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Chapter Pilot: F. GODEFROY *Name/Initials* *Date* *16-11-2012*	
Approved for EDF by: A. MARECHAL *Name/Initials* A.JC-Marechal *Date* *16-11-2012*	Approved for AREVA by: G. CRAIG *Name/Initials* G Craig *Date* *16-11-2012*

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For information address:

AREVA NP SAS
Tour AREVA
92084 Paris La Défense Cedex
France

EDF
Division Ingénierie Nucléaire
Centre National d'Equipement Nucléaire
165-173, avenue Pierre Brossolette
BP900
92542 Montrouge
France

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SUB-CHAPTER 15.3 – PSA OF ACCIDENTS IN THE SPENT FUEL POOL

1. INTRODUCTION

Sub-chapter 15.3 addresses the likelihood of damage to the fuel assemblies located in the spent fuel pool, or of boiling to the fuel building atmosphere. An assessment of the frequency of initiating events affecting the spent fuel pool cooling is presented, together with plant data assumptions and reliability data. The results of the analysis, for events involving both non-draining and draining of the spent fuel pool, are presented in terms of derived event sequence frequencies and the risk of fuel damage expressed as per reactor per year.

2. DESCRIPTION OF INITIATING EVENTS

2.1. DESCRIPTION OF FUEL POOL COOLING SYSTEM

The description is based on the system design documents [Ref-1] [Ref-2].

The Fuel Pool Cooling System (PTR [FPCS]) comprises:

- Two identical main trains:
  - A normal or main PTR [FPCS] train comprises :
    - Two parallel normal PTR [FPCS] lines (or sub train).
    - A tube heat exchanger and a motorised valve.
    - A manual valve (suction side) and a check valve (discharge side).

      A normal line comprises two manual valves, a pump and a series check-valve.
  - Both of the heat exchangers can be cooled by two Components Cooling Water (RRI [CCWS]) trains, and each active component has an emergency power supply;
  - The PTR [FPCS] power supply is provided by four safety trains which are backed-up by emergency diesel generators.
- A third train, which is equipped with a pump (100%) and a tube heat exchanger.
  - The heat exchanger is cooled by an intermediate cooling channel, shared with a Containment Heat Removal System (EVU [CHRS]) train, connected to the dedicated heat sink (SRU [UCWS]).

- The power supply for the third train is independent from the power supply to the main trains of the PTR [FPCS].
- The power supply is provided by two electrical divisions. This third train is backed-up by a Station Blackout generator in states D, E and F.

A simplified flow diagram of the PTR [FPCS] is presented in Sub-chapter 15.3 - Figure 1.

2.2. REPAIR AND RECOVERY ASSUMPTIONS

The following repair possibilities are assumed in the analysis:

Recovery of the cooling chain (RRI [CCWS]-SEC [ESWS])

In the event of a Loss Of Cooling Chain (LOCC), the repair of the RRI [CCWS] and SEC [ESWS] pumps concerned is assumed possible with a Mean Time To Repair (MTTR) of 30 hours.

Recovery of external power supply sources

Total Loss Of Offsite Power (LOOP) situations, discussed in Chapter 2 and section 4 of Sub-chapter 15.1, are assessed on the basis of the maximum time required for recovering the supply sources and not the average repair time. It is assumed that the short external power losses (2 hours) and the long external power losses (24 hours) are restored after 2 hours and 24 hours. Only the long LOOP with a maximum recovery time of 24 hours is considered.

2.3. INITIATING EVENT FREQUENCY ASSESSMENT

The consequence of concern in this sub-chapter is clad rupture affecting the fuel assemblies stored in the spent fuel pool, and leading to radioactive releases. This can be caused by the following conditions:

- a fuel uncovery after draining, or
- an increase in temperature of the SFP giving boiling conditions, or
- a reduction of the boron concentration leading to a criticality accident.

This last potential event is not addressed in the present study (see section 4.1 of this sub-chapter).

For draining events, the set of initiating events is derived from an analysis [Ref-1][1] of all situations in which the spent fuel pool is connected with other pool compartments. The quantification is based on the French experience on existing operating NPPs for events initiated by human error or on expert judgement [Ref-1][1] for pipework ruptures. They take into account the studies on the timescale from the start of pool draining to fuel uncovery.

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[1] This analysis is a Flamanville 3 (FA3) study that takes into account some specific features of the FA3 design but the results are bounding for the UK design. In particular, the analysis considers that the third PTR [FPCS] train is lower than for the UK design. Therefore, the calculations are conservative.

For non-draining events, the set of initiating events is derived from an analysis of the situations leading to the temperature increase, i.e. to the loss of the cooling system. The spent fuel pool is cooled by the PTR [FPCS], and operational experience of French and German NPPs and system analysis of the EPR design enabled loss of PTR [FPCS] to be identified as the potential initiating event. This may be due either to loss of the pump or to failure of the header, or to the loss of the support functions, the electrical supply or the cooling chain.

Hence, the following initiating events are considered:

- Incidents or accidents affecting the support systems of PTR [FPCS] main trains (initiating events), comprising:
    - Loss of Electrical Supply (LESUPPLY).
    - Loss Of Offsite Power (LOOP) for 24 hours.
    - Loss Of Cooling Chain (LOCC).
- Loss of PTR [FPCS] main trains caused by the loss of PTR [FPCS] pump or header (LFPCP and LHEADER).
- Loss of the two PTR [FPCS] main trains (L2FCP) causing the total loss of fuel pool cooling, i.e. simultaneous unavailability of the two PTR [FPCS] main trains with a potential for losing the third train.
- Spent Fuel Pool emptying (fast level drop).

Following such events, the following consequences in the fuel building can arise:

- Saturation conditions in the pool in the event of the total loss of the PTR [FPCS] (boiling),
- Degradation of the fuel assemblies in the pool following boiling of water in the Spent Fuel Pool (fuel damage).

Sub-chapter 15.3 - Table 1 gives the frequency per year of the initiating events studied for the Non Draining Events. All reactor states are covered. The reactor states are described in sub-section 3.1.1 of this sub-chapter.

Sub-chapter 15.3 - Table 2 gives the frequency per year of the initiating events studied for the Draining Events [Ref-2]. All reactor states are covered. The reactor states are described in sub-section 3.1.2 of this sub-chapter.

At power or during shutdown with the core in the vessel, the frequency of Initiating Events affecting the Fuel Pool Cooling System is {CCI} [a]:

- The dominant initiating event is the loss of a PTR [FPCS] pump (49%),
- 97% of the risk of losing the PTR [FPCS] occurs during at-power states.

During refuelling, the frequency of loss of the PTR [FPCS] is evaluated as {CCI} [a]:

- The dominant initiating event is the loss of both PTR [FPCS] operating trains following the loss of the RRI [CCWS]/SEC [ESWS] cooling system (60%),

- The second main cause of the loss of the main PTR [FPCS] trains is the failure of the pumps in operation (32%).

2.4. EXTERNAL EVENT: LOSS OF ULTIMATE HEAT SINK

The impact of the loss of the Ultimate Heat Sink, which is site-specific, is assessed in this section at a generic level, and predicted to be negligible by comparison with loss of PTR [FPCS] due to the internal initiating events assessed in sub-section 2.3 of this sub-chapter.

In the event of a Loss of Ultimate Heat Sink, described in Sub-chapter 15.2, both main trains are lost but the third PTR [FPCS] train remains available because of its diverse heat sink cooling which is shared with the EVU [CHRS] train.

However, following a **LUHS in non refuelling states**, some accident sequences would require the operation of the third PTR [FPCS] train and the EVU [CHRS] trains simultaneously. In that case, priority is given to the EVU [CHRS] as discussed in sub-section 4.4.3.5 of this sub-chapter. To avoid boiling and unacceptable consequences in the spent fuel pool, the remaining levels of recovery are the means of makeup. In this situation, ultimate makeup means, e.g. mobile equipment, must be used. As this depends on procedural and organisational aspects, the probabilistic assessment will not be performed during the GDA. However, it will be carried out when further details of makeup procedures and plant design are available.

