PROBABILISTIC STUDY OF FIRE INFLUENCE ON SMOLENSK NPP SAFE SHUTDOWN CAPABILITY

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INTRODUCTION

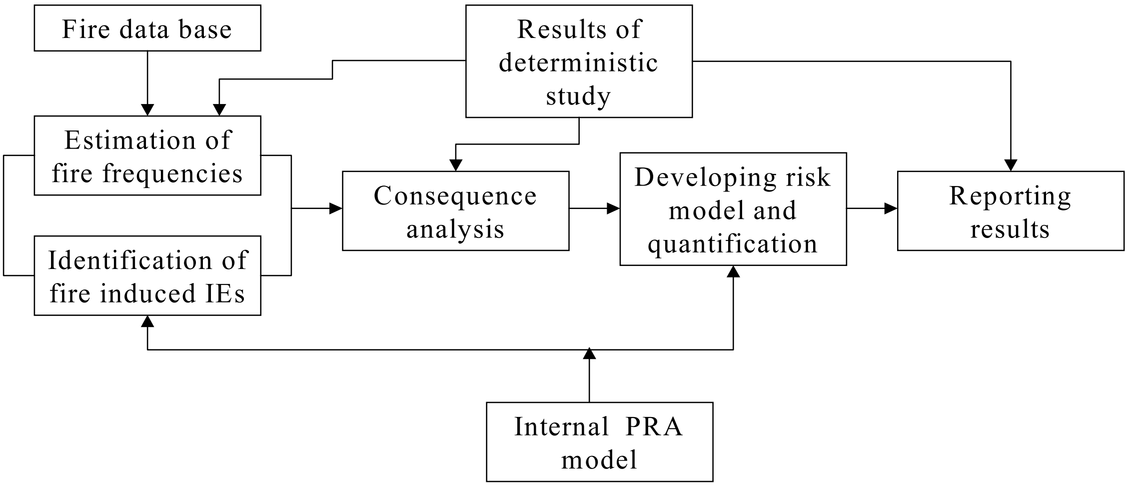
Paper presents a description of the study and the results of probabilistic phase of Smolensk NPP Unit 3 fire safe shutdown analysis. This project is a part of INSP program and it was aimed to enhance of fire safety level of operating NPPs with RBMK type of reactor in Russia. Smolensk NPP Unit 3 was chosen as a reference unit. The project was sponsored by US DOE and performed on the basis of "Reactor Core Protection Evaluation Methodology for Fires at RBMK and VVER Nuclear Power Plants", Rev. 1, 1997". The fire risk analysis was scheduled as a complementary study to deterministic phase and aimed to the following purposes:

- Evaluate explicitly the Unit safe shutdown capacity for the cases, which deterministic study classified as challengeable for the plant safety;
- Estimate the contribution to total unit risk value from fires;
- Perform prioritization over measures proposed on deterministic study aimed to enhanced fire protection and provide other possible measures important for Unit safety that can reduce the fire risk.

The work was performed by Russian project team that included experts from AEP and VNIIAES organizations with participation of NPP representatives and technical support of US experts from PNNL, BNL, EPM and Bechtel.

The results of deterministic study of analysis were used for probabilistic phase as an input data for the risk model development as well as other input documentation including the design drawings, operating procedures, Data Base on fire incidents, results of reference level 1 PSA, etc. The Task flow chart that shows the process of conducting probabilistic part of the project and main interdependences is presented below on fig 1.

Fig.1 The Task flow chart for probabilistic phase of the analysis



1 BASIC METHODOLOGY

According to RCPEM Methodology [1] the purpose of the deterministic phase of safe shutdown analysis is to identify equipment related to the main or alternative safe shutdown paths, which can fail due to a fire in fire compartment to be sure that at least one shutdown paths is available. It is also postulated that, in accordance with the procedures the operator establishes the fact of fire occurrence and initiates the emergency trip of the reactor.

In fact, the transient developing as a result of the equipment damage due to a fire often has a more complicated nature. A failure of the regular equipment may lead to exceeding the safety system actuation setpoints before the operator is able to detect a fire. Besides, fire effect on the electrical components and cables may cause spurious changes in the state of motor-driven equipment. The latter may change the nature of the processes, which in this case will not be limited to the postulated Unit shutdown.

Therefore, probabilistic fire risk study in addition to deterministic one can be used for the more clear understanding of real accident sequences that follow a fire. It is also helpful for prioritizing identified design weak points based on their influence on risk and select effective compensating measures.

Methodology used for probabilistic part of Smolensk NPP safe shutdown analysis is the same as one typically used for fire PSA [2] and includes several basic tasks:

- Development of the list of initiators caused by fire in the Smolensk NPP Unit 3 rooms;
- Determination of fire frequencies for the Smolensk Unit 3 rooms and for individual fire sources;
- Preliminary definition of consequences caused by fire in rooms, selection of rooms for detail analysis;
- Developing fire scenarios in selected rooms;
- Elaboration of the probabilistic models for identified fire scenarios;
- Model quantification, estimation of fire caused contributors to Core Damage Frequency.

As the development of internal level 1 PSA model was out of the project schedule and no Smolensk specific PSA had been conducted earlier is available for the current analysis, the PSA for the project of upgrading Leningrad NPP, Unit 2 developed within the frame of the international project was used as a reference PSA[3]. With this, as a set of the main safety functions for all units of RBMK-1000 NPPs equipped with the bubbling system for accident localization is identical, the initial functional event trees for the indicated types of IE were adopted same as the ones in the mentioned PSA. During the elaboration of the success criteria for the safety functions as well as system fault trees the difference in the design characteristics and structure of the systems of Smolensk NPP, Unit 3, and LNPP, Unit 2, was taken into account.

System component failures not modeled before in the Level 1 PSA fault trees but involved in the main or alternative safe shutdown path are accounted for by developing a simplified fault tree model of the respective system, which contains only fire-induced faults mainly at the train or system level.

In the latter case this fault tree is integrated into the existing Unit model on the basis of the safe shutdown master logic diagram (system dependency diagram) developed on deterministic study.

