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the Order of the Federal Environmental, Industrial and Nuclear Supervision Service
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SAFETY GUIDE IN THE USE OF ATOMIC ENERGY
"BASIC RECOMMENDATIONS FOR DEVELOPMENT OF LEVEL 1 PROBABILISTIC SAFETY ASSESSMENT OF A NUCLEAR POWER PLANT UNIT FOR INITIATING EVENTS ARISING FROM ON-SITE FIRES AND FLOODING"

(RB-076-12)

I. General

1. This Safety Guide "Basic Recommendations for Development of the Level 1 Probabilistic Safety Assessment of a Nuclear Power Plant Power Unit with regard to Initiating Events arising from on-site fires and flooding" (hereinafter the Safety Guide) has been developed in accordance with the Article 6 of Federal Law No. 170-FZ dated November, 21, 1995 "On atomic energy use".

2. This Safety Guide contains the recommendations of the Federal Environmental, Industrial and Nuclear Supervision Service for compliance with the requirements of item 1.2.19 of the General safety assurance provisions of nuclear power plants (NP-001-97) approved by the Ordnance No. 9 of Gosatomnadzor of Russia dated November 14, 1997, with respect to the development of the level 1 probabilistic safety assessment for initiating events arising due to on-site fires (hereinafter PSA for fires) or on-site flooding (hereinafter PSA for flooding). The implementation of these recommendations facilitates the achievement of acceptable quality of PSA for fires or PSA for flooding.

The list of abbreviations used in this Safety Guide is given in Appendix No. 1, terms and definitions in Appendix No. 2, and the recommended PSA report makeup on PSA for fires and PSA for flooding in Appendix No. 3.

3. PSA for fires and PSA for flooding is a constituent part of the full-scale level 1 PSA developed for all the categories of initiating events including internal IE, intrasite IE and external IE of natural and man-induced origin for all the potential operation conditions of the NPP power unit, designed, constructed and operating NPP power units with different types of reactors.

4. The recommendations of this Safety Guide relate to the objectives, scope, composition, content and sequence of performing individual tasks, as well as the content and scope of the reporting documentation and quality assurance when performing PSA for fires and PSA for flooding.

Part 1. Level 1 probability safety assessment of the nuclear power plant power unit for initiating event arising due to on-site fires

II. General issues

5. Probabilistic safety assessment of fires is recommended to perform after the confirmation of the quality of PSA for internal IE by the expert review.

6. The main issues to be solved during PSA for fires are the following:

1) Gathering of information specific for the NPP power unit;

2) Determination of the fire protection areas;

3) Determination of the initiating events arising from fire;

4) Development of a list of systems (components) that fail when exposed to fire effects;

5) Assessment of the probabilities (frequencies) of fire occurrence;

6) Human reliability analysis;

7) Selection analysis of emergency scenarios;

8) Detailed analysis of emergency scenarios;

9) Analysis of fire spreading between the fire protection areas;

10) Presentation and analysis of the results of PSA for fires.

7. The recommendations of the Regulation on basic recommendations for the development of level 1 probabilistic safety assessment for internal initiating events for all modes of operation of the nuclear power plant power unit, approved by the order No. 519 of the Federal Environmental, Industrial and Nuclear Supervision Service dated September 9, 2011 shall be applied to the implementation of the PSA for fires considering the recommendations of this Safety Guide.

8. The recommended sequence and task linkages of PSA for fires is given in Appendix No. 4.

9. The mutual impact of various types of initiating events on each other shall be considered when performing PSA for fires.

10. The PSA for fires is recommended to develop for the following radioactivity sources:

1) Nuclear fuel in the reactor core;

2) Nuclear fuel in the spent fuel storage places (for example, in the spent fuel pool/refueling pool, the drum of spent nuclear fuel assemblies).

11. It is recommended to substantiate the time interval in which the accident and types of safe final states are considered when performing PSA for fires.

12. Infliction of damage (harm to health) to personnel when performing PSA for fires is not analyzed.

III. Gathering of information

13. The composition and scope of information required for analysis and acquisition of information shall be made when performing this task of PSA for fires. Information gathering is recommended to perform based on the analysis of design and operation documentation, as well as during the NPP power unit walk-downs. It is recommended to gather at least the following information:

1) data on the NPP power unit's buildings (name, location, designation);

2) data on all the rooms of each of the NPP power unit buildings (dimensions, area, linkages with other rooms, including ventilation linkage, thickness and material of the walls, floors, ceilings, covering material of the floors, walls and ceilings, parameters of medium in the room during normal operation);

3) data on linkages of each of the rooms (doors, openings, holes, ventilation ducts etc.), which includes information with which room the given room is linked through the given linkage, linkage dimensions; data on leak-tightness, fire endurance rating and material out of which they are manufactured are collected for the doors, and direction of the room door opening (inward/outward) is also ascertained;

4) data on ventilation linkages of the rooms;

5) data on the systems (components) located in the rooms;

6) data on composition, types and quantity of combustible agents;

7) data on frequency of attending rooms;

8) data on the fire sources (stationary and brought in).

14. The following is recommended to use when performing PSA for fires of the NPP power unit:

1) Design Documentation;

2) PSA for fires performed for the power unit analogues;

3) PSA for internal IE;

4) Description of NPP power unit systems including the safety systems and firefighting systems;

5) Operation manuals for the systems (components) containing instructions for procedures during normal operation and anticipated operational occurrences, including pre-accident situations, as well as instructions and guidelines defining personnel actions in case of design-basis and beyond design-basis accidents;

6) Drawings and explanations of NPP power unit buildings and rooms;

7) Information on the location of potential sources of fire outbreak in the rooms of the analyzed NPP power unit (including the quantity of combustible materials);

8) Results of NPP walk-down (when performing walk-down of the NPP power unit);

9) Operation experience of the NPP power unit with similar power units including information on fires at all the power units of the analyzed NPP as well as at other NPP with similar power units;

10) Existing analysis supporting operational safety of the NPP power unit during fire;

11) 3D-models of the NPP power unit buildings (if any);

12) Safety analysis reports of NPP power units;

13) Process regulations for the safe operation of NPP power unit;

14) Certificates of commissioning and operation tests of the systems (components) containing actual information (for example, volume, mass, flow rate) about the systems (components);

15) IAEA documents (Safety Report Series N 10) and documents of other organizations (for example, NUREG/CR-6850, DOE/NE-0113);

16) Documents on control systems (components);

17) Drawings containing routing of cables in the NPP power unit rooms;

18) drawings of ventilation ducts.

15. Walk-downs of the NPP power unit are made for the NPP in operation and to be commissioned. The objective of the walk-down is the establishment of the compliance of the current condition of the NPP power unit to the design and operation documents and getting information which were not available in the documents of the analyzed NPP power unit.

16. Several walk-downs of the NPP shall ebe made (advisability and scope of NPP walk-downs is established in the process of performing PSA for fires when performing PSA for fires):

1) Initial walk-down of NPP is made for the purpose of general familiarization of the NPP (location of buildings and rooms, design specifics, location of systems (components));

2) Qualifying walk-down of NPP is made for the purpose of verification and clarification of information on location of the systems (components), links between the NPP rooms, potential boundaries of fire propagation, sources of fire, location of firefighting systems in the rooms and other required information.

17. A special form of walk-down of the rooms (check lists) shall be developed allowing simplify and formalize the walk-downs of the NPP power unit rooms. The following information shall be included in the check list made for the NPP power unit rooms:

1) about the room (length, width, height, area, availability of doors (air-tight and non air-tight), openings, holes, abutment pieces, ventilation ducts, drain grates and overflow launders);

2) about the systems (components) located in the room (considering the elevation mark with respect to the room floor);

3) on frequency of attending rooms;

4) on availability of control and firefighting equipment;

5) on the sources and masses/volumes of combustible substances (tanks with combustible substances, cables, portable combustible sources, other combustible substances).

18. Provided that walk-downs of the NPP power unit are performed it is recommended to submit the filled check lists on request by the organization authorized to perform expert review of PSA for fires.

19. The design documentation should be used in gathering information on the location of systems (components) in the fire protection areas for the designed power units or operation documentation and results of NPP walk-down (when performing walk-down) for the power units in operation.

20. If detailed analysis is performed it is recommended to gather detailed information about the location of cables in the rooms to the extent of getting information on the location of specific cable in the cable trays located in this room.

21. For power cables it is recommended to collect information on their room routing starting directly from the component related to the power cable, including the entire path up to the corresponding circuit breaker in the unilateral-maintenance three-phase distribution assembly for gate valves or switchgear.

22. For the instrumentation and control cables it is recommended to gather information on their room routing, which includes the entire path from the:

1) source of power supply to the limit switches (for the valve);

2) source of power supply to the MCR, ECR panels, safety systems;

3) sensors to the control panels / presentation of information on MCR, ECR, safety system rooms.

IV. Development of a list of systems (components) that fail when exposed to fire effects

23. As part of this task the systems (components) subject to failures caused by fire are identified, the damage thereof may lead to initiating events (IE) or lower reliability of the safety systems (components) performing the safety functions. The result of resolving this task is the compilation and submission of a list of systems (components) in the reporting documentation of PSA of fires, which shall further be analyzed in the PSA of fires.

24. It is recommended to accept a list of systems (components) considered in PSA for internal initiating events as the basic list of systems (components) considered in PSA of fires. The basic list of systems (components) considered in PSA of fires may be supplemented based on the operability analysis of the systems (components), which may be subject to fire exposure.

25. It is recommended to make a list of the systems (components) in the form of tables specifying their location (rooms and/or fire protection area) and operability status on fire exposure.

26. It is also recommended to identify the power supply cables and control of systems (components) and determine the system (component) control diagrams when performing PSA for fires.

27. It is recommended to consider the failures of systems (component) in the PSA of fires which may originate due to exposure of water input during firefighting.

28. The following failures of cables during fire is recommended to be considered:

1) interruption of circuit viz. the failure causing loss of the conductor (core) electrical integrity;

2) Short circuit on ground – the failure causing the cable core to get in touch with the grounded element (for example, a cable tray);

3) Short circuit wherein the idle wire get in contact with the live conductor; moreover the earlier idle wire becomes live.

29. It is recommended to consider two types of short ciruit:

1) inner cable shirt circuit – provides shirt circuit between the conductors within a multi-core cable;

2) alien short-circuit wherein the idle cable comes in contact with other live cable.

30. When determining the failure types for the systems (elements) during fire, including control and power cable systems, the principle of considering the failures with the worst consequences is recommended for use.

V. Determination of fire protection areas

31. Under this task rooms/sets of rooms or areas at the NPP site are allotted, which in the future shall be used during development of fire scenarios for selective analysis. All the NPP buildings and rooms are divided into fire protection areas following the resolution of this task.

32. It is recommended to accept the list (if available) of fire compartments established under safety justification of the NPP power unit as the preliminary list of fire protection areas. Later the fire protection areas are recommended to determine considering the availability of physical boundaries and linkages between the rooms (openings, non-tight doors etc.) and sufficiency of the justifiability of fire compartment boundaries.

33. The formation of fire protection areas is recommended to perform in three stages:

1) Segregation of the NPP power unit into the main buildings and areas;

2) Determination of fire protection areas inside each building based on available drawings and documents;

3) Making walk-downs of the power unit for confirming the boundaries of the fire protection areas determined in the two previous stages.

