SUB-CHAPTER C.3 PROTECTION AGAINST EXTERNAL HAZARDS

0. SAFETY REQUIREMENTS COMMON TO ALL EXTERNAL HAZARDS

External hazards could potentially affect plant safety. The nature and severity of these hazards depend on the site under consideration. Technical Guidelines A.2.5 specifies, in this respect, that due attention must be paid to the choice of site with a view not to impose excessive requirements on the design.

Technical Guideline A.2.5 specifies that design provisions must be made for external hazards, "consistently with provisions for internal events and internal hazards; that is to say, external hazards must not constitute a large part of the risk associated with nuclear plants". The objective in terms of the overall risk of core meltdown is defined in A.1.1 of the Technical Guidelines: "*The implementation of improvements to the defence in depth of these plants should lead to the achievement of a global frequency of a core meltdown of less than* 10^{-5} *per reactor year, taking into consideration uncertainties and all types of failures and hazards".*

The general objective of the design provisions, defined in the Technical Guidelines (A.2.5) is to ensure that the safety functions of the systems and components required to return the plant to a safe shutdown state and to prevent and limit radioactive release are not adversely affected.

In addition, Technical Guidelines A.2.4 and F.1.1 stipulate that the demonstration of safety for internal hazards should take into account all possible causes including, where necessary, failures caused by external hazards.

Finally, Technical Guideline A.2.5 stipulates that equipment which is required to function during external hazards has to be qualified for the range of parameters assumed to occur during such events.

1. GENERAL PRINCIPLES - LIST OF EXTERNAL HAZARDS CONSIDERED FOR THE DESIGN

1.1. LIST OF EXTERNAL HAZARDS

As external hazards are site dependent, Technical Guideline A.2.5 specifies that, "it is not necessary to take all of the hazards in a standardized design; such external hazards as external flooding, drought, ice formation and toxic, corrosive or combustible gases may be dealt with only for a specific plant, on a plant specific basis".

The Technical Guidelines (F.2.1) stipulate that external hazards, and the associated design measures, are to be defined either at the generic design stage or are site specific (A.2.5) including the following hazards:

- Earthquake,
- Aircraft crash,
- External explosion,
- Lightning and electromagnetic disturbances,
- Groundwater,
- Extreme meteorological conditions (temperatures, snow, wind, rain, etc.),
- External flooding,
- Drought,
- Ice formation,
- Toxic, corrosive or flammable gas.

Other external hazards, which are specific to the chosen site, are to be considered on a case by case basis.

In this Safety Report the external hazards are grouped under the following headings (with requirements in Chapters C.3.X.0, identification of design bases in Chapters C.3.X.1, safety analysis in Chapters C.3.X.2).

- Earthquake (see 2 within Sub-chapter C.3),
- Aircraft crash (see 3 within Sub-chapter C.3),
- Industrial risks and transport routes – External explosion (see 4 within Sub-chapter C.3),
- External flooding (see 5 within Sub-chapter C.3),
- Extreme climate conditions (snow, wind, extreme temperatures…) (see 6 within Sub-chapter C.3),
- Lightning and electromagnetic disturbances (see 7 within Sub-chapter C.3),
- Other external hazards specific to the site (see 8.5 within Sub-chapter C.3).

1.2. GENERAL PRINCIPLES FOR PROTECTION AGAINST EXTERNAL HAZARDS

In accordance with the Technical Guidelines, external hazards are taken into consideration at the design stage consistently with internal events or hazards. Design basis hazards are subject to the same radiological release criteria as other events which do not lead to core meltdown. Hazards are also analysed for their contribution to the overall risk of core meltdown (see Chapter R.4)

The basic design principle is to protect the EPR against external hazards, in accordance with the Technical Guidelines (F.2.1)[1], using a "load case" procedure. This procedure consists of attempting to separate as far as possible:

- the hazard study from the reactor PCC and RRC studies,

- the hazard study and the study of other internal or external hazards.

The consequences of hazards are controlled and limited:

- by ensuring that the hazard does not prevent the safety functions being carried out (as defined on the basis of the internal event analyses) : this is achieved by protecting the equipment required to fulfil the safety functions from the hazard consequences.

- by limiting the consequences of a hazard so they are enveloped by the consequences of PCC events or other hazard load cases

However, it is not always possible to prevent hazards from inducing events not addressed in PCC/RRC analysis, or inducing consequences beyond the load cases associated with other hazards. When this is the case, specific studies must be performed to confirm that the safety objectives have been achieved.

In practice, the design process and the safety case for external hazards involves three stages:

1. Creation of a list of reference operating conditions (PCC). This is a limited list of operating conditions, representative of the different probability categories, resulting from bounding events which could potentially challenge the key safety functions, namely control of reactivity, residual heat removal and containment.

2. Design of the structures and equipment taking into account the different design load cases associated with each hazard. For each external hazard, the design process stipulates the loads which must be considered, as well as the structures, systems and components which must resist such hazards. It also describes, if necessary, the additional event-based approach which assesses the dependencies between external hazards and internal events or hazards, and the safety measures used to resist such events. (See 1.3 below for the consideration of combined events). Two groups of external hazards are distinguished when creating the list of structures, systems and components to be protected against a hazard:

[1] As a general rule, a good means of determining the measures to be implemented against external hazards is to define the load cases. A suitable method must be defined for each external hazard with a view to determining the loads, as well as the structures, systems and equipment which must resist these loads. In addition, for some external hazards, this approach must be completed by an event-based approach, and, if necessary, functional analyses used to assess the dependencies between external hazards and internal hazards or events.

- Hazards, in which all pieces of equipment with are safety classified as a consequence of their safety function or their “barrier” function, are protected, (with the possible exception of equipment whose failure (including combined failures) does not jeopardise compliance with the radiological release criteria) e.g. an earthquake.

- Hazards where the protection is only partial e.g. an aircraft crash. In this instance, the partial absence of protection is justified on a probabilistic basis and/or an by an analysis of the consequences of the failure of the equipment,.

3. For hazards where the protection of safety classified equipment as described before is not total, demonstration that the radiological consequences remain compatible with the radiological consequences objectives

The list of reference operating conditions and the verification of the adequacy of the protection with regard to radiological consequences are presented in Chapter P.

Finally, given the uncertainties in the assessment of potential climatic changes over reactor life, the initial design of the EPR makes provision for adaptation during operation, to allow for climatic changes larger than those initially envisaged.

In general terms, potential climatic change is addressed in three ways:

- o Inclusion at the design stage of additional margins in the cases assessed,
- o Assessment of the feasibility of making modifications to the plant,
- o Assessment of possible changes to plant operation .

An analysis of the adaptability of the plant will be performed for all relevant climate related hazards.

1.3. CONSIDERATION OF COMBINED EVENTS

In general terms, the question of combined events may be addressed in three ways:

a) Combination of physical phenomena inherent in the hazard

Some external hazards which are associated with the meteorological or climate conditions, intrinsically involve a combination of several phenomena. This is the case for natural external flooding. For example a major flood is, for the most part, due to a prolonged period of heavy rainfall. This event cannot be dissociated from an increased level in the water table nor from the arrival of a significant amount of water on the platform. From this perspective, other hazards are more readily susceptible to basic characterisation: earthquake, aircraft crash, external explosion.

b) Combinations of the hazard considered with potentially dependent internal or external events or hazards

In this instance the decoupling principle applied consists of:

- reducing the potential dependency between the external hazard and the reference operating conditions (PCC-2 to 4) or other internal hazards, using specific protection and prevention measures,

- identifying the risks that an external hazard may lead to loss of external power supplies, loss of heat sink, or an other external hazard.

- taking into consideration any potential residual interactions in the design.

c) Combinations of the hazard and independent internal or external initial conditions.

Finally, even when there is no dependency, the analysis of an external hazard may require consideration of independent physical parameters associated with other external hazards.

For example, there is no link between an earthquake and an extreme ambient temperature. However, the choice of certain parameters (e.g. material properties) requires an assumption to be made on temperature.

In general, there is no need to combine extreme values from separate cases. However, the most common combinations of this type are taken into consideration in order to limit the extent of the studies. This approach ensures adequate margins.

As a general rule, combined events are considered when there is a dependency which cannot be excluded by a design measure. Additional combined events may also be introduced when there may only be a potential dependency.

Depending on the case, the consideration of combined events has an influence on:

- the definition of the elementary loading cases (for example, an instance of external flooding),

- the list of equipment to be protected against the hazard and the load combinations to be used (for example, an earthquake),

- system operational design assumptions (for example, extreme temperatures).

Table C.3 TAB 2, provides a summary of each external hazard, and the different combinations of events, external hazards and internal hazards:

- which are taken into consideration in the EPR design and which may either

    - lead to specific design measures,

    - or are already covered;

- or which have been identified but have been dismissed.

2. PROTECTION AGAINST EARTHQUAKES

2.0. SAFETY REQUIREMENTS

The identified risk arising from an earthquake is direct or indirect damage to equipment needed to bring the plant to, and maintain it in, a safe shutdown state. Indirect damage is associated with the failure of adjacent equipment or induced internal hazards.

2.0.1. Objective for protection against earthquakes

Following an earthquake, the objective of the protection is to ensure that the safety functions needed to return and maintain the plant to a safe shutdown state are not unacceptably affected.

2.0.2. Safety requirements concerning civil structures, mechanical equipment and electrical systems

The mechanical equipment, electrical systems and civil structures required to achieve the safety objectives must be subject to seismic classification. The seismic classification principles (SC1 and SC2) are defined in Chapter C.2.

Structures, materials and systems must be designed so that they are able to fulfil their functions, maintain their integrity or remain stable under the conditions caused by the seismic movements. Seismic events must be considered in the design of the plant, as defined in Basic Safety Regulation 2001-01. Sufficient margins to fulfil the overall EPR probabilistic objective must be included (refer to Chapter R.0).

Different types of requirements may be associated with the equipment:

- Stability: the stability of a component is its ability to resist the loads which have a tendency to modify its position or orientation (for example, which have a tendency to cause the component to tilt, fall or slide in an unacceptable manner or which could lead to a breakage of some components). The stability of a component relies upon the stability and resistance of its supports.

- Integrity: this is defined as the ability of a component in a pressurised system to resist the specified loads.