2 DEVELOPMENT OF THE LIST OF INITIATORS CAUSED BY FIRE IN THE SMOLENSK NPP UNIT 3 ROOMS

With regard to above the following is required to use level 1 PSA results for modeling fire consequences in the NPP rooms:

- determine initiating events from the referenced level 1 PSA, which may be consequences of fire affecting the NPP components;
- represent all possible fire consequences in the rooms in terms of the level 1 PSA initiating event groups.

When solving the latter problem, it should be taken into consideration that the same fire scenario allows for different representations in terms of initiating events and component failures. The final form of the process-related fire consequences in the NPP rooms is the result of this analysis. The following principles should be the guidance for modeling fire effects:

The least significant postulated fire-induced initiating event in level 1 PSA is the operator-initiated scram based on the rules set out in the relevant procedure. Events corresponding to NPP system component failures resulting in the loss of component functionality should be modeled as the basic fire-related events (bounding events) on the corresponding system fault trees, postulating the above IE with the Unit trip.

Component failures resulting in the main circulation circuit disintegrity and loss of coolant are interpreted in terms of the groups of the LOCA initiating events with the equivalent leak characteristics.

Component failures causing transients which do not result in the main circulation circuit disintegrity are modeled as separate IE groups only when the requirements to the composition and success criteria of the safe shutdown systems with the retained operability for the modes under consideration are different from those for the basic scram mode.

However, it should be pointed out that expressing fire effects on the process in the NPP rooms in terms of the Level 1 PSA initiating events and safe shutdown system failures cannot be handled as a formal procedure and requires, in the first place, the qualitative evaluation of the reactor system modes realized for each fire scenario under consideration.

Based on the results of the analysis, the following groups of initiating events which potentially may be caused by fire in the NPP rooms and for which safe shutdown logic models are to be made were selected for the room study:

Automatic reactor scram.

Manual reactor scram

Unit blackout.

Opening and subsequent failure to close of more than two MSVs.

Opening and subsequent failure to close of two or less MSVs.

Transient caused by the service water system failure.

Transient caused by the loss of deaerator pressure.

These IEs should be modeled in the fire evaluations with regard to the specific boundary conditions characterizing dependent failures of the safe shutdown systems.

3 DETERMINATION OF FIRE FREQUENCIES FOR THE SMOLENSK UNIT 3 ROOMS AND FOR INDIVIDUAL FIRE SOURCES

For this effort the data from database covering the Russian and Ukrainian NPPs was used and the approach detailed below developed. Fire frequencies were evaluated using the method based on the determination of fire frequencies for certain pieces of equipment considered as potential fire sources. These frequencies were derived statistically, based on the operating experience for the whole pool of equipment. Where no relevant data were available on particular types of the RBMK equipment or the number of events was insufficient, the data on the similar VVER equipment was used. The resulting frequencies obtained for the particular equipment types were assigned to the Smolensk NPP rooms proportionally to the number of pieces of equipment in these rooms. These data were obtained from deterministic study.

Since the direct statistics of fires significant in terms of safety and addressed in the PSA both at Smolensk Unit 3 and all RBMK-1000 NPPs in operation is not representative, fire frequencies were estimated mainly based on the data on the consequences of fire hazardous factors. These factors include events resulting in the equipment faults potentially causing smoke generation or ignition, which in certain cases leads directly to fire occurrence. Data Base reports present statistics on the FHPs occurred both at the Russian and Ukrainian NPPs; they were caused by failures or damage of various groups of NPP equipment. This data were derived by systematization and analysis of the operating data taken from the reports on the interruptions of NPP operation, annual reports on the NPP operational safety evaluation, records of NPP equipment failures, annual and monthly reports on NPP operation. Hence, these reports have collected and analyzed data from various sources, which allows to assess the source data for the FHF consequences evaluation as quite representative.

The total number of FHF recorded at the RBMK-1000 NPPs during this period is 141 cases. Besides, the reports contain data on the distribution of FHF consequences at the Russian RBMK-1000 NPPs, namely, frequencies of smoking, ignitions and fires per types of equipment. Below an approach of ignition frequency evaluation using the data on FHF consequences is described.

FHF include events resulting in short circuits, oil leaks temperature rise over 100°C, sparking, insulation degradation (ageing, destruction). These FHF may in the end cause such consequences at equipment smoking or ignition, and in some cases result in fire occurrence. The number of smoking and ignition cases N divided by the duration of the observation period T times the number of pieces of similar equipment n is the relative frequency F of events which may be regarded as direct precursors of Unit fires for the single source under consideration:

$F=N/(n*T)$ (1)

These events rarely cause large fires, which may jeopardize safe shutdown system operation. The estimate of the conditional probability P of fire occurrence in case of equipment ignition (smoking) is as follows:

$P=M/N$, (2)

where N is the number of smoking and ignition cases occurred.

Fire frequency Fi related to the i-th type of equipment is calculated as follows:

$Fi=fi*pi$, (3)

where fi is ignition frequency for the i-th type of equipment,

pi is conditional probability of fire occurrence in case of ignition on the i-th type of equipment.

Therefore, fire frequency Fi is the generalized estimate derived on the basis of the experience of operation of several NPPs. Priority data are those obtained from the RBMK-1000 Units. In case of their absence or insufficient representativness for some type of equipment VVER data is used. For the types of equipment being estimated same for all VVER NPPs, which is common for the circuit breakers and switchgear, than the data from all VVER types are involved; however, if the RBMK-1000 equipment is closer in design to that of VVER-1000 the VVER-1000 data is used and VVER-440 data is the last to be used.

Since the number of actual fires occurred at the NPPs was rather small, a number of assumptions were made for quantitative estimates. In particular, estimates were based on the so-called zero statistic, which is the upper boundary value of the conditional probability of a direct FHF consequence growing into a fire jeopardizing NPP safety. These estimates correspond to the confidence probability g=0.5 and are of significant uncertainty.

The total frequencies of fire on the i-th type of equipment obtained were distributed per the Smolensk Unit 3 rooms proportionally to the pieces of equipment in each room. The room fire frequency was the sum of fire frequencies related to all types of equipment. Thus, relative distribution of fire frequencies per rooms is Smolensk Unit 3-specific.

It should be noted that only those rooms were considered (and, therefore, the equipment which is potential fire source), for which safe shutdown capability evaluation was required. The list of such rooms was established as a result of the deterministic analysis.

