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CEA-DAS--391 RAPPORT DAS N° 391

PROBABILISTIC ANALYSIS OF 900 MWe PWR.
SHUTDOWN TECHNICAL SPECIFICATIONS.

J.M. MATTEI, G. BARS *

International topical conference
on probabilistic safety assessment
and risk management.
ANS/ENS - "PSA 87"
(Zurich, 31 août-04 septembre 1987)

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PROBABILISTIC ANALYSIS OF 900 MWe PWR SHUTDOWN TECHNICAL SPECIFICATIONS

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1 Introduction

During annual shutdown, preventive maintenance and modifications which are made on PWRs cause scheduled unavailabilities of equipment or systems which might harm the safety of the installation, in spite of the low level of decay heat during this period. The pumps in the auxiliary feedwater system, component cooling water system, service water system, the water injection arrays (LPIS, HPIS, CVCS), and the containment spray system may have scheduled unavailability, as well as the power supply of the electricity boards.

The EDF utility is aware of the risks related to these situations for which accident procedures have been set up and hence has proposed limiting downtime for this equipment during the shutdown period, through technical specifications. The project defines the equipment required to ensure the functions important for safety during the various shutdown phases (criticality, water inventory, evacuation of decay heat, containment).

In order to be able to judge the acceptability of these specifications, the IPSN, the technical support of the "Service Central de Sûreté des Installations Nucléaires", has used probabilistic methodology to analyze the impact on the core melt probability of these specifications, for a French 900 MWe PWR.

2 Analysis method

While the reactor is operating under cold shutdown, decay heat is evacuated by the RHR system. This system is inside containment and enables the flow of primary fluid via two pumps. The heat is transferred by the RHR exchangers to the component cooling water system then to the raw water system. The RHR system also protects the main cooling system from overpressure via two safety valves.

Probabilistic analysis of the risks involved while operating under RHR conditions was run considering two broad categories of situations : primary system closed and primary system open. The first category is subdivided into three phases, with respect to the primary's thermohydraulic state and the systems available for decay heat evacuation. The second category defines the operation phases with the water level at the hot leg median plane, reactor vessel opening and closure, and the refueling phase.

So, the operating period on residual heat removal system was divided into six phases according to primary circuit configuration, thermohydraulic state and decay heat removal systems availability (figure 1).

	Phase 1	Phase 2	Phase 3	Phase 4 Median plane piping	Phase 5 Reactor vessel opening and closure	Phase 6 Refueling
Time after reactor shutdown	4 → 20h	20 → 68h	68 → 548h	68 → 308h	68 → 128h	128 → 488h
Pressure	24 - 28b	P < 28b (solid)	1 - 28b	RCS (opened)	RCS (opened)	RCS (opened)
Temperature	177° - 90°	90° - 60°	90° - 10°	70° - 10°	60° - 10°	60° - 10°
Necessary steam generators	2	2	1			
Spent fuel pool cooling system as back-up of the RHRS	NO	NO	YES	YES	YES	YES
Cold shutdown	4 7 solid 20 → —	→	|—|			
Refueling shutdown	→ ←	→			→ ←	|—|
Cold shutdown (median plane primary piping)	→ ←	→		|—|		
Annual passages / Annual time	6 / 96H	3 / 144	1 / 480	1 / 240	1 / 60×2	1 / 3

FIG 1.

For each phase of reactor shutdown, an assessment of the probability of core meltdown was made, assuming first that all the equipments are available and then assuming that only the equipment required by the technical specifications is available. In this way, the core melting probability was overestimated in the second case ; however the possibility of being able to put the non required equipment back into service after a recovery period was considered.

This double quantification allowed determination of the increase of the core melt probability obtained from combinations of the various items of equipment available as provided for by the technical specifications. Analysis of the increase in core melt probability allowed to judge the acceptability of the specifications and the list of equipment which are to be available during the various shutdown phases.

3 Probabilistic analysis description

3.1 Definition of the initiating events considered

The initiating events used for the probabilistic risk analysis were grouped into two families :

- decay heat evacuation facility losses,
- loss of primary coolant.

3.1.1 Decay heat evacuation facility losses

The following systems are used to evacuate decay heat :

- residual heat removal system (two trains),
- spent fuel pool cooling system, used in certain RHR backup phases,
- component cooling water and service water systems (two trains),
- water intake,
- emergency power busbars (two trains).

For each operating phase, we determined the failure combinations causing loss of decay heat evacuation capability taking into account :

- systems failures,
- cross-over failures of one array in a system and an array in another system powered by a different power line.

