THE EFFECT OF CODE USER AND BOUNDARY CONDITIONS ON RELAP CALCULATIONS OF MTR RESEARCH REACTOR TRANSIENT SCENARIOS

by

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Received on January 9, 2005; accepted in revised form on March 3, 2005

The safety evaluation of nuclear power and research reactors is a very important step before their construction and during their operation. This evaluation based on the best estimate calculations requires qualified codes, qualified users, and qualified nodalizations. The effect of code users on the RELAP5 results during the analysis of loss of flow transient in MTR research reactors is presented in this paper. To clarify this effect, two nodalizations for research reactor different in the simulation of the open water surface boundary conditions of the reactor pool have been used. Very different results are obtained with few choices for code users. The core natural circulation flow with the beginning of core boiling doesn't stop but increases. The increasing in the natural circulation flow shifts out the boiling from the core and the clad temperature decreases below the local saturation temperature.

Key words: research reactor, loss of flow, natural circlulation, user effect, thermal hydraulic, RELAP 5

INTRODUCTION

The thermal-hydraulic system codes are tools developed to estimate the transient behaviour of nuclear power plants during off-normal conditions. The evaluation of safety margins, the operator training, the optimization of the plant design and related emergency operating procedures are some of the applications of these codes [1]. This system codes have been used to evaluate the transient behaviour and the safety margins of research reactor (RR). A preliminary request for all of such applications is the comprehensive code-user–nodalization qualification.

Scientific paper
UDC: 621.039.572:532.54:536.24
BIBLID: 1451-3994, *20* (2005), 1, pp. 16-22

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System codes like RELAP5 are usually assessed and qualified in comparison with separate effect test facilities (SETFs) and integral test facilities (ITFs) or in comparison with the operating conditions in nuclear power plants. But the results of these codes are still not accurate due to some uncertainties in the application process [1]. These uncertainties spring from a lot of sources, such as code model inadequacies, the fact that equations are used out of their validity ranges, inaccurate material properties, user effects, nodalization effects [1-3], *etc*. This paper will be focused on the last two types of the sources – user and nodalization effects.

Code users may interact at different levels with code results [2, 3]. In principle, two or more groups of users having available the same code and the same information for developing a nodalization should obtain the same results. This is not usually true and differences between results may be attributed to the user effect. User effect plays the important role in developing a nodalization, interpreting supplied information, identifying code options and physical model parameters, choosing the time step, accepting a steady state performance of the nodalization, and interpreting transient results.

A nodalization representing an actual system (ITF or plant) can be considered qualified when [4] (a) it has a geometric fidelity with the involved system, (b) it reproduces the measured nominal steady state condition of the system, and (c) it shows a satisfactory behaviour in time dependent conditions. Taking into account these statements, a standard procedure for obtaining a "qualified nodalization" has been defined in [4]. Also, it is very important to know that a nodalization which is qualified to simulate a certain transient may not be suitable to simulate another transient and may need some modifications and re-qualification.

The safety assessment of pool type material testing reactors (MTR) using the best estimate (BE) system codes has been considered in numbers of recent publications [5-8]. These publications show the capability of RELAP5 for analysing the RR transients.

The aim of this work is to identify clearly how much the code results are affected by code user choices. In order to do this, some modifications have been made on the nodalization used in [7, 8] in the analysis of loss of flow transient in MTR RR. Here, this nodalization is called original nodalization (ON) and the new one is called modified nodalization (MN). A comparison between the new and published results has been made. The code used in this study is the RELAP5, the same code used in [7, 8]. To clarify the difference in the results of the two nodalizations, the case of loss of flow transient at fixed power without scram is considered here.

REACTOR DESCRIPTION

The reference reactor is a typical MTR, pool-type research reactor. The considered core power is 1 MW. The main operating as well as thermal-hydraulic and kinetic characteristics of the core are outlined in tab. 1. The core is cooled by a downward flow of light water as shown in fig. 1. Any other data are taken from [7].