The numbers and characteristics of pumps were identified from the design list of assembly pieces. The number and characteristics of cables were identified from the design power and control cable schedules. The number of various electrical components was identified from the design layout drawings. room analysis

3.1Selection of the Smolensk NPP Unit 3 rooms for probabilistic analysis.

The purpose of this task was to perform preliminary identification of influence of internal fires on Smolensk NPP unit safe shutdown capacity. The “safe shutdown” in this report means reactor scram and cooling down the reactor unit up to cold safe state in 72 hours after fire incident.

The development of model aimed to meet the following requirements:

- To define specific initiating events (IE) suppose to occur in the case of fire in unit rooms;
- To assess fire caused failures in systems, which operation is required to bring the unit to the safe state given IE.

The work was performed in two steps. At the first step a screening process was applied in order to select for the probabilistic analysis only those rooms that have potential to contribute to the total fire risk. The initial list of rooms was taken from deterministic study final report, i.e. only rooms were both routine and alternative safe shutdown algorithms could be lost due to fires were analyzed. During this process the room is screened out if the fire in this room can not cause any unit transient or if any, no components failed in systems, which operation is required for unit safe shutdown. For the remaining rooms a preliminary identification of fire induced faults (step 2) was performed. The purpose of this study was to clarify the set of consequences that are possible due to fire in the rooms and select rooms for developing specific fire scenarios resulting in these consequences.

The results of the work are input data for probabilistic modeling of selected fire scenarios.

The initial list of rooms was taken from deterministic study final report (more then 140 rooms were considered), i.e. only rooms were both routine and alternative safe shutdown algorithms could be lost due to fires were analyzed. For this list of rooms a preliminary estimation of fire consequences in terms of initiating events and looses in systems aimed to mitigate corresponding transients or accidents were performed.

As a result of this analysis about 100 rooms were screened out. For the remaining rooms a detail analysis (step 2) was performed. The list of rooms selected for detail analysis included about 40 rooms in which power supply, I&C equipment or associated cables are located.

3.2The basic principles and results of the detail study of room analysis

The purpose of detail study was to clarify the set of consequences that are possible due to fire in the rooms and develop specific fire scenarios resulting in these consequences. The basic conclusion from the detail analysis is that for the major part of unit rooms the fire influence on safe shutdown can be described by single scenario resulting in manual or automatic unit trip accompanied with failures of several components belong to one safety train (electrical). However for some rooms, like unit

Control Room, Auxiliary Control Board and some others, there is a potential for set of consequences of different severity, including BDBA.

For these rooms it is important to reduce the conservatizm in risk value expected to be large taking into account the component redundancy or the specific measures for each room that are aimed to detect and stop or localize the initial fire and, therefore, to prevent the fire propagation throughout the room volume. The detail modeling of fires in these rooms allows the analyst to estimate consequence of fires more accurately. For the most important rooms it can be done on the basis of partial equipment damage from the whole room inventory.

This modeling is performed in the form of Fire Event Trees. An initiating event in the Fire Event Tree is the start of a fire in the specific location of the room that is chosen and postulated under conservative assumptions. Alternatively, a set of possible fire scenarios for the different places of ignition can be considered if consequences of fire are not the same. The node events in a Fire Event Tree are used to define fire detection and suppression as well as the potential for fire propagation. The tree end points characterize consequences of fire in terms of internal Initiating Events and failures in mitigating systems. There are several principles used for the development of the Fire Event Trees. These principles are discussed below.

Fire detection / suppression

The detection of fire in appropriate time is important for measures followed to stop the fire at the initial stage or localize the fire before it propagates over the whole volume of the room. It is assumed that the first action must be taken by the plant staff whereas the second one should be addressed mainly by the fire brigade. The fire detection can be based on fire alarm system or by operators, who are present in the room where fire starts or in the adjacent rooms. Fire suppression can be performed:

- by fire suppression systems actuated automatically or manually if they are specified for the burning room or specific fire area in a large room,
- by the plant staff using manual portable extinguishers, hose streams and fixed fire suppression,
- by the fire brigade.

In the last case the time window needed for fire brigade to reach the accident room has been taken into account.

Early / Late time frame

These terms are used to characterize the fire detection process. If fire detection is based on an automatic alarm system or a fire occurs in the room permanently occupied by the plant staff, the both terms are applied to the model. In this case the first term addresses to the situation when the fire is detected immediately after the ignition, whereas the second one characterizes only manual detection of fire after a period of increasing intensity. When the fire detection is not based on alarm system or no credit is taken for permanent presence of people in the room or room is too large, only late time frames are used. That means that the plant staff is assumed to discover the fire within an appropriate time to initiate suppression actions.

Allocation of Event Tree end points to consequence categories

Typically there is no algorithm for evaluation of consequences for all possible fire scenarios as they all are room specific. However, some general rules that can be applied to this task are discussed here.

If fire starts at specific place in the room and is detected at the early stage, the fast suppression allows the damage to be limited to the equipment directly affected or equipment located in the zone around the ignition point or a small area.

Normally this leads to less severe consequences than in the case of late detection/suppression or when fire propagates over the whole room. The specific consequences for limited fire area can then be estimated by analyzing the equipment pieces in the area. For cables a similar assumption can be made of cable damage in the specific cross-section located in the affected area.

The late suppression can be considered only for a specific room enclosure, i.e. when there are sets of equipment installations (like rows of electrical panels or boards, pumps, oil tanks, etc.) separated by distance. In this case the late fire suppression prevents fire propagation over the whole room and allows the limitation of the consequence of fire to the damage of equipment items separated by distance. For the late fire suppression actions of both the plant staff and fire brigade to be considered. In some cases where the separation distance between groups of equipment is enough large in comparison with fire load, the potential of non-propagation of fire due to distance has been considered as well.

Assignment of nodal probabilities

For the nodal events specified above the following general rules for an assignment of probability values depending on room characteristic can be applied.

Early fire detection

For the rooms or fire areas equipped with automatic alarm system the probability of early fire non-detection can be estimated on the basis of system analysis. As a generic value the probability of 1.E-03 can be also used. If the room is permanently occupied by the plant staff the probability 1.0E-2 can be assigned, which exceeds the previous value by factor 10. If both automatic alarm system and operators are available in the room the former probability to be reduced by factor 10 in order to account human dependency on alarm system failure.