- Operational Capacity is the ability of a component in a pressurised system to resist the specified loads with limited deformation such that its functional capability is not impaired by a possible flow reduction.

- Operability: the ability of a system, or component of a system, including its necessary auxiliaries, supports and electrical power supplies, to perform its functions and meet the safety objectives.

The requirements associated with the civil structures are defined for the different load combinations considered, including those caused by a postulated earthquake (see Chapter C.5.0). They are deduced from the general behavioural requirements arising from the following:

  - Stability: behavioural requirements attributed to the main wind bracing system, the purpose of which is to prevent the collapse of a civil structure.

  - Local stability: behavioural requirements which are expressed in terms of static balance, mechanical resistance and rigidity.

  - The equipment supports: behavioural requirements which describe the fact that the structural elements which support the items of equipment meet the requirements attributed to this equipment.

- Containment: the aim of the containment function is to limit the release of hazardous materials into the environment. For civil structures, this leads to leak-tightness requirements.

- Absence of interaction: the aim is to prevent, during an earthquake, impacts between adjacent components (including structures). This is defined as a limitation in the movements of these components which depends on the separation distance between them.

2.0.3. Applicable Regulation - Basic Safety Regulations - Technical Guidelines - Codes - Standards

The Technical Guidelines are identified in Chapter B.6.

Technical Guidelines A.2.5, F2.1, F2.2.1 are applicable.

Depending on the seismic classification of the buildings and equipment, the main codes used are ETC-C, RCC-M, RCC-E, and the French seismic construction regulations. (see Chapter B.6)

2.1. DESIGN BASIS

2.1.1. Seismic design motions

The design and qualification of seismic classified equipment in the standard section of the plant takes into consideration a set of standard conditions: the sets of EUR design spectra (C.3 FIG 1) scaled at 0.25 g in horizontal direction, associated with six standard ground conditions (SA, MA, MB, MC, HA, HF) described below.

		Soft ground SA	Average ground MA	Average ground MB	Average ground MC	Hard ground HA	Hard ground HF
Shear Modulus	MN/m^2	150	600	1000	2500	6000	10800 / 17100
Density	t/m^3	1.9	2.1	2.1	2.1	2.5	2.5
Poisson’s Ratio	-	0.48	0.40	0.40	0.40	0.30	0.32 / 0.35
Material damping	%	8	5	5	5	3	3

- The SA, MA, MB, MC and HA ground conditions correspond to homogeneous ground. The HF ground condition corresponds to the geological conditions of a specific stratified site

- a first layer of 6 meter thickness under the level of the foundation, with a shear modulus of 10 800 MN/m^2 and Poisson ratio of 0.32,
- a second layer of more than 500 meters thickness, with a shear modulus of 17100 MN/m^2 and Poisson ratio of 0.35.

2.1.2. Load combination rules

In accordance with the Technical Guidelines, some conventional load combinations are used for the design and / or qualification of certain structures or equipment; these load combinations are not intended to suggest a real link between the design earthquake and reference operating conditions (PCC), but are used to provide margins in the design:

- The combination of stresses resulting from the design ground spectrum and those resulting from a LOCA (guillotine break in the pressuriser surge line) is taken into account in designing the inner containment, the reactor building internal structures and the reactor vessel internals.

- The combination of stresses resulting from the design ground spectrum and those resulting from PCC-2 to 4 events is taken into account in the design of seismic category 1 classified equipment, including PCC-2 to 4 events in which the initiating event does not correspond to the failure of non-seismic classified items. The criteria associated with PCC-4 events are considered. These combinations ensure the ability of equipment to resist an earthquake occurring in the long term after a PCC accident .

- The equipment qualification sequence for seismic classified equipment (defined in Chapter C.7) includes a seismic test phase, combined with irradiation and pressure/temperature accident test phases.

In addition, relevant meteorological parameters are included in the seismic design of the civil structures and materials :

- wind : the combination of stresses resulting from the design ground spectrum and the stresses resulting from wind (SDD [DBE, Design Basis Earthquake] + 0.2 maximum wind defined in section 6 of this Sub-chapter C.3) is taken into account for designing the cladding and chimneys.

- snow : the combination of stresses resulting from the design ground spectrum and the stresses resulting from snow (SDD [DBE] + 0.2 maximum snow defined section 6 of this Sub-chapter C.3) are taken into account in the design of buildings.

- external temperatures (within the limits of the high and low design values).

- the level of the water table.

2.1.3. Rules and methods used for the dynamic analysis of the SC1 buildings

Several dynamic analyses are performed for each building :

- The seismic response of each building of the standard section of the plant is calculated using the set of standard conditions (EUR 0,25g ground spectrum associated to six different ground conditions).. These analyses supply the in-structure spectra for the design and/or qualification of the safety related structures, systems and components.

- The seismic response of each building is also calculated for the site ground conditions associated with the corresponding EUR spectrum which is set at:
  - 0.25 g for the standard structures,
  - a suitable level given the site seismicity for the site structures.

  These analyses supply the seismic stresses for design of the civil structures.

2.1.3.1. SC1 buildings analysed

The list of SC1 classified buildings is established by applying the classification rules defined in Chapter C.2. Chapter C.5 describes the general measures which are taken for designing these structures.

The reactor building is a cylindrical structure comprised of reinforced and prestressed concrete. Four rectangular reinforced concrete buildings are attached to the reactor building (safeguard and fuel buildings), forming a cross shape with the reactor building at the centre.

All of these buildings are founded on a common raft of variable thickness. They are designated "buildings on the common foundation raft".

The following five EPR structures are therefore analysed together:

- Safeguard auxiliary buildings 1, 2, 3, 4
- Fuel building
- Internal structures
- Inner containment
- Outer containment

Other dynamic analyses are performed for the Main Pump House, the Nuclear Auxiliaries Building and the Diesel Generator Buildings.

2.1.3.2. Analysis of ground/structure interaction

For the dynamic calculations, the dynamic behaviour of the free field soil is represented by springs and dashpots.

Complex valued stiffnesses (impedance functions) are evaluated and impedance matrices for the nodal points which are common to the structure and the soil region are calculated for different soil conditions. These functions are used to define springs and dampers which are tuned to the global frequencies of the soil-structure system.

For the dynamic analysis, which supplies the in-structure, or floor spectra for the design and/or qualification of equipment, in the standard buildings of the installation, the six standard ground conditions are considered. Apart from the HF condition, the ground is modelled by a homogenous half-space.

For the dynamic analysis, which supplies the in–structure, or floor spectra for design of the site structures, the specific site ground conditions are taken into account, as well as the site stratigraphy. A range from 2/3 to 3/2 of the ground shear modulus is considered.

The calculation of the impedance functions uses the following assumptions:

- the foundation raft is considered to be rigid,
- the impedances, which are complex frequency dependent functions, are calculated for the 6 degrees of freedom for a rigid massless foundation slab. The real parts of these functions represent the frequency dependent stiffness, and the imaginary parts the damping in the ground-foundation system,
- the global foundation stiffnesses are uniformly distributed beneath the foundation raft. This distribution is performed so that the foundation global forces and ground level displacements are consistent with the global stiffness for each of the 6 degrees of freedom,
- the ground is considered to be homogeneous; the term corresponding to the radiative damping is weighted by a coefficient of ½,
- finally, the reduced modal damping value is limited at 30%.

2.1.3.3. Modelling of buildings

2.1.3.3.1. Description of analysed structures

The Nuclear Auxiliaries Building, the Access Towers and the Diesel Generator Buildings are represented both by beam element and lumped mass models, and by three-dimensional finite element models.

The buildings on the common foundation raft of the Nuclear Island are represented by a complete three-dimensional finite element model.

The stiffness of each structural element is represented in a realistic manner by spring, beam or shell elements. The 2D shell elements take into account the bending forces and the membrane stresses.

The model provides a basis for the subsequent dynamic analyses. It has several sub-structures:

- The inner containment: the structure is fabricated from prestressed variable thickness concrete, with an internal leak tight metal liner.
- The outer containment: the structure is fabricated from variable thickness reinforced concrete.
- An external shell for protection against aircraft crashes.
- The towers: reinforced concrete structures connected to the outer containment. These towers are also connected to the external walls of the adjacent structures.
- Reactor Building (BR) internal structures: reinforced concrete, mainly comprising the primary structure (reactor pits), the secondary structure (cylindrical wall with intermediate walls and platforms) and the reactor pool (reactor cavity and storage compartment). The internal structures are mounted on the reactor building foundation raft via a thick concrete slab.
- The Fuel Building: reinforced concrete structure. the main platforms and the vertical walls are modelled. The fuel building internal structures are decoupled from the external walls of the aircraft protection shell.

- The Auxiliary ~~B~~uildings (BAS and BAN): reinforced concrete structures; the main platforms and the vertical walls are modelled.

All of these structures are connected to a common foundation raft which is modelled by variable thickness finite elements.

In order to represent the thickness of the foundation base, the rigidity of the lowest layer of the finite elements which connect the structures to the foundation base is increased.

All of the structures are of reinforced concrete, except for the inner containment wall of the reactor building, which is a cylindrical pre-stressed concrete shell surmounted by a dome.

2.1.3.3.2. Material properties

For the reinforced and pre-stressed concrete structures, the material properties are in accordance with the EPR Technical Code for civil works, ETC-C.

2.1.3.4. In-structure spectra calculations and forces in the civil structures

The floor response spectra are calculated for two horizontal directions and the vertical direction, for each ground condition, using modal time history superposition. They are calculated separately for different levels of the building and are grouped in specific areas. The spectra for each specific area are then enveloped and smoothed.

These spectra are presented for a large range of damping values, and are used for design and/or qualification of the equipment in the relevant buildings.

The rigid body accelerations of the floor response spectra corresponding to the site ground conditions, are used for further quasi-static structural analyses of these buildings.

2.1.4. Criteria and methods applied to the Pumping Station

The Pumping Station is described in Chapter C.5.4.

The Pumping Station is a site structure. It is seismic category 1 (SC1), in accordance with the general classification principles (see Chapter C.2).

The ground response spectra used are the EUR spectra corresponding to the site ground conditions, suitably scaled to take account of the site seismicity, in accordance with the general principles described in section 2.1 of this Sub-chapter.