Table 1. Selected RR operating data

Core material	
Nuclear fuel	MTR, U_3O_8–Al LEU
Fuel element	Plate-type clad in Al
Fuel thickness, [mm]	0.7
Cladding thickness, [mm]	0.4
Cladding material	Al alloy
Meat material	U_3O_8 dispersed in Al
Uranium density, [kg/m³]	3000.0
Coolant	Light water (downward forced flow)
Moderator	Light water
Reflector	Graphite-light water
Core thermal-hydraulics	
Fuel thermal conductivity, [W/m°C]	50
Cladding thermal conductivity, [W/m°C]	180
Radial peaking factor	1.4
Axial Peaking factor	1.5
Inlet coolant temperature, [°C]	38.0
Operating pressure, [Pa]	$1.7 \cdot 10^5$
Core mass flow rate, [kg/s]	61.1

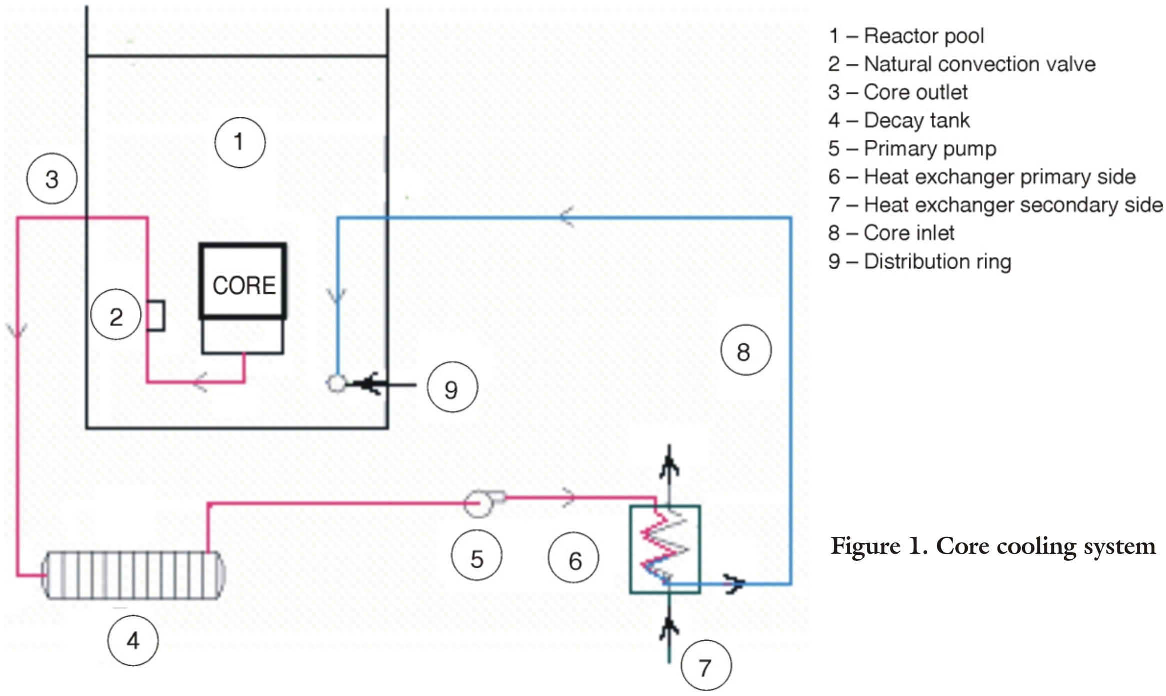

Figure 1. Core cooling system

NODALIZATION AND STEADY STATE QUALIFICATION

The two nodalizations used here, ON or MN, are nearly the same, the only difference between them being in volume 175, which we have enlarged and divided in this study into 10 sub-volumes instead of in 5 sub-volumes (like in the original one). In the ON all of the five sub-volumes are field with water. In the modified nodalization the first sub-volume is filled with water, the second sub-volume is partially filled with water, and all the other sub-volumes are filled with saturated air. This modification has been made to give space for the pool water expansion. Also, the reverse loss coefficient in valve 177 has been increased to a high value, 10, for result stabilization. Due to the oscillations appearing in the core flow with the beginning of boiling in [8], the maximum time step used during the beginning period of core boiling has been 0.001 s. Figure 2 shows the original nodalization and the modifications made to obtain the modified one. Table 2 shows the correspondence between the main reactor components and their equivalent nodes.

Table 2. Main component of the nodalization

Component	Nodalization element
Core	100
Reactor pool	110-120
Pool top	174-175
Natural convection valve	245
Decay tank	280
Pump	310
Primary side heat exchanger	330
Secondary side heat exchanger	340

Steady state conditions

Due to the lack of some data in [7, 8], the nodalization qualification steps as illustrated in [4] have not been completed. Only the steady state core parameters, like thermal power on the primary/secondary sides, core inlet/outlet coolant temperatures, core flow rate, pressure at core inlet and outlet plenums, and mass inventory in the primary system after running the code at steady state (with transient option) for 100 s are outlined in tab. 3.

