
Safety of the fuel storage in French Nuclear Power Plants 900 MWe

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ABSTRACT: To shorten the outage periods of its reactors in order to increase their availability, Electricité de France reduced the time between the reactor shutdown and the end of the fuel unloading. This results in increasing the residual power of the fuel stored in spent fuel pool during plant unit shutdowns.

Therefore, equipment participating in the fuel storage safety is currently operated beyond the limits defined in the safety reports of the nuclear plants. This abnormal situation was highlighted by the experience feedback and by the safety review performed on 900-MWe reactors. In order to deal with such a situation, operating requirements have been temporarily implemented. In the meantime, definitive actions will be defined to improve the conception and operation as a whole of the spent fuel storage facilities in nuclear plants.

In this context, IRSN analyzed the suggestions and studies carried out by Electricité de France to improve the safety of the spent fuel storage and to remove the current requirements concerning the operation of the spent fuel pools of 900 MWe reactors.

Therefore, IRSN studied the incidental or accidental operating situations that may affect the cooling function of the spent fuel pool. The risk of uncovering assemblies stored in the fuel building was assessed by a specific probabilistic risk assessment. The result of these works leads to propose new modifications to improve the monitoring (cooling monitoring, pool instrumentation...) of storage facilities and the management of incidents or accidents (especially support means and procedures) which may affect them.

IRSN assessment conclusions were submitted to the permanent group in charge of the nuclear reactors in November 2002. It appears from this assessment that the control of the cooling of the spent fuel stored in the pool will be significantly improved compared to the current situation, when the modifications considered by Electricité de France are applied.

Until these conclusions and related modifications are taken into account, it was decided to maintain some compensatory measures defined in 1998. Moreover, these conclusions and modifications shall be adapted in order to apply them to the most recent reactors (1300 and 1450 MWe).

Besides, regardless of the residual power stored in spent fuel pool, it was also highlighted that some accidents such as a rapid drainage of the spent fuel pool, a fire or flooding affecting the premises of the fuel storage building might be uncontrolled in the current facility conditions.

The detailed study of these situations may result in new modifications in order to improve their prevention and management.

1 BACKGROUND

The analysis submitted by IRSN to the permanent group in charge of the reactors in November 2002 is the conclusion of long process initiated in 1994 after it was discovered the non-compliance of the limit of residual power released by the fuel stored in spent fuel pool defined from the design on the 900 MWe reactors of CPY series. In a first stage, this report induced the safety authority to issue an exception to this limit (power limit increased from 5.45 to 8 MW) on the basis of a first justification file submitted by Electricité de France and a reinforcement of the operating requirements.

Then, Electricité de France requested authority to increase the limits of the residual power of the fuel stored in spent fuel pool in order to take into account the new fuel managements and operation practices. The following table illustrates the case of the 900 MWe standardized plant:

	Fessenheim	Bugey	CPY
Initial limits (MW)	6,5	6,85	5,45
Suggested limits (MW)	8	8	10

The new suggested limits intend to meet the single failure criterion imposed to the cooling function of the spent fuel pool in the safety reports. Thus, the loss of a component (the most penalizing loss is the loss of an exchanger) must not result in exceeding a 80°C-temperature in spent fuel pool.

Moreover, to justify its relaxation proposal, Electricité de France had to show that a total loss of cooling accident would not have unacceptable consequences. Various total loss of cooling initiators were studied by IRSN within the framework of the processing:

- Initiator 1 : loss of both PTR channels or loss of a common section,
- Initiator 2 : total loss of power supplies,
- Initiator 3 : loss of the heat sink,
- Initiator 4 : pool drainage resulting in dewatering of cooling system suction pipe
- Initiator 5 : hazard (fire or flooding) resulting in a failure of both cooling channels.