Ground-structure interaction phenomena are taken into account using 3D modelling. All ground layers down to the bedrock are considered, as well as the backfill.

2.1.5. Rules and methods applied to the dynamic analysis of the components and internal structures

2.1.5.1. Seismic analysis method

Several methods of seismic analysis may be implemented. The methods which are most generally used are the modal methods (spectral or temporal) and, additionally, the equivalent static method.

2.1.5.1.1. Sub-systems other than the primary loops

The analysis of seismic category 1 systems and components is performed, where possible, using the response spectrum approach, which is based on the natural period, mode shapes and appropriate damping factors for the particular systems.

The floor response spectra determined from the building dynamic analysis are considered. The acceleration values are selected for each mode, based on natural frequency and damping.

Three separate independent analyses are performed for two horizontal directions and the vertical direction. The results obtained for each direction are then combined using a suitable method.

A detailed description of the dynamic analyses is supplied in Chapter C.6.

The dynamic analysis of the different systems and components is based on finite element models. The capacity of current computers and calculation codes allow highly detailed modelling of the different mechanical components, and the appropriate level of complexity in the models must be limited by the validation status of codes.

2.1.5.1.2. Primary Coolant Loops

The response of the primary loops is determined using either the spectral or the temporal method.

The modal spectral analysis uses the set of in-structure spectra corresponding to the anchoring points for the main primary system. The temporal analysis uses the accelerograms extracted from the anchoring points of the primary system three-dimensional ground-structure interaction analysis.

2.1.5.2. Procedure used to model equipment

2.1.5.2.1. General points

The dynamic analysis of seismic category 1 equipment is based on finite elements modelling, adopting the following principles:

- The modelling must be able to include all natural modes which have a significant contribution to the seismic response. By default, all of the modes within the peak range of the floor response spectrum, which is representative of the seismic load applied to the equipment, must be taken into consideration.

- Where necessary, the contribution of those modes whose frequency exceeds the peak range of the floor response spectrum must be taken into consideration.

2.1.5.2.2. Specific analysis of primary coolant loops

The analysis of the primary loops is described in section 1.3 of Sub-chapter C.6. The analysis is performed using the modal spectral analysis method described below.

The modal spectral analysis method is by far the most common method used for this type of calculation. The spectra used correspond to the floor response spectra at the steam generator upper support.

Main assumptions

The model used comprises four primary loops and the reactor vessel. This enables consideration of the possible dynamic coupling (translation and rotation) of the four loops and the reactor vessel on its supports.

The influence of the stiffness of the secondary lines (steam lines and feed water lines) is taken into consideration by associating rigid matrix type elements with these lines. However, because of their relative flexibility and low mass, they have little effect on the system natural frequency.

The boundary conditions do not change during an earthquake. This assumption is inherent to the analysis method which presumes a linear structure and standard conditions at the boundaries. In practice, this restriction requires the clearances to exceed the seismic movements so that there is no contact or significant impact during the earthquake.

Small gaps are considered to be closed in the linear model used in the modal analysis. Hence, additional static calculations are performed to take account of this simplification. The results obtained are then added to the results of the spectral analysis.

The structure itself (excluding gaps) remains linear under seismic load. The supports are designed to remain elastic under the maximum stresses resulting from a design basis earthquake or a break in any auxiliary line connected to the primary system or a break in a main steam line.

The anchor rods are pre-stressed to a value which takes into account the maximum load of the Design Basis Earthquake and the additional load of a pipework break.

The hydraulic snubbers and support legs, described in Chapter E.4.9, also introduce non-linearity. Their stiffness depends strongly on the direction of the acceleration. The tensile and compression loads are not applied to the same mechanical parts, which explains the difference in stiffness. For these supports, the stiffness used in the analysis is equivalent to the average value of the tensile-compression stiffness.

Model

The model comprises the following components: the reactor vessel, the four primary loops, the pressuriser and surge line. Each loop includes a hot leg, a steam generator, a crossover leg, a reactor coolant pump and a cold leg. The primary system is modelled using finite elements. The three-dimensional (3-D) model comprises straight branch legs, bends, lumped masses, springs and rigid elements.

The geometry, the physical properties and the materials which are associated with these elements are representative of the mass, inertia and stiffness characteristics of the equipment described.

Certain gaps are assumed to be closed, i.e. the two opposite surfaces are considered to be in contact with each other. Closure of these gaps is accounted for by additional static analysis, the results of which are added to those of the spectral modal analysis.

With regard to the seismic model, certain degrees of freedom have been considered as being dynamic degrees of freedom (R.J. GUYAN reduction). These dynamic degrees of freedom (approximately 600) are selected by taking into consideration the GUYAN technique (low stiffness and large mass).

Calculation parameters

The seismic calculations for the primary loops are performed using the floor response spectra originating from the dynamic analysis of the building.

The floor response spectra are calculated at different levels and for different damping values.

2.1.5.3. Seismic analysis of reactor internals

The reactor vessel internal structures are studied by temporal analysis using the non-linear modal superposition method. Suitable seismic excitations are used and applied to the modal representation of the system. For this representation, the vessel internal structures, the reactor vessel and the fuel assemblies are modelled in the form of springs, concentrated masses or beam elements. A finite element structural code (for example, SYSTUS) is used to calculate the response of the non-linear system. The result of this analysis is then combined with the other loads for the mechanical design of each component based on the RCC-M (see Chapter B.6).

The dynamic analysis for the vessel and its internal structures also calculates, in a temporal form, the displacements necessary for the analysis of the fuel elements and control rods.

The analysis of the vessel internal structures is described in section 1.3 of Sub-chapter C.6.

2.1.5.4. Use of the equivalent static method

This method is a simplification of the spectral method. For each displacement direction, the response of the structure is calculated by applying a uniform static acceleration.

The rules for combining different displacement directions are identical to those used for the spectral method.

2.1.5.5. Consideration of the three seismic displacement components

The response is calculated for each of three orthogonal earthquake displacement directions (two horizontal, plus vertical). The results are combined in quadrature..

With regard to the components of the nuclear steam supply system, the method used to combine the loads from the three analyses is based on the following:

- The peak responses of the different modes for the same seismic excitation do not occur at the same time.
- The peak responses of a specific mode caused by seismic excitations in different directions do not occur at the same time and are uncorrelated.
- The maximum responses of the different modes and in the three directions are not simultaneous.

In order to implement the above principles, the three seismic translation components are statistically combined using a suitable method.

2.1.5.6. Combination of modal responses

When the spectral method is used, all of the modal responses and the movements, stresses, times and/or accelerations are combined using a suitable method which enables, where necessary, consideration of closely spaced frequency modes.

2.1.5.7. Multi-supported equipment and components

The seismic analysis of multi-supported equipment must take into consideration:

- the different spectra of the floors and platforms which correspond to the different levels of equipment anchoring,
- the differential movements between these different anchoring levels.

2.1.6. Inspection earthquake and seismic instrumentation

An inspection earthquake is defined. It represents the level of earthquake below which, if it were to occur, there would be no requirement for specific verification or inspection of the safety significant components before continued normal operation or return to service. This inspection earthquake corresponds to a maximum horizontal free field floor acceleration of 0.05g. This acceleration corresponds on the site to an intensity below VI on the MSK scale.

The procedure which is implemented when an earthquake is experienced and/or measured on site is illustrated in figure C.3 FIG 2.

In order to collect the data necessary for the analysis of such events, seismic instrumentation is installed which complies with French regulations. The role of this instrumentation, if a certain acceleration level is exceeded on site, is to generate an alarm in the control room and to trigger recording of the seismic displacements. The automatic triggering of the recording is indicated in the control room.

If the maximum accelerations exceed the "earthquake inspection" level, more detailed analyses, with the plant in operation, is required in order to analyse whether or not the installation has been stressed above the elastic range and if it is still within normal operating conditions.

2.2. SAFETY ANALYSIS

2.2.1. Consistency of the design assumptions in relation to the site conditions

The different design assumptions used (design ground spectrum and ground conditions) are to be compared with the design seismic displacements specified in French regulations. The comparison may be performed directly on the spectrum in the free field or, if necessary, on the seismic stresses in the structures and materials. In some instances, a complete new analysis of certain structures or components may be necessary.

2.2.2. Verification of plant design: "earthquake event" procedure

A specific verification is performed. This leads to identification of the seismic category 2 structures and equipment in accordance with the principles in Chapter C.2. The purpose is to identify those items which are not included in seismic category 1, but whose failure, due to local and/or global effects of the earthquake, may have an effect on seismic category 1 components or may jeopardise their qualification and, more generally, may prevent the achievement of the safety objectives as defined in section 2.1 of Sub-chapter C.3. The methodology requires, initially, application of the single failures criterion, and subsequently, the effect of multiple failures is analysed.

2.2.3. Specific analysis of PCC-2 to 4

A specific analysis is performed for all PCC-2 to 4, which assume a seismic event combined with a Total Loss of Off-Site Power Supplies following the earthquake.

The rules for these studies are defined in Chapter P.0.

2.2.4. Verification of seismic margins

The choice of level of seismic event and the conservative nature of the seismic design process ensure the existence of safety margins with respect to earthquakes.

Verification is performed for each site. It is initially based on comparison of the seismic loads used for the design of structures and equipment and the seismic displacements to be considered by the design of the installations in accordance with regulations. If this analysis does not predict a safety margin, a more detailed analysis of a selection of plant items will be performed based on conservative assumptions which are more realistic than those used for the design, (e.g. modelling of the ground conditions, damping, seismic capacity). Experimental data (tests on vibrating tables, analysis of the consequences of actual earthquakes) may also contribute to justification of the margins.

3. PROTECTION AGAINST AIRCRAFT CRASH

3.0. SAFETY REQUIREMENTS

An aircraft crash is an external hazard linked to human activity. It must be taken into consideration for the design of nuclear power stations.

The identified risk is that of the unavailability of the equipment required to shut down the reactor, and maintain the plant in a safe shutdown state.

3.0.1. Safety objectives

Following an aircraft crash, the objective is to ensure that the safety functions for the systems and equipment needed to limit the radiological consequences are not unacceptably affected.

3.0.2. Safety requirements concerning the civil structures, the mechanical equipment and the electrical systems

All of the civil structures and the equipment needed to achieve the safety objectives must be protected. Identification of these structures and items of equipment is based on the applicable regulations, supplemented by additional deterministic requirements.

