Sixth International Information Exchange Forum
on
“Safety Analysis for Nuclear Power Plants of VVER and RBMK Types”
(Forum-6)
to be held 8-12 April 2002; Kiev, Ukraine

RBMK-1500 Accident Management for Loss of Long-Term Core Cooling

E. Uspuras, A. Kaliatka
Laboratory of Nuclear Installation Safety, Lithuanian Energy Institute,
Breslaujos 3, 3035 Kaunas, LITHUANIA

Key words: RBMK-1500, Decay Heat, Thermal-hydraulic Simulations

Results of the Level 1 Probabilistic Safety Assessment (PSA) of the Ignalina Nuclear Power Plant (NPP) have shown that in topography of the risk, transients dominate above accidents with the loss of the coolant accidents. PSA has shown that failure of the core long-term cooling is the main contributor to frequency of the core damage. However, the transition to the condition of the reactor core due to loss of the long-term cooling specifies potential opportunities for the management of the accident consequences. The detail thermal-hydraulic analysis of long-term core cooling accidents should be performed for development of accident management strategy.

1. Introduction

Results of PSA of the Ignalina NPP have shown that failure of the core long-term cooling is the main contributor to frequency of the core damage. From other hand, there is enough time for different measures for mitigation of the accident consequences. Therefore the detail thermal-hydraulic analysis of long-term core cooling accidents should be performed for development of accident management strategy.

The most likely initiating event, which probably leads to the loss of long term cooling accident, is station blackout. The analysis of the station blackout was performed using the RELAP5/MOD3.2 model of Ignalina NPP reactor primary circuit and plant safety systems. The results of analysis showed that approximately half an hour after beginning of the accident, Drum Separators (DS) become empty. One hour later, the dry-out in the core starts. It causes the heating-up of fuel elements and Fuel Channels (FC) tubes. Acceptance criterion for FC tube walls will be reached approximately 2.5 hours after beginning of the accident. Since the pressure in the MCC is close to the nominal value, the possibility several fuel channels rupture is not excluded. However, these results also showed that there is a considerable time interval for the operator’s actions directed forwards the restoration of the core cooling.

Three ways of potential accident management for loss of the long-term core cooling are discussed:

- de-pressurisation of the reactor coolant system and water supply using non-regular means for core re-flooding,
- decay heat removal from the core by ventilation of DS compartments,
- decay heat removal from the core by direct water supply into the Reactor Cavity (RC).

The results of analysis showed that the last two ways are inexpedient. The ventilation of drum separator compartments and direct water supply into the RC are not sufficient to remove the decay heat from the core. However, the de-pressurisation of MCC enables to mitigate the consequences of the loss of long-term core cooling. Therefore, such way of mitigation of accident consequences is recommended to be included in the RBMK-1500 accident management programme.

2. Ignalina NPP RELAP5 model

The RELAP5 system thermal-hydraulic code has been adapted to model the RBMK type reactors and used since 1989. The state-of-the-art RELAP5/MOD3 code originally was designed for Pressurized Water Reactors (PWR) Unlike PWR, the RBMK-1500 is graphite moderated, boiling water, multichannel reactor. Several important design features of RBMK-1500 are unique and extremely complex with respect to western reactors. A brief description of the MCC and plant safety systems of the Ignalina NPP is given in [1]. Key features of the RELAP5 model of the Ignalina plant used for station blackout analysis are as follows:

- The MCC is represented by group of equivalent fuel channels. The equivalent fuel channels model the heat generation in a group of real channels, as well as hydraulic properties of this group. The equivalent fuel channels are modelled by multiple axial and radial control volumes.
- Heat transfer among the equivalent fuel channels and Control and Protection System (CPS) channels is approximated by means of heat exchange through the graphite moderator gaps to the RC gas.
- Steam paths that remove the vapour from drum separators are represented explicitly, including steam lines, steam discharge valves, etc.
- Circuit of the CPS rods cooling and radial reflector cooling is modelled explicitly.
- RC formed on a metal structure of the reactor shell together with bottom and top metal plates is modelled.

The nodalization scheme of Ignalina NPP RELAP5 model is presented in Figure 1. MCC is modelled by one loop. Such model simplification is possible due to the fact that both real loops in the MCC in the case of station blackout are at the same conditions in reality. This loop model consists of three equivalent core pass with FC (12) of three power levels (11 channels of maximum power, 1637 channels of average power and 13 channels of minimum power). For the thermal core power of 4200 MW, the channel average power is assumed to be 2.53 MW, the maximum channel power is 3.75 MW and minimum channel power is 0.88 MW. Heat structures of the equivalent fuel channel simulate the active region in the reactor core. The fuel element is modelled with an equivalent four radial node model. One of these radial nodes is for the fuel pellet, one for the gap region and two for the cladding. The vertical bundle option is used in heat structure description of fuel assembly with 18 fuel elements. The fuel channel and the graphite stack are modelled with an equivalent six radial node model. Two of these radial nodes are for the fuel channel wall, one for the gap and graphite rings region and three for the graphite blocks. Fuel element, fuel channel, graphite rings and graphite blocks are modelled with 14 axial segments, 0.5 m in length each. The square graphite stack is represented by an equivalent cylindrical volume. Approximately 95% of the total energy is deposited in the fuel and 5% - in the graphite.