Late fire detection

This event can be modeled only for the case if no alarm system is installed and no people present in the room on permanent basis or room is too large. The probability of fire non-detection can vary from 1.0E-2 to 1 depending on the portion of attendance time, the room area and enclosure.

Early fire suppression

This can be performed only by the staff or automatic suppression system. The manual suppression failure probability of 1.0E-2 given successful detection can be assumed. For the automatic suppression such figure should de obtained on the basis of system analysis.

Late fire suppression

This event typically follows manual detection. This can be performed both by plant staff and the fire brigade if transportation time for the brigade is not too large for the specific room. As these actions can be considered as independent, the probability to fail both equals to product of staff failure (1.0E-1) and fire brigade failure (1.0E-2), i.e. 1.0E-3. When only plant staff suppression is available, 1.0E-1 is assumed.

Fire propagation over distance

The probability of fire propagation between equipment depends on the distance-load and other room characteristics, such as air inventory and others. However, for the distance of 3 m and more the probability of fire propagation of 1.0E-1 is assumed as a reasonable value except for large fires, which corresponds to a TH oil or hydrogen fire or fire in rooms with significant cable inventory.

Human performance with respect to unit control functions

The typical question addressed here is ability of plant operators successfully escape from MCR given a fire and shutdown the unit from Auxiliary control room. The generic probability value for the plant operator not to perform this function used in many PSAs equals to 1,0E-01.

As an example of fire event trees, one developed for the non-operative MCR section (MCR-N) G320/3 is given below on fig.2

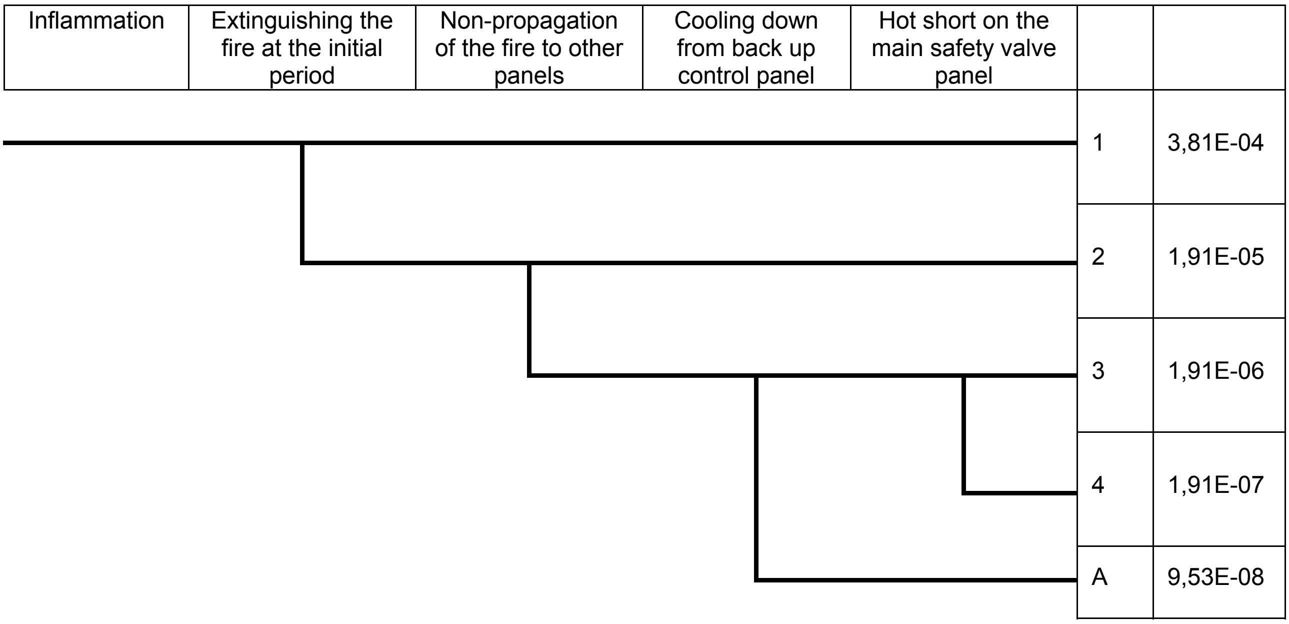
It is assumed that following the ignition operating personnel is able to detect the fire, to identify its place and to take the required measures to stop the fire at its initial phase, i.e. prior to the moment of the technological consequences happened due to the fire in the form of failures of the system components.

Unlike other rooms, the consequences of a fire in room G320/3, wherein a major part of the technological signals of protections and interlocking are normalized, significantly depend upon the specific scenarios which are defined by the place of fire start, by the personnel action to extinguish the fire, by the personnel actions for controlling the unit and by the possibility of the fire propagation to the neighboring panels. The personnel actions to control the power unit, in particular, incorporate the counter-measures aimed at elimination or reduction of the risk of spurious actuation of mechanisms and, if needed, making the decision about the necessity to cooldown the power unit from the back up control panel.

Taking into account the above said, in the form of the event trees below are given the results of the analyses of various fire scenarios where the initiating event is the fire starting on a certain panel located in G320/3, and the final states are the technological consequences in the form of initiating events and failures of the safe shutdown systems.

An event tree presented below describes scenarios possible in the case of fire on panel of the technological systems of the reactor shop (RS), RCP, monitoring of the technological systems of the turbine hall, I&C of the turbines protection.

Fig2. Example of Fire Event Tree for non-operative MCR section



The designations on fire Event Tree are:

1 Shutdown of the power unit by the operator, all systems serviceable;
2 Scram (in response to various technological signals), all main systems of the safe shutdown serviceable;
3 Scram with a failure of the feed water system (main and emergency), blowdown and cooling down system, BRU-K, RCP;
4 Scram, small leak through the main safety valve with a failure of the feed water system (main and emergency), blowdown and cooling down system, RCP;
A Fuel damage in the core (A consequence category).

Consequence 1 is realized at measures timely taken by the operator to extinguish the fire at the initial stage of its course.

Consequence 2 occurs at failed actions of the personnel on fire extinguishing, however, proceeding from the condition that fire does not propagate to other panels.

