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PSA FOR FIRES AT VVER-1000/320 NUCLEAR POWER PLANTS

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ABSTRACT

This paper presents some results of the fire PSA for VVER 1000 in Russia that is currently being carried out by Atomenergoproekt in co-operation with VNIIAES and VNIIPO institutes. Balakovo Unit 4 in operation is under consideration. Sources of ignition and the defence against a fire are analysed. Failure modes of safety related components and types of associated circuits are classified. Initiating events induced by in-plant fires are identified. Fire frequencies are estimated from operational experience that covers the period from early 1989 through 1993. About 130 fire zones are identified. A partitioning rule is established to estimate individual zone fire frequencies for specific fire zones. Two types of screening that were applied to fire zone analysis are discussed. Dominant fire scenarios are analysed in detail. Calculation of the core damage frequency from fire events is performed. Plant vulnerabilities were defined and prioritised depending on their safety significance.

FULL PAPER

A systematic fire hazard analysis has not been performed so far for any of the VVER nuclear power plant in Russia. So a fire PSA for operational unit 4 of Balakovo plant belonging to model 320 version of the 1000 MW VVER is currently being carried out by Atomenergoproekt in co-operation with both institute on NPP operation (VNIIAES) and fire protection institute (VNIIPO).

The fire PSA has two main objectives:

- to estimate VVER fire frequency and frequency of core damage resulting from a fire in a manner that makes the maximum possible use of plant specific data, and
- to identify weaknesses that affect plant safe shutdown capability given a fire [1].

Input probabilistic model was based on the model for internal events developed within TACIS project. It provided the necessary event and fault tree models and identified the safety related components.

The plant was partitioned into fire zones completely surrounded by such physical boundaries as fire qualified walls, fire resistant doors, dampers, and penetrations or separated from other fire zones by a distance. Distance of 6 meters between combustibles was considered as sufficient for fire separation. About 130 fire zones were identified.

Fire frequencies were estimated from operational experience of VVER plants. In the Russia and Ukraine, all fire events are reported within accident reporting systems. VVER specific fire event data were collected for each specific type of equipment including both potential fire incidents and real fires. The data base covers the period from early 1989 through 1993 and includes 596 events each having real or potential fire event. A partitioning rule was established to estimate individual zone fire frequencies based on the collected information (see Table 1).

Fire-induced failure mode and effect analysis (FMEA) was performed for all components as well as power and control circuits of safety related systems. The failure modes considered for cables were as follows:

- Short circuit
- Short to ground
- Open circuit
- Hot short

The last failure mode can lead to spurious actuation of stand-by component because an energized conductor within a cable is shorted to an unenergized conductor of the same or a different cable. Assumptions were that single hot short in C & I cables and components can only occur. Therefore, three phase power circuits are not susceptible to hot shorts.

Besides, associated circuits that include any circuit whose fire-induced damage could lead to failure of safety related systems of interest were also analysed. Three categories of associated circuits that were identified as a concern to safety system operation are as follows:

- Circuits associated by common power supply. The design principles of emergency power supply systems as well as co-ordination of circuit protective devices were analysed.
- Circuits associated by common enclosure. Potential of fire propagation via inadequately protected cables and penetrations was investigated.
- Circuits associated due to current transformer secondary ignition. This was carefully analysed because fire-induced opening of the current transformer secondary circuits could cause excessively high voltage on the

primary side of the current transformer and start a secondary fire at the transformer.

To reduce the scope of the study, two types of screening were applied to fire zone analysis based on conservative assumption:

- **Deterministic screening** - If there were no PSA components in a fire zone, such fire zone was screened out.
- **Probabilistic screening** - If the fire frequency for fire zone was less than 1.0E-7 per year, such fire zone was screened out.