3.0.3. Applicable Regulation - Basic Safety Regulations - Technical Guidelines- Codes - Standards

All of the applicable regulations, codes and standards are identified in Chapters B.6. With regard to an aircraft crash, the safety objectives and principles are defined in French regulations.

The Technical Guidelines are identified in Chapter B.6. The safety objectives are defined in Technical Guidelines A.2.5 (contribution of external hazards to the overall risk) and F.2.2.2 (protection against aircraft crash).

The ETC-C (EPR Technical Code for Civil Works) is applicable to the design of the civil structures. It defines the criteria to be considered for those buildings which must be designed against the individual cases as well as against the combined events to be considered.

3.1. DESIGN BASIS

The initial approach for protection against an aircraft crash is deterministic and is based on defined cases for different groups of aircraft. The protection is achieved by the design of the safety classified buildings or by physical separation of the redundant systems in relation to these cases.

The EPR nuclear island structures house the equipment required for reactor safety and prevention of core meltdown, are protected against the risks caused by an aircraft impact.

In accordance with French regulations, consideration of this risk is based on distinguishing air traffic into three groups of aircraft: general aviation (aircraft weighing less than 5.7 tonnes), military aviation and commercial aviation. The probability of an unacceptable radiological release at the site boundary following an aircraft impact acts as the basis for the definition of the loading case used for plant design.

For the EPR, the general aim of significant safety improvement has led to overall consideration of the risk of aircraft crash (i.e., military and commercial), independent of the probability of occurrence of the event. Protection of the plant is assured either by physical separation of redundant systems or by the existence of a physical barrier referred to as the aircraft shell.

Military aviation which constitutes the initial loading case. The approach used for protecting the installation against a direct impact is as follows:

- Total protection for the buildings that are likely to contain nuclear fuel. This protection is provided by the aircraft shell. This applies to the reactor building and the fuel building.

- Protection for the buildings housing backup systems, either by protecting them with an aircraft shell, or by providing sufficient physical separation of the redundant systems.

- Integration of the F1 classified and non-redundant equipment in the buildings protected by the aircraft shell: this mainly concerns the control room.

The protection requirement against aircraft crash is described in Chapter C.5.0. It distinguishes between buildings protected by geographical separation and those protected by the aircraft shell. In order to design the protection structures in the latter, aircraft impact is modelled via two curves (force in relation to time) - C1 and C2.

The purpose of these load diagrams (see figures in Chapter C.5.0) is to represent two types of effect, firstly, a local perforation caused by the impact and secondly, a more general effect of vibrations experienced in the buildings. They are used in the following ways:

- The C1 curve is used for the design of the internal structures in the buildings in relation to the vibrations experienced. By utilising the linear elastic behaviour of the material and the different points of impact of an aircraft on each external protection wall, the response spectrum is deduced and used to design the relevant equipment. The separation of the internal structures and the external walls of the buildings which receive the impact reduces the stress on the equipment to be protected.

- The C1 curve is used for the same buildings to design the external walls in relation to the loads generated by a direct impact so as to ensure that there is neither penetration nor creation of secondary missiles and that deformations to the steel and concrete remain limited.

- The C2 curve represents impact on a rigid target and is used to verify the final local resistance to perforation of the external walls with a reduced margin. The corresponding safety demonstration may be based on the existence of walls located beneath the aircraft shell in the protected buildings.

Commercial aviation. This comprises an additional loading case introduced following the aircraft crashes of 11 September 2001. The design has been verified and modified where necessary to take into consideration all of the direct, indirect and potential consequences of the hazard. The definition of an appropriate loading case has been used to ensure the capability of the EPR nuclear island to resist such a hazard.

In conclusion, the risks arising from all air traffic - general, military and commercial aviation - are considered in the design of the EPR.

3.2. SAFETY ANALYSES

The verification used to check that the design provisions are sufficient in terms of safety and the regulatory requirements is performed in accordance with a similar methodology to that used for the other French pressurised water reactors. The result of the study is shown in section 8 of this Sub-chapter C.3.

The verification used to check that the design provisions are sufficient with regard to the additional requirements is included in a restricted document.

4. PROTECTION AGAINST THE RISKS ASSOCIATED WITH THE INDUSTRIAL ENVIRONMENT AND TRANSPORT ROUTES - EXTERNAL EXPLOSION

4.0. SAFETY REQUIREMENTS

4.0.1. Identification of risk

The industrial installations and transport routes which may pose a risk to the plant are identified for each site. The risks to be considered are:

- Explosion: compression wave, ground movements, missiles, etc.
- Off-site Fire: thermal radiation, smoke.
- Movement of toxic, corrosive or radioactive gases.

Three groups of risk sources are considered:

- Fixed industrial installations, such as storage or production installations.
- Fuel or gas networks.
- Road, rail, river or maritime transport routes.

4.0.2. Probabilistic Objectives

All of the civil structures and equipment which are necessary for the following basic safety functions are considered:

- Shutdown of the reactor and removal of decay heat,
- Storage of spent fuel,
- Treatment and containment of radioactive effluents.

The maximum probability of an unacceptable radiological release at the site boundary is fixed in accordance with the general protection objectives of the EPR, in relation to external hazards as indicated by the Technical Guidelines (A.2.5).

Given their low combined probability, external hazards associated with industrial environment or transport routes are not combined with other external hazards such as earthquakes.

4.0.3. Applicable Regulation - Basic Safety Regulations - Technical Guidelines- Codes - Standards

The applicable regulations, codes and standards are identified in Chapter B.6. With regard to the industrial environment and transport routes, the safety objectives and verification principles used for the FA3 unit are defined in French regulations.

The Technical Guidelines are identified in Chapter B.6. With regard to the risks associated with the industrial environment and transport routes, the general safety objectives are those which are associated with the external hazards and which are explained in the Technical Guidelines A2.5. The design cases to be used are defined in Technical Guidelines F2.2.3 : *"With regard to external explosions, design of the next generation of nuclear power plants must take into consideration, as a standard load over time, a triangular shaped pressure wave with a vertical leading edge and a maximum over-pressure of 100 mbar and a duration of 300 ms. This means that, given the possible reflections on the walls and roofs of the buildings, the load over time on the building walls will consist of a maximum pressure wave of 200 mbar on the flat walls"*. The EPR safety objectives are more restrictive than those described in French regulations, and the design loading cases are greater than those in French regulations.

4.1. DESIGN BASES

4.1.1. General principles

The design takes into consideration the external explosion risk based on Technical Guideline F.2.2.3. A case by case analysis is performed for drift of gas clouds (toxic, corrosive or radioactive) and, where necessary, design measures are adopted for protection against this risk (by design of suitable closed circuit ventilation systems or filtration).

Plant design in relation to the external explosion risk uses a loading case which is referred to as an Explosion Compression Wave. It is included in the design of the following buildings (see Chapter C.5.0):

- Reactor Building (BR)

- Fuel Building (BK)
- Safeguard buildings (BAS)
- Diesel-Generator Buildings (DB)
- Pumping Station
- Nuclear Auxiliaries Building (BAN)
- Effluent-Treatment Building (BTE)

4.1.2. Design Parameters

The standard loading case which is representative of the incident wave, used for design, is a triangular over-pressure wave, reaching a maximum over-pressure of 10 kPa and duration of 300 ms (C.3 FIG 3). It represents a detonation wave. The detonation is expected to occur at the accident location, i.e. at a transport route or a fixed industrial installation. The benchmark wave is expected to arrive in a horizontal direction.

This incident overpressure wave covers, in terms of structural loads, an on-site deflagration wave.

The stress applied on the walls takes into consideration the effects of reflection and focus effects, without the assumption that there is a preferential horizontal component for the incident wave.

On the flat walls, consideration of reflections and severity leads to the use of an over-pressure wave with a maximum over-pressure of 200 mbar. More specifically:

- Due to the horizontal direction of the incident wave, a possible reflection effect on the walls of a factor of 2.0 will be considered.
- Three cases are considered. The general approach described above is divided into 3 cases for the roofs:
    - For high buildings with flat walls: maximum overpressure will be equal to 1.5 times the maximum value of the incident over-pressure wave.
    - For high buildings with round and cylindrical walls: maximum overpressure will be equal to 1.0 times the maximum value of the incident over-pressure wave, as the reflection is diffused.
    - If there are no high buildings: no reflection will be considered. The maximum overpressure will be equal to 1.0 times the maximum value of the incident over-pressure wave.

The duration of overpressure on the vertical walls is expected to be at least equal to half of the incident overpressure wave.

It is assumed that the duration of the overpressure on the roofs which are exposed to reflections originating from taller buildings is equal to that of the incident overpressure wave.

4.2. SAFETY ANALYSIS

The verification used to confirm that the design provisions meet the safety and regulatory requirements will be performed in accordance with French regulations adapted to the more restrictive probabilistic objectives of the EPR.

The plant safety assessment in terms of the risks associated with the industrial environment (explosion, toxic, corrosive or radioactive gases) is performed and described in section 8 of this Sub-chapter C.3.

5. PROTECTION AGAINST EXTERNAL FLOODING

5.0. SAFETY REQUIREMENTS

5.0.1. Safety objectives

Following an internal or external flood, the basic objectives are:

- maintaining the integrity of the primary system,
- tripping the reactor and removing the decay heat,
- limiting any possible release of radioactive substances to an acceptable level.

5.0.2. External flooding safety requirements

The requirements related to the protection against external flooding and consistent with the French Regulations are to:

- Keep the building housing safety classified equipment dry, by setting the platforms at a level at least equal to the Maximum Design Flood Level.
- Prevent as far as possible the water, in case of presence on the platforms, from flowing inside these buildings.

The different hazards taken into account as well as their potential combinations are described below.

5.0.2.1. Hazards taken into account into the external flooding protection

5.0.2.1.1. River flooding

The Maximum Design Flood level is the maximum of the following values:

- level reached by a flood whose flow rate is that of a thousand-year flood, increased by 15%,
- level resulting from the combination of the highest recorded flood (or at least a hundred-year flood) with the effect of a dam failure.