2 LOSS OF THE COOLING FUNCTION OR ONE OF THE SUPPORT FUNCTIONS

During refueling outage, the residual power of the fuel stored in spent fuel pool may result in the pool boiling in the short term in case of total loss of cooling (between 8 and 16 hours). So as to prevent this accident, Electricité de France reinforced the operating requirements and the preventive maintenance program concerning the cooling function of the spent fuel pool. Moreover, modifications will be soon integrated to suppress the losses of cooling linked to the suction of foreign bodies in the cooling system (installation of a strainer on the suction pipe) and enable a more reliable supply of PTR pumps, while authorizing the maintenance of the electrical switchboards during this period.

However, despite these measures intended to improve the prevention of a loss of cooling, the probability of the spent fuel pool boiling remains high when the reactor is unloaded (probability higher than 10^{-4}). The operator should therefore be able to manage a situation of prolonged loss of cooling which might lead, in the long term, to the dewatering of the fuel stored in spent fuel pool.

For this purpose, Electricité de France defined a operating strategy applicable when the loss of cooling initiator is the failure of the cooling function or one of its support functions (initiators 1 to 3 listed above). This strategy is based on a reinforcement of the accident detection and monitoring means (addition of instrumentation sensors and creation of alarms detecting a loss of cooling efficiency, water level reduction and high temperature in spent fuel pool) as well as action means (modification of the emergency make-up line so that it is supplied either by the demineralized water system or by the fire protection system). Then, Electricité de France had to check that this strategy would enable to cope with the most penalizing scenario considered (loss of the heat sink over 100 hours). IRSN lists below the new design requirements resulting from the study of this scenario, which must be satisfied:

- acceptability of the doses received at the site limits after opening the fuel pool area door leading to the outside in order to avoid a pressurization by the pool water vaporization;
- accessibility of the make-up means and the various premises of the fuel building, out of the fuel pool area. Modifications shall be necessary to improve the static isolation between the fuel pool area and its adjacent premises (addition of isolation dampers in the ventilation ducts, modification of the doors...);
- operability of the equipment required for managing and recovering a prolonged boiling situation of the spent fuel pool, as this requirement should imply some modifications on some equipment;
- upon restart of cooling, the PTR system should suck up sub-saturated fluid only. This condition is required for its proper operation and for the return to the safe condition of the storage in spent fuel pool. On Electricité de France 900 MWe reactors, this requirement does not require any specific measure;
- mechanical integrity of the pool equipment (doors and gates) of the cooling system at 100°C;
- PTR system capacity to restart after pool boiling.
- consideration of a pessimistic leak rate value for the pool liner in accidental situation for the design of the support means and the recovery and process networks of this leak. The elements issued from the study of the liner resistance at 100°C show that a maximum leak rate of 3 m³/h can be considered as envelope in the accidental situation considered. Electricité de France justification is based in particular on an inspection program of the spent fuel pools and on the development of a repair process used to ensure the good condition of the metallic liners in normal operation.

As a result of this assessment, IRSN considered that the accidental situation of total and prolonged loss of cooling of a spent fuel pool would be managed using the measures suggested by Electricité de France, especially by implementing the modifications resulting from the new requirements.

3 ACCIDENTAL DRAINAGE OF THE SPENT FUEL POOL

The safety analyses submitted by Electricité de France focused on the risks related to the increase of the residual power in spent fuel pool. Accidental drainage situations were studied considering the loss of cooling initiator. For these drainage situations, Electricité de France transmitted a deterministic study of the different conceivable scenarios. However, the assessment of the potential consequences and the operating strategy to be applied still need to be studied more thoroughly.

IRSN considers that several scenarios (break or leak on a compartment drainage pipe, spent fuel pool drainage via the reactor building pool by a break or leak on a pipe connected to the primary cooling system, spent fuel pool drainage using a pump from the primary cooling system at reactor shutdown, loss of tightness of a joint of a gate...) may involve a kinetic rapid enough to result in an assembly uncovering during handling as well as the loss of cooling by the PTR suction pipe dewatering.

For example, IRSN noticed that the dewatering of an assembly during handling may obstruct or prevent some actions which are currently intended to manage an accidental level reduction or a loss of cooling of the spent fuel pool. Electricité de France shall therefore assess the risk linked to an accidental drainage of the spent fuel pool, suggest operational operating strategies covering the various drainage scenarios and define, if necessary, measures used to control these situations and limit their consequences.