Consequences 3 and 4 are implemented in the case when the fire propagates to a large part of the room. In this case the operating personnel must make the decision to go on with cooling down from the back up control panel. In this case consequence 3 occurs with the absence of failures of the “hot short” type in the electric circuits of the main safety valve panels causing their spurious opening, and consequence 4 occurs with these failures existence.

Consequence A is implemented on a failure of the personnel to fulfill the action specified above.

4 ELABORATION OF THE PROBABILISTIC MODELS FOR THE MAIN FIRE SCENARIOS

The probabilistic model of fire influence on plant safe shutdown was elaborated in the form of the event trees and fault trees. According to the common practice the elaboration of the specified models for the assessment of the fire risk is performed basing on PSA for internal IEs. Due to the fact that up till now such PSA has not been developed for Smolensk NPP, Unit 3, the approach to solving the task, which key assumptions and restrictions are described below, was selected in the given project.

Elaboration of event trees

The considered types of the fire scenarios are reduced to the transients with power unit shutdown or to the accident with a small leak through the main safety valves (GPK). The specified IEs are reviewed and reported in the reference PSA for the project of upgrading LNPP, Unit 2. The initial functional event trees for the indicated types of IE were adopted same as the ones in the mentioned PSA. With this, further on, for each scenario of a fire under consideration in the unit rooms, the specific event trees from the above mentioned ones were established attributing the unique identification. The frequency of the indicated IEs was accepted basing on the calculation of the probability of each fire scenario and general frequency of fires in the room. During the elaboration of the success criteria for the safety functions the difference in the design, characteristics and structure of the systems of Smolensk NPP, Unit 3, and LNPP, Unit 2, was taken into account.

Elaboration of fault trees

During the elaboration of the fault trees the structure of the front line systems of Smolensk NPP, Unit3, was analyzed according to the valid design documentation:

- on ECCS 27-23.62-28 (GIDROPROEKT, 1984 г.);
- on the Feed Water System 27-62-0040ГЗ (GIDROPROEKT, 1984 г.)

In addition, during the elaboration of the fault trees the following assumptions or restrictions of the analysis have been adopted.

Data base on independent failures

The characteristics of the components reliability as well as other probabilistic characteristics used to calculate the probabilities of the basis events, independent upon a fire, were adopted the same as the ones in the PSA report for LNPP.

Simulation of fire-dependent failures

According to the procedure of the analysis of the safe shutdown it was assumed that all electric-powered equipment and cables located in the area of the fire were damaged. In this case the simulation of fire-dependent failures was performed on the level of the front line systems which directly perform the functions of the safe shutdown. The dependencies from the supporting and control systems during the fire were accepted according to the results of the detailed analysis of the fire scenarios in the unit compartments. During elaboration of the fault trees in the format of the RISK SPECTRUM code the indicated dependencies were taken into account using the House Events, each switching on if corresponding scenario is considered and which substitute for the independent basic event gates correspond to system trains lost during the fire with postulated events of one probability.

<u>Simulation of the components having the unchangeable operating mode during the safe shutdown in a fire</u>

Due to the lack at the moment of the specific PSA for Smolensk NPP, Unit 3, the elaboration of full-scale models of the system analysis with account for all components of the supporting systems as well as the components of the I &C system is not possible within the frame of the given activity. Therefore, in elaboration of the fault trees the full-scale simulation was performed exclusively for the systems which are able to perform the safe shutdown function directly. In other systems (except for power supply) only those components were taken into account that can change their initial (before the fire) state either due to the necessity of performing the safe shutdown by front line systems or due to the cause connected to the fire impact. The given assumption was based on the fact that fire-independent probabilities of failures of components in the unchanged state for the cooldown period (24 hours) of the unit are low as compared to the probabilities of other basis events, the major part thereof belongs to the components unavailability and common cause failures in the standby conditions as well as to human errors.

To illustrate an approach have been implemented, the Figures below present one class of Event Trees correspond to various fire scenarios in plant rooms identified at previous step, namely for administrative shutdown. Rooms and scenarios, which represent the same boundary conditions (initiating event type and system faults) then are binned to specific analysis cases to minimize the number of code runs.

The event tree is given on fig. 3. The basic structure of event tree, definitions of functional events in event tree headings and different hazard states are introduced in accordance with Leningrad NPP PRA model. These hazard states are:

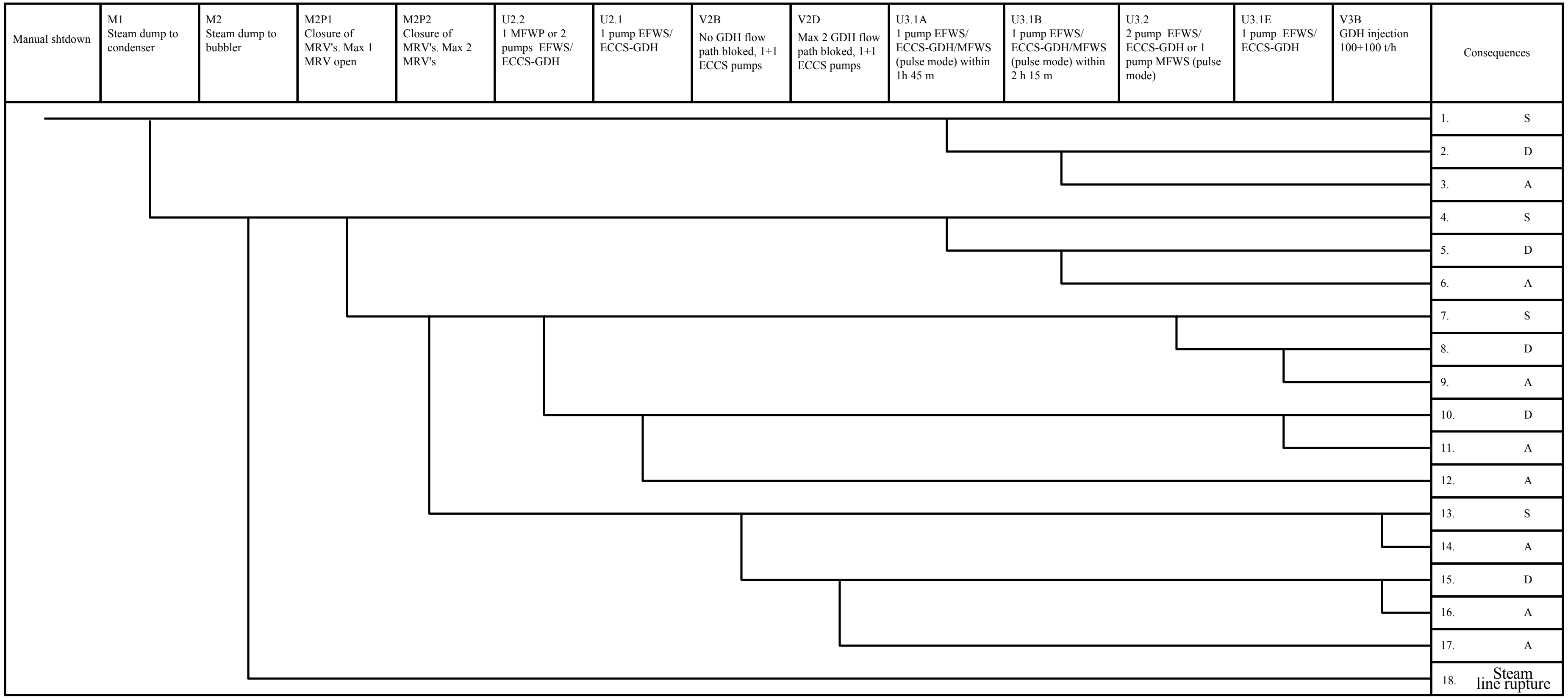
S - safe state;