Fuel channels are connected on one end to the Group Distribution Header (GDH) (9) by the lower water communication lines (10) via its flow control valve. The other end of the equivalent channels is connected to the DS by the steam-water communication line (14). Four real DSs are modelled as one volume (1). All downcomers are represented by a single equivalent pipe (2), further subdivided into a number of control volumes. Main Circulation Pump (MCP) suction (3) and pressure (8) headers are represented as branch objects. Six operating MCPs are represented by one equivalent element (5) with check and throttling-regulating valves. Stand-by MCPs are not modelled. Bypass line (7) between the MCP suction and pressure headers is modelled with manual valves closed. This is in agreement with a modification recently implemented at the Ignalina NPP. Steam from the separators is directed to turbines via steam lines (15). Two “servo valve” [2] model the supplying of the steam to the turbines. The control of these valves was modelled on the algorithm of steam pressure regulators used at Ignalina NPP. Steam pressure is controlled and peaks of pressure are eliminated by two Steam Discharge Valve (SDV-A) and twelve Main Safety Valves (MSV) by steam dump to pressure suppression pool of the Accident Confinement System (ACS). The model also considers steam mass flow rate through the SDV-D to the deaerators. The SDV-A and MSV were modelled by “motor valve” [2] elements with corresponding algorithm of theirs opening and closure.

All 235 CPS rods cooling channels are modelled by one equivalent channel (16). The elements (18) simulate 156 radial reflector cooling channels having a design “Field’s pipe”. Water in to these channels is supplied from top distribution header and removed into bottom distribution header. Reactor cavity is formed by a metal structure of the reactor shell (19) together with bottom (20) and top (17) metal plates. The fuel channels and CPS channels are allocated inside the holes of graphite columns. There are 2488 graphite columns, which construct the reactor graphite stack. The graphite stack was modelled as thermal structure in the presented RELAP5 model.

ECCS in the Ignalina NPP is divided into two subsystems: a system which provides emergency coolant water immediately after the initiation of the break (the short-term system) and a long-term system served by auxiliary feed water pumps and ECCS pumps. The short-term system consists of main feed water pumps and 16 ECCS accumulators. The accumulator means a pressurised tank with volume of 25 m3, which is just over half-full with water with temperature of 30 0C. The remaining part of the volume is filled with nitrogen gas at 9.8 MPa pressure. The nodalization scheme of an ECCS train from accumulators is shown in Figure 2. The 16 accumulators are modelled by one element (1), which is described by special RELAP5 accumulator model. In the case of station blackout all pumps are unavailable due to loss of normal electrical power supply for local needs. However, the water of about 170 m3 from accumulators can be used for MCC feeding. Water supply starts after opening of fast-acting valves (4). In the analysed cases, the manual opening of this valve was considered. The water from the accumulators is supplied to the GDH (7) of both loops of MCC through pipelines, check valves (5) and flow limiter (6). In order to prevent pressurised gas entering to the reactor, fast-acting shut-off valve (2) automatically closes when the water level falls down to a certain set point. The fast-acting valves were represented by motor valve elements in the RELAP5 model.

There are four deaerators, which contain 480 m3 of water in the one unit of RBMK-1500. Initial pressure in the deaerators is 1.2 MPa, water temperature - 190 0C. The relative pipe (9), which connects the deaerators and GDH (this pipe does not exist in the reality) were assumed in this analysis.

In the RELAP5 model the water packing scheme normally is used only for specific components (e.g. "pressuriser"). Therefore in all volume control flags, the water packing is turned off for all elements. In the model for all MCC pipelines, the vertical stratification model is turned on. In the elements, which model CPS and ECCS pipelines, vertical stratification is turned off. The wall friction model is turned off in the elements with large water volume (elements, modelling DS and headers) where wall friction has no influence in the reality. The wall friction is turned on in all other elements. The counter current flow model was used in the fuel elements. The choking flow model is applied for the safety valves (SDV-D, SDV-A and MSV) elements.

In order to provide confidence in the ability of the models correctly represent the plant response to the upset conditions, the models have been benchmarked for several operational events, such as trip of all MCPs and spurious opening of three MSVs, inadvertent actuation of ECCS, etc. Calculation results obtained using Ignalina NPP RELAP5 model agree well with the plant data when similar boundary conditions are imposed [3], [4], [5].