The following families of initiating event groups were identified from internal PSA model as possible for fire accidents:

- LOCA through reactor coolant pump seals
- Inadvertent opening of pressurizer safety valves
- Reactor trip
- Trip of reactor coolant pumps
- Loss of off-site power
- Loss of normal heat removal through secondary side
- Inadvertent opening of steam generator safety valves or steam dump valves on secondary side

The fire scenarios in terms of initiating events and safety systems that were affected by a fire were identified by reviewing the layout of cables and components in the fire zones. Special attention was given to cable locations. Preliminary analysis of fire-induced consequences was based on the assumption that a fire in a given fire zone would fail all cables and equipment in that fire zone. Two concurrent scenarios of a fire were considered for every zone of interest:

- loss of every electrical circuit due to open, short or ground
- in addition to the former damage state, an assumption was that the worst case of a single hot short was supposed to occur

The worst case was found to be the scenario that may occur given a fire in high pressure steam line room. Fire-induced spurious closure of all steam isolating valves leads to the loss of normal heat removal through secondary side. Following this initiating event, all atmospheric steam dump valves have to be opened. After that power cables of those valves may be lost, followed by valve failure to close. This is beyond design accident that is supposed to affect reactor core damage.

Pipes, heat exchangers and manual valves were supposed not to be susceptible to a fire. Based on fire zone definition, it was also assumed that fire impact on zone boundaries including structures, doors, penetrations, and dampers would not lead to their damage. Two exceptions were only made for turbine oil fires and fires in cable spreading rooms. To justify an assumption of fire localisation inside the fire zone boundaries in those cases, the impact of a fire on barriers was evaluated based on direct deterministic fire propagation analysis using computerised model. After that the turbine hall fire zone, where consequences of fire were completely unclear, were analysed using computerised model to obtain the best estimate consequences of a fire.

The results of qualitative fire consequence analysis were defined for each selected zone in terms of both initiating event groups and failures of safety system components.

The final step of study was estimation of fire-induced core damage frequency. For this purpose an internal event risk model developed for Balakovo Unit 4 was modified to account for the degradation of equipment as a result of a fire. This model is based on Risk Spectrum PSA computer code [2] which allows user to insert fire-induced failures directly to available fault tree structure using special logic gates.

Total frequency of fire-induced core damage is estimated to be 1.55E-5 1/year. However, it should be noted that contribution some scenario has not estimated yet due to lack of supported thermohydraulic calculations. Those scenarios which total frequency is 4.8E-5 1/year are concerned with failures of two steam dump valves in open position.. Such accident sequences have not modelled within PSA for internal initiating events. However, they seem not to lead to core damage directly. Therefore, additional thermohydraulic analyses needs to develop probabilistic models.

Based on results of qualitative and probabilistic analysis, plant vulnerabilities were defined and prioritised depending on their safety significance. The most significant contributors to core damage frequency were estimated to be combinations of such fire-induced initiating events as loss of normal heat removal through secondary side, inadvertent opening of steam generator safety valves or steam dump valves on secondary side, and simultaneous trip of both reactor coolant pumps and make-up pumps which may be followed by leaks through pump seals. Among fire zones, the main contributor to core damage frequency is a fire in high pressure steam line room which is estimated to give 71%. Fires initiated in some cable spreading corridors as well as in the turbine hall are also important contributors.

Plant modifications based on fire PSA are under development.

REFERENCES

[1] G.Soldatov, V.Morozov, and G.Tokmachev Safe shutdown analysis for fires at NPP with VVER-1000. International Atomic Energy Agency

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[2] Ulf Berg and Lars Sardh. RISK SPECTRUM. User's Manual. RELCON Teknic AB. April 1994.

Fire frequencies for the most important fire zones

Table1

Room name	The number of fire zones	Frequency, 1/year
Turbine hall	1	1.1E-2
Emergency core cooling pump rooms	3	7.9E-4
MCP oil pump rooms	2	4.7E-4
Switchgear compartments in reactor building	3	4.1E-4
MCP motor drive compartments	2	3.2E-4
Control room	1	2.4E-4
Switchgear compartments in turbine building	1	1.8E-4
Control panel rooms of safety trains	3	6.7E-5
High pressure steam line room	1	2.2E-5