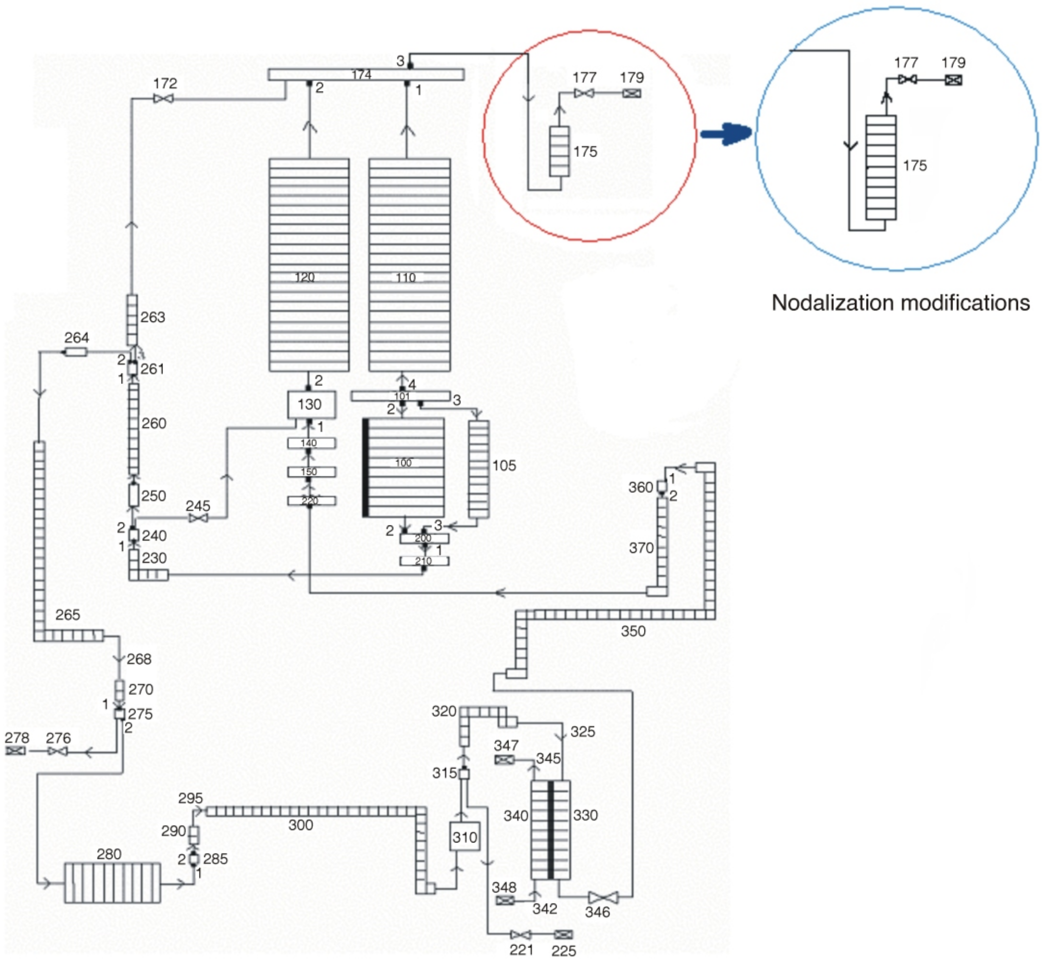

Figure 2. The reactor nodalization

Table 3. Steady state conditions

	Quantity	Value [8]	Calculated
1	Primary circuit power balance, [MW]	1.0	1.0
2	Secondary circuit power balance, [MW]	1.0	1.0
3	Inlet core temperature, [°C]	38.0	38.1
4	Pump velocity, [rad/s]	150.0	150.7
5	Core pressure drop, [Pa]		$9.4 \cdot 10^3$
6	Mass inventori in primary circuit, [kg]		78500
7	Flow rates (primary/secondary circuit), [kg/s]	61.1	61.5/60.5
8	By-pass mass flow rates, [kg/s]		2.0

SELECTED TRANSIENT

Problem identification

The results published in [7, 8] for the loss of flow transient at constant power without scram have shown that the core natural circulation flow is stopped with the beginning of core boiling. The core boiling is accompanied with pressure and flow oscillations in the core channels. This instable behaviour evacuates a big amount of water from volume 110. Due to this fact, the upper pool branch 174 becomes empty of coolant, *i. e.* the flow between volumes 110 and 120 and consequently the natural circulation flow stops. In order to perform a better simulation by avoiding this phenomenon, water free sub-volumes are added to volume 175 and the time dependent volume 179 is filled with saturated air to simulate the real conditions above the pool. Also, the maximum time step is decreased to 0.001 s to compensate the oscillations in the pool with the beginning of boiling.