Nevertheless, the risk of fuel damage is assessed to be insignificant on the basis of the following arguments:

- In non refuelling states, the LUHS frequency is estimated as {CCI} [a]. Based on operational experience feedback [Ref-1] from analysis of incidents that have affected the heat sinks of nuclear plants, a maximum duration of 100 hours is assumed for the recovery of the SEC [ESWS]. These range from five hours for fouling to approximately 100 hours in the event of blockage. The time window to perform recovery actions in order to prevent fuel damage in the SFP is at least 106 hours with conservative assumptions. This is shown in the table “Chronology of events and corresponding Time Window” in sub-section 4.4.1.4 of this sub-chapter.
- In refuelling states (REF), the LUHS frequency is {CCI} [a].
  The mean recovery time of the heat sink is 30 hours [Ref-1]. The time window to perform recovery actions in order to prevent fuel damage in the SFP is at least 32 hours. This is shown in the table “Chronology of events and corresponding Time Window” in sub-section 4.4.1.4 of this sub-chapter. In this case, the whole plant decay heat removal is provided by the PTR [FPCS], with the third train fully available.

The makeup means and their capacities are presented in sub-section 4.4.1.5 of this sub-chapter.

3. INITIAL DATA AND PSA ASSUMPTIONS

This analysis is based on the operating profile of the Level 1 PSA described in Sub-chapter 15.1.This analysis is based on a reactor power of 4900MW. This is a conservative assumption in relation to an equivalent analysis with the EPR reactor power of 4500MW[2].

This PSA uses the methodology presented in Sub-chapter 15.1.

Note: Fuel Handling accidents are presented in Sub-chapter 15.5.

3.1. OPERATIONAL MODES

3.1.1. Non-Draining Initiating Events

It is necessary to study each plant state because of the different configurations or characteristics of the support systems of electrical supply or cooling chain.

The probabilistic assessment is carried out for the following situations:

- Situations arising during power or shutdown states with the core in the reactor vessel. In these circumstances one PTR [FPCS] train is required to be in operation with one pump. This phase covers the operational modes A, B, C, D and half of state E of the reactor. The initial conditions of state D are applied conservatively to all of the reactor states while making a distinction between the state prior to unloading and the state following refuelling. The highest thermal power in the Fuel Pool is at the Beginning Of Cycle (BOC) and corresponds to state D following refuelling.

- Situations arising during shutdown for refuelling. In these circumstances, both PTR [FPCS] main trains are required to be in operation with one pump each. This phase covers half of state E and state F of the reactor. This means that all the fuel assemblies are in the Spent Fuel Pool.

The following table defines the PTR [FPCS] configuration in, and duration of, the different plant states:

Plant States	**Code**	**Duration**	**PTR [FPCS] configuration**
Power operation	AB	8225 h	1 Train with 1 pump
RCP [RCS] closed	C	137 h	1 Train with 1 pump
Vessel head lifting	D	44 h	1 Train with 1 pump
Fuel handling	E/2	60.5 h	1 Train with 1 pump
Refuelling	REF	293.5 h	2 Trains with 1 pump each

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[2] The reactor power value is directly linked to the decay heat to be considered for the event evaluation.

The following terms are also used to describe the states considered for the reactor: Beginning of Cycle (BOC), End of Cycle (EOC) and Refuelling (REF).

3.1.2. Draining Initiating Events

For pool draining, the standard reactor states as defined in Sub-chapter 15.1 are used.

The probabilistic assessment is carried out for the following situations:

- While the reactor is at power or shutdown, the Spent Fuel Pool is isolated from the reactor building pool (states A, B, C and D).

- In shutdown during the unloading or the refuelling of the reactor, when the Spent Fuel Pool and the reactor building pool are connected (state E).

- In shutdown with the core unloaded, when the Spent Fuel Pool and the reactor building pool are isolated from each other (state F).

3.2. RELIABILITY DATA

For this specific analysis, the reliability data [Ref-1] are taken from EDF operating experience, German operating experience and the EG&G generic database as described in Sub-chapter 15.1.

For the PTR [FPCS] pumps, the reliability data gathered is from EDF [Ref-1]. The same reliability data is used for the components of the PTR [FPCS] main trains and the emergency train (third train).

Common Cause Failure (CCF) between the main trains and the third train is discounted because the main components, heat exchanger, pumps etc. are diverse apart from the electrical supply components.

The equipment repair times are taken from EDF operating experience feedback [Ref-2] from the units in operation and the repair times are estimated using the Human Cognitive Reliability (HCR) Model [Ref-3].

3.3. CONSEQUENCES

Two consequences can occur due to loss of the active fuel pool cooling:

- Boiling to the atmosphere of the fuel building is assumed to occur once a temperature of 97°C is reached in the Spent Fuel Pool as discussed in sub-section 4.4.1 of this sub-chapter. An adequate level in the Spent Fuel Pool is maintained by a makeup system thus preventing fuel uncovery and damage;

- The more severe consequence, fuel damage, is assumed if the fuel assemblies in the Spent Fuel Pool are uncovered for an extended period of time.

3.4. PREVENTIVE MAINTENANCE

Preventive maintenance is considered in the probabilistic assessment of the loss of the Fuel Pool Cooling System:

- Preventive maintenance on the second RRI [CCWS] / SEC [ESWS] train during the at-power state,
- Preventive maintenance in at-power states on the first sub-train of PTR [FPCS] train 2.

  Note: Preventive maintenance in at-power states on the PTR [FPCS] should be considered on train 1, for which cooling is affected by the preventive maintenance on the RRI [CCWS] / SEC [ESWS], but this modelling choice is made to accurately calculate the risk of boiling and fuel damage for initiating events inducing the loss of PTR [FPCS] train 1.
- Preventive maintenance on the second RRI [CCWS] / SEC [ESWS] train during state E/2.

4. PSA FOR NON-DRAINING EVENTS

4.1. INTRODUCTION

Following a loss of cooling of the Spent Fuel Pool, and if there is no recovery of the situation, the consequences are a temperature rise up to 100°C, boiling off of the water and fuel damage due to the uncovery of the fuel assemblies.

Several signals exist to inform the operator about the abnormal situation following the loss of cooling of the Spent Fuel Pool. In particular, various alarms indicating unavailability of a pump, high temperature, low flow rate, low suction or discharge pressure. These lead the operator to start the stand-by PTR [FPCS] pump or train. In the event of the lack of indication, the temperature of the Spent Fuel Pool increases up to boiling. To support the restart of another PTR [FPCS] train or pump, and hence avoid fuel uncovery, the operator initiates the Spent Fuel Pool makeup. This uses either normal means or a backup until the failed components have been repaired.

The safety functions for the Spent Fuel Pool that are challenged by the event are the following:

- **Reactivity Control**: the boron concentration must be sufficient to avoid criticality. Details on reactivity control in the Spent Fuel Pool are given in Sub-chapter 9.1.
- Removal of decay heat and stored heat. This safety function is divided into:
    - **Residual Heat Removal**: In order to prevent boiling, the Spent Fuel Pool must be cooled by the dedicated Fuel Pool Cooling and Purification System.
    - **Long term cooling**: In order to avoid fuel uncovery, the Spent Fuel Pool must be cooled by the dedicated system Fuel Pool Cooling and Purification System and makeup must be activated when necessary.

- **Spent Fuel Pool [FPCS] integrity** (containment): in the event of fuel damage, there is a risk of radioactive release. Thus, the integrity of the containment system must be maintained and the different components should be protected.

- **Spent Fuel Pool inventory control**: the inventory needs to be maintained above the minimum level to support PTR [FPCS] operation and prevent fuel uncovery. As discussed above, in the long term, makeup would be required.

4.2. SPECIFIC ASSUMPTIONS FOR THE NON-DRAINING INITIATING EVENTS

The following assumptions, specific to non-draining initiating events, are made in addition to the general PSA assumptions described in section 3 of this sub-chapter.

External leaks from the Fuel Pool are assumed not to have any direct effect on the Fuel Pool Cooling System. Such leaks are assumed to be detected by the leak detection system and to be covered by the makeup function of the Fuel Pool Purification System, which is started manually following a fuel pool low-level signal.

External leakage and rupture on the RRI [CCWS] and SEC [ESWS] systems are assumed to lead to the Loss of the Cooling Chain of the PTR [FPCS] (LOCC initiating event).

External leakage from the PTR [FPCS] header is assumed to lead to the loss of PTR [FPCS] main train as an initiating event.

Reliability data are used for the assessment of the probability of failure per demand of the PTR [FPCS] pumps, which is the initiating event.

4.3. EVALUATION OF THE FREQUENCY OF LOSS OF THE PTR [FPCS]

4.3.1. Events studied

Analyses of the postulated events involving the PTR [FPCS] are carried out for:

- The reactor at–power state or during shutdown with the core in the vessel (states A to D and half of state E): non refuelling states.