Individual buildings and/or structures and/or complex of rooms and/or area territorially separated from each other are highlighted at the first stage of determining the fire protection areas.

The fire protection areas specific for this building or structure are determined at the second stage for each of the segregated individual buildings and constructions of the NPP, comprising the rooms of the buildings and constructions.

The adequacy of formation of the fire protection areas is provided at the third stage of analysis of fire protection areas.

34. It is recommended to develop the criteria determining the necessity of inclusion/exclusion of the NPP power unit rooms from further analysis during determination of the fire protection areas when performing PSA for fires.

35. The following attirbutes for example may be used when performing PSA for fires for determining the fire protection areas:

1) If the room is segregated from other rooms by the fire barrier having fire endurance rating of the structure 1.5 hour (ceiling, walls, floor and doors), the room is considered as an individual fire protection area;

2) If the ventilation duct is equipped with automatic insulation device (such as fire damper), the relevant boundary is considered when determining the fire protection area;

3) If the rooms are not equipped with fire barrier having fire endurance rating 1.5 hours and above, but do not contain combustible materials or contain them in the quantity not having influence of the fire barriers, they are determined are individual fire protection areas;

4) If the staircases in the buildings are segregated from other rooms of the NPP by passages or openings or their doors have fire endurance rating 0.5 hours or more, they are considered as individual fire protection areas located vertically for the entire height of the stair well;

5) Elevator shafts (passenger and cargo) if they are segregated from other rooms of the NPP by passages or openings or their doors have fire endurance rating 0.5 hours or above are also defined as individual fire protection areas located vertically along the entire height of the elevator shaft;

6) Ventilation shafts passing vertically through various elevation marks of the buildings, limited by concrete walls contain passages for ventilation ducts connected with other areas of the building; of these ducts are equipped with automatic insulation devices in case of fire, then such ventilation ducts are considered as individual fire protection areas;

7) Cable shafts are considered as individual fire protection areas;

8) Fire protection areas in the rooms without explicitly defined boundaries or complex configuration containing the safety-related systems (elements) are determined considering the physical and space segregation.

36. It is recommended to assign unique identifiers to the fire protection areas.

VI. Determination of initiating events, resulting from fire

37. The full list of IE which may take place due to fire is developed under this task. The deliverables of this PSA task is the formation of the list of IE and/or groups of IE arising out of fires.

38. The list of IE or groups of IE identified under PSA for internal IE is recommended to take as the basis list of IE or groups of IE for PSA for fires.

39. It is recommended to perform analysis aimed at the possibility of occurrence IE following fire and included in the basic list.

40. On selection of IE it is recommended to identify the failures of systems (elements) caused by fire which lead to occurrence of IE not included in the basic list.

41.For PSA, when detecting the IE caused by fires, IE should be considered that results in the full loss of the power unit control by the personnel or to justify the absence of the possibility of the said events occurrence. If the said IE has been detected it is recommended to consider the state of instruments and cables responsible for provision of information to the main control room and to define a list of critical parameters (for example, by interviewing the NPP power unit personnel) the data thereof guarantees safe NPP shutdown.

42. It is recommended to take into account the dependent failures of the systems (components) and diagrams of their management arising out of fires when identifying the list of IE caused by fires. The recommendations for analysis of the management chains of the systems (elements) when performing PSA for fires are given in Appendix No. 5.

43. It is recommended to identify all the IE, which may be caused by fire (for example, due to damage of cables of various systems (components) located in the fire protection area).

VII. Estimation of the probabilities (frequencies) of fires

44. The probability (frequency) of fire occurrence in each of the identified fire protection area for each individual NPP buildings is determined under this task.

45. The following approaches may be used in the fire protection areas for probability (frequency) assessment of fire occurrence:

1) Component-oriented - may be used as the main approach for determining the frequency of fire in the fire protection area; it consists in that the probability (frequency) of fires is assessed for each component type of the fire protection area considered as a potential source of combustion;

2) zone-oriented approach consisting in the probability (frequency) assessment of fire depending on the area occupied by the source of combustion, - may be used for MCR, ECR, control instrumentation rooms due to the specific content of these rooms or nature of the sources of combustion; on calculation of the probability (frequency) of fire arising due to portable combustive substances, welding, metal cutting, self-ignition at high temperature

46. It is recommended to determine the probability (frequency) of fire as the number of fires reduced to a year, and subsequently distributed between the fire protection areas using various criteria.

47. The overall probability (frequency) of fire for the fire protection area is recommended to determine as the sum of probability (frequency) components from all sources of combustion (including contribution from portable sources of combustible materials, welding, cutting), located in the fire protection area.

48. It is recommended to assess the probability (frequency) of fire based on statistical data on fires at the investigated power unit and similar NPP power units by using the Bayes estimation methods. The probability (frequency) assessment algorithm of fire or flooding is given in Appendix No. 6.

VIII. Human reliability analysis (HRA)

49. The objective of human reliability analysis during PSA for fires is aimed at determination and assessment of impact of different fire-related factors on the operator undertaking actions of accident management (presence of smoke, fire, enhanced stress level, reduced time to perform actions, spurious actuation of alarm, loss of data on MCR) with obtaining human error probabilities (HEP).

50. The analysis of HEP during fire is recommended to perform using the same method as for performing PSA for internal IE considering fire.

51. The list of human erroneous actions designed during implementation of PSA for internal IE is recommended to apply as the basic list. If additional IE in PSA for fire are found, new human erroneous actions and assessment of their probability is recommended to determine.

52. The factors, affecting the probability of personnel not performing the actions, revealed under assessment of HEP in PSA for internal IE may be used under assessment of HEP in PSA of fires as the basic list. It is recommended to reconsider and reassess the impact factors due to change of the conditions during fire. If reliability analysis of personnel is required, additional factors impacting on non-performance of actions by the personnel should be included.

53. When performing a human reliability analysis during fire the following factors affecting on personnel non-performance of required actions is recommended to take into account:

1) enhanced stress;

2) reduced time to perform actions;

3) impossibility to perform actions required in situ due to presence of fire, increasing ambient temperature;

4) reduced information provision on MCR;

5) smoke formation.

54. The probability of failure to perform required actions by personnel in the fire protection area characterized by the presence of fire/hot gases is recommended to take as equal to 1.0.

55. When performing PSA for fires, re-estimation and/or estimation of HEP during fire is recommended to perform in several stages. At the first stage it is recommended to postulate that the analyzed fire zone contains control and monitoring cables which, if damaged, impairs the personnel information management. Taking into account this condition and fire affecting factors re-estimation of HEP is performed. At the second analysis stage an additional re-estimation is undertaken to lower the conservatism component taking into account the actual presence of control and monitoring cables in the fire zone.

56. It is recommended to perform preliminary quantification (calculation) of PSA model with assignment of HEP equal to 1.0 for all the basic events simulating human error for complete identification of all dependent actions of the personnel. Reassessment of the dependent actions of personnel is recommended to perform considering the conditions arising out of fire.

IX. Analysis of fire propagation between fire protection areas

57. The analysis of possibility of propagation of fire and combustion products through the various linkages between the fire protection areas and determination of set of fire protection areas between which fire, hot gas and smoke can spread.

58. It is recommended to establish and consider the possibility of spread of fire, hot gas and smoke between the fire protection areas for identifying all the potential consequences following fire.

59. When performing fire spread analysis between the fire protection areas it is recommended to assume that every area represents a fire source if containing combustible substances.

60. It is recommended to develop the propagation category of fire, hot gases and smoke (hereinafter fire) between the fire protection areas. For example, the criteria given below in the table 1 may be used during analysis of fire propagation.

Table 1

FIRE PROPAGATION CRITERIA BETWEEN THE FIRE PROTECTION AREAS

|  |  |
| --- | --- |
| Linkage type between the fire protection areas | Possibility of propagation |
| Leak-tight door | No propagation |
| Door is not leak-tight, not locked, opens outwards of the room | Hot gas and smoke spread |
| Door is not leak-tight, not locked, opens inwards into the room | Smoke spread |
| Door is not leak-tight, is locked | Smoke spread |
| Holes and openings with equivalent diameter more than 150 mm | Hot gas and smoke spread |
| Holes and openings with equivalent diameter less than 150 mm located in the upper part of the room (more than 1/2 the room height) | Hot gas and smoke spread |
| Holes and openings with equivalent diameter less than 150 mm located in the lower part of the room (less than 1/2 the room height) | Smoke spread |

61. It is recommended to show that all the potential scenarios of fire propagation have been considered.

62. It is recommended to use the following assumptions for carrying out an analysis of fire spread between the fire protection areas:

1) hot gases penetrating via apertures/openings damage the cables and systems (elements) in the adjacent rooms if the design does not provide protection against hot gases;

2) hot gases which have penetrated into the adjacent fire protection area shall not spread further provided that the volume of this zone is sufficient to prevent ignition of the systems (elements) due to the temperature of miscible gases in this fire protection area;

3) fire does not spread through the long and high fire protection areas that prevents flame propagation, and rooms containing no combustible materials;

4) fire in the rooms adjoining the cable shafts does not lead to integrity violation of the boundaries of cables shafts and does not penetrate into the shafts from outside (the penetrations are assumed as airtight);

5) pressure relief valves are efficient barriers against hot gases but do not prevent smoke spread;

6) apertures and ventilation shafts are smoke propagation paths if:

fire dampers are not installed;

if they are not equipped with automatic closure mechanisms reacting to temperature increase or smoke concentration;

7) hot gases and smoke spread upwards and horizontally; fire does not penetrate in the zones below the elevation mark.

63. It is recommended to set fire scenarios based on the assumptions, fire propagation criteria, information on location of the system components in the fire zones. The list of fire propagation zones and list of damaged system (components) including cables should be included in the description of each scenario.

X. Analysis of fire scenarios

64. The analysis of fire scenarios should be performed in two stages:

1) Screening analysis stage;

2) Detailed analysis stage.

65. Under the screening analysis a conservative probabilistic quantitative assessment of fire scenarios implementation is performed assuming fuel element damage from the point of view of the most significant scenarios determination for which, at the stage of the detailed analysis, an additional investigation is conducted in order to clarify the obtained assessment.

66. The detailed analysis is made for the fire scenarios not excluded during the screening analysis (substantial contribution to FDP). The objective of detailed analysis is the reappraisal of FDP by reducing the level of conservatism put in when performing screening analyses, getting realistic risk assessments and identification of fire-safety systems (components) susceptible to fire.

Screening analysis of fire scenarios

67. Screening analysis of fire scenarios should start with the identification of the list of scenarios wherein the fires do not lead to IE occurrence; they should be excluded from further analysis.

68. Under this task it is recommended to identify the fire scenarios which may be assessed as of low significance by contribution to the cumulative probability of fuel element damage. Simplified conservative assessment methods are used for assessment of the significance.

69. The following conservative assumptions should be used during the screening analysis of fire scenarios:

1) All the systems (components) and cables located in the fire propagation zone are damaged in such manner that the consequences of this damage are the worst from the point of view of increasing FDP; provided that if several types of failures caused by fires are possible, it is recommended to consider all the potential types of failures;

2) all possible false actuations caused by fire (due to sticking of the cables located in the fire propagation zone), i.e. it is assumed that:

all the systems (components) in standby mode go into the worst state from the point of view of accident scenario development (for example, closed valve opens, and vice versa, motor does not start on origin of the requirement and starts if this start deteriorates the accident development scenario);

operating systems (elements) cease operation (for example, pumps, fans stop);

restoration of the initial state of systems (components) is impossible after spurious operation.