5.0.2.1.2. Coastal flooding by excess of water level

The Maximum Design Flood level corresponds to the combination of the maximum tide (coefficient 120) with a thousand-year excess of sea water level.

5.0.2.1.3. Coastal flooding by tidal wave

A tidal wave, or *tsunami*, is a high-amplitude wave created following a landslide or an undersea earthquake. The risk of tidal wave is covered by the LFEWL hazard.

5.0.2.1.4. Dam rupture or failure (DRF)

It corresponds to an instantaneous and complete collapse of the dam.

The "Dam rupture or failure" hazard generates a high-speed submersion wave and floods installations located at low levels.

5.0.2.1.5. Estuary flooding

The Safety-Increased Maximum Water Level is the highest of the following three levels:

- Thousand-year flood combined with high tide with a coefficient of 120 or (if >),
- Coastal flooding by excess of water level (LFEWL) or (if>),
- Hundred-year flood (or historical flood if >) combined with a Dam Rupture or Failure (DRF) combined with a high tide with a coefficient of 70.

The combination of events corresponding to this level depends on the site's position in the estuary.

5.0.2.1.6. Coastal flooding due to heave

Heave represents all the waves on the surface of the sea. Normally the "significant height" parameter H_s is used to refer to heave effects. The other parameters concern the period, propagation length, and return level.

5.0.2.1.7. Deterioration of water channel structures (DOWCS)

This concerns risks related to a possible deterioration of structures (such as canal embankments, reservoir ponds, water retainers, tanks of air coolant towers) located near the site and located at a level higher than the site platform. The DOWCS hazard is analysed considering a certain number of potential load cases (earthquake, explosion, airplane crash, hydraulic deterioration, etc.). This hazard is characterised by the quantity of water potentially released and the maximum flow rate resulting from the deterioration, as well as the dynamics of the phenomenon.

5.0.2.1.8. Break of Systems or Equipment (BSE)

The "Break of Systems or Equipment" hazard is characterised by the amount of water released by the break taking into account the specific flow rate of the opening and the event, until isolation of the flow (manually, automatically, etc.).

The configuration taken into account corresponds to a "VANDELLOS" type of situation with the partial break of a CRF banner headline. In that configuration, it is considered that a manual isolation of the leakage can be performed in all cases within at most 30 minutes.

5.0.2.1.9. Swell (INT)

A malfunction of isolation valves (e.g. valves located on the driving force channel of a hydroelectric plant, the sudden stoppage of a Service Water pump, etc.) can cause strong variations in the water level, which may flood certain installations located upstream (or even downstream). The "Swelling" hazard is characterised by the maximum overflow rate or the maximum corresponding height on the site, as well as the duration of the fast dynamic phenomenon.

5.0.2.1.10. Brief, Intense Rainfall (BIR)

The "Brief, Intense Rainfall" hazard is characterised by the maximum average intensity parameter. This intensity corresponds to the maximum amount of water that falls during a relatively short period. It characterises the violence of the initial phase of a storm taking into account a 100-year return level.

5.0.2.1.11. Regular, Continuous Rainfall (RCR)

The "Regular, Continuous Rainfall" hazard is characterised in the same way, but using daily maximum hundred-year average intensities (maximum of 95% confidence interval).

5.0.2.1.12. Rise in Groundwater

The Groundwater hazard is characterised by the evaluation of the water table level and the speed of change (the initial condition of the water table corresponds to the maximum historical level).

5.0.2.1.13. Influence of Wind on the surface of a River or a Canal (IWR / River wave)

The risk evaluated is similar to the heave but for river. The "River wave" hazard is characterised by hundred-year wind conditions.

5.0.2.2. Potential combinations of hazards

- River sites: hundred-year flood (or historical, if higher) *combined* with a Dam rupture or failure (DRF);
- coastal sites: maximum tide with a coefficient of 120 *combined* with a thousand-year excess of water level;
- Sites in estuaries: thousand-year river flood *combined* with a high tide with a coefficient of 120, or a thousand-year excess water level *combined* with a high tide with a coefficient of 70, or a hundred-year flood *combined* with a DRF and *combined* with a high tide with a coefficient of 70.

- Combinations of hazards considered as part of additional measures:

  The same deterministic logic applied to BSR I.2.e is used. No quantified probabilities are associated with the combinations of the various hazards considered. However, the selected combinations are such that their frequency is of the same order of magnitude as that implicitly accepted for an exceptional river flood (thousand-year flood + 15%) defined in BSR I.2.e.
  These various combinations are first defined for the hazards they represent for a given level of dependency. But they may also be defined for certain other hazards which, although *a priori* considered to be relatively mutually independent, are associated by convention.

  - Coastal sites or sites in estuaries:

    - exceptional flood (LFEWL) *combined* with a hundred-year swell (LFS),
    - exceptional flood (EF) *combined* with a hundred-year swell (LFS) or "River wave" (I.V.F) according to the influence of the sea or the river,
    - a hundred-year coastal flood (including an excess of water level and a high tide) *combined* with a hundred-year RCR,
    - coastal flood SIMWL *combined* with a ten-year RCR for 24 hours (as part of defence in depth),
    - exceptional flood (LFEWL or EF) *combined* with Swelling INT ("CRF pump" scenario for coastal sites),
    - seawater submersion (LFEWL or EF) *combined* with groundwater at the maximum historical level,

  - River sites:

    - thousand-year flood *combined* with "River wave" (IWR) determined for a hundred-year wind,
    - hundred year river flood *combined* with a hundred-year RCR,
    - SIMWL river flood *combined* with a ten-year RCR for 24 hours (as part of defence in depth),
    - Swelling INT *combined* with various flooding situations,
    - River flood *combined* with groundwater at the maximum historical level,
    - Groundwater *combined* with a Dam Rupture or Failure (DRF),

  - Other combinations:

    - External flooding *combined* with a Loss Of External Power (for certain sites LOOP of 1 day to 3 days, according to sites),

- External flooding *combined* with an additional H1 situation (total loss of coolant – for certain sites).

Note : DOWCS and RSE hazards are characterised independently from any other potential flooding phenomena. The BIR hazard is not combined with the River Flooding and LFEWL hazards.

5.0.2.3. Failures caused by earthquakes affecting non-seismic equipment located on the platform

It shall be ensured that (eventually multiple) failure of non-seismic equipment located on the platform will not affect equipment required to return the installation to a safe state.

5.1. DESIGN BASIS

There are different types of protection against external floods:

- setting of the platform level and volumetric protection,
- fixed or mobile protection devices,
- design of a suitable water drainage system.

5.1.1. Setting of the platform and volumetric protection

5.1.1.1. Classified Civil Engineering Structures

The platform level is defined in accordance with French regulations, and bounds the Maximum Design Flood level (CMS) obtained by summing:

- Sea level at high tide with a tide coefficient of 120,
- the 1000-year sea water level at the 70% confidence level.

In terms of defence in depth, and in order to control any risk associated with transient overflows or limited failures of protection devices, volumetric protection is implemented for:

- the lower parts of buildings housing safety classified structures and equipment up to the CMS level, increased by a margin to allow for expected climate change effects in the medium term (the same procedure as applied to protection systems),
- increased as a general rule to the site platform (0.0m) level,

This procedure is applied to the nuclear island rooms, the main circulating water tunnels and the Pumping Station.

5.1.1.2. Other buildings or equipment

Non-classified plant is protected from flood water corresponding to the known historical maximum flood level or the highest known tides. In theory, this position can be translated as setting the site platform on a lower level than that of the nuclear island platforms. However, in practice, for commercial and design reasons, the site platform level is generally set at the same as that of the nuclear island platform.

Setting of the platforms is described in section 8 of this Sub-chapter C.3

5.1.2. Protection devices

The fixed protection devices are principally barriers for coastal (and estuary) sites and dykes along river banks for riverside sites to protect the site, taking into account swell and wave effects.

Mobile protection devices may be used if their effectiveness has been demonstrated and adequate robustness is assured.

The design procedures for protection against external flooding are divided into three stages:

1- Design of protection based on the hazards, characterised in a conservative manner and in accordance with the French regulations and associated principles;

2- Elevation of safety classified equipment to levels above the CMS with an added height margin to allow for climatic changes expected in the medium term;

3- Verification that the margins are adequate for the functioning of all associated systems.

In addition, when more precise assessments of the long term climatic developments become available and, as a minimum during the ten-yearly periodic safety reviews, site vulnerability to all aspects of external flooding will be re-examined.

5.1.3. Design of the water drainage network

Rainwater is drained by gravity.

The water drainage system is designed on the basis of flood levels at 100 year return frequency values.

5.1.4. Design of condenser neck

Multiple failures of the main condenser neck due to common cause effects , e.g. earthquake or fire, is ensured by adequate design and construction measures.

5.2. SAFETY ANALYSIS

The safety analysis are performed in accordance with current French regulations and consider in addition eight other hazards and hazard combinations.

The general methodology which was updated after the incident at the Blayais Nuclear Power Station in 1999 is used to confirm that the risk of external flood is acceptable. This includes specific verification of the acceptability of additional failures.

The Design Flood level (CMS) used for assessment against hazards and hazard combinations is increased by a margin to allow for expected climatic developments in the medium term. The adequacy of the margin will be verified and justified for all of the hazards after each ten-yearly periodic safety review.

In addition, given the uncertainties in the assessment of external flooding over reactor life, the initial design of the EPR reactor makes provision for enhancements for realistic climatic change developments larger than those initially planned. As explained in section 1 of this Sub-chapter, the potential enhancements may be in three forms:

- inclusion of additional margins in the load cases assumed at the design stage,
- allowing in the design the ability to make future physical modifications to the installation,
- consideration of changes to plant operation

The enhancements being considered for external flooding are described in section 8 of this Sub-chapter. The safety analysis is also described in section 8.

6. PROTECTION AGAINST EXTREME CLIMATIC CONDITIONS

6.0. SAFETY REQUIREMENTS

6.0.1. Safety objectives

The objectives for protecting against extreme climatic conditions are both to prevent or limit the propagation of the resulting adverse effects and to limit possible radioactive releases.

Within the design procedure, this involves ensuring that satisfactory ambient conditions are maintained for those systems where failure is likely to adversely affect the following safety functions:

- integrity of the primary cooling system,
- shutdown of the reactor and removal of residual heat,
- limiting possible release of radioactive substances on the site to an acceptable level.