- The reactor shutdown with the whole core in the Spent Fuel Pool (half of state E and state F): refuelling states (REF).

Depending on the reactor operational modes, the events are grouped as follows:

- Loss of the PTR [FPCS] line (states A to D) or two[3] PTR [FPCS] lines in-service (REF) requiring the start-up of another PTR [FPCS] line.

- Loss of the PTR [FPCS] main train in service (states A to E/2) requiring the start-up of another PTR [FPCS] train or the loss of both main PTR [FPCS] trains in-service (REF).

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[3] During refuelling, the loss of both lines in service is assumed as an initiating event as it leads to more severe consequences than the loss of one line out of two in service.

- Loss of Offsite Power (LOOP).
- Loss of Electrical Supplies.
- Loss of pool water cooling (Loss Of Cooling Chain).
- Loss of PTR [FPCS] header.

4.3.2. Failures of the third PTR [FPCS] train

The unavailability of the cooling channel dedicated to the emergency (third) train during the repair time of a PTR [FPCS] main train is considered.

4.4. EVALUATION OF BOILING AND FUEL DAMAGE RISKS

4.4.1. Analysis assumptions

4.4.1.1. Decoupling criterion

Following the loss of the PTR [FPCS], either as a result of random failure or following the loss of a support system, heat sink or power supply, the temperature of the fuel pool water rises to 100°C and the water then boils. Without water makeup, the level of the fuel pool drops, resulting in the uncovering of, and possible damage to, the fuel assemblies.

Nevertheless, because of the ability to restart the PTR [FPCS] at 100°C as discussed in sub-section 4.4.1.2 of this sub-chapter, the following decoupling criterion is used in the analysis. “The beginning of fuel uncovery {CCI} [a] is assumed to mean that the threshold of ‘Unacceptable Consequences’ (fuel damage or boiling) as defined in Sub-chapter 15.1 for the fuel assemblies has been reached”. Note that, even if the PTR [FPCS] suction degradation threshold is at {CCI} [a], it will be possible to recover this level from {CCI} [a], using the makeup means with sufficient flow capacity.

4.4.1.2. Restarting at 100°C

The entire PTR [FPCS] system, including the third train, is designed to be capable of restart at 100°C. In the event of total loss of cooling of the Spent Fuel Pool and of restarting the PTR [FPCS], the PSA uses the following assumptions:

- Restarting the PTR [FPCS] is possible without makeup if it is brought back into service before reaching a temperature of 97°C in the Spent Fuel Pool. [4]
- Beyond this threshold, restarting of the PTR [FPCS] is only assumed to be possible if water makeup has been actuated and if the water level in the fuel pool remains above {CCI} [a], the level of the PTR [FPCS] suction ducts.
- Makeup is possible as long as the level does not drop below the decoupling criterion {CCI} [a].

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[4] A conservative assumption which eliminates the risk of vaporisation in the PTR [FPCS] suction line [Ref-1]. The analysis [Ref-1] is a Flamanville 3 (FA3) study that takes into account some specific features of the FA3 design but the results are bounding for the UK design. In particular, the analysis considers that the third PTR [FPCS] train is lower than for the UK design. Therefore, the calculations are conservative.

4.4.1.3. Calculation assumptions

To determine the accident kinetics, the following general assumptions are used in the analysis:

- Fuel management regime: MOX with 18-month cycle.
- Volume in the Spent Fuel Pool: 1486 m^3 [Ref-2].
- Reduced volume in the Spent Fuel Pool[5]: 1195 m^3.
- 15% margin on decay heat. The assumed decay heat is 6800 kW for beginning of cycle, 2700 kW for end of cycle and 22300 kW during refuelling [Ref-1].
- Initial temperature in the pool is related to the reactor state.

The evaporation rate following the total loss of the PTR [FPCS] is calculated on the basis of the following formula:

$$Ve = v'' \times Q / r$$

Whereby: Ve: vaporisation rate [m^3/s]

Q: decay heat [kW] or [kJ/s]

r: specific heat of evaporation [kJ/kg]

v'': specific volume of steam [m^3/kg]

The evaporation rates are listed in the following table:

	VAPORISATION RATE (m^3/h)
Beginning of cycle (BOC)	10.8
End of cycle (EOC)	4.3
Refuelling (REF)	35.6

Vaporisation rates in the pool at T0 corresponding to the case of total loss of PTR [FPCS]

4.4.1.4. Chronology of events

The following table shows the time windows available to the operator that are important for the analysis, starting from T0, the time of the initiating event:

- The time following the loss of the PTR [FPCS] before 97ºC is reached (T1).
- The time window, in the absence of makeup, before the start of the uncovery of the fuel assemblies (T2).

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[5] A reduced spent fuel pool inventory (1195 m^3) following a loss of inventory is taken into account: this value corresponds to {CCI} [a] (level limited by siphon breaker) on the suction line [Ref-1].

	TIME WINDOW (hours)		
	REF	**BOC**	**EOC**
For normal volume in the Spent Fuel Pool (1486 m^3)			
Total loss of PTR [FPCS] T0	0	0	0
97°C reached T1	4.0	13.6	35.3
Level {CCI} [a] **reached without makeup T2**[6]	*33.0*	*107*	*272*
In case of reduced volume in the Spent Fuel Pool (1195 m^3)[7]			
97°C reached T1	*3.3*	*11.1*	*28.9*
Level {CCI} [a] **reached without makeup T2**[4]	*32.0*	*105.9*	*266*

Chronology of events and corresponding Time Windows

4.4.1.5. Makeup systems

The main characteristics of the makeup systems for the Spent Fuel Pool are summarised in the following table:

	Intervention	**Makeup rate**	**Water storage**	**Comments**
REA [DWS + RBWMS]	Control room	> 40 m^3/h	800 m^3	Unavailable in the event of LOOP
IRWST + FPPS (fuel pool purification system)	Control room + local line	90 m^3/h	1895 m^3	Unavailable in the event of LOOP
JPI (fire fighting system)	Local line	> evaporation rate	~ 1000 m^3	Available in the event of Station Blackout (SBO) PTR [FPCS] loss resulting from LOOP
SDR [DWS] Direct	Local line	> 40 m^3/h	~ 800 m^3	Unavailable in the event of LOOP

Characteristics of Spent Fuel Pool makeup systems

Note: Due to the functional dependencies between RBWMS and DWS makeup and the DWS direct makeup, the effectiveness of redundancy will be limited. For this reason, the availability of DWS direct makeup is not assumed in this analysis.

4.4.1.6. I&C functions

In this kind of event, with few self-actuated functions, the information available to the operator in the control room is essential. Thus the I&C is included in the PSA model in order to take into account the generation of alarms.

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[6] The time window available before fuel uncovery is assessed assuming 1018 m^3 for the spent fuel pool, i.e. {CCI Removed} [a] [Ref-1].

[7] The loss of PTR [FPCS] header assumes a reduced spent fuel pool inventory (1195 m^3) following the loss of inventory due to the leak in the header (only the water inventory above {CCI} [a] is considered)

The signals that are included in the analysis, low PTR [FPCS] flow rate, low discharge pressure and high temperature of Spent Fuel Pool (two diversified signals in the Safety Automation System and the Non-Computerised Safety System), are those relevant for each group of initiating events.

4.4.1.7. Analysis of operator actions

In the event of activation of the alarms used to detect loss of fuel pool cooling, the operator must implement the appropriate emergency operating procedures to manage the accident.

Nevertheless, the activation of the 'fuel pool low level MIN1' alarm is sufficient indication for the operator to start a makeup device and prevent fuel damage.

In all cases, fuel pool makeup is initiated as soon as the 'fuel pool very low level MIN2' alarm is activated in the control room.

Conservatively, these intermediate makeup actions are not taken into account; only the time window available before fuel uncovery is assessed.

In the event of failure of I&C indications and failure of activation of the makeup countermeasures by the operator, the possibility of repairing failed components is taken into account for non refuelling states where the time window available is about 107 hours. For the refuelling phase, it is conservatively assumed that the failure of I&C followed by the failure of makeup actuation by the operator, would lead directly to fuel damage as the time window available is about 30 hours.

4.4.2. Analysis of the accident

The following chronology relates to the most severe case that can be envisaged, namely the total loss of the fuel pool cooling during the refuelling phase, when the decay heat is at its maximum.

Following the loss of cooling, the fuel pool water reaches 97°C in 4.0 hours. The 'fuel pool very low level MIN2' setpoint is reached less than one hour later. Therefore, it is necessary to initiate the third train.