70. All the systems (elements), cables thereof were found in the fire propagation zone should be considered during screening analysis of fire scenarios.

71. The potential initiating events should be determined for each fire scenario. The occurrence of several IE is possible for one scenario. However the consideration of one IE is sufficient on the condition of justification of the worst consequences from the view point of possibility of nuclear fuel damage.

72. It is recommended to use the model of emergency sequences developed in level 1 NPP PSA for internal IE for simulation of the fire scenarios. Consideration of the specific features caused by fire should be made by imposition of specific boundary conditions. The use of ES models developed at NPP PSA for internal IE is not possible for simulation of a series of accident scenarios due to necessity of accounting for multiple spurious actuations, usually excluded from consideration during analysis for internal IE. In these cases it is recommended to develop new ES models on condition that the simulation principles and basic allowances accepted under performing level 1 NPP PSA for internal IE are saved.

73. HEP assessments used in lNPP PSA for internal IE when performing PSA for fires if required shall be corrected considering the impact factors (stress, potential loss of information at MCR and other factors). For the purpose of screening analysis it is recommended to postulate that all the cables used in the fire scenarios of the systems (elements) are located in the fire propagation area.

74. Implementing actions in-situ in the fire areas where potential penetration of fire/gases is possible is taken as impossible.

75. FDP assessment during screening analysis should be made using the software used for creating PSA model of the level 1 NPP unit for internal IE considering the potential failures of the systems (components) caused by fire.

76. It is possible to use simplified methods allowing reduce the scope of analysis without loss of significant results and conclusions during simulation of the failures of systems (components) for reducing the PSA model, for example:

1) if a large number of cables of one channel of several systems are in the fire zone or fire zones (for the scenarios with fire propagation between the fire zones), the postulation of failure of the supporting system common for these channels is possible;

2) the postulation of the nonoperability of the relevant system channel is possible on location in the fire zone or fire zones of the valve cables of the system channel (for the scenarios with fire propagation between the fire zones).

77. During the screening analysis the status of the systems (elements) is presumed the worst from the point of view of the impact on the development of the emergency process if the control cables of these systems (elements) are in the fire zone or fire zones (for the scenarios with fire propagation between the fire zones).

78. The criterion/criteria of screening the fire scenarios for detailed analysis should be formulated.

79. The result of screening analysis is the following lists of scenarios:

1) scenarios with fuel damage, excluded in accordance with the assigned screening criteria; when using several screening criteria the lists of fire scenarios excluded from further analysis are made in accordance with each of the accepted exclusion criteria;

2) scenarios, included in the general assessment of FDP;

3) scenarios selected for detailed analysis.

Detailed analysis of fire scenarios

80. The purpose of detailed analysis of fire scenarios is the reappraisal of FDP by reducing the level of conservatism included in performing screening analysis and getting realistic risk assessment.

81. Detailed analysis is made with respect to the fire scenarios not excluded in the course of screening analysis.

82. Lowering of the level of conservatism of scenarios is recommended to perform by specifying the following factors:

1) clarifying the scenario of fire propagation between the fire zones taking into account detailed information about fire load of the systems (elements) and the room geometry;

2) analysis of the control diagrams for excluding those control diagrams from consideration, damage thereof during fire does not lead to spurious actuation of the systems (elements);

3) performing a detailed analysis taking into account the operative personnel actions on control of the alternate systems (elements) and actions restricting and preventing flooding.

83. The analysis of fire scenarios in the control panels and fire scenarios in the rooms of the cable routes (fire propagation between the trays and inside the cable route) should be performed for reducing conservatism (if required) when performing PSA for fires.

84. A repeat analysis of the linkages between the rooms for those scenarios, which had undergone screening analysis shall be made on detailed analysis of the scenarios with fire propagation between the rooms. The objective of this updated analysis is the assessment of realistic scenarios starting from the instant of combustion up to the instant of critical damage of the systems (components) (contributing to the damage of nuclear fuel) simulated in PSA. The objective of updated analysis is the assessment of the time interval between the start of combustion and critical damage.

85. Detailed analysis of the fire scenarios should be made in the following sequence:

1) analysis of information on location and characteristics of the systems (elements) in the fire propagation zone screened for detailed analysis;

2) determination of the potential sources of combustion and critical paths of fire propagation (identified following screening analysis);

3) performing deterministic analysis of the possibility of fire/hot gases propagation along the selected path;

4) assessment of the results of analysis in terms of possibility in principle of damage of systems (elements) simulated in PSA or time to critical damage of the systems (components).

86. Conclusion on the possibility of fire propagation along the explored path and possibility of critical damage of the PSA systems (components) (or time before damage) should be formulated following the detailed analysis.

87. If following the detailed analysis it has been found that the systems (elements) do not lose their functionality (due to insufficient fire load in the fire initialization zone or due to other factors supporting the fire propagation process), this scenario is excluded from consideration. Otherwise the time before the failure of the systems (elements) is estimated which is used for efficiency analysis of the systems (elements) for fire extinguishing as well as of the actions detection and extinguishing of fire.

88. A detailed analysis of the scenarios beginning with the fire start and up to the critical damage of the systems (elements) should be performed for the most significant emergency scenarios assuming fuel element damage.

89. The system (component) control circuits are analyzed for the purpose of identifying the possibility of unauthorized actuation of specific system components. The recommendations for performing system (component) control circuit analysis are stated in Appendix No.5.

90. FDP assessment should be made during detailed analysis considering:

1) specified quantity of systems (components) in the propagation area, potentially subject to failure in specific fire scenarios with fuel damage;

2) specified quantity of control circuits in the propagation area, potentially subject to failure in specific fire scenario with fuel damage;

3) possibility of fire suppression to the moment of critical damage of the systems (components).

91. It is recommended to perform detailed analysis of the flooding scenarios at MCR, ECR and cable shafts (if not proved that only screening analysis is enough).

Part 2. Level 1 probability safety assessment of the nuclear power plant power unit for initiating event arising due to on-site flooding

XI. General issues

92. Probabilistic safety assessment for flooding is recommended to perform after the confirmation of the quality of PSA for internal IE by the expert review.

93. The main tasks to be solved during PSA for flooding are the following:

1) Gathering of information specific for the NPP power unit;

2) determination of flooding zones;

3) Determination of the initiating events arising from flooding;

4) Development of a list of systems (elements) that fail when exposed to flooding effects;

5) Assessment of the probabilities (frequencies) of flooding occurrence;

6) Human reliability analysis;

7) Selection analysis of emergency scenarios;

8) Detailed analysis of emergency scenarios;

9) analysis of flooding propagation;

10) presentation and analysis of the results of PSA for flooding.

94. The recommendations of the Regulation on basic recommendations for the development of level 1 probabilistic safety assessment for internal initiating events for all modes of operation of the nuclear power plant power unit, approved by the order No. 519 of the Federal Environmental, Industrial and Nuclear Supervision Service dated September 9, 2011 shall be applied to the implementation of the PSA for flooding considering the recommendations of this Safety Guide.

95. The recommended sequence and task linkages of PSA for flooding is given in Appendix No. 4.

96. It is recommended to consider the mutual impact of various types of initiating events on each other when performing PSA for flooding.

97. The PSA for flooding is recommended to develop for the following radioactivity sources:

1) Nuclear fuel in the reactor core;

2) Nuclear fuel in the spent fuel storage places (in the spent fuel pool/refueling pool, in the drum of spent fuel assemblies).

3) Spent nuclear fuel when transported.

98. It is recommended to substantiate the time interval in which the accident and types of safe final states are considered when performing PSA for flooding.

XII. Gathering of information

99. The composition and scope of information required for analysis and acquisition of information shall be made when performing this task of PSA for flooding. Information gathering is recommended to perform based on the analysis of design and operation documentation, as well as during the NPP power unit walk-downs. It is recommended to gather at least the following information:

1) data on the NPP power unit's buildings (name, location, designation);

2) data on all the rooms of each of the NPP power unit buildings (dimensions, area, linkages, including ventilation and drainage linkages, thickness of the walls, floors, ceilings, parameters of medium in the room during normal operation);

3) data on the linkages of each of the rooms (doors, openings, holes, ventilation ducts, drainages), which include information on with which is the given room linked through this linkage, linkage dimensions; information on leak-tightness and sill plate height of each of the doors are gathered;

4) data on ventilation linkages of the rooms;

5) data on drainage linkages of the rooms;

6) data on the systems (elements) located in the rooms;

7) data on the composition, type and quantity of sources of flooding;

8) data on frequency of attending rooms;

100. The following is recommended to use when performing PSA for flooding of the NPP power unit:

1) Design Documentation;

2) PSA for flooding performed for the power unit analogues;

3) PSA for internal IE;

4) Description of NPP power unit systems including the safety systems;

5) Operation manuals for the systems (components) containing instructions for procedures during normal operation and anticipated operational occurrences, including pre-accident situations, as well as instructions and guidelines defining personnel actions in case of design-basis and beyond design-basis accidents;

6) Drawings and explanations of NPP power unit buildings and rooms;

7) Information on the location of potential sources of flooding in the rooms of the analyzed NPP power unit (including the reserves and environment parameters);

8) Results of NPP walk-down (when performing walk-down of the NPP power unit);

9) Operation experience of the NPP power unit with similar power units including information on flooding at all the power units of the analyzed NPP as well as at other NPP with similar power units;

10) Existing analysis supporting operational safety of the NPP power unit during flooding;

11) 3D-models of the NPP power unit buildings (if any);

12) Safety analysis reports of NPP power units;

13) Process regulations for the safe operation of NPP power unit;

14) Certificates of commissioning and operation tests of the systems (elements) containing actual information (volume, mass, flow rate etc.) about the systems (elements);

101. Walk-downs of the NPP power unit for the NPP in operation and to be commissioned. The objective of the walk-down is the establishment of the compliance of the current condition of the NPP power unit to the design and operation documents and getting information which were not available in the documents of the analyzed NPP power unit.

102. It is recommended to perform several walk-downs of the NPP when making PSA for flooding (advisability and scope of NPP walk-downs is established in the process of performing PSA for flooding):

1) Initial walk-down of NPP is made for the purpose of general familiarization of the NPP (location of buildings and rooms, design specifics, location of systems (components));

2) Qualifying walk-down of NPP is made for the purpose of verification and clarification of information on location of the systems (components), links between the NPP rooms, potential boundaries of fire propagation, sources of fire, location of firefighting systems in the rooms and other required information.

103. It is recommended to develop a special form of walk-down of the rooms (check lists) allowing simplify and formalize the walk-downs of the NPP power unit rooms for walk-downs of the NPP power unit. The following information shall be included in the check list made for the NPP power unit rooms:

1) about the room (length, width, height, area, availability of doors (air-tight and non air-tight), openings, holes, abutment pieces, ventilation ducts, drain grates and overflow launders);

2) about the systems (components) located in the room (considering the elevation mark with respect to the room floor);

3) on frequency of attending rooms;

4) on availability of control facilities of water in the room etc.;

5) on sources (pipelines, tanks, vessels) and masses/volumes of the medium (water, steam, oil, acid, alkali) for PSA for flooding.

104. Provided that walk-downs of the NPP power unit are performed it is recommended to submit the filled check lists on request by the organization authorized to perform expert review of PSA for flooding.