6.0.2. Protection against snow and wind

All of the civil engineering structures are designed in accordance with the appropriate "Snow and Wind[2]" regulations.

6.0.3. Protection against wind generated missiles

Any potential missiles which are likely to cause a threat to other structures or materials must be considered.

The following equipment located outside of the buildings is protected against missiles which are likely to be generated by high wind at the level considered in the design of the installation:

- F1 classified,
- F2 classified required to return the unit to a safe shutdown state as defined in Chapter C.2, including MDTE [LOOP] or total loss of the main heat sink, as well as the combination of MDTE + total loss of the main heat sink.

In addition, it is necessary to ensure that damage caused by missiles (possibly multiple) on external equipment (tanks, pipes, gas systems…) which is located on the platform is not likely to affect equipment which is needed to return and maintain the installation to a safe condition (e.g. by causing a flooding risk or internal explosion) including an MDTE [LOOP], or total loss of the main heat sink and the combination of MDTE + total loss of the main heat sink.

6.0.4. Protection against extreme low ambient temperature

6.0.4.1. Safety requirements

For the design basis low temperature conditions, the F1 and F2 equipment must be able to complete its functions.

This design low temperature is claimed to be restricted in duration and is thus taken into consideration in continuous operation.

Extreme Cold is considered to be a natural external hazard. Extreme Cold is referred to when the temperatures fall below the temperature used for the design. The installation must be able to withstand any PCC-2 to 4 situations which is combined with Extreme Cold.

To enhance defence in depth, other combinations are considered. These ensue that certain items of equipment are protected against Extreme Cold which are vital for management of RRC-A (prevention of core melt) situations involving loss of the final heat sink or loss of electrical power supplies.

In addition, the equipment which must be protected against Extreme Cold is that which is required to return and maintain the installation to a safe shutdown condition and to limit the radiological consequences; even in the event of loss of external electric power supplies (see section 6.0.4.2 within this Sub-chapter C.3).

However, certain specific instances are excluded:

[2] That is, the Eurocodes (and in particular Eurocode 1) which are transposed in to French standards, which have not yet been published but which will be applied in 2007.

- lifting equipment which is prohibited from being used during periods of Extreme Cold. This includes certain handling equipment and equipment ensuring safety during fuel handling (DWL, KRT chains…)

- equipment which is used in those conditions where the frequency of occurrence relates to the residual risk (notably, the combination of Extreme Cold + Loss of external power supplies + Accident)

However, the fire detection and fighting devices must be available in periods of Extreme Cold.

Equipment which is vital for Extreme Cold management must be F2 classified. Depending on the case, we ensure either:

- the availability of the equipment. This equipment must be able to fulfil its function during the period of Extreme Cold, or

- the non-deterioration of the equipment. This equipment may not be able to fulfil its safety function during the period of Extreme Cold, but is subsequently functional on demand, once the Extreme Cold has ceased.

6.0.4.2. Consideration of the loss of external power supplies (MDTE) [LOOP]

The loss of external power supplies is more likely to occur during a period of cold where the grid is subject to greater loads.

It is therefore necessary to ensure that the reactor can be shut down and maintained in a safe shutdown condition following loss of grid. The demonstration must consider the equipment which is required during this operating condition and its ability to fulfil the required functions.

The other F1 and F2 classified equipment, which is required in periods of Extreme Cold in other operating conditions, must be available after the MDTE. [LOOP]

The postulated loss of off-site power in Extreme Cold conditions is assumed to be due to a grid overload (functional loss of off-site power) and not to an equipment failure.

It is necessary to consider both the situation where the unit is initially in a shutdown condition and the situation where the unit is initially in an at-power state, and then is shutdown due to the loss of the external electric power supplies.

6.0.5. Protection against frazil (sea) ice and freeze-up

The cooling water intakes are protected from the possible effects of frazil (sea) ice and freeze-up. (Frazil ice consists of micro particles transported in suspension.)

6.0.6. Protection against high ambient temperatures

Three types of temperature are used in the design of the installation:

- two temperatures for the air: a maximum daily average ($T_{daily\ air\ max}$), and an instantaneous maximum ($T_{prompt\ air\ max}$)

- a temperature for the heat sink water: daily maximum.

These temperatures, and their application, are explained below:

- Maximum daily air temperature, with associated relative humidity ($T_{daily\ air\ max}$), to be used for the buildings with high thermal inertia [3]. The temperatures are the 12 hour averages with a 100 year return level;

- Maximum prompt air temperature, with associated relative humidity ($T_{prompt\ air\ max}$), to be used for the buildings with low thermal inertia or the external materials. The temperatures are the maximum instantaneous temperatures with a 100 year return level;

- Heat sink temperature: this is determined at the 100 year return level.

The basic values defined for the EPR are chosen to cover 100 % of the actual geographical installation zones for the nuclear site.

The upper limit heat sink temperature which is used is consistent with the installation of an EPR on the English Channel or any site with a lower heat sink temperature.

Unless mentioned specifically, all of the standard structures and equipment are designed using the temperatures defined above. The site temperatures are taken into consideration when design the site specific structures and equipment.

6.0.7. Protection against drought

The cooling water intake structures are protected from the possible effects of drought.

For a coastal site, due account is taken of anticipated tidal condition, particularly during spring and autumn. Extreme low sea levels over a prolonged period (several days) are very unlikely.

Exceptional very low tide conditions occur during a combination of extreme meteorological and tidal conditions. Meteorological effects include atmospheric pressures and wind.

The following should be considered for coastal sites:

- normal predicted (‘astronomical’) tidal variations with a maximum coefficient of 120

- additional effects caused by extreme atmospheric pressures variations and high wind. Characterisation of these effects is derived from statistical analysis of extreme events.

For safety assessment, the lowest safe water for a coastal site is based on the 1000 year return frequency condition, taking account of normal predicted tidal variations and meteorological effects. The 70% confidence interval is used for the statistical estimate.

The margin of uncertainty is calculated as a fraction of the difference (positive) between the lowest astronomical sea level (coefficient 120) and the thousand-year level.

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[3] The 12 hour air values indicated take into consideration cooled ventilation, but they do not prejudice the decoupling temperature used to define the respective role allocated to each item of equipment (i.e. the role of cooled ventilation / intrinsic capability of the safety classified equipment).

For a riverside site, there are two main causes of low water levels: natural phenomena, which occur rather slowly, and the use (or malfunction) of flow management systems.

For a riverside site, exceptional climatic conditions may lead to an extreme low level in the heat sink.

In the specific case of an estuary, the effect of combined marine and river influences must be considered.

6.1. DESIGN BASIS

As noted above, because of the uncertainties in the climatic parameters to be covered over the service life of the reactor, the initial design of the EPR reactor makes provision for enhancement during operation, to address potential realistic climatic developments beyond those initially considered.

As explained in section 1 of this Sub-chapter C.3, facilities for implementing these enhancements may be planned in three ways:

- o Consideration at the design stage of additional margins with regard to the design cases used,
- o Feasibility of installation of modifications,
- o Acceptability of operational development.

The particular potential enhancements which are planned for the different climatic conditions are explained in section 8 of this Sub-chapter.

6.1.1. Snow and wind

The buildings are designed in accordance with the NV65 regulations [4] /1/.

The specific site loading cases are described in section 8 of this Sub-chapter.

The adaptability of the design of the installation to accommodate future climatic changes does not require a specific study for snow. Considering predicted climatic changes, cold weather conditions, including snow, are expected to be less severe in the future.

6.1.2. Wind generated missiles

Two types of missiles are considered:

- heavy missiles which are propelled along the ground,
- light missiles which are considered at all heights and in all directions.

The maximum wind speed used for the site in question is as defined by the NV65 regulations [5] /1/ /1/ (see section 8 within this Sub-chapter).

In these conditions the missiles reach the following speeds. The maximum wind speed is site specific.

[4] That is, the Eurocodes (and in particular Eurocode 1) which are transposed in to French standards, which have not yet been published but which will be applied in 2007.

Missiles	Dimension (m)	Mass (kg)	Maximum height (m)	Speed
Automobile	3.8 x 1.5 x 1.3	900	0	3 m /s
Wooden board	3.7 x 0.3 x 0.09	50	Any height	50 % of the maximum wind speed
Cladding sheets	1 x 6	60	Any height	Maximum wind speed

6.1.3. Low air temperatures

The following three characteristic values are used for the design:

a) the minimum average temperature observed over more than 7 consecutive days with a return period of 50 years,

b) the minimum average temperature over 24 hours, with a return period of 100 years,

c) the minimum instantaneous temperature with a return period of 100 years (or three-hourly if instantaneous temperature is not available),.

The scope of these temperatures is as follows:

- The <u>long duration</u> temperature represents the conditions which could frequently occur and persist (normal and continuous operating conditions). It is thus assumed that this temperature may exist permanently. In practice a value of -15°C is used.

- The <u>short duration</u> temperature is representative of a temperature which could only occur for periods limited both in terms of time and frequency. This defines the short duration temperature which is used in the design with duration of 7 days. In practice –25°C is used.

- The <u>prompt</u> (i.e. instantaneous) temperature is used instead of the short duration temperature for low thermal inertia items. This defines the temperature which is used in the design with duration of 6 hours. In practice a value of -35°C is used.

For the design of the civil engineering structures the thermal stresses take into consideration the long duration temperature. The short duration temperature is used to design the ventilation systems and the protection against freezing.

<u>Consideration of wind associated with cold conditions:</u>

Wind may have two effects:

- the wind chill factor, enhancing heat loss from walls and structures,

- high wind may have a detrimental effect on equipment housed in rooms which have openings.

However, it should be noted that available information indicates that periods of extreme cold are, in practice, associated with conditions of low or no wind. As a general indication, a boundary occurs around values of –15°C. Below this temperature, wind is very unlikely to occur. The wind value used is 4 m/s.

The typical anticipated cause of loss of off-site power during periods of Extreme Cold is such that the duration is unlikely to exceed 6 hours. However, a duration of 24 hours is conservatively assumed in order to encompass the duration of the MDTE [LOOP] considered in PCC-3.