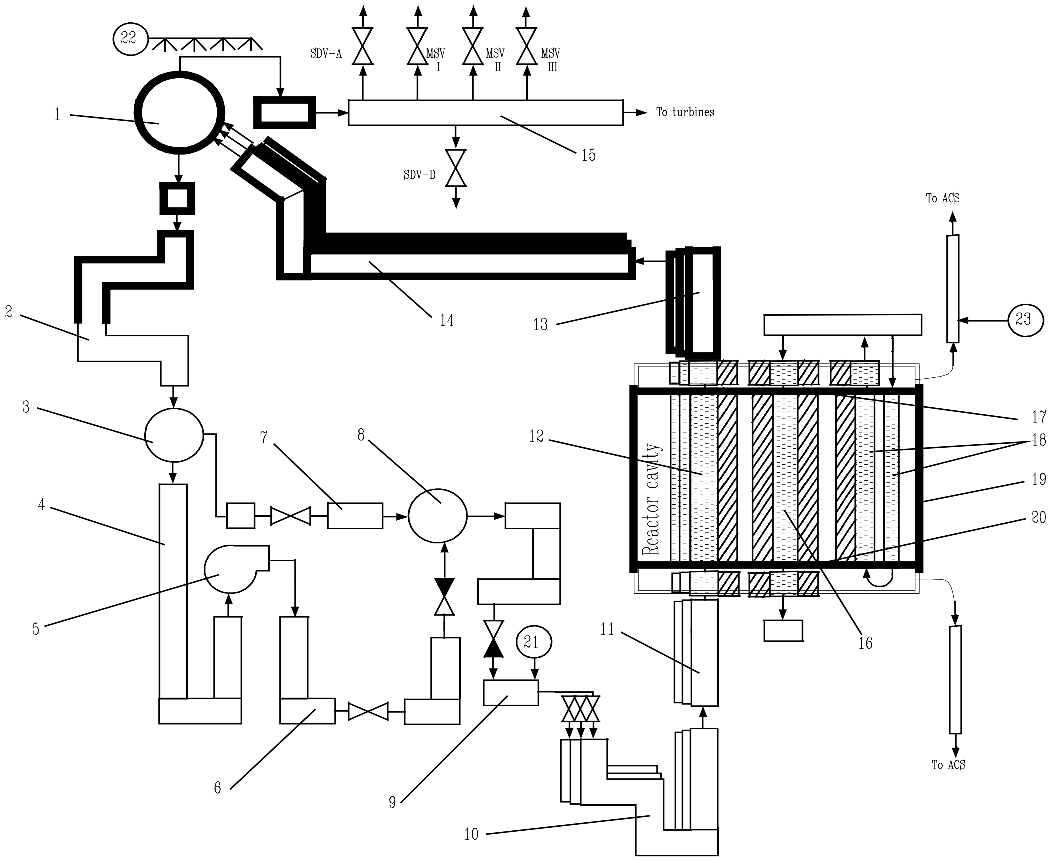

Figure 1. RELAP5 Ignalina NPP model nodalization scheme:

1 - DS, 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 - reactor core inlet piping, 12 - FC, 13 - reactor core outlet piping, 14 - steam-water communication line, 15 - steam line, 16 - CPS rods cooling channel, 17 - top metal plate, 18 - radial reflector cooling channel, 19 – reactor shell, 20 - bottom metal plate, 21 - water supply in to GDH, 22 - water supply in to spry system for air humidification in the DS compartments, 23 - water supply direct in to the RC

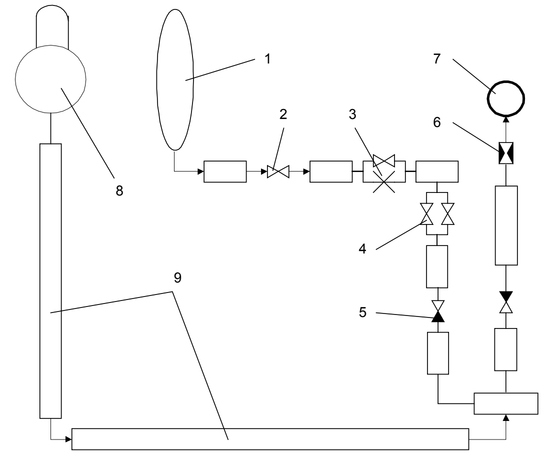

Figure 2. Nodalization scheme of deaerators and ECCS accumulators connection with GDH:

1 – accumulators, 2 - fast-acting shut-off valves, 3 – intermediate throttling, 4 - fast-acting valves, 5 – check valve, 6 – ECCS flow limiter, 7 – GDH, 8 – deaerators, 9 – assumed (relative) pipe for direct water supply from deaerators to GDH

3. Analysis of plant blackout without operator intervention

The Ignalina NPP belongs the category of “boiling water” reactors. During normal reactor operation the coolant is supplying by MCP into fuel channels. In the FC the cooling water is brought to boiling and is partially evaporated. The steam-water mixture then continues to the DS, the elevation of which is above the reactor. Here the water settles, while the steam proceeds to the turbines. The feed water from the deaerators is supplied to the MCC by Main Feed Water Pumps (MFWP). In the case of loss of electrical power supply MCPs, the circulating pumps of the service water system and MFWPs are switched-off. At the same time, TCV of both turbines are closed within 0.4 seconds. The closure of TCV leads to the imbalance between steam removal and steam generation in the core. The pressure in the DS starts to increase. The excessive steam is discharged through MSV and SDV-A and MCC pressure is maintained at proper level. During first seconds the coolant is supplied by cost down of MCP, whose have massive flywheel in order to prolong the rotation. Later the decay heat from reactor core is removed by natural circulation of coolant.