Because of this, the start-up of a makeup device is conservatively assumed to be required about 30 hours following the loss of cooling by the PTR [FPCS]. The water makeup rate must be sufficient to compensate for the evaporation of the pool water.

The various makeup means envisaged and, more specifically, the REA [RBWMS-DWS] system, are capable of providing this function. Stored water is likely to compensate for the evaporation of the Spent Fuel Pool for several hours. This additional time may be used to carry out repairs on the PTR [FPCS] system or other faulty systems.

If the PTR [FPCS] has not been restored during the time period when makeup means are activated, other makeup systems must be used, e.g. the Fuel Pool Purification System-IRWST, JPI etc.

If the repairs are unsuccessful and no pool makeup is implemented, i.e. normal and other makeup means, including ultimate means, fuel uncovery starts and Unacceptable Consequences cannot be avoided.

4.4.3. Quantification

4.4.3.1. Classification of the situations involving total loss of PTR [FPCS]

To analyse the consequences of the total loss of fuel pool cooling, the various total loss of PTR [FPCS] situations are grouped according to the following representative criteria:

- Situations which lead or do not lead to the boiling of the fuel pool i.e. situations where repair before the boiling point is reached is successful or unsuccessful.
- Situations which allow or do not allow recovery and/or repair.
- Situations involving the availability of countermeasures, i.e. makeup systems.

4.4.3.2. Quantification of human factors

The operator has:

- Various means, alarms and other indications in the main control room, to establish the diagnosis and the need for makeup.
- Between 4 hours, in the least favourable refuelling state, and 35 hours, in the most favourable case at end of cycle, for activation of the necessary stand-by pump/train (see sub-section 4.4.1.4 of this sub-chapter).
- Between about 32 hours, in the least favourable refuelling state, and 260 hours, in the most favourable case at end of cycle, (see sub-section 4.4.1.4 of this sub-chapter) for activation of the makeup countermeasures.

The probability of failure to initiate the stand-by pump/train and water makeup in the fuel pool is a function of the time window available, and is estimated using the human reliability model presented in Sub-chapter 15.1.

In the case of failure of the SPPA-T2000 platform, the initiation of a stand-by pump and/or trains is performed locally. The reliability for this local action is conservatively decreased despite there being a long grace period available.

4.4.3.3. Quantification of the makeup system missions

Failure to start and the failure rate in operation of the main makeup systems are assessed taking into consideration the design of these systems. The other means, e.g. Fuel Pool Purification System-IRWST, JPI etc. and ultimate means, of makeup are taken into account assuming a global failure rate derived by expert judgement.

4.4.3.4. Quantification of instrumentation and control (I&C) missions

The model chosen for the I&C modelling is presented in Sub-chapter 15.1.

Due to the functional and component diversity of the various classifications of instrumentation channels, failure of the instrumentation and control mission is mainly due to the failure of common logic. However, a local action to initiate a stand-by PTR [FPCS] pump or train in case of failure of the common logic part is considered in the PSA.

Furthermore, it is assumed that when the time window available to the operator is above 30 hours, the makeup system can be actuated even if the instrumentation is faulty. In this period of time, monitoring of the fuel pool can be performed by the operator and a makeup device can be actuated.

Using a conservative approach, the study is based on the principle that the failure of the instrumentation and control over occurs during the whole mission period. In this event, recovery by the operator is possible in most cases.

4.4.3.5. Evaluation of the EVU [CHRS]/PTR [FPCS] combination risks

The third PTR [FPCS] train and the EVU [CHRS] system are cooled by the same heat sink. This cooling channel is designed for the separate water requirements of the two systems. The probability of the simultaneous use of the third PTR [FPCS] train and the EVU [CHRS] is then evaluated to show the acceptability of the current design.

The probability that the third PTR [FPCS] train is required at the same time as the EVU [CHRS] during accident situations must be taken into account for the situations involving a loss of PTR [FPCS].

In the light of the particular characteristics of the combined scenarios[8], an evaluation of the increase in the risk of reaching boiling and Unacceptable Consequences in the pool is carried out, assuming that priority is always given to the EVU [CHRS] and that the third train is deliberately deprived of heat sink in core accidents.

This evaluation shows that the impact on the risk is not significant.

4.4.4. Results

4.4.4.1. Overall boiling and fuel damage Frequency

Boiling following the loss of cooling of the Spent Fuel Pool may result from the following initiating events:

Initiating Event	Boiling /ry
Loss of PTR [FPCS] pump	7.22E-05
Loss of electrical supply	8.48E-06
Loss of Offsite Power (24h)	5.13E-06
Loss of PTR [FPCS] header	2.20E-07
Loss of Cooling Chain	1.96E-04
Total (boiling)	**2.82E-04**

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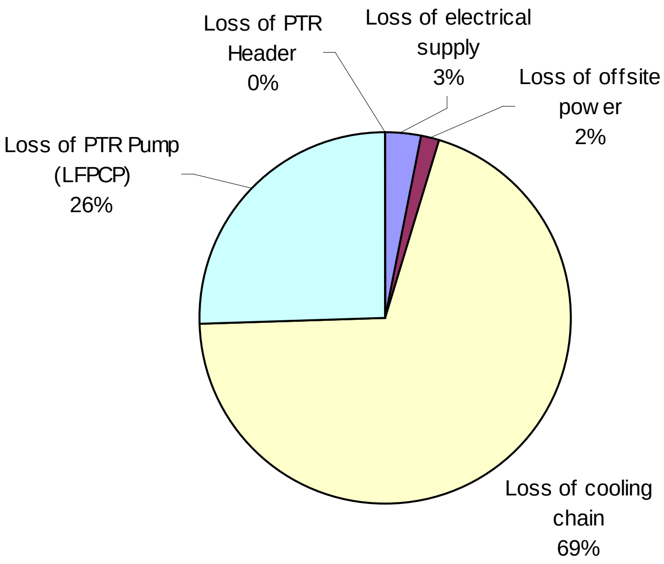
[8] The IRWST cannot be used as a makeup device for the PTR [FPPS/FPCS] during core accidents as the water is needed to manage the accident in the reactor building.

The distribution of the risk of boiling by initiating event is shown below:



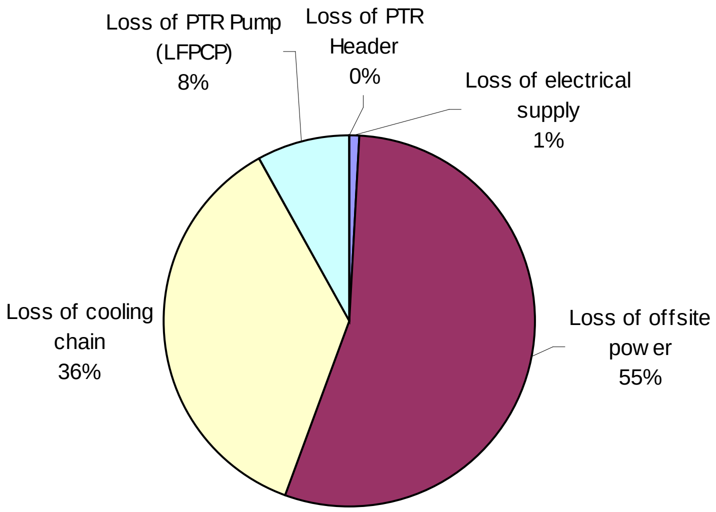
The overall frequency of boiling is 2.82E-04/ry.

The two main contributing events are the LOCC and the loss of PTR [FPCS] pump.

Fuel damage following the loss of cooling of the Spent Fuel Pool may result from the following initiating events:

Initiating Event	fuel damage frequency /ry
Loss of PTR [FPCS] pump	2.06E-11
Loss of electrical supply	2.16E-12
Loss of Offsite Power (24 hours)	1.39E-10
Loss of PTR [FPCS] header	5.85E-14
Loss of Cooling Chain	9.25E-11
Total (fuel damage)	**2.54E-10**

The distribution of the risk of fuel damage resulting from the various initiating events is shown below:



The overall frequency of fuel damage is 2.54E-10/ry. The two main contributing events are LOOP and LOCC.

The contributions from the different plant operation states are shown in the following table:

Plant State	FUEL DAMAGE	BOILING
A+B	1.64E-10	2.72E-04
C	1.59E-12	4.27E-06
D	5.10E-13	1.37E-06
E/2	7.40E-13	2.03E-06
REF	8.73E-11	2.88E-06
OVERALL	**2.54E-10**	**2.82E-04**

The dominant contribution for the total frequency of fuel damage is provided by initiating events in at-power state (A+B) (65%). The refuelling state contributes 34%.