105. It is recommended to use the design documentation when collecting information on the location of systems (elements) in the flooding zone for the designed power units or operation documentation and results of NPP walk-down (when performing walk-down) for the power units in operation.

106. It is recommended to gather information on the availability, routing of the chutes of active drains in the flooding zone rooms and their status (open/closed), on availability of active drain trays and their routing, on routing of ventilation ducts and pressure relief valves installed in them.

107. For PSA for flooding it is recommended to gather information on the availability of sensor determining moisture and liquid level in the rooms of the NPP power unit with output of information to MCR (ECR) and information on validation of measuring sensors of the NPP power unit for operation in the conditions of very humid environment and steam lock.

XIII. Determination of flooding zones

108. Under this task the rooms/sets of rooms or areas at the NPP site are allotted, which in the future shall be used during development of emergency scenarios for selective analysis. All the NPP buildings and rooms are divided into flooding zones following the resolution of this task.

109. It is recommended to determine the flooding zones taking into account the physical boundaries of the rooms and linkages between the rooms (openings, non-tight doors etc.).

110. The flooding zones is recommended to be formed in three stages:

1) Segregation of the NPP power unit into the main buildings and areas;

2) Determination of flooding zones inside each building or area based on available drawings and documents;

3) Performing walk-downs of the power unit for confirming the boundaries of the flooding zones determined in the two previous stages.

Individual buildings and/or structures and/or complex of rooms and/or areas territorially separated from each other are highlighted at the first stage of determining the flooding zones.

The flooding zones specific for this individual building and structure are determined at the second stage for each of the segregated individual NPP buildings and constructions, comprising of the rooms of the buildings and constructions.

The third stage of analysis of the flooding zones provides reliability of the formation of flooding zones.

111. It is recommended to develop the criteria determining the necessity of inclusion/exclusion of the NPP power unit rooms from further analysis during determination of the flooding zones when performing PSA for flooding.

112. It is recommended to use the following attributes when performing PSA for flooding for determining the flooding zones:

1) the rooms with non-tight linkages with other rooms provided that there is a possibility of flood spreading are included in flooding zone;

2) a room without non-tight linkages with other rooms is considered as a separate flooding zone;

3) there is no spreading of water to the adjacent rooms through the walls, including if water level of the flooded room is higher than the cladding;

4) there is no spreading of water to the adjacent rooms through the leak-tight pipeline and cable penetrations in the walls and floor slabs;

5) there is no spreading of water to the adjacent rooms through the door sills (wooden, firefighting), if their height is above the flooding level.

113. It is recommended to assign unique identifiers to the flooding zones.

XIV. Determination of initiating events caused by flooding

114. The full list of IE which may take place due to flooding is developed under this task. The deliverables of this PSA task is the formation of the list of IE and/or groups of IE arising out of flooding.

115. The list of IE or groups of IE identified under PSA for internal IE is recommended to take as the basic list of IE or groups of IE for PSA for flooding.

116. It is recommended to perform analysis aimed at the possibility of IE occurrence following flooding and included in the basic list.

117. On selection of IE it is recommended to identify the failures of systems (elements) caused by flooding which lead to occurrence of IE not included in the basic list.

118. It is recommended to take into account the dependent failures of the systems (elements) and diagrams of their management arising out of flooding when identifying the list of IE caused by flooding.

119. When selecting IE caused by flooding the following assumptions shall be used:

1) during the analysis it is recommended not to consider a concurrent and independent occurrence of various types of initiating events such as flooding and the primary circuit leak, flooding and fire, flooding and blackout of the power unit etc.; it is also recommended not to consider simultaneous occurrence of flooding caused by different flooding sources;

2) it is recommended to not consider flooding caused by breaks/leaks of lines in the analysis, if the flooding effects following breaks/leaks of lines have been taken into account when performing first level PSA for internal IE;

3) impact of potential sources of flooding of the analyzed NPP unit on the failures of systems (components) of another NPP power unit (if there are several power units) is not considered, if the specified systems are not considered in PSA of the analyzed NPP power unit; it is recommended to take into account the linkage between the units for correct accounting of the flooding at the analyzed power unit;

4) the following shall be considered as potential causes of room flooding occurrence:

erroneous actions by the personnel;

line ruptures/leaks;

tank leaks;

failures of systems (elements) leading to flooding of the rooms;

5) Under selection of the IE caused by flooding it is recommended to consider the IE caused by steam locking and spattering effects.

120. It is recommended to identify all the IE, which may be caused by flooding (for example, due to damage of systems (elements) located in various room of the flooding zone).

XV. Development of a list of systems (elements) that fail when exposed to flooding effects

121. Under this task the systems (elements) liable to failures due to flooding, the damage thereof may give rise to IE or reduce the reliability of the systems (elements) performing safety functions are identified. The result of resolving this task is the drawing up and submission of a list of systems (elements) in the reporting documentation of PSA for flooding, which shall further be analyzed in the PSA for flooding.

122. It is recommended to accept a list of systems (elements) considered in PSA for internal initiating events as the basic list of systems (elements) considered in PSA for flooding. The basic list of systems (elements) considered in PSA for flooding may be supplemented based on the operability analysis of the systems (components), which may be subject to flooding exposure.

123. It is recommended to make a list of the systems (elements) in the form of tables specifying their location (rooms and/or flooding zones) and operability status on flooding exposure.

124. It is recommended to consider the possibility of damage and failures of cables due to flooding.

125. It is recommended to consider the effects of steam lock and spattering of systems (elements) in drawing up the list of systems (elements) subject to flooding.

126. In PSA for flooding it is recommended to postulate the failure of systems (elements) located in the room and not qualified for the relevant impacts where flooding takes place on reaching the following elevation point of water level in the room:

1) for pumps and fans – the lower generating line of the pump electric motor or switching box;

2) for electrically-driven valves – the lower generating line of the drive electric motor or switching box;

3) for electric panels and power circuit-breakers – the water level of the location elevation point of the open electrical connections (terminals, buses).

127. In PSA for flooding it is recommended to postulate the failure of electrical equipment not fit for operation in the relevant conditions due to steam lock taking place at any room of the flooding area, and due to spattering taking place in the flooding area room, where the flooding was initiated.

XVI. Assessment of the probabilities (frequencies) of flooding

128. The probability (frequency) of flooding occurrence in each of the identified flooding zone for each identified flooding area for each of the individual NPP buildings is determined under this task.

129. Zonal component approach may be used for probabilistic (frequency) assessment of flooding occurrence in the flooding zones, which is based on the probabilistic (frequency) assessment of flooding using statistical data on the number of flooding for each type of component of flooding zone, considered as the potential source of flooding.

The component-oriented approach is based on the assessment of the frequency of flooding using statistic data on the number of flooding for each type of flooding zone component considered as potential source of flooding.

Zonal-oriented analysis is based on estimation of the flooding frequency with the help of the statistical data related to the number of flooding precedents within the specific flooding zone and during the total period of monitoring (at this one shall take into account the number of the similar NPP rooms).

130. The probability (frequency) of flooding should be determined as the number of flooding reduced to a year, and subsequently distributed between the flooding zones using various criteria.

131. The complete probability (frequency) of flooding for the flooding zone should be determined as the sum of the constituents of the probabilities (frequencies) from all sources of flooding located in the flooding zone.

132. The probability (frequency) of flooding should be assessed based on statistical data on flooding at the investigated power unit and similar NPP power units by using the Bayes estimation methods. The probabilistic (frequency) assessment algorithm of flooding is given in Appendix No. 6.

XVII. Human reliability analysis (HRA)

133. The objective of human reliability analysis in PSA for flooding is aimed at determination and assessment of impact of different flooding-related factors on the operator undertaking actions of accident management (damping, spattering, enhanced stress level, reduced time to perform actions, spurious actuation of alarm, loss of data on MCR) with obtaining human error probabilities (HEP).

134. The analysis of HEP during fire is recommended to perform using the same method as for performing PSA for internal IE considering flooding.

135. The list of human erroneous actions designed during implementation of PSA for internal IE is recommended to apply as the basic list. If additional IE in PSA for flooding are found, new human erroneous actions and assessment of their probability should be determined.

136. The factors, affecting the probability of personnel non-compliance, revealed under assessment of HEP in PSA for internal IE may be used under assessment of HEP in PSA for flooding as the basic list. It is recommended to reconsider and reassess the impact factors due to change of the conditions during flooding. If reliability analysis of personnel is required, additional factors impacting on non-performance of actions by the personnel should be included.

137. When performing a human reliability analysis during flooding the following factors affecting on personnel non-performance of required actions should be taken into account:

1) enhanced stress;

2) reduced time to perform actions;

3) impossibility to perform actions required in the flooding site due to flooding, steaming and spattering.

138. The probability of failure to perform required actions by personnel in the flooding zone characterized by the presence of spattering/steaming is recommended to take as equal to 1.0.

139. HEP assessed in PSA for internal IE should be taken during performance of PSA for flooding at the accident scenarios screening analysis stage. If new actions of the personnel are included in the model, HEP shall be assessed in compliance with the impact factors used when performing PSA for internal IE. HEP during flooding should be reassessed and/or assessed at the detailed analysis stage of emergency scenarios.

140. It is recommended to perform preliminary quantification (calculation) of PSA model with assignment of HEP equal to 1.0 for all the basic events simulating human error for complete identification of all dependent actions of the personnel. Reassessment of the dependent actions of personnel is recommended to perform considering the conditions arising out of fire.

XVIII. Determination of flooding propagation

141. The possibility of water spreading between the flooding zones and/or NPP rooms through various linkages is analyzed under this task and the list of damaged systems (elements) is determined.

142. The flooding scenarios are determined based on the results of resolution of tasks of PSA for flooding "Determination of the flooding zones" and individually for each NPP power unit buildings.

143. The list of scenarios with flooding is formed in several stages.

Stage 1. Determination of the potential sources of flooding

The list of systems containing sources of flooding which are identified with specific rooms is established.

Stage 2 Determination of water dispersal in the flooding zone

The occurrence of flooding from the piping and/or containers with water in the room is postulated for identifying the flooding scenarios in each room of the flooding zone and the maximum possible water level in the flooding zone is determined.

Stage 3 Determination of the list of systems (elements) subject to flooding

144. The spread of water between the rooms of the flooding one for identifying the list of systems (components) which may be damages following flooding should be investigated during PSA for flooding. Besides, engineering assessments of leaktightness of the floors/ceilings and drainage systems in the NPP power unit rooms should be made

145. The results of resolving the tasks of PSA for flooding "Preparation of the list of elements of the systems and types of their failures" are used under the determination of the list of systems (elements) subject to flooding under which the systems (elements) in one or another room are identified.

146. The set of equipment for which the failure due to flooding is postulated is determined after determination of the flooding level set in a specific room and considering the failure criteria of equipment.

147. Such flooding effects as direct flooding, splashing, steaming should be considered when determining the failures of systems (elements). All possible water spreading paths are identified as a result and set of damaged systems (elements) during flooding is determined.

148. A list of flooding scenarios which are analyzed under the screening and detailed analysis is formed following the performance of the stages 1 - 3 in sequence with respect to all the flooding zones and buildings of the NPP power unit.

149. The leakages of the tanks through the spillovers during their filling, failures of systems (elements) (for example, closing failure of check valve on the group A process water line after its opening during scheduled inspection (imitation of outage)) and damage of piping, including formation of cracks should be considered when determining the sources of flooding.

