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Uncertainty and sensitivity analysis of MCPs' trip events at Ignalina NPP

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Abstract

Eight main circulation pumps (MCPs) are employed for the cooling water forced circulation through the RBMK-1500 reactor at the Ignalina nuclear power plant (NPP). There have been a few events when one or more MCPs were inadvertently tripped.

This paper presents investigation of a one MCP trip event and all MCPs' trip events at Ignalina NPP. Thermal-hydraulic analysis was conducted using the best estimate system code RELAP5/MOD3.3. Uncertainty and sensitivity analysis of flow energy loss in different parts of the main circulation circuit (MCC), initial conditions and code-selected models was performed. Such analysis allows to estimate the influence of separate parameters on the calculation results and find those modelling parameters that have the largest impact on the investigated events. Uncertainty analysis indicates that natural circulation provides adequate cooling in the case of all MCPs tripped, and that the reactor is reliably cooled by forced circulation in the case of a single tripped MCP. On the basis of this analysis, recommendations for the further improvement of model are developed.

1. Introduction

The Ignalina nuclear power plant (NPP) is a twin-unit with two RBMK-1500, graphite moderated, boiling water, multichannel reactors. Several important design features of RBMK-1500 are unique and extremely complex with respect to western reactors (the single coolant loop has a very long flow path of more than 200 m and consists of 1661 parallel pressure tubes and numerous components such as headers, pumps, valves, etc.) (Almenas et al., 1998). The main circulation circuit (MCC) consists of two identical halves—the left and right loops. The schematic representation of one MCC loop is shown in Fig. 1. Eight main circulation pumps (MCPs) are employed for the cooling water forced circulation through the RBMK-1500 reactor at the Ignalina NPP. The MCPs (Fig. 1(5)) are joined in groups of four pumps each (three for normal operation and one on standby). The MCPs feed a common pressure header (Fig. 1(8)) on each side of the reactor. Each pressure header provides coolant to 20 group distribution headers (GDH) (Fig. 1(9)), each of which in turn feeds from 38 to 43 fuel channels (FCs) (Fig. 1(11)). The coolant flow rate through individual FCs is regulated by isolating and control valves (ICV) (Fig. 1(10)) mounted in the lower water communication lines. Coolant passing through FCs is boiled and part of the water is evaporated. Steam–water mixture flows through steam–water communication lines (Fig. 1(12)) to drum separators (DS). Steam, separated in the DS, is supplied to the turbines through steam lines (Fig. 1(13)).

In the all pumps trip case, the coolant during the first few seconds was supplied to the reactor by pumps

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Nomenclature

AZ-1	emergency protection
AZ-4	emergency protection
CCFL	counter current flow limit
CHF	critical heat flux
DS	drum separator
ECCS	emergency core cooling system
FC	fuel channel
GDH	group distribution header
ICV	isolating and control valve
MCC	main circulation circuit
MCP	main circulation pump
NPP	nuclear power plant
RBMK	Russian acronym for “Channelled Large Power Reactor”

Subscript

th	thermal

coastdown due to the high inertia of pump flywheel. Later natural circulation through the core was established. Reactor scram was initiated by the emergency protection system in response to multiple pump trips. In the case of one MCP trip the throughput of the two running pumps in the affected MCC loop is increased, however, the total coolant flow through the affected loop is decreased. The reactor power was decreased down to 60% from design (4800 MW_{th}) in response to one MCP trip signal.

For validation of the RELAP5 model of Ignalina NPP a benchmark analysis of natural circulation phenomenon was performed. Data of operational occurrences, measured at Ignalina NPP were compared with the RELAP5 calculations. This paper presents benchmark analysis of one and all MCP trip events. Similar analysis is presented in the preceding works (Kaliatka and Uspuras, 2000; Uspuras et al., 2001; Kaliatka et al., 2001; Vileiniskis et al., 2002). In contradistinction to preceding works, this paper presents uncertainty and sensitivity analysis of these events. Such analysis allows to estimate the influence of separate parameters to the calculation results. On the basis of this analysis the recommendations for the further improvement of model are developed.

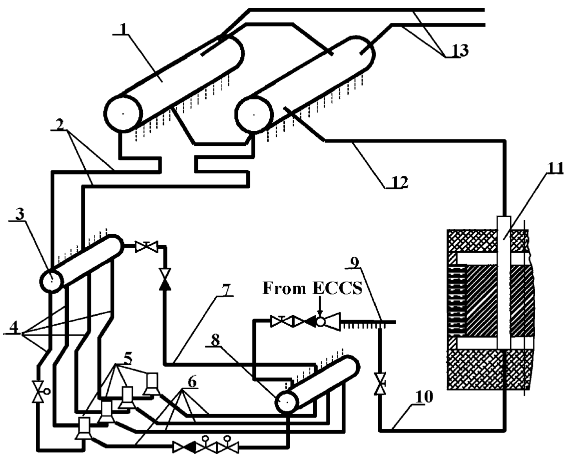

Fig. 1. Schematic representation of one loop of the RBMK-1500 MCC: (1) drum separtor; (2) downcomers; (3) MCP suction header; (4) MCP suction piping; (5) MCPs; (6) MCP discharge piping; (7) bypass line; (8) MCP pressure header; (9) GDHs; (10) lower water communication line; (11) fuel channel; (12) steam–water communication line; (13) steam lines.

2. MCPs’ trip events modelling

One and all MCPs’ trip events benchmark analyses were performed using the best estimate system code RELAP5/MOD3.3. According to international practice, if a best estimate code is used for the analysis, the code and model uncertainties should be evaluated. Such analysis allows to find out the modelling parameters that have the largest impact to the investigated events. The GRS methodology and the developed package SUSA 3.2 (Kloos and Hofer, 1999) was used for sensitivity and uncertainty calculations.

The RELAP5 (RELAP5, 1995) system thermal-hydraulic code has been adapted to model the RBMK type reactors and it has been used since 1989. The RELAP5 model of Ignalina NPP is used for operational transients and design basis accidents analysis for RBMK-1500 reactor. Key features of this model are the following:

- Both loops of the MCC are represented. Flow paths within a loop are modelled by either one or more passes. In turn, a core pass model uses one or more equivalent FCs. The equivalent FCs are an abstract that conserves the heat generated in a group of real channels, as well as hydraulic properties of this