The total frequency of boiling is dominated by the contribution from the initiating event in the at-power state A+B (96%).

4.4.4.2. Loss of PTR [FPCS] pump

LFPCP	Frequency of fuel damage (/ry)	Frequency of Boiling (/ry)
AB	1.79E-11	7.00E-05
C	2.96E-13	1.16E-06
D	9.53E-14	3.73E-07
E/2	1.31E-13	5.13E-07
REF	2.14E-12	1.22E-07
OVERALL	**2.06E-11**	**7.22E-05**

The frequency of boiling is dominated by the contribution from the at-power states AB (97%). The contribution to the overall frequency in state AB is about 26%.

The frequency of fuel damage due to pump loss is dominated by the contribution from the at-power state AB (87%). However, the absolute value is low. Moreover, the contribution to the overall frequency in state AB is about 11%.

4.4.4.3. Loss of Electrical Supply

LESUPPLY	Frequency of fuel damage (/ry)	Frequency of Boiling (/ry)
AB	2.11E-12	8.27E-06
C	3.01E-14	1.20E-07
D	9.48E-15	3.83E-08
E/2	1.30E-14	5.27E-08
REF	1.83E-15	1.21E-10
OVERALL	**2.16E-12**	**8.48E-06**

The frequency of boiling is dominated by the contribution from the at-power state AB (98%). However, the contribution to the overall frequency in state AB is low (3%).

The frequency of fuel damage is dominated by the contribution from the at-power state AB (97%). However, the absolute value is very low. Moreover, the contribution to the overall frequency of fuel damage in state AB is low (1%).

4.4.4.4. Loss of PTR [FPCS] Header

LHEADER	Frequency of fuel damage (/ry)	Frequency of Boiling (/ry)
AB	5.71E-14	2.15E-07
C	7.68E-16	3.10E-09
D	2.36E-16	9.94E-10
E/2	3.40E-16	1.37E-09
REF	7.00E-17	2.10E-13
OVERALL	**5.85E-14**	**2.20E-07**

The frequency of boiling is dominated by the contribution from the at-power state AB (98%). However, the contribution to the overall frequency in state AB is 0.1%.

The frequency of fuel damage is dominated by the contribution from the at-power state AB (98%). However, the absolute value is very low. Moreover, the contribution for the overall frequency of fuel damage in state AB is only 0.03%.

4.4.4.5. Loss of Cooling Chain

LOCC	Frequency of fuel damage (/ry)	Frequency of Boiling (/ry)
AB	4.81E-11	1.88E-04
C	7.56E-13	2.96E-06
D	2.42E-13	9.51E-07
E/2	3.71E-13	1.45E-06
REF	4.3E-11	2.72E-06
OVERALL	**9.25E-11**	**1.96E-04**

The frequency of boiling is dominated by the contribution from at-power state AB (96%). In addition, the LOCC provides the majority contribution (69%) to the overall frequency in state AB.

The frequency of fuel damage is dominated by the contribution from at-power states AB (52%) and from the Refuelling state (47%). However, the absolute values remain low. The contribution to the overall frequency in state AB is 29% and in the Refuelling state is 49%.

4.4.4.6. Loss of Offsite Power

LOOP	Frequency of fuel damage (/ry)	Frequency of Boiling (/ry)
AB	9.59E-11	5.05E-06
C	5.10E-13	2.71E-08
D	1.63E-13	8.69E-09
E/2	2.25E-13	1.20E-08
REF	4.22E-11	3.63E-08
OVERALL	**1.39E-10**	**5.13E-06**

The frequency of boiling is dominated by the contribution from the at-power state AB (98%). However, the contribution for the overall frequency in state AB is low (2%).

The frequency of fuel damage is dominated by the contribution from the at-power state AB (69%). Moreover, the contribution to the overall frequency in state AB is 58%.

4.4.4.7. Dominant Accident Sequences

4.4.4.7.1. Boiling

The following table lists the main Spent Fuel Pool accident sequences leading to boiling, in all reactor states. They represent around 88% of the overall risk of boiling in the Spent Fuel Pool.

Initiating event	Description	Freq. (/ry)	%
Loss of Cooling Chain in state AB	Failure of the SPPA-T2000 platform **and** the operator fails the local action to initiate the stand-by pump before 97°C	1.6E-04	57.8
Loss of pump in state AB	Failure of the SPPA-T2000 platform **and** the operator fails the local action to initiate the stand-by pump before 97°C	5.7E-05	20.2
Loss of pump in state AB	Failure of the operator to initiate the stand-by pump before 97°C	1.1E-05	4.0
Loss of Cooling Chain in state AB	Failure of the operator to initiate the stand-by pump before 97°C	9.6E-06	3.4
Loss of Cooling Chain in state AB	Failure of PTR [FPCS] train 2 due to a mechanical failure (including support systems) **and** preventive maintenance on train 3.	9.1E-06	3.2

4.4.4.7.2. Fuel Damage

The following table lists the main Spent Fuel Pool accident sequences due to accidents leading to fuel damage, in all reactor states. They represent around 81% of the overall risk of fuel damage in the Spent Fuel Pool (for non draining events).

Initiating event	**Description**	**Freq. (/ry)**	**%**
Long Loss of Offsite Power in state AB	Failure of fuel pool cooling due to failure of emergency electrical supply and/or preventive maintenance **and** failure of makeup with backup means **and** failure to repair the failed components	6.14E-11	24.1
Loss of Cooling Chain in state AB	Failure of the SPPA-T2000 platform **and** the operator fails the local action to initiate the stand-by pump before 97°C **and** the operator fails to initiate makeup of the fuel pool **and** failure to repair the failed components before 107 hours	3.07E-11	12.1
Loss of Cooling Chain in Refuelling state	Failure of the third PTR [FPCS] train (cooling chain or intrinsic) **and** failure of the operator to initiate the makeup device **and** failure to repair failed components before 33 hours	2.86E-11	11.3
Loss of Offsite Power in Refuelling state	Failure of the SPPA-T2000 platform **and** the operator fails the local action to initiate the stand-by pump before 97°C **and** failure of makeup with backup means **and** failure to repair the failed components before 33 hours	1.96E-11	7.7
Loss of Offsite Power in Refuelling state	Failure of fuel pool cooling due to failure of emergency electrical supply and/or preventive maintenance **and** failure of makeup with backup means **and** failure to repair the failed components before 33 hours	1.73E-11	6.8
Long Loss of Offsite Power in state AB	Failure of the SPPA-T2000 platform **and** the operator fails the local action to initiate the stand-by pump before 97°C **and** failure of makeup with backup means **and** failure to repair the failed components before 107 hours	1.57E-11	6.2
Loss of Cooling Chain in state AB	Failure of the SPPA-T2000 platform **and** the operator fails the local action to initiate the stand-by pump before 97°C and failure of makeup of the fuel pool due to failure of normal and backup means **and** failure to repair the failed components before 107 hours	1.09E-11	4.3

Initiating event	Description	Freq. (/ry)	%
Loss of PTR [FPCS] pump in state AB	Failure of the SPPA-T2000 platform **and** the operator fails the local action to initiate the stand-by pump before 97°C **and** the operator fails to initiate makeup of the fuel pool **and** failure to repair the failed components before 107 hours	1.07E-11	4.2
Loss of Cooling Chain in Refuelling state	Failure of the third PTR [FPCS] train (cooling chain or intrinsic) **and** failure of makeup of the fuel pool due to failure of normal and backup means **and** failure to repair failed components before 33 hours	1.03E-11	4.1

The dominant cause of boiling to the atmosphere within the fuel building is the failure of the operator to initiate another PTR [FPCS] pump or train from the main control room or locally. This action has to be performed locally in the case of failure of the SPPA-T2000 platform. The overall boiling frequency is judged conservative; the reliability allocated to the local action is underestimated considering the significant grace period before unacceptable consequences are reached.

The dominant cause of fuel damage is the failure of the fuel pool cooling due to failure of the emergency electrical supply and the failure of the makeup of the fuel pool with back-up means which remain available in case of LOOP.

The second most important cause of fuel damage is the failure of the operator to initiate the makeup after the dominant boiling sequences identified above.

In addition, the need to repair the failed component and the third PTR [FPCS] train, both its components and the cooling chain, is significant.