The emergency power supply for the Ignalina NPP is provided by six diesel generators per unit. In the event of a loss of normal electrical power supply they are started up automatically following trip of all turbines or loss of grid and can supply emergency loads in about 35 seconds. The diesel generators provide power for the EFWPs, ECCPs, CPS pumps, but MFWPs and MCPs are tripped in the case of loss of normal electrical power supply. The station blackout is the loss of normal electrical power supply with an additional failure on start-up of all diesel generators. Failure of diesel generators leads to the non-operability of the ECCS long-term cooling subsystem. It means the impossibility to feed MCC by water.

The station blackout analysis with RELAP5 showed that, in case of no operator intervention, approximately 2000 s (half an hour) after beginning of the accident, drum separators become empty. One hour later, the dry-out in the core starts. The heat transfer coefficient from fuel rods to coolant decreases. When reactor is operated in steady state condition (while MCPs are in operation), heat transfer coefficient is 36 - 64 kW/m^2·K. After MCP trip, heat transfer coefficient decreases rapidly down to 8 - 16 kW/m^2·K. After core uncovering, heat transfer coefficient from the fuel cladding to the superheated steam equals only 93 - 110 W/m^2·K. It causes the heating-up of fuel elements and FC tubes. Acceptance criterion for fuel element claddings (700 ^{0}C) in the channels with maximum power is reached approximately 6000 s (more as 1.5 hours) after beginning of the accident (Figure 3). Approximately 9000 s (2.5 hours) after beginning of the accident safety criterion for FC tube walls (650 ^{0}C) is reached (Figure 4). Since there are 11 maximum loaded fuel channels and the pressure in the MCC is close to the nominal value the possibility several fuel channels rupture is not excluded.

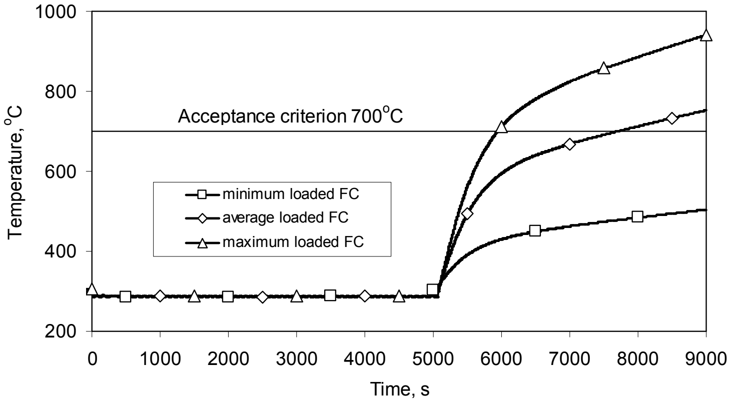

Figure 3. Station blackout without operator intervention. Peak cladding temperature in the FC of different power

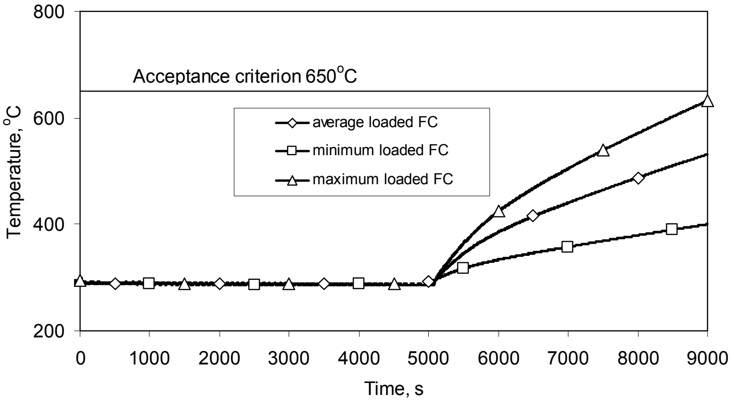

Figure 4. Station blackout without operator intervention. Peak channel wall temperature in the FC of different power

4. Analysis of different possibilities for operator intervention

The results of station blackout showed that there is a considerable time interval for the operator's actions directed forwards the restoration of the core cooling. Three ways of potential accident management for loss of the long-term core cooling are discussed in this section:

- de-pressurization of the reactor coolant system and water supply from ECCS accumulators, deaerators or using non-regular means to the GDH for core re-flooding,
- water supply from non-regular means in to spray system for air humidification in the DS compartments (for decay heat removal from the reactor core by ventilation of DS compartments),
- water supply from non-regular means direct in to the reactor cavity.

4.1 Analysis of plant blackout with water supply from ECCS accumulators and deaerators

Analysis of decay heat removal from core due to station blackout without operator intervention shows that approximately 2000 s (~ 0.5 hours) after beginning of the accident, DS are completely empty. Heating-up of fuel element cladding and fuel channel tube walls starts approximately 6000 s (~1.6 hours) after beginning of the accident. Acceptance criterion for fuel element claddings (700 ^{0}C) in the channels with maximum power is reached approximately 7200 s (2 hours) after beginning of the accident. Approximately 12000 s (more as 3 hours) after beginning of the accident safety criterion for FC tube walls (650 ^{0}C) is reached. Since the pressure in the MCC is close to the nominal value, the possibility of several fuel channels rupture is not excluded.