XIX. Analysis of flooding scenarios

150. Analysis of flooding scenarios should be made in two stages:

1) Screening analysis stage;

2) Detailed analysis stage.

151. Under the screening analysis a conservative probabilistic quantitative assessment of flooding scenarios implementation is performed assuming fuel element damage from the point of view of the most significant scenarios determination for which, at the stage of the detailed analysis, an additional investigation is conducted in order to clarify the obtained assessment.

152. The detailed analysis is made for the scenarios not excluded during the screening analysis (substantial contribution to FDP). The purpose of detailed analysis is the reappraisal of FDP by reducing the level of conservatism included in performing screening analysis and getting realistic risk assessments.

Screening analysis of accident scenarios

153. Screening analysis should start with the identification of the list of scenarios wherein the flooding (considering the propagation of flooding) do not lead to IE occurrence; they should be excluded from further analysis.

154. Under this task it is recommended to identify the flooding scenarios which may be assessed as of low significance by contribution to the cumulative probability of FDP. Simplified conservative assessment methods are used for assessment of the significance.

155. The following conservative assumptions should be used during the screening analysis of scenarios:

1) All the systems (components) and cables located in the flooding propagation zone are damaged in such manner that the consequences of this damage are the worst from the point of view of increasing FDP; provided that if several types of failures caused by flooding, then they all should be considered;

2) all possible spurious actuations caused by flooding take place (due to moisture penetration into the electric distribution, electric switches, control devices, motors, under cable insulation etc. located in the propagation zone if the listed systems (elements) have not been designed or not qualified for operation in conditions of flooding and steam impact), i.e. it is assumed that:

all the systems (components) in standby mode go into the worst state from the point of view of accident scenario development (for example, closed valve opens, and vice versa, motor does not start on origin of the requirement and starts if this start deteriorates the accident development scenario);

operating systems (elements) cease operation (for example, pumps, fans stop);

restoration of the initial state of systems (components) is impossible after spurious operation.

156. The potential IE should be determined for each flooding scenario. The occurrence of several IE is possible for one scenario. However the consideration of one IE is sufficient on the condition of justification of the worst consequences from the view point of possibility of nuclear fuel damage.

157. The assessments of HEP used in NPP PSA for the internal IE on performance of PSA for flooding must be corrected considering the impact factors (stress, potential loss of information at MCR and other factors).

158. The performance of actions in-situ in the flooding zones where water/steam penetration is possible is taken as impossible.

159. FDP assessment during screening analysis should be made using the software used for creating PSA model of the level 1 NPP unit for internal IE considering the potential failures of the systems (components) caused by flooding.

160. During screening analysis the conditions of the systems (elements) is assumed as the worst from the point of view of impact on the development of flooding scenario if the control cables of these systems (elements) are in the flooding zone and not qualified for operation in conditions of water and steam impact.

161. The criterion/criteria of screening the flooding scenarios for detailed analysis should be formulated.

162. The result of screening analysis are the following lists of scenarios:

1) scenarios with fuel damage, excluded in accordance with the assigned screening criteria; when using several screening criteria the lists of flooding scenarios excluded from further analysis are made in accordance with each of the accepted exclusion criteria;

2) scenarios, included in the general assessment of FDP;

3) scenarios selected for detailed analysis.

Detailed analysis of flooding scenarios

163. The purpose of detailed analysis is the reappraisal of FDP by reducing the level of conservatism included in performing screening analysis and getting realistic risk assessments.

164. Detailed analysis is made with respect to the flooding scenarios not excluded in the course of screening analysis.

165. Lowering of the level of conservatism of scenarios is recommended to perform by resolving the following tasks:

1) clarifying the scenario of water/steam spreading between the flooding zones taking into account detailed information about flooding of the systems (elements) and the room geometry;

2) analysis of the control diagrams for excluding those control circuits from consideration, damage thereof during flooding does not lead to spurious actuation of the systems (elements);

3) Performing a detailed analysis taking into account the operative personnel actions on control of the alternate systems (elements) and actions restricting and preventing flooding.

166. A repeat analysis of the linkages between the rooms for those scenarios, which had undergone screening analysis shall be made on detailed analysis of the scenarios with propagation of flooding between the rooms. The objective of this updated analysis is the assessment of realistic scenarios starting from the instant of flooding up to the instant of critical damage of the systems (components) simulated in PSA. In addition, the objective of the updated analysis is the assessment of the time interval between the start of flooding and damage of the systems (elements) contributing to fuel damage.

167. A detailed analysis of the scenarios with flooding propagation should be performed in the following sequence:

1) analysis of information on location and characteristics of the systems (elements) in the flooding propagation zone screened for detailed analysis;

2) determination of the potential sources of flooding and critical paths of propagation (flooding propagation paths, which lead to damage of the systems (components) inducing damage of nuclear fuel), identified following screening analysis;

3) performing deterministic analysis of the possibility of water/steam propagation along the selected path;

4) assessment of the results of analysis in terms of possibility in principle of damage of systems (elements) simulated in PSA or time to damage of the systems (components) inducing fuel damage.

168. Following detailed analysis it is recommended to formulate the conclusion on possibility of flooding propagation along the investigated path and damage of the systems (elements) conditioning the nuclear fuel damage, as well assess the time before the damage of systems (elements) and nuclear fuel.

169. If following the detailed analysis it has been found that the systems (elements) do not lose their functionality (due to insufficient water level in the bench mark room of lower generating line of the motors or due to other factors supporting the flooding propagation process), this scenario is excluded from consideration. On the contrary the time to failure of the systems (elements) which are used for accounting the actions for preventing flooding.

170. The most significant flooding scenarios assuming fuel element damage require performing a detailed analysis, beginning with the flooding start and up to the critical damage of the systems (elements)

171. The system (component) control circuits are analyzed for the purpose of identifying the possibility of unauthorized actuation of specific system components.

172. FDP assessment should be made during detailed analysis considering:

1) specified quantity of systems (components) in the propagation area, potentially subject to failure in specific flooding scenarios with fuel damage;

2) specified quantity of control circuits in the propagation area, potentially subject to failure in specific flooding scenario from fuel damage;

3) possibility of preventing flooding to the moment of critical damage of the systems (components).

173. It is recommended to perform detailed analysis of the flooding scenarios at MCR and ECR (if not proved that only screening analysis is enough).

Appendix No 11
to the Safety Guide "Basic recommendations for development of level 1 probabilistic safety analysis of nuclear power plant unit for initiating events, stipulated by intra-site fires and flooding" (RB-076-12), approved by the order No 496 of the Federal Environmental, Industrial and Nuclear Supervision Service
dated September 5, 2012 .

ABBREVIATIONS

HRA - Human Reliability Analysis

NPP - Nuclear Power Plant

ES - Emergency Sequence

MCR - Main Control Room

BRU-A – fast acting steam dump valve for steam discharge into atmosphere

PSA - Probabilistic Safety Assessment

PSA-1 - Level 1 probabilistic safety assessment

FDP - nuclear fuel (fuel element) damage probability

HEP - Human Error Probability

ET - Event Tree

IE – initiating Event

RS - Radioactive Source

PRZ - Pressurizer

SC - Short Circuit

I&C - Instrumentation and control device

GIS - Gas insulated switchgear

IAEA - International Atomic Energy Agency

SV - Safety Valve

SPM - Scheduled Preventive Maintenance

SW - Software

RF – Reactor Facility

ECR - Emergency Control Room

RT30 - Power valve distribution equipment

FE - Fuel Element

CPS - Central Pumping Station

Appendix No 2
to the Safety Guide "Basic recommendations for development of level 1 probabilistic safety analysis of nuclear power plant unit for initiating events, stipulated by intra-site fires and flooding", approved by the order No 496 of the Federal Environmental, Industrial and Nuclear Supervision Service
dated September 5, 2012 .

TERMS AND DEFINITIONS

Automatic fire extinguishing is the process of fire suppression which includes the use of automatic stationary fire extinguishing systems.

Flooding is an accidental event, characterized by the formation of water level, water spraying or steaming leading to failure of the systems and/or their components.

Intrasite flooding is an event consisting in the creation stipulated water level limits exceeding the normal operation limits of water level in the buildings, civil constructions, constructions or in individual parts (rooms), caused by failures of equipment, piping and other components or human errors of NPP.

Flooding due to external reasons viz. flooding taking place outside the buildings and constructions located at the NPP site.

Flooding zone is a room or several rooms of the NPP not having barriers for mutual penetration of water due to various types of linkages and separated from other rooms of NPP by the availability of such barriers.

Intrasite fire is an event consisting in combustion and burning (up to complete burning) of combustible substances and materials located or circulating in the buildings, constructions, their individual parts (rooms) or on the open area of the NPP site.

Fire due to external reasons viz. fire taking place outside the buildings and constructions located at the NPP site.

Fire zone is a room or several rooms of NPP not having barriers between them that prevent the fire propagatio due to various kinds of linkages and separated from other NPP rooms by fire resistance barriers or physical segregation.

Room is a territorially denoted place at the NPP power unit of specific configuration with systems (elements) installed in it.

Open loop is the failure condition wherein the loop (each cable or individual conductor inside the cable) loses electrical integrity.

Hand-held firefighting is the extinguishing of fire using hoses, portable fire extinguishers or using firefighting systems launched manually by the NPP personnel.

The flooding scenario is a potential development of events during flooding starting from water discharge from the elements of systems located in one room with possibility of flooding in other rooms due to different linkages between the rooms, capable of leading to damage of the systems (elements).

Fire scenario is a potential development of events during fire, which starting from ignition of combustible materials and ending with complete termination of the combustion process and may include the fire propagation on other combustible substances, heat of the medium in the rooms, formation of hot gases or smoke which may propagate in the area outside the fire area, damage of the systems (elements) and cables, actuation of fire sensi=ors and actuation of automatic fire extinguishing systems, and actions of fire brigades.

Appendix No 3
to the Safety Guide "Basic recommendations for development of level 1 probabilistic safety analysis of nuclear power plant unit for initiating events, stipulated by intra-site fires and flooding" (RB-076-12), approved by the order No 496 of the Federal Environmental, Industrial and Nuclear Supervision Service
dated September 5, 2012 .

RECOMMENDED COMPOSITION OF THE REPORT ON PSA FOR FIRES (FLOODING)

Chapter I. General information

Information on characteristics of radioactive sources, operation states considered, tasks set, scope of surveys and goals set in the scope of research and tasks performed under the PSA-1 are given in this chapter, and the main assumptions and limitations adopted in the analysis are stated.

Brief information about the NPP deployment site, reactor plant, monitoring and control of the unit, principal and emergency power supply systems, main equipment cooling systems and about the systems involved in the performance of safety functions should be given. References to the respective sources of more detailed information shall be given.

Brief characteristics of methodologies, manuals and computer programs used for resolving the following taks should be provided:

1) Gathering of information specific for the NPP power unit;

2) Determination of fire zones and flooding zones;

3) Determination of initiating events caused by a fire or flooding;

4) Development of a list of systems (components) that fail when exposed to fire and flooding effects;

5) Assessment of the probabilities (frequencies) of fire and flooding occurrence;

6) Human reliability analysis;

7) Determination of the flooding scenarios (for PSFA for flooding);

8) Analysis of fire propagation between the fire zones (for PSA for fires);

9) Screening analysis of emergency scenarios;

10) Detailed analysis of emergency scenarios;

11. Analysis and presentation of the results of PSA for fires or flooding;

12) Analysis of other PSA tasks characteristic for internal IE.