D - core partial damage,

A - core gross damage and loss of the core structural integrity.

The list of event tree functional events is given in attachment A.

Fig.3 Event Tree for the Manual Shutdown



5 RESULTS OF MODEL QUANTIFICATION AND MAIN FINDINGS

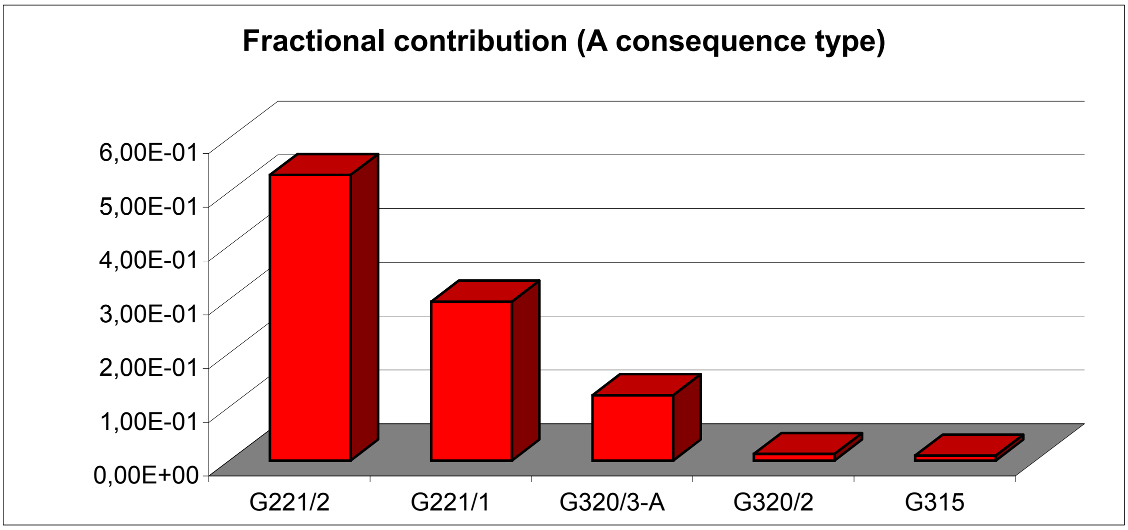
5.1Results of estimating A and D consequence type frequency

The total value of A end state category frequency equals to 9,47E-07 per reactor-year. A category, as it mentioned above corresponds to severe accident consequence with a large core damage and serious radiological impact. In Table 1 the top ten rooms contribution to this consequence type is presented in comparison to fire induced IE frequency. For rooms where different fire scenarios to be assumed for detail modeling, IE frequency and A consequence frequency were assigned to specific scenarios. Analysis of result s obtained indicates that main contributors to the total value are two sections of Cable semifoor under MCR (A-221/2, A-221/1), MCR itself, scenarios directly leading to A-consequence (A-G320/3, A-G320/2) and room for EPS train 1, DC panels (ShPTS) and UPS (A-G315). The fractional contribution of these rooms to the total value is also presented on Figure 4 given below.

Table 1 Contribution to A category of CD end states from different rooms

#	Rooms ID	IE frequency	Mean frequency of A consequence
1.	A-221/2	4,02E-04	5,03E-07
2.	A-221/1	2,57E-04	2,80E-07
3.	A-G320/3__A	1,62E-07	1,62E-07
4.	A-G320/2__A	1,17E-08	1,17E-08
5.	A-G315	1,39E-03	8,65E-09
6.	A-402/1	3,64E-03	4,26E-09
7.	A-402/2	3,64E-03	4,26E-09
8.	A-G124,128	5,78E-04	3,06E-09
9.	A-G123,127	5,77E-04	2,98E-09
10.	A-G122,126	5,62E-04	2,89E-09