Water supply from the ECCS accumulators enables considerably to postpone beginning of the water evaporation from the core. As the additional water reservoir the deaerators could be seen. In case of valves closure on steam supply piping from steam lines to the deaerators and guaranteeing connection from deaerators to the GDH, deaerators can serve as water reservoir. Water supply from the deaerators starts when pressure decreases in the GDH below the pressure in deaerators.

In the first hour after beginning of the accident MCC thermal hydraulic parameters changes similarly as in case of without operator intervention. In the modelling it was assumed that within one hour after beginning of the accident operator opens fast acting valves on the water supply piping from accumulators to the GDH (Figure 5).

However, soon pressure in the accumulators and GDH becomes equal and cold water supply is stopped. Approximately 6100 s after beginning of the accident fuel cladding temperature in average loaded channels starts to increase. In the modelling it was assumed that temperature increase is a signal for operator to initiate depressurisation. MCC depressurisation is executed via opening one SDV-A (Figure 6). After beginning of MCC depressurisation, water supply to the GDH from accumulators is restored. Closure of fast acting valves at the accumulators' outlet prevents them from compete emptying and gas passage to the core (Figure 5).

Water supply from deaerators becomes possible only after pressure decrease in the GDH approximately down to 1.2 MPa (i.e. down to pressure in the deaerators). Water from deaerators reaches the core, heats-up there, boils-up and, thus, maintains the MCC pressure. Such pressure maintaining process lasts approximately one hour (Figure 6). Further due-to decrease of water amount in the deaerators, water supply to the GDH reduces and pressure in the MCC starts to decrease. The use of non-regular means with low-pressure water source is possible from this moment because the pressure in the MCC is low.

As it is shown in Figure 7, repeated increase of fuel cladding and fuel channel wall temperatures starts more than three hours after beginning of the accident. Water supply from the deaerators suppresses process of temperatures' increase. However, approximately five hours after beginning of the accident temperatures starts to increase once again. It means that it is necessary to resume water supply to the GDH via non-regular means. Acceptance criterion for fuel cladding (700 ^{0}C) in the average loaded channels is reached within approximately 310 minutes (more than within five hours) after beginning of the accident. In this case of modelling, heat transfer by radiation from fuel cladding to the fuel channel wall was not taken into account. Acceptance criterion for fuel channel walls (650 ^{0}C) in the average loaded channels was not reached during the analysed time period.

The CPS rods cooling and radial reflector cooling circuit remove the part of heat distributed in graphite. However, after plant blackout the pump of the CPS cooling circuit are switched-off. From this moment the water in the channels flows from the top storage tank. This tank becomes empty more than after 10 minutes and delivery of water stops. It leads to dry out of the CPS rods cooling and radial reflector cooling channels. From this moment, heat generated in these channels through graphite bricks and reactor gas circuit is transferred to FC.

Analysis results of plant blackout with water supply ECCS accumulator and deaerators showed that water supply to the GDH via non-regular means (fire machine) is necessary to start approximately 5 - 6 hours after beginning of the accident. Prior to that core could be cooled by water resources from accumulators and deaerators. If no operator action will be taken, this station blackout accident can transform into severe accident during this time span.

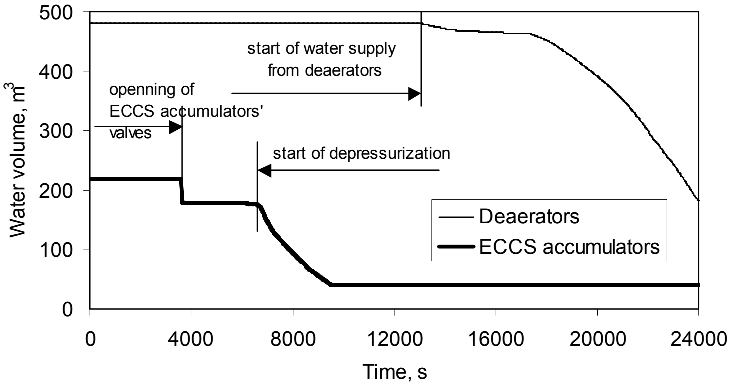

Figure 5. Water supply from ECCS accumulators and deaerators. Water volume in the equipment

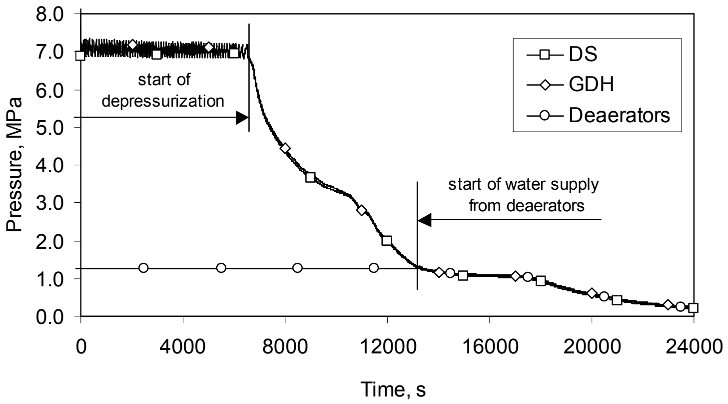

Figure 6. Water supply from ECCS accumulators and deaerators. Pressure in the MCC and in the deaerators

