Executive summary of PhD thesis

Development of an experimental device for the study of neutron flux density deformation due to the drop of the control rod into the reactor core

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Introduction

One of the crucial aspects of nuclear power plant operation is the immediate and safe stop of the nuclear chain reaction if needed, i.e., SCRAM. Clear understanding of the SCRAM mechanism, i.e. control rod drop to the core, and consequent evolution of neutron flux, is still important even though nuclear power plants have been in commercial operation for more than five decades. Theoretical calculations and computer modelling of reactor operational states, including transients, should be verified by experiments. Research reactors are suitable nuclear installations for carrying out verification experiments for many operational states of nuclear power plants. In order to provide experimental data for SCRAM analysis, new experimental device. The device for SCRAM Induced Transient (DESIT) was developed as a goal of this PhD work. This includes the development of device design and detection system, including fast response detectors. In addition to this complex experimental device, methodology, data analysis software, and models in reactor codes were developed as well. This allows to compare experimental data with results from calculation and then later for example to improve code performance.

Detection system

The first objective of this thesis was to develop a detection system of an experimental device for the study of neutron flux density deformation due to the drop of the control rod into a nuclear reactor. The following objective was to develop a methodology for modelling of fast transition processes caused by prepared equipment for the future use of experimental equipment for benchmark experiments. The last objective was, in cooperation with an external design company, to prepare a design of the initial part of the experimental device for the study of neutron flux density deformation due to the drop of the control rod into the reactor.

Therefore, a new experimental device called the Device for SCRAM Induced Transient (DESIT) was designed. This device consists of a control rod equipped with a tailored position measurement and detection system. The detection system was developed as part of this Ph.D. work. To examine the transient, the methodology of modelling of fast transient processes created by DESIT in Serpent code was prepared. The rod drop transient was calculated using this methodology, and an experiment with a newly developed detection system was carried out. The experimental device itself was not manufactured.

The detection system was developed on the basis of diamond detectors. The final setup of the detection system is shown in Figure 1.

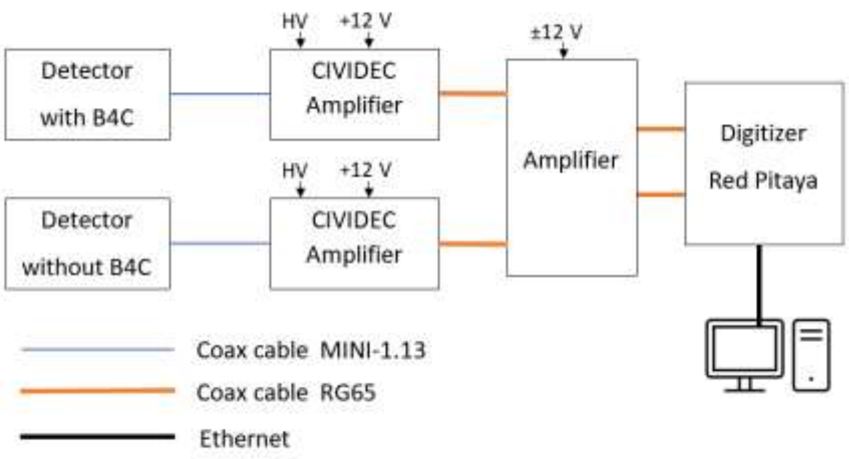

Figure 1:Schema of the detection line

Each detection line consists of a pair of diamond-based detectors with B_4C conversion layer placed in a custom housing.

Several different versions of detectors were manufactured in order to test improvements and modifications to adjust detectors for this application and increase its performance. The manufacturing process was also improved to increase the detector sensitivity by improving the design of the deposition mask and crystal holders for the PVD machine. The detection system was changed to use subtractive gamma ray discrimination instead of pulse shape discrimination. This modification was motivated by the unavailability of the high-performance digitizer, which was identified after the initial test of the detection system. This modification consists of introduction of a second detection line that is non-sensitive to thermal neutrons (therefore a pair of detectors) and development of an additional amplifier to allow usage of digitizers with lower performance. The new amplifier extends the pulse duration so lower sampling rate digitizers can be used. More than 39 different versions of the amplifier were created during the development and were tested with the pulse generator and later by detectors developed with neutron sources or in the VR-1 reactor core.