Figure 4 - The fractional contribution of rooms to the total value



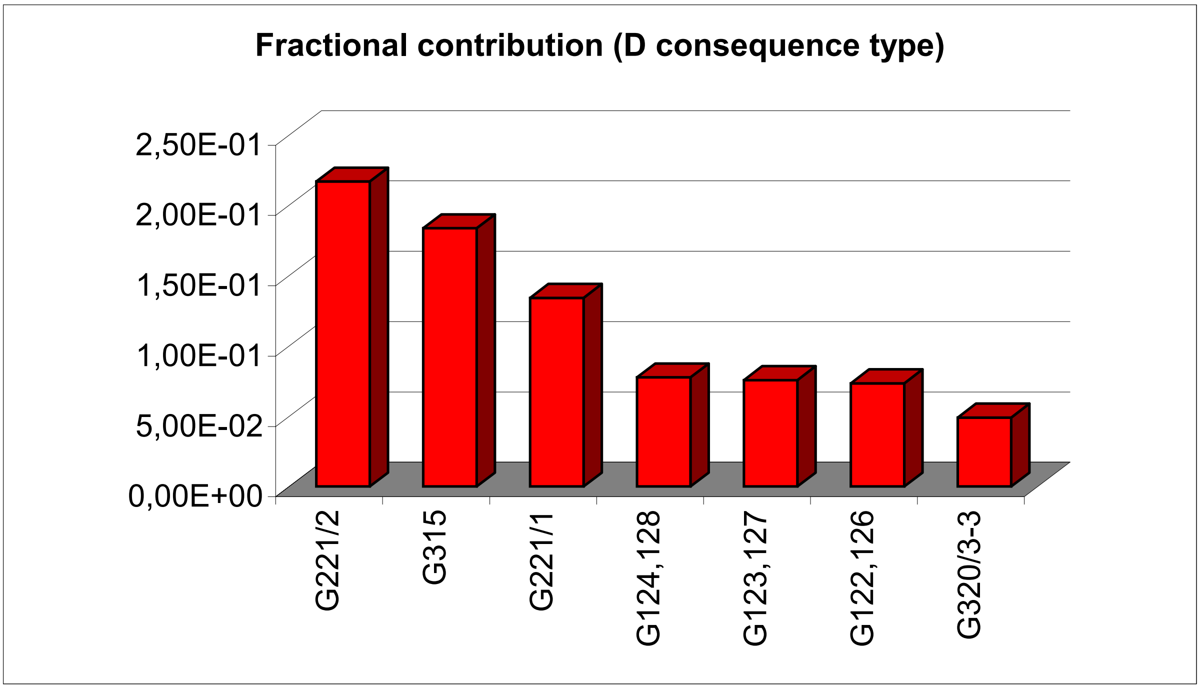
D-type consequence corresponds to those end states, which characterize damage of limited number fuel channels resulting in medium radiological impact. The total value of D-type consequence frequency equal to 4.3E-8 per reactor-year. The top ten contributors to this value are listed in the Table 2. The fractional contributions are also illustrated by figure 5.

The results obtained show that the dominant contributors to D-type consequence frequency are mainly rooms that contribute to A-type consequence as well. Examples of this are G221/1, G221/2, G320/2, G320/3, G315.

Table 2 Contribution to D category of CD end states from different rooms

#	**Rooms ID**	**IE frequency**	**Mean frequency of D consequence**
1.	D-221/2	4,02E-04	9,38E-09
2.	D-G315	1,39E-03	7,87E-09
3.	D-221/1	2,57E-04	5,74E-09
4.	D-G124,128	5,78E-04	3,32E-09
5.	D-G123,127	5,77E-04	3,24E-09
6.	D-G122,126	5,62E-04	3,14E-09
7.	D-G320/3__3	2,44E-06	2,11E-09
8.	D-010	3,30E-03	9,90E-10
9.	D-G018	1,29E-04	8,67E-10
10.	D-G016	1,17E-04	7,70E-10

Figure 5 The fractional contribution of rooms to the total value



5.2 Assessment of Risk Reduction Factors

For the purpose of ranking plant hazardous compartments relative risk reduction measure can be also helpful. The risk reduction factor for the specific room can be as

$$R = \lg\frac{F_f}{F_{CD}},$$

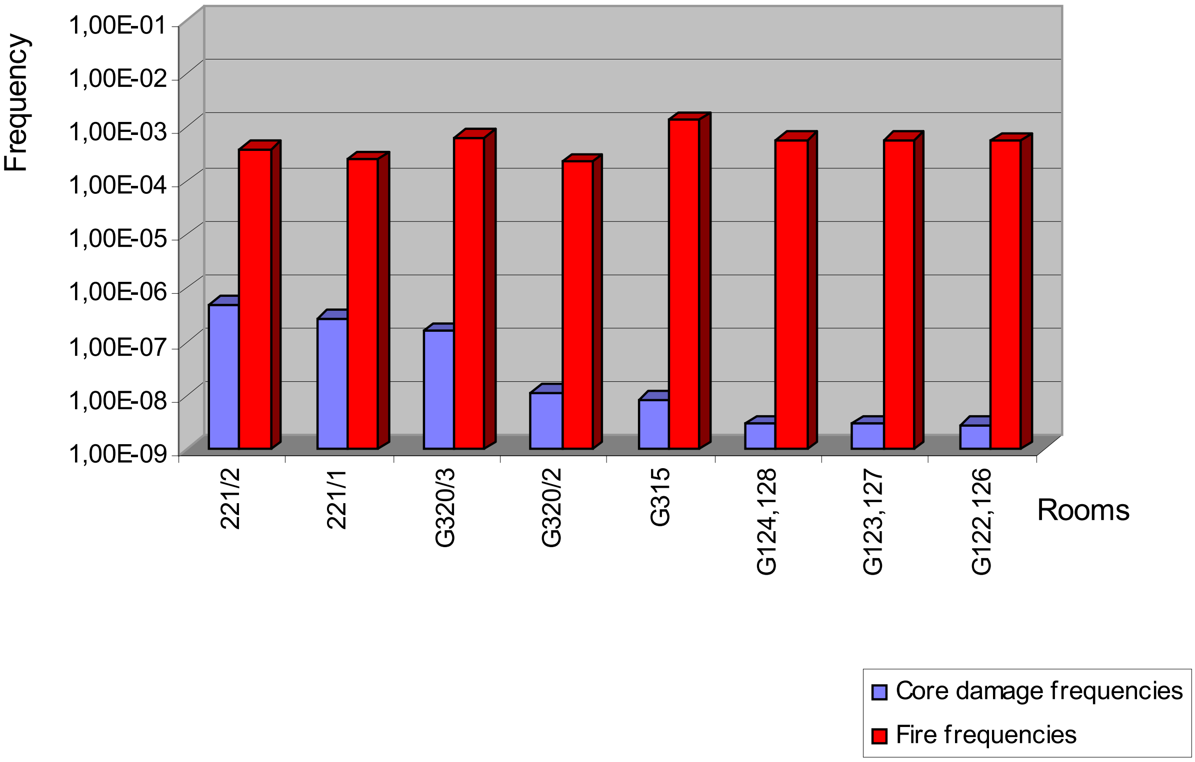
where F_f - frequency of fire in specified room,

F_{CD} - core damage frequency, associated with this room.