Chapter II. Accumulation of information specific for the NPP unit

Information about the NPP power unit, which is assembled for performing PSA for fires or PSA for flooding should be presented in the deliverables on PSA for fires or PSA for flooding.

In particular, the following information should be presented.

1) List of all buildings located at the site related to the analyze NPP power unit.

2) List of all the rooms in each of the NPP power unit buildings.

3) The following information should be presented for each room (for PSA for flooding information on the sources of fires and fire-extinguishing systems is not required, for PSA for fires information on the flooding sources is not required):

name of building where the room is located;

name of room;

plant designation of the room;

room floor elevation;

category of room by fire protection A, B, C, D, E;

length, width, height of room;

room area;

room attendance by personnel (non-serviced, semi-serviced, serviced or other variant);

frequency of room attendance and what document regulates the room attendance with the given frequency;

thickness of walls, floor, ceiling of the room (if suspended ceiling is available please specify the material);

materials of walls, floor, ceiling;

cladding material of walls, floor, ceiling;

fire resistance of the walls, floor, ceiling;

figure or layout of the room;

room temperature during normal operation;

list of equipment located in the room; for each equipment unit specify the station designation, name of process system to which the equipment belongs, channel number of the safety system to which the equipment belongs, present the diagram specifying all the units of equipment, plant designation, coordinates of unit equipment in the room, specify the distance between the equipment units;

the following information should be presented for each unit of electrical and electromechanical equipment: 1) name and station designation; 2) quantity, voltage, power, length, height, width; 3) availability of cooling system (if cooling system is available please specify the cooling fluid; if the cooling fluid is a combustible substance, give the quantity of combustible fluid); 4) equipment qualification for operation in humid environment (specify what is qualified viz. equipment, zone boxes, marshalling boxes); 5) electromechanical equipment start type (automatic/manual); 6) possibility of disconnection/connection of electromechanical equipment in situ;

the following information should be given for the vessels, containers and tanks: name and station designation, scope, quantity, fluid type, fluid temperature, fluid pressure, availability of fluid heating (if there is heating please specify the type of heating viz. water, steam);

the figures/layouts where the length, height, width of unit equipment, foundation or pedestal (if any) of the tray for gathering leakages (if any) should be provided for each unit of electrical, electromechanical equipment, vessels, containers and tanks, as well as specify the distance from the floor to the electrical junction box/boxes (where there is supply and control) on the figures and up to the rotation axis (for motors);

availability of stationary fire sources (electrical, electromechanical equipment, tanks, containers, vessels) and possibility of equipment damage in the room during fire from stationary sources of fire;

availability of brought-in sources of fire (electric welding, gas welding, metal cutting, heaters transformers, gas cylinders, chemical substances and liquids, combustible substances) and possibility of equipment damage in the room during fire from stationary fire sources;

the following information should be provided for the sources of fire occurrence "Stationary electrical equipment" (supply cabinet, automation cabinet, lighting panel, DC cabinet, AC cabinet, lighting distribution board, transformer, stabilizer, rectifier, electric panel, power cubicle, electrical section, thyristor, inverter, unilateral-maintenance three-phase distribution assembly for gate valves, power supply section, accumulator, motor, zone box, junction box, cable and other electrical elements) and "Stationary combustible substances": 1) name and plant designation; 2) number of equipment units; 3) types of combustible substances (PVC, plastic, oil, fuel oil, bitumen, petrol, kerosene, diesel fuel, paper (cellulose), fabric, wood (hard and soft wood), paint, hydrogen, oxygen, propane, coal, chemical reagents, highly-inflammable liquids and other combustible substances) in unit equipment; 4) overall dimensions of unit equipment; 5) packaging density with combustible material in unit equipment; 6)weight or volume of combustible substances in unit equipment (for each type of combustible substance); 7) type of storage place (piping, cylinder, tank, box etc.) for stationary combustible substances;

the following information should be presented for the brought-in sources of fire occurrence: 1) name of brought-in source of fire; 2) parameters of brought-in source of fire (voltage, gas type, gas pressure etc.); 3) type of storage place (cylinder, box, fuel can etc.); 4) overall dimensions; 5) frequency and duration of presence of the brought-in source of fire in the room; 6) weight or volume of combustible substance in the brought-in source of fire;

availability of cable routes; the following information should be presented if cable routes are available: 1) availability of cables related to various safety system channels; 2) figure/figures with image of the cable trays/brackets location, and specifying the height from the floor to the tray/bracket, number of trays/brackets, distance between the trays/brackets; 3) belonging of cables to the safety system channel or equipment; 4) cable location type (trays, brackets); 5) cable tray dimension (width, height); 6) share of filling each cable tray with cable; 7) preferred diameter of cable in the cable tray; 8) cable type and brand; 9) cable fire protection type and brand (if any); 10) thickness of cable fire protection coating (if any); 11) leaktightness/non-leaktightness of cable penetrations in the walls and ceilings;

linkages with other rooms through the doors, apertures and leakages, ventilation (provide a figure with image of the linkages); for linkage of the room through the door for each door it is recommended to specify the following information: 1) leaktightness/non-leaktightness; 2) is the door closed/not closed; 3) opening of door (outwards/inward into the room; 4) identifier of the room with which this room is connected through a door; 5) door overall dimensions (width, height, thickness); 6) door material; 8) sill height; for linkage of room through the opening, aperture, leakage in the passages, pressure relief valves or other elements the following information should be presented: 1) linkage type (opening, aperture, leakage in the passages, pressure relief valves or other components); 2) number of same-type linkages; 3) linkage location (floor, ceiling, wall, on location of linkage in the wall specify the height from the floor to the lower link generator); 4) linkage dimension (height, width, diameter); 5) room identifier with which the given room is linked through the given linkage type; the following information should be presented for linkage of the room through the ventilation systems: 1) type of ventilation (plenum, exhaust, combined, natural) and station designation of the ventilation system; 2) size of ventilation windows (width, height) and distance from the floor to the lower generator of the ventilation window/windows; 3) room identifier with which this room is connected through this type of ventilation; 4) size of ventilation ducts (width, height, diameter) and availability of fire retardant coating; 5) availability of chimney valves for protection against fire and/or smoke, chimney valve drive type, availability of automatic closure, closure signals;

availability of fire extinguishing systems; the following information should be presented for the fire extinguishing: 1) name of fire extinguishing; 2) availability automatic actuation (specify actuation signal); 3) type of fluid for extinguishing fire (water, foam, gas, other variants); 4) availability of stationary firefighting means (deluge guns, fire extinguishers (specify quantity), fire cocks, sand boxes); 5) availability of fire alarm (type of alarm and place of alarm); 6) availability and quantity of smoke sensor; 8)amount of water which may be input to the room during fire, productivity and availability of drainages in the room for water drain during fire;

availability of sources of flooding; the following information should be presented if sources of flooding are available: 1) type of flooding source (pipeline/pipelines, tank/tanks, container/containers, vessel/vessels; 2) a figure with piping routing specifying the location coordinates in the room for each source of flooding "Piping" is given, name of piping, outer diameter and metal wall thickness, belonging to the component (system) and safety system channel, fluid in the piping (water, steam, gas, oil or other fluid), pressure and temperature of fluid, piping length, filled with fluid or empty during normal operation, reserves of fluid during pipeline rupture; 3) for other sources of flooding (different form piping) the number of units, sources of flooding are given, if they comprise of tanks, containers, vessels, fluid volumes in the unit of flooding source, belonging to the component (system) and safety system channel, fluid type (water, steam, gas, oil or other fluid), fluid pressure and temperature, filled with fluid or empty during normal operation; 4) characteristics of drainages (size and quantity of drainage apertures); 5) availability of floor slope towards the drainage apertures; 6) drainage output; 7) availability of drainage protection means against clogging; 8) volume of water which may be accepted by the drainage system; 9) name of components (systems), with which the drainage pipes of the rooms and identifier of the room/rooms are linked, in which the drain collection components (systems) are located.

Information on malfunctioning of NPP power units due to fire or flooding (reasons of fire occurrence, initiating element or source of flooding, fire power or flooding volume, list of damaged systems (components), other information which may be used during probabilistic (frequency) assessment of fire or flooding) should be gathered and presented in table form.

Chapter III. Determination of fire zones and flooding zones

It is recommended to present information on the criteria in the chapter on the basis thereof the fire zones or flooding zones were identified.

The source documentation for determining the fire zones or flooding zones should be presented in the PSA deliverable for fires for PSA for flooding, viz. room schedule of NPP unit, characteristics of the room (height, length, width etc.), characteristics of linkages between the rooms (leak-tight doors, non-leaktight doors, apertures, ventilation apertures), scope of systems (components) in the room, routing of cables related to the systems (components), simulated in PSA for fires or PSA for flooding, combustible material quantity in the room, analysis for identified fire zones or flooding zones, results of analysis (list of fire zones or flooding zones, list of systems (elements) in the fire zone or flooding zone, list of rooms forming the fire zone or flooding zone, fire load of fire zone).

The analysis on formation of the flooding zones containing justification that all the rooms included in the fire zone or flooding zone is presented in this chapter, meet the accepted criteria for including the room in the fire zone or flooding zone.

It is recommended to present the NPP site territory layout with indication of all the buildings as part of the deliverables for PSA for fires or PSA for flooding. A letter coding is recommended to assign for separately assigned NPP buildings.

Chapter IV. Determination of initiating events caused by fire or flooding

It is recommended in the deliverable for PSA for fires or PSA for flooding to present analysis for identifying the initiating events caused by fire or flooding, results of resolution of this task (list of identified initiating events due to fire or flooding is recommended to present in the deliverables of PSA for fires or PSA for flooding).

The following information is given in this chapter:

1) Basic list of IE (from PSA-1 for internal IE);

2) Analysis for excluding IE from the base list on postulation of fire/flooding in each fire zone/flooding zone;

3) Analysis for inclusion of new IE in the basic list on postulation of fire/flooding in each fire zone/flooding zone;

4) Analysis for identification of the simultaneous occurrence of several IE (opening of PRZ SV and opening of BRU-A);

5) Final list of IE;

6) Summary table/table (matrix/matrices - in the rows of the fire zones or flooding zone, and IE in the columns), containing information on possibility of IE occurrence for various fire zones or flooding zones.

On identification of a large number of IE it is recommended to group the IE in accordance with the approaches used during grouping of internal IE. It is required to present the analysis of IE selection and their grouping in the deliverables on PSA for fires or PSA for flooding.

Chapter V. Development of a list of systems (components) that fail when exposed to fire and flooding effects

It is recommended to present a list of systems (components) subject to failure due to fire or flooding in the deliverables on PSA for fires and PS for flooding, the damage thereof may cause IE or reduce the reliability of the systems (components) performing the safety functions.

It is recommended to present an analysis for determining the list of analyzed systems (components) in the deliverables on PSA for fires or PSA for flooding, as well as the list of identified potential failures of the system (components)

Chapter VI. Assessment of the probabilities (frequencies) of occurrence of fires and flooding

It is recommended to provide analysis of probabilistic (frequency) safety assessment of initiating events caused by fires or flooding in the deliverables on PSA for fires or PSA for flooding. It is recommended to provide detailed information on the fires or flooding at NPP with similar units, information about the time of operation of considered power units, results of probabilistic (frequency) assessment of fires or flooding for all the considered fire zones or flooding zones and fire segments, results of assessment of the frequency of fires or flooding in the fire zones or flooding zones and fire segments.