Description of imposed events

The main imposed events involved in this transient are outlined in tab. 4. After the pump trip the core flow is decaying exponentially with the time constant of 1 s. At core flow 14.5 kg/s the natural convection valve opens. After this, the flow is accelerated and due to the buoyancy forces the direction of flow is inversed and the natural convection regime established. The sequences of the loss of flow transient are as follows.

Table 4. Imposed sequence of events

Time	Imposed event
Time 0–100 s	Steady state and forced circulation
At 100 s	Pump trip
At core flow 14.5 kg/s	Natural convection valve open
At 25000 s	End of calculation

RESULTS FROM THE ANALYSIS

The results for a transient initiated after 100 s of steady state operation in order to stabilize all the relevant parameters are shown here. After 100 s (at 0 time in the figures) the pump is tripped and the coast down phase followed by the natural convection phase are considered. After the pump trip the power remains fixed at 1 MW during the transient. In all the figures the steady state period, the first 100 s, is considered negative and the beginning of the transient is at zero time.

Natural convection flow

Figure 3 shows the ON and MN mass flow rate through the NCV. In ON the natural convection flow increases with increasing the coolant temperature and reaches a value equal to nearly 17 kg/s before the beginning of core boiling. At nearly 15 700 s the boiling in the core begins and at the same time the natural convection flow stops. In MN the natural convection flow increases with increasing the coolant temperature and reaches the same value of nearly 17 kg/s before core boiling. At nearly 16 300 s the boiling in the core begins and the natural convection flow increases and reaches 55.5 kg/s. This means that the beginning of boiling enhances the natural convection instead of stopping it.

This difference in the behaviour is explained as following. When the coolant temperature at the outlet of core channels reaches nearly the saturation temperature, and with continuation of heat addition, an onset of flow instability (OFI), accompanied by pressure oscillations, occurs at the core outlet as shown in fig. 4 (the initial difference between the two curves is due to the change of the content of volume 175). These pressure oscillations push up the water from the core and pool. In the ON there are no additional water free volumes above the pool and a big quantity of liquid is rejected to the control volume 179, but in the MN there are wide water free volumes containing the oscillations, as shown

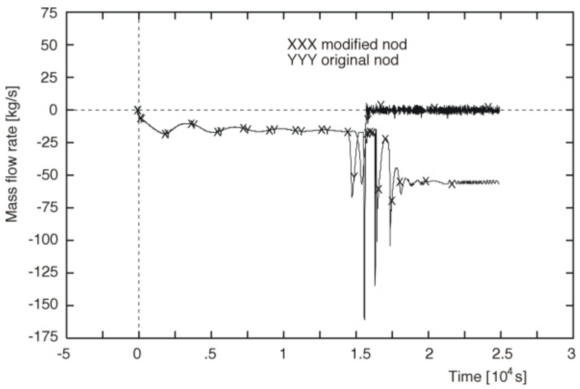

Figure 3. Nodalizations ON and MN: NCV mass flow rate

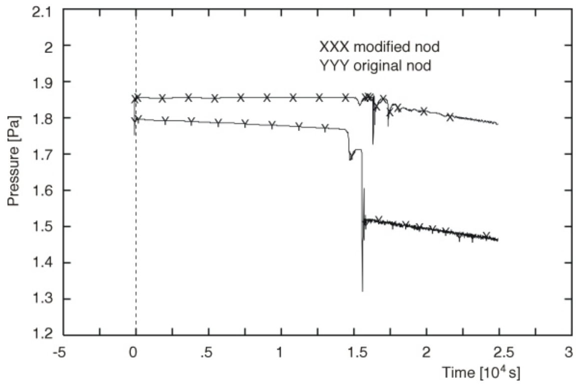

Figure 4. Nodalizations ON and MN: core outlet pressure

in fig. 5. After that branch 174 in ON completely turns into vapor and the flow rate between volumes 110 and 120 stops, but in the MN the branch 174 is still occupied by water, as shown in fig. 6. Due to this fact, the core natural convection in the ON stops but in MN persists.