5. PSA FOR DRAINING EVENTS

5.1. INTRODUCTION

At this stage, this section only considers the frequency of the Spent Fuel Pool rapid draining initiating events and the associated risks of damage to fuel assemblies stored in the Spent Fuel Pool or in handling operations (e.g. fuel transfer between the loading pit and the fuel building transfer compartment).

This quantification forms a basis for the ranking of the Plant Condition Categories (PCC) of draining initiating events and aims to confirm that there is practically no risk of fuel damage in handling operations or while stored in the pool following draining of the Spent Fuel Pool.

The following are excluded:

- Draining scenarios which lead to leaks that can be made up by normal makeup means (<40 m^3/h).

Non-isolable gross failures of piping penetrations in the Spent Fuel Pool and connected compartments have previously not been considered within the UK EPR design basis and the PSA, by invoking the break preclusion arguments. In addition, gross failure of technical openings, doors and the cask loading pit were not considered. Such events could in principle lead to drainage of the Spent Fuel Pool and connected compartments, leading to overheating of fuel assemblies being handled. The UK EPR safety case has been revised to include these additional failures within the design basis to avoid the need to make a High Integrity Component (HIC) claim on the associated penetrations and closures, which is likely to lead to rapid draining of the Spent Fuel Pool. The revised elements of the safety case are presented in section 8 of PSCR Sub-chapter 16.4.

The current PSA model has not been updated to take into account the new pool draining events identified in PSCR Sub-chapter 16.4. This is because, taking account of their low frequency of occurrence and safeguards systems available to protect against them presented in section 8 of PSCR Sub-chapter 16.4, the fuel damage frequency contribution due to the new pool draining events is expected to be similar to the fuel damage frequency due to other draining events that is currently calculated. These events will be incorporated into the PSA section of the PCSR during the site licensing phase, which will also consider the risk reduction measures proposed for the UK EPR design.

5.2. IDENTIFICATION OF RAPID DRAINING EVENTS

5.2.1. Draining via a break in the pipes connected to the reactor building pools

During unloading and refuelling (state E), the reactor building pools are in contact with the Spent Fuel Pool via the transfer tube. A break in the primary system or one of the systems connected to it is therefore likely to result in the draining of the Spent Fuel Pool.

The following table presents the initiating events of this group and the break equivalent area or piping nominal diameter (DN). Depending on the nature and position of the break, it indicates whether it is isolatable or not.

Nature and position of break	Plant state	Isolatable or not	Equivalent diameter	Area (cm^2)
RCP [RCS]	E	no	-	1 to 5
RIS/RRA inside isolatable containment	E	yes	-	20 to 125
RIS/RRA inside isolatable containment	E	yes	-	125 to 830
RIS/RRA outside isolatable containment	E	yes	-	1 to 5
RIS/RRA outside isolatable containment	E	yes	-	5 to 20
RIS/RRA outside isolatable containment	E	yes	-	125 to 830
RIS/RRA relief valves (re-closable)	E	yes	-	5 to 20
RIS/RRA relief valves (blocked)	E	yes	-	5 to 20
Reactor building purification upstream of the pump	E	yes	DN150	-
Reactor building skimming	E	yes	DN50	-
Reactor building purification downstream of the pump	E	yes	DN150	-

5.2.2. Draining via a break in the pipes connected to the fuel building pools

The following table presents the initiating events of this group and the equivalent nominal diameter (DN) of the break surface area. Depending on the nature and position of the break, it indicates whether it is isolatable or not.

Nature and position of break	Plant state	Isolatable or not	Equivalent diameter
Clean break on the suction of a main PTR [FPCS] train	A - D	yes	DN300
	E	yes	DN300
	F	yes	DN300
Clean break on the discharge of a main PTR [FPCS] train	A - D	yes	DN300
	E	yes	DN300
	F	yes	DN300
Clean break on the suction of fuel building purification	A - D	yes	DN150

Nature and position of break	Plant state	Isolatable or not	Equivalent diameter
	E	yes	DN150
	F	yes	DN150
Clean break on the discharge of fuel building purification	A - D	yes	DN150
	E	yes	DN150
	F	yes	DN150
Clean break on the suction of the third PTR [FPCS] train	A - D	yes	DN300
Clean break on the discharge of the third PTR [FPCS] train	A - D	yes	DN300
Break on the draining piping of the fuel building transfer compartment towards IRWST	A - D	yes	DN50

5.2.3. Draining due to alignment error on the pipes connected to the reactor building pools

The following table presents the initiating events of this group and the associated draining flow rates in m^3/h [Ref-1][9]. These errors are only likely to lead to the draining of the Spent Fuel Pool in state E.

Description of initiating event	Plant state	Flow rate (m^3/h)
Spurious opening of a zero flow pressure line LHSI/RHR	E	106
Draining via the RCV [CVCS] draining line	E	< 72
Deliberate draining of the reactor building pool, fuel building pool not isolated	E	180
Spurious opening of the draining valve for the reactor building compartments towards the IRWST	E	< 880

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[9] This analysis is a Flamanville 3 (FA3) study that takes into account some specific features of the FA3 design but the results are bounding for the UK design. In particular, the analysis considers that the third PTR [FPCS] train is lower than for the UK design. Therefore, the calculations are conservative.

5.2.4. Draining due to alignment error on the pipes connected to the fuel building pools

The following table presents the initiating events of this group and the associated draining flow rates in m^3/h [Ref-1]. These errors are only likely to lead to the draining of the Spent Fuel Pool in state A.

Description of initiating event	Plant state	Flow rate (m^3/h)
Inadequately prepared transfer between the loading pit and the fuel building transfer compartment	A	90

5.3. PRELIMINARY EVALUATION OF THE RISK OF DAMAGE

5.3.1. Study assumptions

5.3.1.1. Decoupling criteria

Two decoupling criteria are defined:

- Uncovery of the fuel during handling operations (state E): The level of the Spent Fuel Pool reaches the top of the fuel during handling due to the draining with a failure to place the fuel in a safe position and if the leak is not isolated beforehand;

- Uncovery of the fuel in the pool: Cooling is lost due to the lowering of the pool level due to the draining. Loss of cooling leads to boiling, which leads to a further drop in the level of the Spent Fuel Pool. The assemblies stored in the pool are uncovered if makeup and the recovery of cooling are not achieved before the water level reaches the top of the assemblies.

When one of these two criteria is reached, fuel damage is assumed to have occurred.

5.3.1.2. Restarting at 100°C

The PTR [FPCS] cooling system is designed to restart at 100°C. Nevertheless, the PSA evaluation for draining is conservatively based on the following assumptions:

- Start-up of the third PTR [FPCS] train is possible without makeup if the level remains above {CCI} [a].

- Recovery of cooling requires makeup to be undertaken if boiling conditions have been reached.

5.3.1.3. Calculation assumptions

The following general assumptions are made in the transient analysis of the accident.

5.3.1.3.1. Chronology of events

If there is no makeup, the time window available for operator intervention prior to reaching the various threshold levels in the pool is calculated in accordance with the volume of the pool in the state in which the initiating event occurs and the leak flow rate.

The various threshold levels in the pool are:

- Tripping of the pumps of the main PTR [FPCS] trains.
- Tripping of the gamma radiation signal.
- Maximum elevation of a fuel assembly during handling operations.
- Acceptable zone for the fuel stored in the Spent Fuel Pool.

5.3.1.3.2. Makeup systems

Conservatively, in this assessment only the makeup systems whose flow rates are compatible with a rapid return to a level, which allows cooling to be restarted, are claimed. Their characteristics are listed below:

	Location of intervention	**Makeup flow rate**	**Water storage**
Purification + IRWST	Control room + local line	90m^3/h	1895m^3/h
Nuclear Island Fire-Fighting Water Protection and distribution	Control room + local line	~150m^3/h (and by leg)	~800m^3 + 2600m^3

5.3.1.3.3. Consideration of uncertainties related to repair/recovery

Conservatively, as in the Level 1 PSA EPR (see section 3.6.2 of Sub-chapter 15.1), repair is not claimed.

5.3.2. Analysis of the accident

The water level starts to drop after the leak occurs.

For very rapid falls in water level where the required response times are less than 15 minutes, the response is automated. A group of I&C channels or passive devices such as a siphon breaker, terminate the draining prior to fuel uncovery.

For slower scenarios, isolation of the break is likely to depend on operator action, either in the control room or locally.