For data recording, the field-programmable gate array was programmed to optimise pulse processing from this detection system. This newly developed detection system was used for neutron flux measurements during rod drop experiments at the VR-1 reactor.

Modelling

The methodology of modelling fast transient processes created by rod drop (DESIT) was developed for the Serpent code. This code contains a dynamic calculation tool that can calculate reactor transients using the Monte Carlo approach. The transient part of this code is not often used or documented, and therefore the methodology was written based on several test calculations and communication with developers. Some not working parts of the code were discovered during the process and were fixed by developers on request. The method can be used to calculate transients at various reactors. It provides additional recommendations above the information needed to set the calculation. These recommendations result in a faster and more stable calculation. This methodology was later used for the calculation of the rod drop transient at the VR-1 reactor.

The initiation part of the DESIT

The initiation part of the DESIT device was designed with an external company. The company created the design based on the requirements provided that were formulated as an outcome of this PhD work. The device is based on the control rod mechanism for the VR-1 reactor and is equipped with an additional apparatus to measure the position of the control rod during the drop. The device is also equipped with a channel to house the detection system in proximity to the control rod. The position signal of the control rod is prepared for connection to the detection system so that the time synchronisation between the count rate and the position of the control rod can be achieved during the drop of the control rod. See the DESIT in Figure 2.

Figure 2: Vizualization of DESIT

Experiments, Calculations, and Results

To test the detection system and investigate changes in neutron flux as a result of rod drop, several experiments were performed. Two experiments were based on static deformation and one on dynamic deformation. Static deformation was introduced by repositioning the control rods in the critical reactor. The flux deformation was measured by the SNM 13 gaseous detector and by activation foil detectors.

These experiments were also calculated in Serpent code. The measured and calculated data are in agreement. The relative difference in reaction rate is approximately 7 % for the 450 mm position. A similar relative difference occurs in the deformation of the thermal neutron flux. The dynamic deformation of the neutron flux was introduced by a drop of a control rod in the reactor core. For this experiment, the VR-1 reactor core was modified by adding a control rod and vertical channel. A newly developed detection system was placed in the vicinity of the rod to the vertical dry channel, and the deformation of neutron flux during rod drop was measured. This experiment was performed with a standard control rod, not with the newly designed experimental device, as this device is not yet manufactured. Several drops of rod were measured. The results of the experiment were compared with the results of the dynamic calculation.

The results of both types of experiments are in agreement, to some extent, with the results obtained from the calculation. The calculation was performed for different core configurations because it was performed significantly earlier than the experiment, and the VR-1 reactor core changed since then. However, the phenomenon studied is similar for both configurations, since only the vicinity of the control rod is studied. After completion of the initiation part of the DESIT device, the experiment presented should be repeated. The experiments presented cannot be considered final because the main part of this thesis was the development of the detection system, and the experiments presented were the first tests. Experiments proved the capability of measurement delay in the deformation of neutron flux during the drop of the control rod. The results presented in this work can also be used outside the boundaries of topics related directly to the assignment of this dissertation thesis. The methodology of modelling of fast transient processes by DESIT can be adjusted and used for the calculation of other fast reactor transients at the VR-1 reactor or in other research reactors as this tool is versatile and allows calculation of cases that cannot be calculated by different approaches. The developed detection system could be adjusted and used for other transient measurements or for measurements of neutron flux during steady states, where a small size and low material volume of the detectors are needed, as these detectors are unique in their tiny size. The pulse stretching amplifier that was developed for the detection system can be used for different detectors to allow a reduction of the requirements on the digitizers needed for them, because pulse stretching amplifiers for this short pulse duration are not available on the market.

Conclusions

In summary, a new experimental device was designed with a customized detection system to measure rod drop induced transient. This development of a detection system and design of an experimental device was supported by the development of a methodology for the calculation of fast transient processes in the Serpent code. Calculations and experiments were carried out to measure the rod drop transient in the VR-1 reactor in order to test and examine the performance of the newly developed detection system and to prove its ability to measure neutron flux deformation during rod drop transient. These rod drop experiments should be performed in the future on a newly designed experimental device.

PhD thesis

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