To summarise, the temperature values used for the EPR are shown in the following table:

Type	**Long duration temperature**	**Short duration temperature**		**Prompt temperature**
Temperature-duration rates	-15 °C permanent + wind (4 m/s) + MDTE [LOOP]	-25 °C (7 days) excluding MDTE	-25 °C (7 days) + MDTE (24 h)	-35 °C (6 h) + MDTE (24 h)
CONDITION OF EQUIPMENT TO MAINTAIN				
F1 and F2 classified materials required during an MDTE	Available	Available	Available	Available
Other (F1 and F2) "Extreme Cold" systems not required during an MDTE	Available	Available	Not damaged	Not damaged

The choice of a standard temperature limits the number of cases to be calculated during the engineering studies. However, short duration and prompt site temperatures can be used for designing the site structures and equipment. The site temperatures are described in section 8 of this Sub-chapter C.3.

The adaptability of the design of the installation to accommodate future climatic changes does not require a specific study for extreme cold. Considering predicted climatic changes, cold weather conditions are expected to be less severe in the future.

6.1.4. Frazil (sea) ice and freeze-up

Provisions are implemented for the cooling water intake structures in order to protect against the risk of a loss in the heat sink caused by frazil (sea) ice or freeze-up.

The adaptability of the design of the installation to accommodate future climatic changes does not require a specific study for frazil ice. Considering predicted climatic changes, cold weather conditions are expected to be less severe in the future.

6.1.5. High ambient temperature

6.1.5.1. Air temperatures and associated relative humidity (HR)

$T_{daily\ air\ max}$

- Air temperatures with associated relative humidity for buildings with high thermal inertia: average over 12 hours, taking account of climatic developments forecast for the end of the century, with a 100 year return frequency, and based on a pessimistic assessment of the effect of greenhouse gases on climate change (A2 scenario).

Base values	Alternative standard used for northern French sites
$T_{daily\ air\ max}$ = 42°C HR seafront = 29 % HR other sites = 24 %	$T_{daily\ air\ max}$ = 36°C HR = 40 %

$T_{prompt\ air\ max}$

- Air temperatures with associated relative humidity for buildings with low thermal inertia: prompt (instantaneous) temperature taking account of climatic developments forecast for the end of the century, with a 100 year return frequency, and based on a pessimistic assessment of the effect of greenhouse gases on climate change (A2 scenario).

Base values	Alternative standard used for northern French site
$T_{prompt\ air\ max}$ = 47°C HR seafront = 24 % HR other sites = 19 %	$T_{daily\ air\ max}$ = 42°C HR = 29 %

6.1.5.2. Maximum heat sink temperature

For the cold coastal alternative criterion, the maximum temperature used for the overall heat sink is 26°C.

6.1.6. Drought

The cooling water intake structures are protected from the possible effects of drought by siting and designing them to the Lowest Safe Water Levels (PBES). Thus, the plant is protected against the risk of a loss of the heat sink during a drought.

For a coastal site, the adaptability of the installation in relation to the climatic developments for drought does not require a specific study. In practice, the anticipated situation is an increase in sea level.

6.1.7. Durations for loss of ultimate heat sink and MDTE [LOOP]

Loss of the ultimate heat sink and loss of off-site power supplies, as well as their combined effect are considered to be a plausible consequence of climatic external hazards.

The following overall durations are used:

Elementary situations for the whole site			
Case	**MDTE [LOOP] site**	**Loss of site ultimate heat sink**	**Alert phase**
MDTE only	15 days (*)		
Loss of site ultimate heat sink		100 hours	24 hours
Combined			
MDTE + loss of final heat sink	8 days	24 hours	24 hours

(*) The 15 day duration for the MDTE [LOOP] is used in consideration of an earthquake and envelopes the expected durations of climatic external hazards which are of climatic origin.

Safe shutdown and maintenance of a safe shutdown state are assured in the different periods indicated in the above table.

6.2. SAFETY ANALYSIS

6.2.1. Resistance to snow

All safety and non-safety classified buildings are designed to withstand the effects of snow.

6.2.2. Resistance to wind

All buildings and external equipment are designed to withstand the effects of wind. Hence, all F1 and F2 safety classified equipment is protected against the direct mechanical and aerodynamic effects of wind.

The safety classified ventilation systems are designed to withstand the aerodynamic effects of wind.

6.2.3. Protection against wind generated missiles

The external F1 classified equipment and the F2 classified equipment which is required to shut down the reactor and maintain it in a safe state, including during an MDTE [LOOP], a loss of heat sink and during a combined MDTE [LOOP] + loss of heat sink, are protected from potential wind generated missiles.

6.2.4. Protection against extreme cold

A thermal assessment is undertaken for each site building or installation, for the different plant states, to determine the ambient temperature of the rooms containing equipment to be qualified for Extreme Cold conditions.

This assessment is undertaken on the basis of the site temperatures for the site specific structures and equipment.

6.2.5. Protection against frazil (sea) ice and freeze-up

Two phenomena may occur during a cold spell: the appearance of a layer of ice on the surface and/or the formation of frazil (sea) ice (ice micro particles transported in suspension).

Three types of risk can be identified:

- o Active frazil ice (equivalent to super cooling frazil ice): this has highly adhesive properties, which can cause blockage of the water inlet grills.
- o Passive frazil ice: (relatively large plates which float with the water, and which are likely to be ingested by the water intake; or they may become stacked and cause "column" blocking): this has the ability to block the intake strainers.
- o Freeze-up: this causes a reduction in the water flow area and may eventually obstruct the water intake by forming an ice cover. The elevation of the cooling water pumps allows for an appropriate maximum ice thickness.

6.2.6. Protection against high ambient temperature

Unless specifically stated, the civil engineering structures and the ventilation and air conditioning systems are designed to accommodate high ambient temperatures.

The maximum temperature of the heat sink is used for the design of the cooling systems.

The design of the ventilation systems and structures will be based on site specific UK climatic data. The structures and equipment are designed on the basis of site specific temperatures.

Note that this is a design procedure and not, as for plants in operation, a hazard assessment. Definition of the maximum temperatures is associated with the design bases which means that consideration of specific combinations is not necessary.

6.2.7. Protection against drought

The choice of, and design against, the Lowest Safety Water Level (PBES) for the cooling water intakes ensures that loss of heat sink will be avoided in the event of drought.

7. PROTECTION AGAINST LIGHTNING AND ELECTROMAGNETIC DISTURBANCES

7.1. PROTECTION AGAINST LIGHTNING

7.1.0. Safety requirements applicable to lightning

FA3 in common with other French plants are subject regulations with regard to lightning described in technical report CEI 61 662 technical report (/2/).

7.1.1. Characteristics of the phenomenon

The applied standards are CEI 61024-1-2 (/3/) or NFC17-100 (/4/).

Lightning parameters:

- Value of peak current, Imax 200 kA,
- T1, initial rise duration 10 µs,
- T2, time to half-value 350 µs,
- Total charge, Q_{total} 300 C
- Pulsed charge, Q_{pulse}. 100 C,
- Specific energy W/R 10 MJ/Ohm.

7.1.2. Verification of installation design against lightning

The analysis procedure which is based on technical report CEI 61 662 (/2/) is used to demonstrate:

- the robustness of the nuclear power plant in relation to lightning,
- the acceptability of the environmental consequences and the protection of personnel.

This approach complies with the protection requirements for lightning risk. It provides, via the above reference (/2/), the tools needed to assess the risks of damage associated with the direct or indirect effects of lightning and identifies the required protection measures.

Procedure assumptions:

The construction requirements for lightning protection are addressed via application of weighting coefficients (reduction of the probabilities of damage).

The methodology which has been developed is based on an elemental approach where the smallest element is the building (BK, BL, etc.)

The three risks which are associated with lightning are:

- step and touch voltages,
- fires / explosions,
- overvoltages.

Combination assumptions:

- the lightning strike occurs during a standard plant state (category 1 situation),
- coincident lightning strikes and a degraded plant condition (PCC-2 to PCC-4 situations) are not considered,
- consideration of coincident lightning strikes and loss of off-site power (MDTE) [LOOP] is not required if off-site supplies are redundant and protected.

Calculations include consideration of:

- structural characteristics (ground surface, metallic structure, …),
- content of the structure (flammability, explosiveness, …),
- the presence or absence of lightning protection devices (External Installation of Lightning Protection "IEPF"…),
- the type of connections (thickness of clamps…),
- the connection to the ground and/or earth network…

Calculation of both the damage probabilities (Px) and lightning strike frequencies, enables the S1 to S7 values defined in this technical report to be assessed.

- **Risks frequency for different types of lightning strike**

	Direct effect of lightning	**Indirect effect of lightning**	
		Neighbouring ground	**Inputting service**
Electrification of step and touch voltage	S1 (H) = $N_d.P_H$	-	-
Fire / Explosion	S2 (A) = $N_d.P_A$	S6 (B) = $N_n.P_B$	S7 (C)* = $N_k.P_{Ck}$
Overvoltage	S3 (D) = $N_d.\ P_D$	S4 (E) = $N_n.P_E$	S5 (G)* = $N_k.P_{Ck}$

(*) Addition for all of the connections entering the building

The appropriate addition of the S1 to S7 parameters for each of these effects leads to the calculation of the damage frequency considered.

- **Components which comprise the damage frequency**

No.	Risks	S1 H	S2 A	S3 D	S6 B	S4 E	S7 C	S5 G
1	Personnel injury or loss of human life	X	X		X		X	
2	Damage causing equipment loss with no environmental impact		X	X	X	X	X	X
3	Damage causing equipment loss with potential environmental impact		X	X	X	X	X	X

The calculated damage frequency value is then compared with the admissible frequency value (Fa), see below.

Based on these characteristics of the plant and its environment, we calculate the probabilities of a direct lightning strike, on the neighbouring ground or inputting service, generating a pace voltage, a fire / explosion or an overvoltage.

- **Acceptability thresholds according to the type of damage (per building, per year)**

Type of damage	Personal injury	Equipment loss with possible environmental impact	Equipment loss without environmental impact
(Fa) : Global acceptability threshold used for the damage frequency	10^{-3}	10^{-3}	10^{-2}

The acceptability thresholds used originate from damage threshold numbers 1, 4 and 5 defined in technical report CEI 61 662 (/2/).

If the risk is acceptable, no specific measure is recommended. Conversely, if the acceptable threshold is exceeded, plant modifications are proposed to reduce the level of risk.