If the leak occurs during fuel handling, the operator places the assemblies in a safe position. The time available to undertake this operation determines the probability of failure to place the assemblies in a safe position.

In the event of the draining having been isolated following the loss of cooling, the operator initiates makeup to the Spent Fuel Pool to allow recovery of cooling by the PTR [FPCS]. Initiation of makeup must be carried out as quickly as possible to avoid situations in which cooling is recovered after the start of boiling.

If cooling is not recovered, boiling increases the rate of level drop in the Spent Fuel Pool until the fuel assemblies are uncovered.

5.3.3. Risk of fuel damage following a breach of pipework connected to the reactor building pools

The following table presents the risk of fuel damage due to initiating events of this group.

Nature and position of break	Surface area (cm^2) or DN	Risk of fuel damage (/ry)
Reactor Coolant System	1 to 5	1.54E-11
SIS/ RHR inside isolatable containment	20 to 125	< 1E-12
SIS/ RHR inside isolatable containment	125 to 830	1.2E-12
SIS/ RHR outside isolatable containment	1 to 5	< 1E-12
SIS/ RHR outside isolatable containment	5 to 20	< 1E-12
SIS/ RHR outside isolatable containment	125 to 830	2.4E-12
SIS/ RHR relief valves (re-closable)	5 to 20	< 1E-12
SIS/ RHR relief valves (blocked)	5 to 20	< 1E-12
Reactor building purification upstream of the pump	DN150	< 1E-12
Reactor building skimming	DN50	< 1E-12
Reactor building purification downstream of the pump	DN150	< 1E-12

5.3.4. Risk of fuel damage following a break of pipework connected to the fuel building pools

The following table presents the risk of fuel damage due to these initiating events in this group.

Nature and position of break	Plant state	Equivalent diameter	Risk of fuel damage (/ry)
Guillotine break on the suction of a main PTR [FPCS] train	A - D	DN300	1.64E-10
	E	DN300	1.26E-11
	F	DN300	2.23E-11
Guillotine break on the discharge of a main PTR [FPCS] train	A - D	DN300	2.12E-10
	E	DN300	1.68E-11
	F	DN300	3.11E-11
Guillotine break on the suction of fuel building purification	A - D	DN150	0
	E	DN150	< 1E-12
	F	DN150	0
Guillotine break on the discharge of fuel building purification	A - D	DN150	0
	E	DN150	< 1E-12
	F	DN150	0
Guillotine break on the suction of the third PTR [FPCS] train	A - D	DN300	7.52E-10
Guillotine break on the discharge of the third PTR [FPCS] train	A - D	DN300	1.06E-09
Break on the draining piping of the fuel building transfer compartment to the IRWST	A - D	DN50	< 1E-12

5.3.5. Risk of fuel damage following an alignment error on pipework connected to the reactor building pools

The following table presents the risk of fuel damage due to the initiating events of this group.

Description of initiating event	Flow rate (m^3/h)	Risk of fuel damage (/ry)
Spurious opening of a zero flow pressure line LHSI/RHR	106	< 1E-12
Draining via the unloading line RCV [CVCS]	< 72	< 1E-12
Voluntary draining of the reactor building pool, Spent Fuel Pool not isolated	180	< 1E-12
Spurious opening of the draining valve of the reactor building compartments to the IRWST	< 880	< 1E-12

5.3.6. Risk of fuel damage following an alignment error on the pipework connected to the fuel building

The following table presents the risk of fuel damage resulting from the initiating events of this family.

Description of initiating event	Flow rate (m^3/h)	Risk of fuel damage (/ry)
Inadequately prepared transfer between the loading pit and the fuel building transfer compartment	90	< 1E-12

5.4. SUMMARY OF RESULTS

This evaluation confirms that there is negligible risk of fuel damage in the Spent Fuel Pool or during handling as a result of draining initiating events. The total risk of fuel damage from all the rapid draining initiating events is calculated to be 2.3E-09/ry.

These results reveal the effectiveness of the means for mitigating the initiating events and, in particular, the effectiveness of the automatic isolation of the leak paths. These are highly reliable due to their redundancy, diversity and, in some instances, their classification. These means will also enable the risk of boiling to be severely restricted in the Spent Fuel Pool, in compliance with the technical directives.

6. CONCLUSION

The evaluation of consequences in the Spent Fuel Pool in the event of non-draining events (loss of cooling chain) or in the event of draining confirms that there is a negligible risk of fuel damage in the Spent Fuel Pool. The global risk of fuel damage is calculated to be 2.6E-09/ry, for which the draining events are the main contributors (90%).

Following the loss of cooling of the Spent Fuel Pool and before the occurrence of fuel damage due to the uncovery of the fuel assemblies, the analysis takes into account boiling off of the water when 100°C is reached in the Spent Fuel Pool. The overall frequency of boiling in the Spent Fuel Pool is 2.82E-04/ry, dominated by the at-power state, and mainly caused by the LOCC and the loss of PTR [FPCS] pump.

In all accident sequences, I&C signal effectiveness enables accurate automatic and manual actions to be performed in the time window before unacceptable consequences.

In addition, the importance of the third train of the PTR [FPCS] (both its specific components and its cooling chain) has been highlighted.

SUB-CHAPTER 15.3 - TABLE 1

Frequency of the Non-Draining Initiating Events considered in the Probabilistic Assessment

{CCI Removed}

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SUB-CHAPTER 15.3 - TABLE 1 (CONT'D)

Frequency of the Non-Draining Initiating Events considered in the Probabilistic Assessment

{CCI Removed}

a

SUB-CHAPTER 15.3 - TABLE 2

Frequency of the Draining Initiating Events considered in the Probabilistic Assessment [Ref-1]

<u>Risk of Fuel Damage and Frequency following a break on Pipes connected to the Reactor Building Pools</u>

Nature and position of break	**Risk of fuel damage (/ry)**	**Frequency (/ry)**
Reactor Coolant System	1.54E-11	{CCI}[a]
SIS/ RHR inside isolatable containment	< 1E-12	{CCI}[a]
SIS/ RHR inside isolatable containment	1.2E-12	{CCI}[a]
SIS/ RHR outside isolatable containment	< 1E-12	{CCI}[a]
SIS/ RHR outside isolatable containment	< 1E-12	{CCI}[a]
SIS/ RHR outside isolatable containment	2.4E-12	{CCI}[a]
SIS/ RHR relief valves (re-closable)	< 1E-12	{CCI}[a]
SIS/ RHR relief valves (blocked)	< 1E-12	{CCI}[a]
Reactor building purification upstream of the pump	< 1E-12	{CCI}[a]
Reactor building skimming	< 1E-12	{CCI}[a]
Reactor building purification downstream of the pump	< 1E-12	{CCI}[a]

SUB-CHAPTER 15.3 - TABLE 2 (CONT'D)

Frequency of the Draining Initiating Events considered in the Probabilistic Assessment

Frequency of a Break of pipes connected to the Fuel Building Pools and consequent Risk of Fuel Damage

Nature and position of break	Plant state	Risk of fuel damage (/ry)	Frequency (/ry)
Guillotine break on the suction of a main PTR [FPCS] train	A - D	1.64E-10	{CCI}[a]
	E	1.26E-11	{CCI}[a]
	F	2.23E-11	{CCI}[a]
Guillotine break on the discharge of a main PTR [FPCS] train	A - D	2.12E-10	{CCI}[a]
	E	1.68E-11	{CCI}[a]
	F	3.11E-11	{CCI}[a]
Guillotine break on the suction of fuel building purification	A - D	0	{CCI}[a]
	E	< 1E-12	{CCI}[a]
	F	0	{CCI}[a]
Guillotine break on the discharge of fuel building purification	A - D	0	{CCI}[a]
	E	< 1E-12	{CCI}[a]
	F	0	{CCI}[a]
Guillotine break on the suction of the third PTR [FPCS] train	A - D	7.52E-10	{CCI}[a]
Guillotine break on the discharge of the third PTR [FPCS] train	A - D	1.06E-09	{CCI}[a]
Break on the draining piping of the fuel building transfer compartment to the IRWST	A - D	< 1E-12	{CCI}[a]

SUB-CHAPTER 15.3 - TABLE 2 (CONT'D)