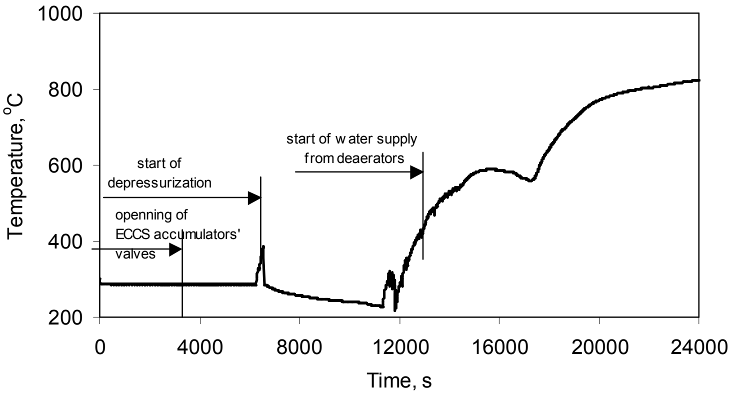

Figure 7. Water supply from ECCS accumulators and deaerators. Peak cladding temperature in the FC of average power

4.2 Analysis of plant blackout with DS compartment ventilation

Another possible way of accident consequences mitigation in case of station blackout is ventilation of DS compartments. There are two DS compartments (one for each reactor side) at Ignalina NPP. Equipment and piping in the DS compartments have considerable area of cooling: DS, steam header, part of the steam lines, part of the downcomers, steam-water piping and part of the channels, which are above the core. In Figure 1 above discussed equipment and pipes are marked by thick lines. DS compartments are connected by SWP piping corridor (Figure 8). Both compartments at the top have five rupture panels, which open at the excessive pressure in the compartments of 2 kPa. These panels are of 20 m^2 in each DS compartment and open to the accident steam release shaft. In the ceilings of the each steam relief shaft there are one or two pipes for air release in case of accident. There are nine such 1800 mm diameter pipes for each DS compartment. Each pipe is covered with a lid, which opens at the excessive pressure of 1.5 kPa [6]. Each DS compartment has four doorways of 1.2 m^2. Two doorways in each compartment are located at the bottom and other two - approximately eight meter higher (Figure 8). DS compartments are connected via SWP compartments, where there is a connection to the reactor hall through the gaps between the biological defence blocks - biological shielding. According to the design, effective area of gaps is 5 m^2 [6].

During normal reactor operation the maximal air temperature in the DS compartments can reach 270 ºC. If mentioned doors, rupture panels and lids of pipe are open, natural circulation of the air will be created in the DS compartments (it is marked by arrows in Figure 8). This natural circulation will be capable to remove a part of decay heat, generated in the core. The effect will be higher if the spray system for humidification of air will be installed. The DS compartments ventilation analysis was performed using CONTAIN code. The results of calculations shown that the total heat removal capacity, with 68.6 kg/s water with temperature of 30 ^{0}C through the spray to one DS compartment is about 10.5 MW.

Analysis of station blackout with DS compartments ventilation was performed using RELAP5 model. It was assumed in the modelling, that approximately 5500 s after beginning of the accident (then the fuel cladding temperature in average loaded channels start to increase) the 10.5 MW of heat starts to be removed from hot outside surface area of DS, steam header, part of the steam lines, part of the downcomers, steam-water piping and part of the channels, which are above the core. The amount of removed heat is approximately seven times smaller than heat generated in the core. The behaviour of fuel cladding temperatures in case of station blackout without operators intervention and in case with ventilation of DS compartments is compared in the Figure 9. As it is seen, the decrease of temperatures due to ventilation is negligible.

Analyses results show that implementation of this measure would not be expedient because:

- Heat removal by means of ventilation is not effective;
- Technically it is complicated (when even emergency diesel-generators are not operated) to equip sprays for air moistening and to open mentioned doors, rupture panels and lids for air release in case of accident.