It is recommended to conduct and present in the deliverables on PSA for fires or PSA for flooding an analysis on selection of events of type "fire" or "flooding" used for assessment of the probabilities (frequencies) of fires or flooding in the deliverables on PSA for fires or PSA for flooding during probabilistic (frequency) assessment of fires or flooding.

It is recommended to present information on the probabilities (frequencies) of fires or flooding for each fire zone or flooding zone in the deliverables on PSA for fires or PSA for flooding.

Chapter VII. Human reliability analysis (HRA)

 It is recommended to present the results of HRA including a brief description of the used HRA procedure, list of considered human errors and their identifiers, results of analysis on selection of human errors, results of analysis on determination of HEP, results of analysis on assessment of the dependencies of OP in the deliverables of PSA for fires and PSA for flooding.

It is recommended to present the human reliability analysis during fire or flooding in the deliverables on PSA for fires or PSA for flooding, and its results in accordance with the recommendations on PSA task on human reliability analysis for internal initiating events.

Chapter VIII Analysis of fire propagation between fire protection areas

It is recommended to present the analysis on identification of the propagation scenarios of fires between the fire zones in the deliverables on PSA for fires.

It is recommended to formulate and justify the criteria accepted for analysis of fire propagation when identifying the fire propagation scenarios.

It is recommended to present a description of the used method for determining the fire propagation scenarios, and results of analysis (in the form of a list of scenarios of fire propagation between the fire zones containing information about the fire zones through which fire is propagated and information on the paths of its spreading).

It is recommended to present all the engineering and deterministic calculations used for analysis of the fire propagation and information on the models, programs and design diagrams based on which the calculations were made.

The following is given subsequent to the resolution of this task:

1) List of scenarios of possible propagation of fire (considering the propagation of flame, hot gases and smoke) including a list of fire propagation rooms;

2) List of elements (systems), failure thereof takes place on implementation of each fire scenario.

Chapter IX. Determination of flooding scenarios

It is recommended to present an analysis on identification of the propagation scenarios of water between the rooms of the NPP power unit in the deliverables on PSA for flooding.

It is recommended to formulate and justify the criteria accepted for analysis of flooding propagation when identifying the flooding propagation scenarios.

It is recommended to give the results of analysis consisting in the presentation of the list of scenarios of water propagation between the rooms of the NPP power unit containing information on the flooding zones through which the flooding spread, and information on its propagation paths.

It is recommended to present all the engineering and deterministic calculations used for analysis of the flooding propagation and information on the models, programs and design diagrams based on which the calculations were made.

The following is given subsequent to the resolution of this task:

1) List of scenarios of potential spread of flooding, which includes the list of rooms where the flooding is propagated;

2) List of elements (systems), failure thereof takes place on implementation of each flooding scenario.

Chapter X. Analysis of accident scenarios

It is recommended to include both the selective analysis and its results in the deliverables on PSA for fires or PSA for flooding.

It is recommended to present screening analysis of fire scenarios or flooding scenario in the deliverables on PSA for fires or PSA for flooding. Information on the accepted criteria for screening of fires or flooding which shall be subject to detailed analysis shall be presented during screening analysis. It is recommended to present detailed information on the quantitative calculations (postulated events of failures, accepted for assessments of IE) on assessment of HVDC or conditional HVDC and present them in the chapter X. Information is presented in the chapter X based thereof a report is formulated on the necessity or lack of necessity of performing detailed analysis for each scenario of fires or flooding.

The following list of scenarios is presented in the chapter X following screening analysis:

1) scenarios with fuel damage, excluded in accordance with the assigned screening criteria; when using several screening criteria the lists of fire scenarios or flooding scenarios excluded from further analysis excluded from further analysis in accordance with each of the accepted exclusion criteria;

2) scenarios selected for detailed analysis.

It is recommended to present a detailed analysis of fire scenarios or flooding scenario in the deliverables on PSA for fires or PSA for flooding.

The analysis and its results excluding the conservative assumptions made during screening analysis are presented within the framework of detailed analysis for each scenario, information on the calculations, calculation methods used in the software, engineering assessments and other information justifying the development of emergency scenario.

The conclusions drawn based on the analysis of the results of PSA for fires or PSA for flooding are stated in the deliverables on PSA for fires and PSA for flooding:

1) Assessment of NPP power unit safety level;

2) List of identified most significant factors considerably influencing the formation of risk profile due to fires or flooding; assessment of the effect of uncertainties on the conclusions and recommendations of PSA for fires or PSA for flooding;

3) Assessment of the achievement of objectives when performing PSA for fires or PSA for flooding.

It is recommended to present the description of results obtained during analyses of the significance, sensitivity and uncertainty.

The obtained results of quantitative assessment of implementing the emergency shall be analyzed with respect to the uncertainty and sensitivity to the basic assumptions and limitations of analysis.

It is recommended to group the fire scenarios or flooding scenarios by the type of rooms (for example, cable shafts, tunnels, ECR) and assess the contribution of each group in the common HVDC when presenting the results of PSA for fires or PSA of flooding. The results of PSA for fires or PSA for flooding is recommended to present as a contribution of fire scenarios or flooding scenarios with fuel damage in HVDC for various types of rooms. The contribution of scenarios which were trivial and were dismissed at the screening analysis stage is recommended to add to the overall estimate of HVDC.

The recommendations developed following PSA for fires or PSA for flooding for enhancing the safety level of the NPP power unit and probabilistic assessments of their efficiency including technical and organizations measures are given in the deliverables on PSA for fires or PSA for flooding.

Appendix No 5
to the Safety Guide "Basic recommendations for development of level 1 probabilistic safety analysis of nuclear power plant unit for initiating events, stipulated by intra-site fires and flooding" (RB-076-12), approved by the order No 496 of the Federal Environmental, Industrial and Nuclear Supervision Service
dated September 5, 2012 .

RECOMMENDED SEQUENCE AND MUTUAL RELATION OF THE TASKS FOR PSA FOR FIRES AND PSA FOR FLOODING

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 1. Gathering of information specific for the NPP power unit |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  | 3. Determination of the initiating events arising from fire |  | 2. Determination of the fire zones |  | 5. Assessment of the frequency of fire occurrence |  |
|  |  |  |  |  |  |  |
|  | 4. Development of a list of systems (components) that fail when exposed to fire effects |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  | 10. Analysis and presentation of the results of PSA for fires10.1. Determination of risk contributors10.2. Analysis of uncertainty and sensitivity10.3. Documentation of PSA |  | 8. Selection analysis of emergency scenarios |  | 7. Analysis of fire spreading between the fire propagation between the fire zones |  |
|  |  |
| 9. Detailed analysis of emergency scenarios | 6. Human reliability analysis |

Fig. 1. Sequence of performing tasks of PSA for fires

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 1. Gathering of information specific for the NPP power unit |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  | 3. Determination of the initiating events arising from flooding |  | 2. Determination of flooding zones |  | 5. Assessment of flooding frequencies |  |
|  |  |  |  |  |  |  |
|  | 4. Development of a list of systems (components) that fail when exposed to flooding effects |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  | 10. Analysis and presentation of the results of PSA for flooding10.1. Determination of risk contributors10.2. Analysis of uncertainty and sensitivity10.3. Documentation of PSA |  | 8. Selection analysis of emergency scenarios |  | 7. Determination of flooding scenarios |  |
|  |  |
| 9. Detailed analysis of emergency scenarios | 6. Human reliability analysis |

Fig. 2. Sequence of performing tasks of PSA for fires

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RECOMMENDATIONS
FOR ANALYSIS OF THE SYSTEM (COMPONENT) MANAGEMENT CHAINS WHEN PERFORMING PSA FOR FIRES

Objective of the analysis of system (component) management system is the justification of the possibility of unintended actuation of the systems (components) arising out of damage of cables due to fire found in the specified rooms.

It is recommended to study the management circuits on the possibility of short-circuits between their conductors arising out of activation of control switches and possibility of elimination of short-circuit and return of control the relevant components when analyzing the control circuits of the systems (components). It is recommended to consider the restoring actions for management of systems (components) in PSA for fires on availability of the corresponding operating instructions (for NPP power units in operation).

Analysis of the control circuits of the systems (components) is recommended to perform jointly with the personnel of NPP I&C Shop or other competent services of NPP.

It is recommended to perform analysis at least for the following rooms (fire zones) of the NPP where the system (component) management systems are located:

1) MCR;

2) Relay cabinet;

3) Emergency control room;

4) Cable shafts.

If in the process of execution of PSA for fires other fire zones containing the system (component) management chains shall be identified, it is recommended to subject such rooms and system (component) management systems to analysis.

The effects of fire on I&C cables located in the above specified rooms should be established based on the results of analysis of system (component) management chains.

Identify different types of control diagrams of the systems (components) and perform analysis of fire effect on each of the types of control diagrams of systems (components) is recommended based on the analysis of systems (components) management diagrams.

It is recommended to analyze the effect of earth short-circuit for each of the identified types of control circuits of the systems (components) that may cause loss of control over the system (component) but not lead to unauthorized actuation or disconnection and cause unauthorized actuation.

The results of analysis of the control systems (components) should be presented in the deliverables on PSA for fires.

Appendix No 6
to the Safety Guide "Basic recommendations for development of level 1 probabilistic safety analysis of nuclear power plant unit for initiating events, stipulated by intra-site fires and flooding" (RB-076-12), approved by the order No 496 of the Federal Environmental, Industrial and Nuclear Supervision Service
dated September 5, 2012 .

PROBABILITY (FREQUENCY) ASSESSMENT ALGORITHM OF FIRES AND FLOODING

Total number of fires or flooding and relevant observation time is recommended to assess using the following two equations:

Fi = SUM fi,k, (1)

Power units from all NPP

Ti = SUM(Ni,k x Tk), (2)

Power units from all NPP

where:

i - type number of the components considered as the source of combustion or flooding;

k - power unit of considered NPP;

Fi - number of incidents of fires or flooding related to i-th type of component;

fi,k - number of incidents of fires or flooding related to i-th component type of k--th NPP unit;

Ti - full observation time related to i-th component type;

T k - operation time of k-th NPP unit;

N i,k - total number of components of i-th type in the k-th NPP power unit.

If the full observation time for all the components and number of fires or flooding for all the components are calculated as the sum of observation time for all the components TH = SUM Ti and total sum of fires or flooding F = SUM Fi arising from the considered components then respectively the mean value of the probability (frequency) of FR for fire or flooding may be assessed for Poisson stream of events using Bayesian procedure with inconclusive prior distribution according to the formula (3):

 \_\_ (2F + 1)

 FR = --------. (3)

 2TH

Low FRH and high FRB parameter limits FR were determined with the use of xi2‑distribution for bilateral confidential interval with confidence probability p=0.9 according to the following formulae:

 xi2 (1+p)/2 х (2F + 2)

 FRB = --------------------, (4)

 2TH

 xi2 1-(1-p)/2 х 2F

 FRH = ----------------, (5)

 2TH

where:

p - confidence probability;

FRB - upper limit of confidence interval;

FRH - lower limit of confidence interval.

