acts as a barrier between the reactor coolant and the substance. External sources are often injected directly into the reactor core.

To produce neutrons, the primary source of neutrons does not need to be irradiated. These sources can be used, particularly for the first core. The spontaneous fission reaction is the principal source of neutrons.

However, to produce neutrons, the secondary source of neutrons must be irradiated. These sources often have two components. The first component is a substance that, when exposed to fission neutrons, generates particles capable of knocking out a neutron from the second component. The second component is a neutron emitter element, which has the lowest neutron emission threshold. The primary and secondary sources in mechanical construction are analogous to a control rod. Stainless steel is used to cover both types of source rods.

Source neutrons have a crucial role in reactor safety, particularly during reactor shutdown and startup. There would be no subcritical multiplication if there were no source neutrons, and the neutron population in the subcritical system would eventually approach zero. Since is less than one, each neutron generation has fewer neutrons than the earlier one.

The source neutron population stays at levels that can be checked by the source range of excore neutron detectors, allowing operators to always monitor how quickly the neutron population changes (can always monitor the reactivity of a subcritical reactor). However, fission will occur if neutrons and fissionable material are present in the subcritical reactor (even a deep subcritical reactor will always produce a small number of fissions).

Source neutrons enter the life cycle and meet the same conditions as fission neutrons. It should be noted that source neutrons have varied energy, which are often lower than fission neutrons.

When a critical reactor is converted to a subcritical state, the neutron population first experiences a prompt drop due to a quick decrease of prompt neutrons. After a brief time, it begins to fall exponentially, with a timeframe matching to the decay of the longest-lived delayed neutron precursors (i.e., about 80 seconds). The neutron flux stabilizes at a similar level with source neutrons, which is governed by the source strength, S, and the multiplication factor, .

To achieve reactor core criticality, the control rods must be withdrawn after the safety rods have been completely removed from the core, such that a rise in core reactivity ensures the critical condition of this system.

When the neutron flux in the reactor is exceptionally low at the start of a nuclear reactor's operation, the indications of the exterior neutron detectors are prone to stochastic fluctuations. To avoid these statistical fluctuations, an added neutron source is added to the system to increase the initial neutron flux and therefore provide safe average values. Despite its low intensity, this source directs the neutron flux distribution at the start of a new operation cycle. As a result, while the reactor is subcritical and distant from criticality, neutrons from an external source have a greater influence than when the reactor is close to criticality.

When positive reactivity is added to a subcritical reactor, the power increases to a new equilibrium value. The size of the rise, as well as the time required for power to stabilize, are determined by the value of . The closer is to one, the greater the rise in power for a given increase in reactivity and the longer it takes for power to stabilize.

The neutron population in a critical reactor with no neutron sources other than induced fission stays constant from generation to generation. In other words, neutron losses due to absorption and leakage precisely account for the excess neutrons produced by fission that are not needed to sustain the chain reaction. Now consider a neutron source emitting so many neutrons in each neutron generation time to be inserted into the reactor, and let this reactor be subcritical with a value of slightly less than 1.

Since that is how many neutrons are emitted in that time, the number of neutrons present at the end of the first generation will be . At the end of the second generation, these neutrons will have become neutrons, and the source will have added another neutron, giving us a total of . These neutrons will have become neutrons by the conclusion of the third generation, and the source will have added another S\_o neutron to give us a grand total of .

If we pursue this type of argument endlessly, we will notice that we will eventually arrive at a final neutron population, , which is given by

With , the sum

Therefore, we can say that

The factor  is also known as the subcritical multiplication factor.

We can see that expression appears to be sensible, because if is our end population, it will become after one more generation. If k is less than one, it shows that neutrons have been replaced by new ones.

Upon this observation,

We can rewrite [1] as

When , [1] and [2] do not apply as the reactor is critical. This is because, they assume that the sequence has a finite total. When constant, and new ones are added every generation, the neutron population will simply increase indefinitely and at a constant rate of neutrons each generation. This rate of rise is minimal if the reactor power is more than and is often disguised by the reactor's automatic regulation. Any effects of the sources can be ignored in a supercritical reactor.

**Exercise 2: Reactor stability during oscillatory reactivity insertion**

Recently, there has been a resurgence of interest in the kinetics produced by reactivity oscillations in a subcritical nuclear multiplication system. Given the present interest in source-injected, subcritical systems, a full understanding of the system response to periodic reactivity oscillations is critical. As demonstrated by Ravetto (1997) and Dulla et al. (2006), reactivity oscillations in a multiplying system can destabilize its response and result in exponentially diverging power transients.

Molten salt reactors are an important example of where such destabilizing mechanisms can occur, as reactivity oscillations can be seen when lumps of precipitated fissile material spontaneously form inside the system. As these microscopic structures are immersed in the fluid fuel, the fluid flow transports them through the core and primary circuits, causing periodic reactivity changes. Furthermore, the examination of the power transient created in a nuclear reactor by vibrating control rods, which constitutes another fascinating subject in nuclear reactor physics, may benefit from the understanding of the kinetics induced in a multiplication system by reactivity oscillations.