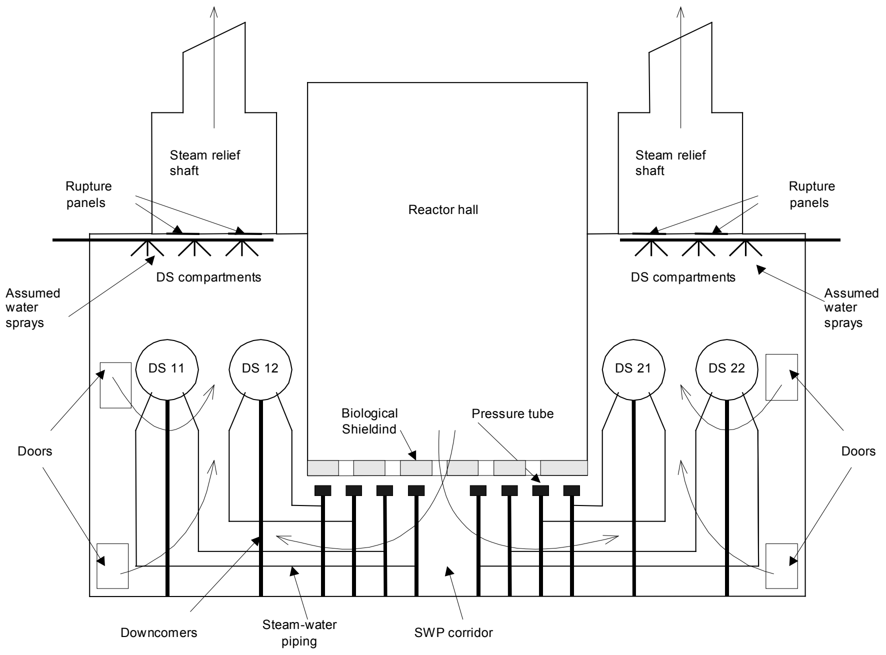

Figure 8. DS compartment ventilation. Schematic view of the DS compartments

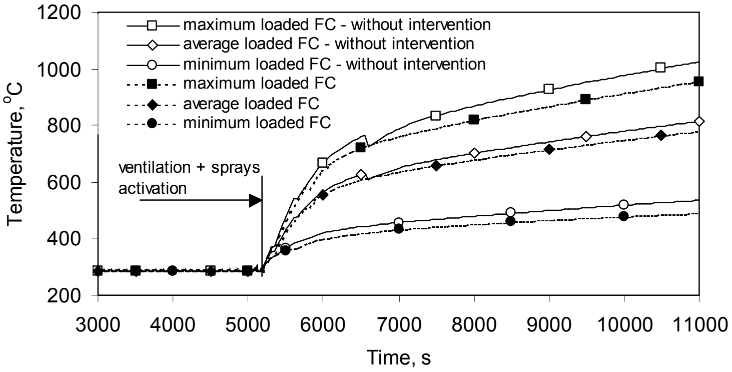

Figure 9. DS compartment ventilation. Peak cladding temperature in the FC of different power

4.3 Analysis of plant blackout with direct water supply into the reactor cavity

Sequence of the basic events and operating of the systems during first 5000 s in the below presented case is similar as in case with DS compartments ventilation or without operator intervention. It was assumed in the analysis, that at the moment of beginning of core heat-up (5800 s after beginning of the accident) the supplying of water into the top part of the RC starts. Flow rate of water was assumed equal 68.6 kg/s (the capacity of one ECCS pump) and temperature 30 ºC. In the paper the interaction of cold water and hot graphite, which might lead to the degradation of the graphite stack, was not analysed. The aim of the performed analysis was to evaluate the expediency of such kind of core cooling in order to assess the possibility to escape the heat-up and melting of the fuel rods, when other measures do not provide required cooling. This kind of cooling is used only in the critical case. Advantage of such way of accident management is that pressure in the RC is close to atmospheric. It means that for water supply it is possible to use any non-regular sources at low pressure.

By getting in the top part of RC, water flows down along the outer surface of the graphite stack into ring space between a reactor shell and stack. Gaps between the graphite columns are very narrow (1.2 mm [6]), and temperature of the graphite blocks at centre of the core is higher than 300 ºC when water supply starts. Thus, a water flow downwards along these gaps is practically impossible. Coolant flow rate inside the graphite stack - through the gaps between the graphite columns is presented in Figure 10. In comparison with the flow rate of supplied water, flow rate through gaps is insignificant. Through area outside of the graphite stack the water flows into the bottom part of the RC and through the pipelines is removed in to the reinforced leak-tight compartments of ACS.

Injected water cools the metal structures of RC, bottom and top graphite moderator blocks and outer surface of radial graphite reflector. However, because the water does not reach a deep lines of the graphite blocks, the temperature of graphite at the centre of the core increases. Changes of peak temperature of the fuel cladding without intervention of the operator are compared with attempt to cool down the reactor core by direct water supply in to RC. As it is shown from the Figure 11, the rate of the fuel cladding heat up decreases because of water supply. However, the reactor cool down does not begin. The stabilisation of the fuel cladding and FC tube walls temperature in the channels of average power 10000 - 11000 s after beginning of the accident is caused by features of modelling. In modelling was accepted, that the channels of average power are located near to radial reflector channels. As the channels of the reflector are cooled well by water, which is passing down along an outer surface of the graphite stack, these channels are capable to remove a part of the heat from the adjacent fuel channels. In reality, such approach will be correct only for peripheral channels.

Performed analysis results clearly indicates that proposed solution of heat removal by direct water supply in to RC is not feasible.