As it can be seen from above sections of the report the main contributors to both A-type and D-type consequences are presented by the same set of rooms. Therefore, for this case F_{CD} can be defined for each room as a sum of frequencies correspond to A and B categories estimated over all possible fire scenarios.

Results of estimating risk reduction factors for main contributors are presented on the figure 6.

Figure 6 Risk reduction factors for main contributors



5.3Comparison of risk characteristics against proposed modernization measures

Several measures aimed to improve fire protection of Smolensk NPP Unit 3 were proposed at deterministic study of analysis. To select the optimal strategy of modernization that allows to reduce the cost of modernization program and at the same time provides significant benefit in enhancing plant safety these measures should be checked with respect to their effect on risk characteristics. From this point of view the results of probabilistic analysis would be useful to:

- Define the list of room, where modernizations are the top level of priority,
- Estimate level of risk reduction after their implementation,

– Propose additional measures followed probabilistic study (if any).

The results of calculations described above show that a few rooms provide major contribution to risk (both A and D types of end states). These rooms are cable semifloor sections G221/1 and G221/2, Main control room sections G320/2 and G320/3, DC boards G315, G321/1, G327/1, Main circulating pump rooms 402/1, 402/2 and 0.4 kV and 6 kV switchgear compartments G122, G123, G124, G126, G127, G128. Therefore, over all proposed measures only those associated with listed above rooms can be further considered having potential for the significant influence on plant safety and the main attention should be focused at Cable semifloor and Main control rooms dominate over all others.

For the first one distribution of cables correspond to redundant groups of components over two separated sections will reduce the risk. As alternative, additional fire protection of critical cables, which credit appropriate grace time for automatic fire suppression operation can be also recommended.

For the Main Control Room the distribution of critical control room panels using already existing fire separated sections of MCR (MCR-O, MVR-L, MCR-R), as well as changes in emergency operator procedures could be considered as a measures for further risk reduction.

As it can be seen from given above charts and tables implementation of measures for both MCR and Cable semifloor has a potential to reduce the total plant risk by factor 5.

The actual level of risk reduction can be estimated more accurately after selection of specific measures to be implemented.

With this, it should be pointed out that since improving measures for MCR and Cable semifloor have been implemented the plant fire risk profile change significantly. Therefore, the other listed above rooms, which now are placed at the next level below, should be also considered for the task of selection of safety improving measures.

CONCLUSION

The purpose of this study was a development and quantification of probabilistic model for the assessment of fire risk for Unit 3 Smolensk NPP. The term “fire risk” in this report means fire caused contribution to core damage frequency to be calculated for each of pre-defined core damage states.

The paper provides the results of development and quantification such a model. The analysis was performed for plant rooms a fire wherein leads to the events which require shutdown and cooldown of the power unit and, in addition, are accompanied with dependent failures of components of the systems involved in the unit shutdown.

The frequency of the indicated IEs was accepted basing on the calculation of the probability of each fire scenario and general frequency of fires in the room. The characteristics of the components reliability as well as other probabilistic characteristics used to calculate the probabilities of the basis events, independent upon a fire, were adopted the same as for the reference internal level 1PSA.

The results of analysis in general confirm that the Unit 3 of Smolensk NPP has the level of fire safety that meets requirements applied to operating NPPs. The total values of A and D type core damage category frequencies equal correspondly to 9,47E-07 and 4.3E-8 per reactor-year. This means that the total core damage frequency is about 1E-06 per reactor-year, that is typical for the second - third generations of NPPs.

The results also indicate that the main contributors to the total risk value are cable semifloor sections G221/1 and G221/2, Main control room sections G320/2 and G320/3, DC boards G315, G321/1, G327/1, Main circulating pump rooms 402/1, 402/2 and 0.4 kV and 6 kV switchgear compartments G122, G123, G124, G126, G127, G128.

Therefore, over all proposed measures to improve fire protection those associated with above rooms can be further considered having potential for the significant influence on plant safety. The main attention at the same time should be focused at Cable semifloor and Main control rooms dominate over all others.

REFERENCES

1. Reactor Core Protection Evaluation Methodology for fires at RBMK and VVER NPPs. US DOE, Revision1 June 1997
2. Treatment of Internal Fires in Probabilistic Safety Assessment for Nuclear Power Plants, IAEA Safety Reports Series No10, Vienna 1998
3. Eugene Shiversky et al. Core Hazard States Definitions and Criteria for LNPP Unit 2 PSA, LNPP Unit-2 PSA Project Report lpr158

ATTACHMENT A

The list of ET functional events for Manual Shutdown With All Systems Available

Description	Functional event name
Pressure control of the primary circuit	
Steam dump with BRU-K to turbine condensers	M1
Steam dump with BRU-B and/or GPK to bubbler condensers	M2
Closure of GPKs and BRU-B exept for 1 GPK	M2P1
Closure of GPKs and BRU-B exept for 2 GPK	M2P2
Intermediate term GDH injection	
No GDH flow path blocked, 1+1 ECCS pumps	V2B
Maximum 2 GDH flow paths blocked, 1+1 ECCS pumps	V2D
Intermediate term DS makeup	
1 pump MFWS/EFWS/AFWS/ECCS-GDH/ECCS-DS	U2.1
1 pump MFWS or 2 pumps AFWS/EFWS/ECCS-DS/ECCS-GDH	U2.2
Long term GDH injection	
GDH-injection with ECCS, 100+100 ton/h	V3B
Long term DS makeup	
1 pump AFWS/EFWS/ECCS-DS/ECCS-GDH or 1 pump MFWS (pulse mode), start within 1 h 45 min	U3.1A
1 pump AFWS/EFWS/ECCS-DS/ECCS-GDH or 1 pump MFWS (pulse mode), start within 2 h 15 m	U3.1B
1 pump AFWS/EFWS/ECCS-DS/ECCS-GDH pump	U3.1E
2 pumps AFWS/EFWS/ECCS-DS/ECCS-GDH or 1 pump MFWS (pulse mode)	U3.2