The beginning of flow instability with the persistence of natural circulation shifts out the boiling

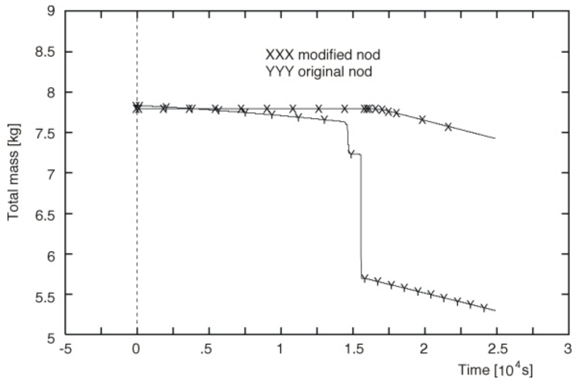

Figure 5. Nodalizations ON and MN: total coolant mass

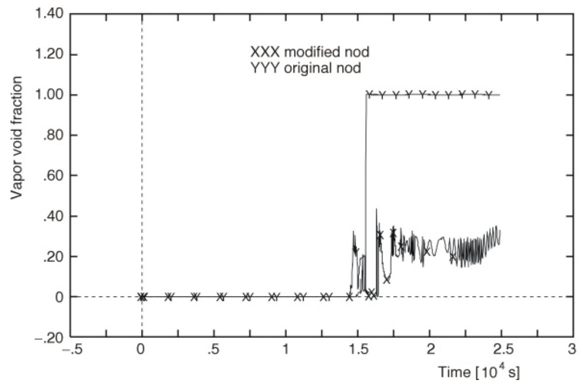

Figure 6. Nodalizations ON and MN: vapor void fraction in branch 174

from the core into the pool which creates a large decrease in the average density in pool volume 110 with respect to that in volume 120. Consequently, the pressure difference between volumes 110 and 120 increases. Due to this, the flow rate through the NCV increases and reaches nearly 55.5 kg/s.

The core and by-pass flow in the ON and MN are shown in Figs. 7 and 8 respectively. It appears that in the ON the by-pass volume 105 makes a natural convection loop with the core volume 100 and the flow in it is downward. In the MN the NCV

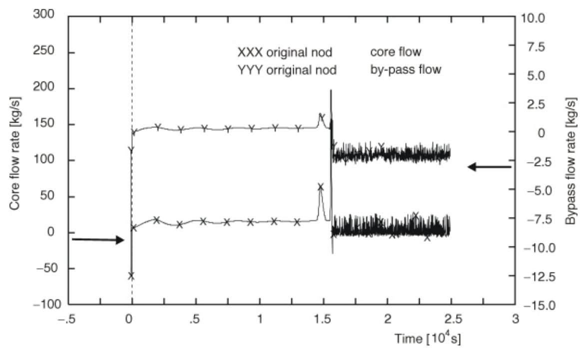

Figure 7. Nodalization ON: core and by-pass mass flow rate

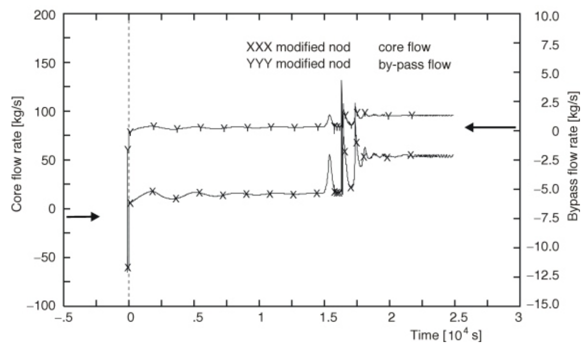

Figure 8. Nodalization MN: core and by-pass mass flow rate

flow is divided between the core and the by-pass and the flow is upward.

Clad temperatures

Figure 9 shows the MN clad temperatures. The behaviour is similar to that in [7, 8] during the convection stage and till the beginning of boiling in the core. The flow oscillation accompanying the beginning of boiling shifts the boiling out of the core to the pool upper nodes, where the local saturation temperature is lower than that in the core, and the vapor void fraction in pool volume 110 increases as shown in fig. 10. The difference in the average density between volumes 110 and 120 increases and, consequently, the natural circulation flow increases. Due to this, the core coolant and clad surface temperatures decrease below the local saturation temperatures. During the time period from 14 650 to 17 300 s the clad temperature, especially at node no. 5, in the middle of the core, increases three times above the local saturation temperature. But generally the clad temperature doesn't increase above the onset boiling temperature.