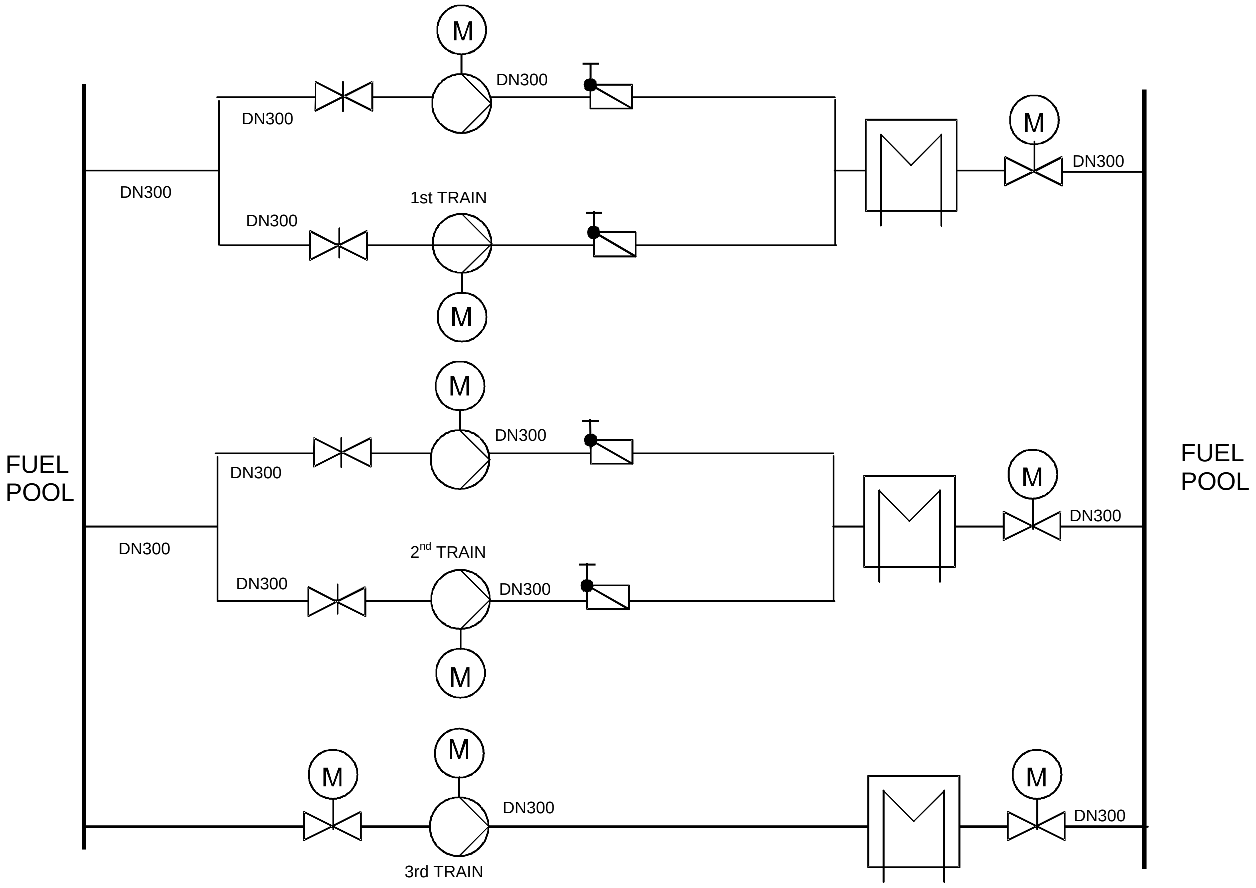
Frequency of the Draining Initiating Events considered in the Probabilistic Assessment

Frequency of an Alignment Error on Pipework connected to the Building Pools and consequent Risk of Fuel Damage

Description of initiating event	Risk of fuel damage (/ry)	Frequency (/ry)
Pipework connected to the Reactor Building		
Spurious opening of a zero flow pressure line LHSI/RHR	< 1E-12	{CCI}[a]
Draining via the unloading line RCV [CVCS]	< 1E-12	{CCI}[a]
Intentional draining of the reactor building pool, Spent Fuel Pool not isolated	< 1E-12	{CCI}[a]
Spurious opening of the draining valve of the reactor building compartments to the IRWST	< 1E-12	{CCI}[a]
Pipework connected to the Fuel Building		
Inadequately prepared transfer between the loading pit and the fuel building transfer compartment	< 1E-12	{CCI}[a]

SUB-CHAPTER 15.3 - FIGURE 1

Simplified Diagram of PTR [FPCS]



SUB-CHAPTER 15.3 - REFERENCES

External references are identified within this sub-chapter by the text [Ref-1], [Ref-2], etc at the appropriate point within the sub-chapter. These references are listed here under the heading of the section or sub-section in which they are quoted.

2. DESCRIPTION OF INITIATING EVENTS

2.1. DESCRIPTION OF FUEL POOL COOLING SYSTEM

[Ref-1] System Design Manual Fuel Pool Purification and Cooling Systems (PTR [FPPS/FPCS]) Part 5 – Instrumentation and Control. SFL–EFMF 2006.751 Revision F1. Sofinel. November 2009. (E)

[Ref-2] System Design Manual - Fuel Pool Cooling System (PTR [FPPS/FPCS]) - Part 2 System Operation, SFL–EF-MF 2006-712 Revision G1. Sofinel. August 2009. (E)

2.3. INITIATING EVENTS FREQUENCY ASSESSMENT

[Ref-1] Functional study on the treatment of PCCs and RRC-As involving spent fuel pool cooling loss and draining. ECEF080499 Revision B1. EDF. November 2012. (E)

[Ref-2] EDF FA3 EPR - Preliminary Safety Analysis Report, Chapter 18.3.2, “Accidents in the Spent Fuel Pool”. 2006. (E)

2.4. EXTERNAL EVENT: LOSS OF ULTIMATE HEAT SINK

[Ref-1] Long term probabilistic analysis of Loss Of Off-site Power (LOOP) and Loss of Ultimate Heat Sink (LUHS) situations.
EDF/SEPTEN Report ENFCFF040206 Revision C. March 2006. (E)

3. INITIAL DATA AND PSA ASSUMPTIONS

3.2. RELIABILITY DATA

[Ref-1] Summary of the input data for the UK EPR Probabilistic Safety Assessment.
NEPS-F DC 565 Revision A. AREVA. May 2010. (E)

[Ref-2] FA3 EPR - Preliminary Safety Analysis Report, Chapter 18.3.2, “Accidents in the Spent Fuel Pool”. EDF. 2006. (E)

[Ref-3] G W Hannaman et al. Some Developments in Human Reliability Analysis Approach and Tools, Reliability Engineering and Tools.
Reliability Engineering and Systems Safety 1988, Vol. 22, 235-256. (E)

4. PSA FOR NON-DRAINING EVENTS

4.4. EVALUATION OF BOILING AND FUEL DAMAGE RISKS

4.4.1. Analysis assumptions

4.4.1.2. Restarting at 100°C

[Ref-1] Functional study on the treatment of PCCs and RRC-As involving spent fuel pool cooling loss and draining. ECEF080499 Revision B1. EDF. November 2012. (E)

4.4.1.3. Calculation assumptions

[Ref-1] Functional study on the treatment of PCCs and RRC-As involving spent fuel pool cooling loss and draining. ECEF080499 Revision B1. EDF. November 2012. (E)

[Ref-2] System Design Manual - Fuel Pool Cooling System (PTR [FPPS/FPCS]) - Part 2 System Operation, SFL–EF-MF 2006-712 Revision G1. Sofinel. August 2009. (E)

4.4.1.4. Chronology of events

[Ref-1] Functional study on the treatment of PCCs and RRC-As involving spent fuel pool cooling loss and draining. ECEF080499 Revision B1. EDF. November 2012. (E)

5. PSA FOR DRAINING EVENTS

5.2. IDENTIFICATION OF RAPID DRAINING EVENTS

5.2.3. Draining due to Alignment Error on the Pipes connected to the Reactor Building Pools

[Ref-1] Functional study on the treatment of PCCs and RRC-As involving spent fuel pool cooling loss and draining. ECEF080499 Revision B1. EDF. November 2012. (E)

5.2.4. Draining Due to Alignment Error on the Pipes connected to the Fuel Building Pools

[Ref-1] Functional study on the treatment of PCCs and RRC-As involving spent fuel pool cooling loss and draining. ECEF080499 Revision B1. EDF. November 2012. (E)

SUB-CHAPTER 15.3 - TABLE 2

[Ref-1] EDF. FA3 EPR - Preliminary Safety Analysis Report, Chapter 18.3.2, “Accidents in the Spent Fuel Pool”. 2006. (E)