The probability (frequency) of fire or flooding may be taken as abiding by the lognormal distribution law. The error factor "ef" is used as the parameter of uncertainty for the lognormal model at confidence probability p = 0.9, the value thereof is determined by the gamma distribution approximate formula to the lognormal model:

 ┌ \_\_\_\_\_\_

 │ /FR

 │ / 0.95 \_\_

 │\/ ------ FR >= 3.87 FR

 │ FR 0.95

 │ 0.05

 ef = < \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ , (6)

 │ / FR

 │ /2 0.95 \_\_

 │exp[z (z - \/z - 2ln(------))] FR < 3.87 FR

 │ 0.95 0.95 0.95 \_\_ 0.95

 └ FR

where:

ef - error factor of lognormal distribution;

Z0.95 - 95-percentile standardized normal distribution (~ 1.645).

If specific data are available using the Bayesian treatment, updates of the integrated assessment using specific data on the fire or flooding events occurring at the examined power unit are made.

The probability (frequency) reappraisal procedure of fires or flooding is recommended to perform in several stages given below.

Stage 1. Determination of the standard logarithmic deviation for distribution of generalized probabilities (frequencies) of fires or flooding:

 ln(ef)

 sigma = ------, (7)

 Z0.95

where:

sigma - standard logarithmic deviation;

ef - logarithmic normal factor of error for generalizing the probabilities (frequencies) of fires or flooding;

Z0.95 - 95-percentile standardized normal distribution (~ 1.645).

Stage 2 Determination of the variation for distribution of generalized probabilities (frequencies) of fires or flooding:

 \_\_2 sigma2

 Var = FR (e - 1), (8)

where:

Var - variation for distribution of generalized probabilities (frequencies) of fires or flooding;

\_\_

FR' - mean value of generalized probability (frequency) of fire or flooding;

sigma - standard logarithmic deviation.

Stage 3 Determination of the parameters of gamma-distribution of alpha and beta:

 \_\_2

 FR

 alpha = ---, (9)

 Var

 \_\_

 FR

 beta = ---. (10)

 Var

Stage 4. Determination of the parameters of posterior distribution of alpha' and beta'

alpha' = alpha + Ft, (11)

beta' = beta + Tt,

where:

Tt is the observation period of analyzed systems (components)/rooms for specific data;

Ft - number of fires or flooing for specific data.

Stage 5 Determination of the mean posterior (up to date) probability (frequency) of fire or flooding:

 \_\_ alpha'

 FR' = ------, (13)

 beta'

 \_\_ alpha'

 Var' = ------, (14)

 beta'2

where:

\_\_\_

FR' - aposterior mean value of probability (frequency) of fire or flooding;

Var' - aposterior variation.

Stage 6. Determination of logarithmic normal factor of error for posterior distribution (ef'):

 \_\_\_\_\_\_\_\_\_\_

 / Var'

 ef' = exp[Z0,95 \/ln(1 + ----)]. (15)

 \_\_\_2

 FR'

Determination of the number of events caused by fires or flooding

It is recommended to analyze all the incidents related to fires or flooding at the NPP when determining the number of events caused by fires or flooding.

It is recommended to use information on the acts about the NPP operational occurrences as well as the shop reports for determining the number of events caused by fires and flooding.

It is recommended to use the following rules when determining the number of events caused by fires and flooding:

1) if the expert opinion is ambiguous (to include the event in the analysis or not include) the event is conservatively included in the analysis;

2) events of type "fire" or "flooding" which took place during the NPP power unit shutdown are included in the analysis;

3) events of the type "fire" are not included in the analysis for assessment of the probabilities (frequencies) of fires, if the only the source component viz. source of fire was subject to the effect of fire and the event did not give rise to initiating events; the specified events usually have been considered during probabilistic (frequency) assessment of fires for internal IE;

4) events of type "flooding" are not included in the analysis for assessment of the probabilities (frequencies) of flooding, if the event did not give rise to IE.

When analyzing the events caused by fire or flooding (MCR, ECR, turbine hall, diesel generator room, CPS etc.) it is recommended to form the list of rooms where fire or flooding took place, and specify the type of component causing fire or flooding (turbine, generator, diesel generators, 6 kV pumps, 0.4 kV pumps, power cables, control cables electric panels, transformers > 6 kV, transformers <= 6 kV, switchgears 6 kV, switchgears 0.4 kV, fans, portable combustible materials, invertors, equipment containing hydrogen, heat insulation, tank, pipeline etc.).

IE of fires or flooding is recommended to group considering the individual summarized data and specific data.

It is not recommended to consider during assessment of the probabilities (frequencies) using component-oriented approach and vice versa when performing PSA for fires the events on fire used for assessment of the probabilities (frequencies) of fires using the zonal-oriented approach.

It is required to present detailed information on the real IE related to the fires or flooding and own analysis of these IE and its results in the deliverable on PSA for fires or flooding.

Determination of the observation time

It is required to determine the time period in which the events caused by fire or flooding were identified and accepted for further analysis for probabilistic (frequency) assessment of fires or flooding .

The following information is required for determining the observation time:

1) operation time of NPP from the time of physical start-up (including the operation modes viz. shutdowns, outage);

2) total number of components considered as the source of combustion or flooding;

3) total number of rooms similar to each other.

The observation time is recommended to determined by multiplying the number of components considered as the source of combustion or flooding by the duration of operation of each considered NPP when using the component-oriented approach during probabilistic (frequency assessment) of IE.

The observation time is recommended to determine by multiplying the number of similar rooms by the duration of operation of each considered NPP when using the zonal-oriented approach during assessment of the probabilities (frequencies) of IE.

Probabilistic (frequency) assessment of flooding for the flooding zone of the NPP building power unit

After determination of the probabilities (frequencies) of flooding for each of the buildings of the NPP power unit, the probabilities (frequencies) of flooding for each of the flooding zone of each of the buildings of the NPP power unit are determined.

Since the flooding may be of different scope, the time before damage of the systems (components) other things equal for the events with different volume of flooding shall differ as the time reserve which the operating personnel has for preventing damage of the systems (components). As a result the risk of flooding of various volume shall be different. Hence when determining the probabilities (frequencies) of flooding it is recommended to determine the probability (frequency) of flooding for the sources of flooding of various intensity. It is recommended to consider the following scopes of flooding:

1) minor - flooding in the quantity of one cubic meter of leakage from the gate valve;

2) moderate - flooding in the quantity 10 cubic meters (leakages of pumps, ruptures of small tanks, piping leakages);

3) large - flooding in the quantity 100 cubic meters (pipe or tank ruptures);

4) very large - flooding in the quantity 1000 cubic meters and above, for example rupture of circulation or service water piping.

Probability (frequency) of flooding for the flooding zone of the NPP power unit building is determined by multiplying the probability (frequency) of the event for the NPP power unit building by the fraction of components in the flooding zone from the total number of components considered as the sources of flooding considering the volume of the flooding source.

Since the main sources of flooding are the piping, the share of components in the flooding zone of any volume may be determined based on the length of piping passing through the considered flooding zone and causing flooding of this volume.

It recommended to relate the piping of various diameter, ruptures thereof may be the sources of flooding with one of the above specified flooding volumes.

Fire assessment probability (frequency) for fire zone

Probability (frequency) of fire for fire zone shall include two constituents:

1) Probability (frequency) from the system components considered as stationary sources of combustion;

2) probability (frequency) of portable combustible materials, and welding, metal cutting etc.

Probability (frequency) of fire from the system components considered as stationary sources of combustion

A knowledge of the quantity and type of components in the fire zone which may be the sources of combustion is required for determining the probability (frequency) of fires in the fire zone. Probability (frequency) of fire occurrence for the fire zone FZ is recommended to determine as the sum of frequencies from all sources of combustion:

 N

 FстацFZ = SUM(Fi x ni), (16)

 i=1

where:

FстацFZ - probability (frequency) of fire occurrence for the fire zone

FZ for stationary sources of combustion;

i - component type considered as the source of combustion;

N - total quantity of the types of components;

Fi - probability (frequency) of fire per year on the component for i-th component type;

ni - number of i-th components in the fire zone FZ.

Probability (frequency) frequency from the portable combustible materials

The probability (frequency) of fire occurrence from portable combustible materials is recommended to assess for the entire NPP and then divide between the various fire zones based n the floor area of the fire zone and frequency of human personnel presence in the fire zone. The probability (frequency) of fire from portable combustible materials for fire zone F2FZi is recommended to determine according to the following formula:

 NZ

 Fперi = Fпер x Si x Fvisit I / (SUM(Si x b Fvisit i), (17)

 i=1

where:

Fпер - general frequency of fires at the NPP power unit due to portable sources;

Si - floor area of the fire zone of i in sq.m;

Fvisit i - frequency of human presence in the fire zone i;

i - fire zone number;

NZ - number of fire zones.

The assessment of Fvisit i is based on the number of visits of the fire zone and duration of the visit. The human visit duration of the fire zones and flooding zones shall be established. The visit of fire zones or flooding zone may be classified as follows: 1) not visited; 2) thrice a month; 3) thrice a week; 4) once a day; 5) thrice a day; 6) once in two hours; 7) once an hour; 8) continuous presence.

Probability (frequency) of fire during welding, metal cutting

Fire occurrence is possible on ignition of combustible substances (oiled insulation etc.) following spark entry during welding or metal cutting, and following self-ignition of heat insulation. It is recommended to assess the probability (frequency) of fire occurrence during welding, metal cutting etc for the entire NPP and then divide between the various fire zones based on the coefficients (assigned by the expert personnel of NPP) characterizing the potential hazard related to fire due to metal works (welding or cutting), and possibility of heating from hot piping and self-ignition. Besides, the availability of combustible materials, combustible pipelines and scope of repair works which are performed in the analyzed fire zone. For assessment of potential hazard during welding, metal cutting etc. it is recommended to arrange all the fire zones using points from 1 to 10 (for example, highest point (10) may be assigned to the turbine hall, medium values of the points may be assigned to such rooms as mechanical workshops or zones containing oil, lowest point (1) may be assigned to such rooms as the stair cases, or rooms of plant personnel, which were considered as less dangerous zones with respect to the considered events). The danger coefficients for the fire zone are assessed by dividing the assigned point by the amount of points assigned for all the fire zones, and multiplying by the full probability (frequency) of fire due to welding, metal cutting.

Probability (frequency) of fire in the control instrumentation rooms

When performing probabilistic (frequency) assessment of fire in the MCR, ECR, control instrumentation rooms it is recommended to divide the potential areas of fire occurrence into MR (electric panels) into segments (in accordance with the boundaries of the electric panels). It is recommended to divide the probability (frequency) of fire occurrence assessed for the fire zone (MCR, ECR, control instrumentation etc.) into the probabilities (frequencies) of fire occurrence in the individual segments based on the data on density of cables and conductors in the electric panels. It is recommended to enter the filling coefficients for the characteristics of density of filling the electric panels. For example, the segments may be characterized by the following filling coefficients:

1) Very rare filling - 5;

2) Rare filling - 50;

3) Average filling - 100;

4) Significant filling - 150;

5) Very significant filling - 250.

The probability (frequency) of fire in the segment considering the distribution of the probability (frequency) of fire between the segments is determined by multiplying the probability (frequency) of fire in a fire zone on the filling coefficient of the segment determined as the ratio of the coefficient of filling for this segment to the sum of coefficients for all the segments.