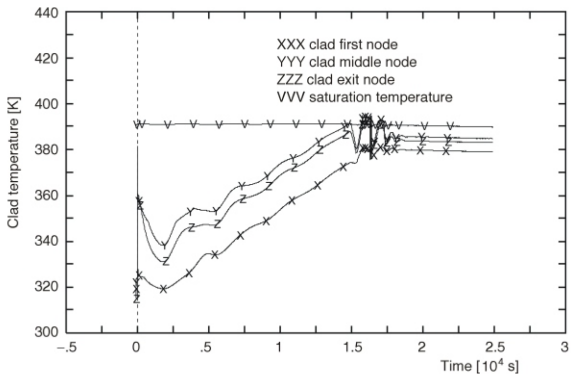

Figure 9. Nodalization MN: clad temperature at the first, middle, and exit nodes with the saturation temperature at core exit

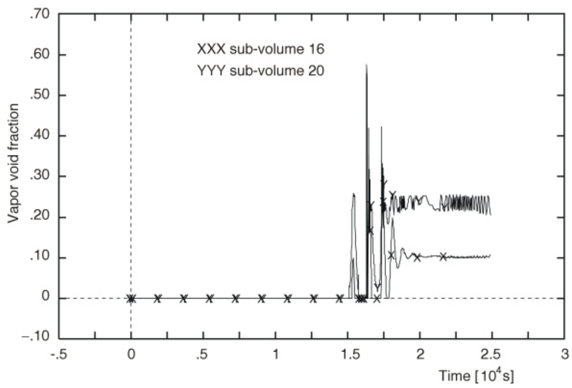

Figure 10. Nodalization MN: vapor void fraction at sub-volumes 16 and 20 of volume 110

CONCLUSION

Due to the increasing dependency on BE system codes in safety evaluation of the power/research reactors, it is very important to assure the qualification of the tools used in the evaluation. These tools are represented in the code, user and nodalization. The BE codes are usually qualified against the separate effect and the integral effect test facilities or real measurements in the nuclear reactors. The user should be qualified in respect to the use of the code according to its manual and to the result analysis. The nodalization qualification should be executed at the steady state, against design parameters, and on transient against a qualified experimental data. In case there is no sufficient experimental data to qualify the nodalization, especially in the on transient stage, the qualification process will depend mainly on the user interpretation of code results. This means that the user effect on the code results will be increased.

The user effects in the simulation of the atmosphere above the pool, and the time step used during the code run are considered here. The addition of water free volumes above the pool, the increase of the reverse loss coefficient of upper pool valve, and the decrease of the maximum time step used, change the results completely. The results show that the core boiling continues for a very short time and then stops, due to the increase of core natural circulation flow. During the core boiling period, the clad temperature attains the onset of boiling temperature and after increasing the core flow it decreases down the saturation temperature. The increasing of core flow is due to the bulk boiling in the reactor pool.

ABBREVIATIONS

	– best estimate
ITF	– integral test facility
	– material test reactor
NCV	– natural convection valve
OFI	– onset of flow instability
ON	– original nodalization
MN	– modified nodalization
	– research reactor
SETF	– separate effect test facility

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Ахмед КЕДР, Мартина АДОРНИ, Франческо ДАУРИЈА

УТИЦАЈ ГРАНИЧНИХ УСЛОВА И КОРИСНИКА ПРОГРАМА RELAP НА ПРОРАЧУН ПРЕЛАЗНИХ СТАЊА MTR РЕАКТОРА

Оцена сигурности реактора нуклеарних електрана и истраживачких реактора представља веома значајан корак пре њихове изградње или током њиховог рада. Ова оцена заснована на најпрецизнијим прорачунима захтева квалификоване програме, оспособљене кориснике и одговарајућу нодализацију. У раду је приказан утицај корисника на резултате програма RELAP5 током анализе прелазних стања услед губитка струјања у MTR истраживачким реакторима. Да се расветли овај утицај коришћене су две различите нодализације за симулацију граничних услова слободне површине воде у реакторском суду. Добијени су веома различити резултати за неколико избора који су на располагању кориснику програма. Природни кружни ток у језгру не зауставља се већ се увећава са почетком кључања. Пораст природног кружног тока уклања кључање из језгра и температура кошуљице пада испод локалне температуре засићења.

Кључне речи: истраживачки реактор, губитак тока, природна циркулација, утицај корисника, термохидраулика, RELAP5