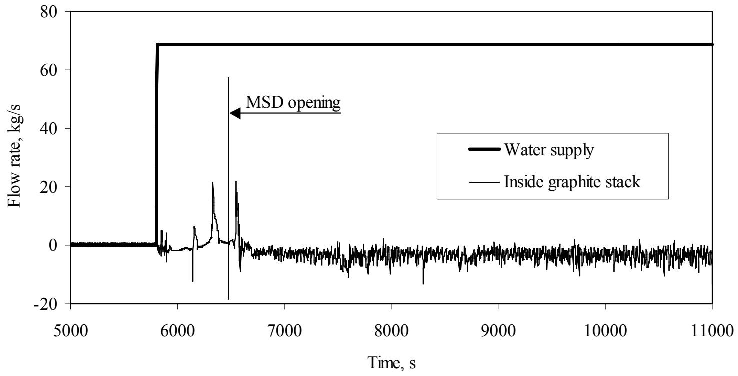

Figure 10. Direct water supply into the RC. Water flow rate through gaps between graphite columns (inside graphite stack)

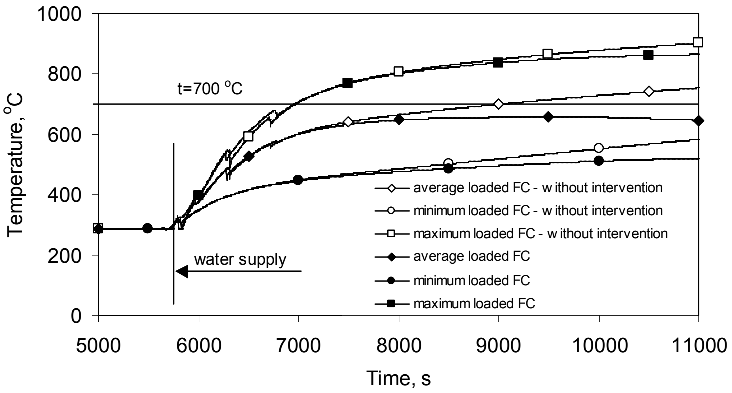

Figure 11. Direct water supply into the RC. Peak cladding temperature in the FC of different power

5. Conclusions

Results of the Level 1 PSA of the Ignalina NPP have shown that in topography of the risk, the failure of the core long-term cooling is the main contributor to frequency of the core damage. However, the transition to the condition of the reactor core due to loss of the long-term cooling specifies potential opportunities for the management of the accident consequences.

The most likely initiating event, which probably leads to the loss of long term cooling accident, is station blackout. The analysis of the station blackout was performed using the RELAP5 model of Ignalina NPP reactor primary circuit and plant safety systems. Three ways of potential accident management for loss of the long-term core cooling are discussed:

- de-pressurisation of the reactor coolant system and water supply from ECCS accumulators, deaerators or using non-regular means to the GDH for core re-flooding,
- decay heat removal from the core by ventilation of DS compartments,
- decay heat removal from the core by direct water supply into the reactor cavity.

The results showed that the last two ways are inexpedient. The ventilation of drum separator compartments and direct water supply into the RC are not sufficient to remove the decay heat from the core. However, the de-pressurisation of MCC enables to mitigate the consequences of the loss of long-term core cooling. Therefore, such way of mitigation of accident consequences is recommended to be included in the RBMK-1500 accident management programme.

Nomenclature

ACS	Accident Confinement System
CPS	Control and Protection System
DS	Drum Separator
ECCS	Emergency Core Cooling System
FC	Fuel Channel
GDH	Group Distribution Header
MCC	Main Circulation Circuit
MCP	Main Circulation Pump
MFWP	Main Feed Water Pump
MSV	Main Safety Valve
NPP	Nuclear Power Plant
PSA	Probabilistic Safety Assessment
PWR	Pressurized Water Reactors
RBMK	Russian Acronym for "Channeled Large Power Reactor"
RC	Reactor Cavity
SD-VA	Steam Discharge Valves to Accident Localization System
SD-VD	Steam Discharge Valves to Deaerators and to in-house needs
TCV	Turbine Control Valve

References

1. ALMENAS K., KALIATKA A., USPURAS E. Ignalina RBMK-1500. A source book. Extended and updated version. Lithuanian Energy Institute, Kaunas, 1998, 198 p.
2. The RELAP5 Code Development Team. RELAP5/MOD3 Code Manual, Volume 1, Code Structure, System Models, and Solution Methods, NUREG/CR-5535, INEL-95/0174, 1995.
3. KALIATKA A., USPURAS E. Benchmark analysis of main circulation pump trip events at the Ignalina NPP using RELAP5 code, Nuclear Engineering and Design, vol. 202, No. 1, 2000, Elsevier Science S. A., pp. 109-118.
4. USPURAS E., KALIATKA A. RELAP based safety analysis of the Ignalina NPP, Proc. of the Topical Meeting on Safety of Operating Reactors, 1995, Seattle, pp. 307-313.
5. VILEMAS J., USPURAS E., KALIATKA A. Benchmark analysis of inadvertent ECCS actuation using RELAP5 and ATHLET codes, Proc. 6th Int. Conf. on Nuclear Engineering, ICONE - 6355. 1998.
6. VATTENFALL. Ignalina NPP Safety Analysis Report. Volume 3 Task Group 5, 1996, (CD version).