3.1.2 Loss of primary coolant

Loss of coolant accidents under RHR conditions are marked by the absence of the automatic devices used to maintain a sufficient water supply to prevent the core from being uncovered, except for a containment high pressure signal which may intervene specially during the first phase of RHR use.

For the probabilistic analysis, loss of coolant from a pipe break was assumed at hourly occurrence rates equivalent to those for full power, whatever the phase considered. This assumption has been taken into account as reasonable given particularly the results published in : "A Study of Piping Failures in US Nuclear Power Reactors". P. Janzen - AECL - MISC 204 (figure 2). When the primary system is open, only small pipe breaks were assumed possible in the primary system.

		Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
LOCA	RCS	3.0 E-6	4.5 E-6	1.5 E-5	0	0	0
	RHRS	8.7 E-6	1.3 E-5	4.3 E-5	2.17 E-5	1.08 E-5	3.25 E-5
	Total	1.17 E-5	1.75 E-5	5.8 E-5	2.17 E-5	1.08 E-5	3.25 E-5
Medium loca	RCS	3.0 E-6	4.5 E-6	1.5 E-5	0	0	0
	RHRS	8.7 E-6	1.3 E-5	4.3 E-5	2.17 E-5	1.08 E-5	3.25 E-5
	Total	1.17 E-5	1.75 E-5	5.8 E-5	2.17 E-5	1.08 E-5	3.25 E-5
Small break	RCS	5.5 E-6	8.2 E-6	2.7 E-5	1.4 E-5	6.8 E-6	2.05 E-5
	RHRS	6.09 E-3	6.3 E-4	1.93 E-3	2.17 E-4	1.08 E-4	3.25 E-4
	Total	6.09 E-3	6.38 E-4	1.96 E-3	2.31 E-4	1.15 E-4	3.45 E-4

Assumed loss of coolant probabilities (event/year)
including stuck open of the RHR safety valves

FIGURE 2.

3.2 Quantification methods

The processing of each initiating event was run based on event trees integrating accident procedures and what actions to take in the event of their failure. Regarding system losses in a closed primary system, the applicable accident procedures recommend trying to put the steam generators into operation when a function is lost ; in the case of an open primary system, water additions must be made to compensate for the vaporized flow rate. Regarding losses of primary coolant, the procedure which only applies to pressurized conditions has been used as a guide for the operator.

The quantification of core melt probability related to coolant losses led to the examination of several long term strategies for equipment use and taking into account the various levels of contamination (refer to Mr. DUCAMP's paper presented in the present meeting).

The event trees were quantified by fault trees.

Quantification was supported by a data base resulting from French experience, except for the human factor for which the SWAIN Methods were used.

4 Results

The study showed up the following.

4.1 In the all equipment unavailable situation

The risk value is essentially tied to initiating event : RHR safety valve jammed open or breaks. This result is associated with the short time that the operator has for taking adequate safeguards in the absence of automatic devices, and with losses of recirculation systems in the long term phase.

4.2 In situations where the proposed technical specifications apply

Regarding coolant losses, a significant increase in core melt probability occurs, when only the equipment required by the technical specifications is available, during the time when the primary system is open. These increases are due to the fact that the existence of breaks were assumed using hourly rates equivalent to those at power.

Regarding the losses of systems, the study showed situations where the number of required equipment items seemed to be inadequate ; this led to the proposal of adding items to the required equipment list to decrease the core melt probability.

The principal requirements are :

- in the cold shutdown, the number of equipment items necessary to evacuate the residual heat has to be increased to cope especially with the failure of an emergency busbar and a train of a system (RHR) ;

- it is necessary to maintain for all the phases including refueling one train of the containment spray system and one train of the low pressure injection system to ensure primary fluid recirculation.

These requested availabilities of systems permit to reduce the probability per year of core melt from $4\ 10^{-5}$ to a value below 10^{-5} for the cold shutdown phases of the reactor.

The study also points out the fact that the risk is expected to be reduced by the change of the RHR safety valves model.

5 Conclusion

The analysis of the main sequences contributing to the core melt probability increase due to the scheduled unavailability of equipment showed :

- the necessity, for certain phases, to have additional items available in addition to those proposed by the utility ;
- the necessity of reviewing the scope of application of certain procedures and the creation of new ones.

After putting into place shutdown technical specifications, completed following the analysis, it is possible to conclude that the scheduled equipment unavailabilities do not significatively increase the core melt probability.

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