As for the assessment of the consequences resulted from an assembly dewatering during handling, studies carried out in 1984 by IPSN if this accident occurred in the reactor building are used to assess the damage undergone by the fuel clads and the induced radioactive waste. However, the results of these studies shall be reassessed taking into account the weaknesses of the containment of the fuel storage building and the possibility of zirconium oxidation, addressed by the NRC in its report NUREG 1738 of February 2001. As this reaction may be highly exothermal at high temperature, it might result in the assembly failure. This reassessment should be based on research efforts and, in all probability, the study results cannot be presented by the end of 2005.

4 HAZARDS

The current design of the reactors operated in France is such that there is no physical separation of both cooling channels of PTR system. Indeed, both pumps of this system are in the same room. IRSN considers that an internal hazard (fire, flooding...) may result in the total loss of cooling of the spent fuel pool.

During the processing of the file dedicated to the safety of storage in spent fuel pool, Electricité de France assessed the accessibility and the operational aspect of the emergency support means for the pool in case of fire or flooding in the premises of the fuel storage building.

Since then, studies related to fire risk are currently being examined at IRSN. The potential consequences of a flooding and the related responses are still subject to studies within Electricité de France.

5 MODIFICATIONS CONSIDERED

The principle of the modifications considered by Electricité de France in order to improve the safety of fuel storage in spent fuel pool is almost identical for all nuclear plant reactors. It is addressed above and currently comprises:

- Reinforcement and leveling of the instrumentation of the pool parameters (level and temperature) in order to ensure a functional redundancy of the thresholds necessary for the monitoring of the facility in normal, incidental and accidental operation;
- Addition of a strainer to the suction of the cooling system of the spent fuel pool in order to prevent the loss of the cooling function by common mode in case of suction of a foreign body;
- Burn-in of the electrical supply of spent fuel pool cooling and treatment (PTR) pumps during interventions performed on electrical switchboard for preventive maintenance during unit shutdowns;
- Implementation of a valve manifold, accessible when the pool is boiling, used to compensate the pool water losses due to evaporation using a make-up line supplied by the demineralized water or fire protection systems;
- On thresholds equipped with a crosshead to the suction of the PTR system (case of the 1300 and 1450 MWe thresholds), the pool make-up line will be designed also in order to cool the suction line and prevent the formation of a vapor lock likely to stall or damage the pumps or other PTR system devices;
- On some reactors, it shall be necessary to open the fuel pool area outwards in order to enable the exhaust of water vapor in accidental situation and thus prevent pressurization and damage of the fuel storage building structures.

Moreover, out of these modifications intended to improve the safety of storage in spent fuel pool, Electricité de France provided for integrating on all thresholds a modification allowing the parallel operation of both cooling trains of the PTR system in order to increase its thermal exchange capacity and thus increase unit availability.

6 CONCLUSION

For a total loss of cooling accident linked to the failure of the cooling function or one of its support functions (initiators 1 to 3 cited above), the functional analysis taking into account the material modifications and the application of the accidental operating strategy considered by Electricité de France shows that, despite a high boiling probability (higher than 10^{-4} per unit and per year), the available time limits before reaching unacceptable consequences allow considering that the fuel dewatering risk is residual for this type of scenario (risk estimated at 10^{-8} per unit and per year for CPY series). Moreover, the growth of the risk related to the increase of the residual power storable in spent fuel pool is insignificant.

As a conclusion, IRSN assessment shows that some loss of cooling initiators, for which occurrence probability has not been quantified during processing, such as a rapid drainage of the spent fuel pool, a fire or flooding affecting the premises of the fuel storage building, are likely to be uncontrolled. Indeed, these accidents might result either in the simultaneous loss of cooling and make-up means of the pool, or in the dewatering of a fuel assembly during handling. Moreover, the risk that these situations result in unacceptable consequences is, in most cases, independent from the residual power stored in spent fuel pool. The detailed study of these situations might result in new modifications in order to improve their prevention and management.

APPENDIX: Diagram of the Fuel Pool Cooling System of a 900 MWe reactor