However, an additional analysis will be performed when the frequency of damage occurrence is close to the admissible frequency (within an order of magnitude). This additional analysis is performed outside of the lightning study.

7.1.3. Constituent elements of the lightning protection device

The protection of relevant buildings and structures is performed where possible by a mesh cage.

Treatment of the direct effects is covered by application of standard NFC17-100 (/4/). The indirect effects are treated in accordance with standard CEI 61000-5-2 (/6/).

Input and output services are earthed or grounded in a way which does not adversely affect the protection using the meshed cage.

These arrangements ensure that equipment and systems are resistant to electromagnetic disturbances in line with the levels specified in RCC-E D 5000.

The earth network and the ground networks, which are the basic elements for protection against the effects of lightning, are interconnected, strongly meshed and are equipotential.

7.2. PROTECTION AGAINST HF ELECTROMAGNETIC FIELDS

Standard CEI 61000-6-5 (/5/) defines an electromagnetic environment which is representative of a power plant. It establishes the immunity provisions for devices and systems which require stable operation when working in electromagnetic fields.

The installation of the electrical and instrumentation and control equipment in accordance with the recommendations in technical report CEI 61000-5-2 (/6/) ensures electromagnetic compatibility between the electrical devices or systems.

Compliance with these standards offers a high level of confidence for protection against electromagnetic disturbances. The former ensures that the installed equipment functions despite the existence of an industrial electromagnetic environment and the second ensures that their installation is compatible with correct operation.

Chapter D5000 of RCC-E provides more details on the type of disturbances encountered and on the devices which are installed to provide protection against electromagnetic disturbances: decoupling system, meshed ground networks, ~~certain systems placed beneath screen~~, shielding of cables.

8. SAFETY ANALYSIS FOR THE SPECIFIC EPR SITE

The objective is to verify, for external hazards, that the design assumptions established in the previous sections of Chapter C.3 are appropriate for the site conditions. This section will be completed when a specific site is selected for a UK EPR.

LIST OF REFERENCES

[1] NV65 regulations – Revision 2000 (including the 1999 Wind revision and the 2000 Snow revision).

[2] CEI 61662 technical report "Assessment of the risks of damages associated with lightning".

[3] CEI 61024-1-2 standard, "Protection of structures against lightning".

[4] NF C 17-100 standard, "Protection of structures against lightning - Installation of a conductor."

[5] CEI 61000-6-5 standard, "Immunity of materials for electrical power plant environments and for electrical power plant workstations - sections".

[6] CEI 61000-5-2 Technical report "electromagnetic compatibility – section 5 – Installation and attenuation guides – Section 2 – Earthing and wiring".

TAB 1: SUMMARY OF THE REQUIREMENTS FOR PROTECTION AGAINST EXTERNAL HAZARDS

This Table presents a summary of the requirements for protection against external hazards for the main systems, based on the principles explained in this chapter, the purpose of which is to ensure that the functions which are needed to achieve the safety objectives are not unacceptably affected.

High ambient temperatures does not appear in this table as the relative requirements are embodied in the design assumptions for the different systems.

The detailed consideration of these requirements in the design of the basic systems is shown in the relevant chapters.

	Earthquake	Aircraft crash	External explosion	External flooding	Snow and wind	Extreme cold	IEM (*)
AAD [SSS]	No	No	No	No	No	No	No
F1 electrical power supply	Yes	Yes	Yes	Yes	Yes	Yes	Yes
APG [SGBS] (F1 functions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ARE [MFW(S)] (F1 functions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ASG [EFW(S)]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CFI [CWFS] (F1 functions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CRF (F1 function)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DCL	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DEL	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DER (1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DFL	No	No	No	No	No	No	No
Main diesel generators	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Final emergency diesel generators	Yes	Yes	No	No	Yes	Yes	No
DMK	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DVD	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DVL	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DVP (F1 functions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DWB	No	No	No	No	No	No	No
DWK (F1 isolations)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DWL [CSBVS]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DWN	No (4)	No	No	No	No	No	No
DWQ	No	No	No	No	No	No	No
DWW	No	No	No	No	No	No	No
EBA [CSVS] (F1 functions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
EDE [AVS]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ETY	No	No	No	Yes	Yes	Yes	No
EVF	No	No	No	No	No	No	No
EVR [CCVS]	Yes	No	No	No	No	No	No
EVU [CHRS]	Yes(5)	No	No	Yes	Yes	Yes	No

Enclosure isolation	Yes	Yes	Yes	Yes	Yes	Yes	Yes
JAC	Yes	Yes	Yes	Yes	N/A	N/A	N/A
JDT [FDS]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
JPI	Yes	Yes	Yes	Yes	Yes	Yes	Yes
JPV	Yes	Yes	Yes	Yes	Yes	Yes	Yes
KER [LRMDS] (EPR collector)	No	No	No	No	No	No	No
KRT [PRMS] (F1 functions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PTR [FPPS/FPCS] (2)	Yes	Yes(3)	Yes(3)	Yes	Yes	Yes	Yes

	Earthquake	**Aircraft crash**	**External explosion**	**External flooding**	**Snow and wind**	**Extreme cold**	**IEM (*)**
RBS [ABS]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RCP [RCS]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RCV [CVCS] (F1 functions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
REA [RBWMS]	No	No	No	No	No	No	No
REN [NSS] (F1 functions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RIC (F1 functions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RIS [SIS]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RPE [NVDS] (1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RPN	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RRI [CCWS] (F1 functions)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SAR (1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SAT (1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SDD [DBE] (1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SEC [ESWS]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SEK [CILWDS] (EPR collector)	No	No	No	No	No	No	No
SGN (DEA tanks)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SIR (1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SNL (1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SRU [UCWS]	Yes(6)	No	No	Yes	Yes	Yes	No
TEG [GWPS] (1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TEP [CSTS]	No	No	No	No	No	No	No
TER [ExLWDS] (EPR collector)	No	No	No	No	No	No	No
TES [SWTS]	No	No	No	No	No	No	No
TEU [LWPS]	No	No	No	No	No	No	No
VDA [MSSS]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
VVP [MSSS]	Yes	Yes	Yes	Yes	Yes	Yes	Yes

(*): Electromagnetic disturbances

N/A: not applicable.

(1) Isolation functions for enclosure only.
(2) Cooling trains, enclosure passages and isolation of the draining pipework.
(3) Does not apply to the third cooling train.
(4) With the exception of the air intake isolation dampers.
(5) The two main lines are SC1
(6) The two main lines are SC1

TAB 2: SUMMARY OF THE COMBINATIONS CONSIDERED IN THE DESIGN OF THE EPR

For each external hazard table 2 below presents:

- the combinations explicitly considered,
- The combinations implicitly considered (covered elsewhere).

Hazard	References other than TG	Chapters	Totals		
			Events	Internal hazards	External hazards
Earthquake	The Design Complies with French Regulation	C.3.2 (Earthquake) C.2 (Classification) P.0.2 (Accident studies regulations) C.4.7 (Fire)	Explicitly considered SDD [DBE]+ PCC + MDTE[LOOP] SDD + MDTE[LOOP] long term	Explicitly considered all (SC2) with the specific measures for fire and explosions, including internal flooding of the platform	Explicitly considered External flooding (in general not applicable for shoreline sites) Wind, Snow, External temperatures, Height of the water table (in terms of the initial conditions) Implicitly considered SDD [DBE] + External explosion

Hazard	References other than TG	Chapters	Totals		
			Events	Internal hazards	External hazards
Aircraft crash	The Design Complies with French Regulation	C.3.3 (aircraft crash) C.4.7 (fire)	Explicitly considered None Implicitly considered PCC (covered by the earthquake) total loss of SF	Explicitly considered Aircraft crash + Flooding of platform Implicitly considered Fire Everything inside the buildings is covered by the measures taken for an earthquake	Explicitly considered External flooding Implicitly considered Wind, Snow, External temperatures, Height of the water table (covered by the measures used for an earthquake)
External explosion	The Design Complies with French Regulation	C.3.4	Explicitly considered MDTE [LOOP] Implicitly considered PCC (covered by the measures taken for an earthquake).	Explicitly considered None Implicitly considered Everything inside the buildings protected (covered by the measures taken with regard to an earthquake) Internal flooding of the platform	Explicitly considered External flooding (in general not applicable for a shoreline site)

Hazard	References other than TG	Chapters	Totals		
			Events	Internal hazards	External hazards
External flooding	The Design Complies with French Regulation	C.3.5	<u>Explicitly considered</u> MDTE [LOOP] Total loss of heat sink MDTE [LOOP] + loss of heat sink	<u>Explicitly considered</u>	<u>Explicitly considered</u> Rain, wind, high level of Water Table (characterisation of the problem)
Extreme meteorological conditions	The Design Complies with French Regulation	C.3.6			
Snow	Eurocode 1		<u>No combination explicitly considered</u>		
Wind - Aerodynamic and mechanical effects in Civil Structures and Ventilation systems	The Design Complies with French Regulation		<u>Implicitly considered</u> PCC (covered by Civil Engineering design)		<u>Explicitly considered</u> Earthquake (initial conditions)

Hazard	References other than TG	Chapters	Totals		
			Events	Internal hazards	External hazards
Wind - Missiles	The Design Complies with French Regulation		Explicitly considered MDTE [LOOP]+ loss of heat sink Implicitly considered PCC (covered)	- Explicitly considered Internal flooding Internal explosion Fire (on the Platform)	
Cold Frazil ice and freeze-up	The Design Complies with French Regulation		Explicitly considered GF + PCC GF + loss of heat sink or total loss of main electric sources Implicitly considered F +MDTE [LOOP]+ PCC	Explicitly considered Fire	Explicitly considered Wind (initial conditions)
High ambient temperature Drought	The Design Complies with French Regulation		Implicitly considered All PCC (high temperatures considered in the design)	Implicitly considered All	Implicitly considered All
Rain					
Lightning – Electromagnetic disturbances	The Design Complies with French Regulation	C.3.7	Explicitly considered None	Explicitly considered Fire	Implicitly considered Rain (covered due to gravity network)

FIG 1: EUR GROUND DESIGN SPECTRA (HORIZONTAL, 5% DAMPING)

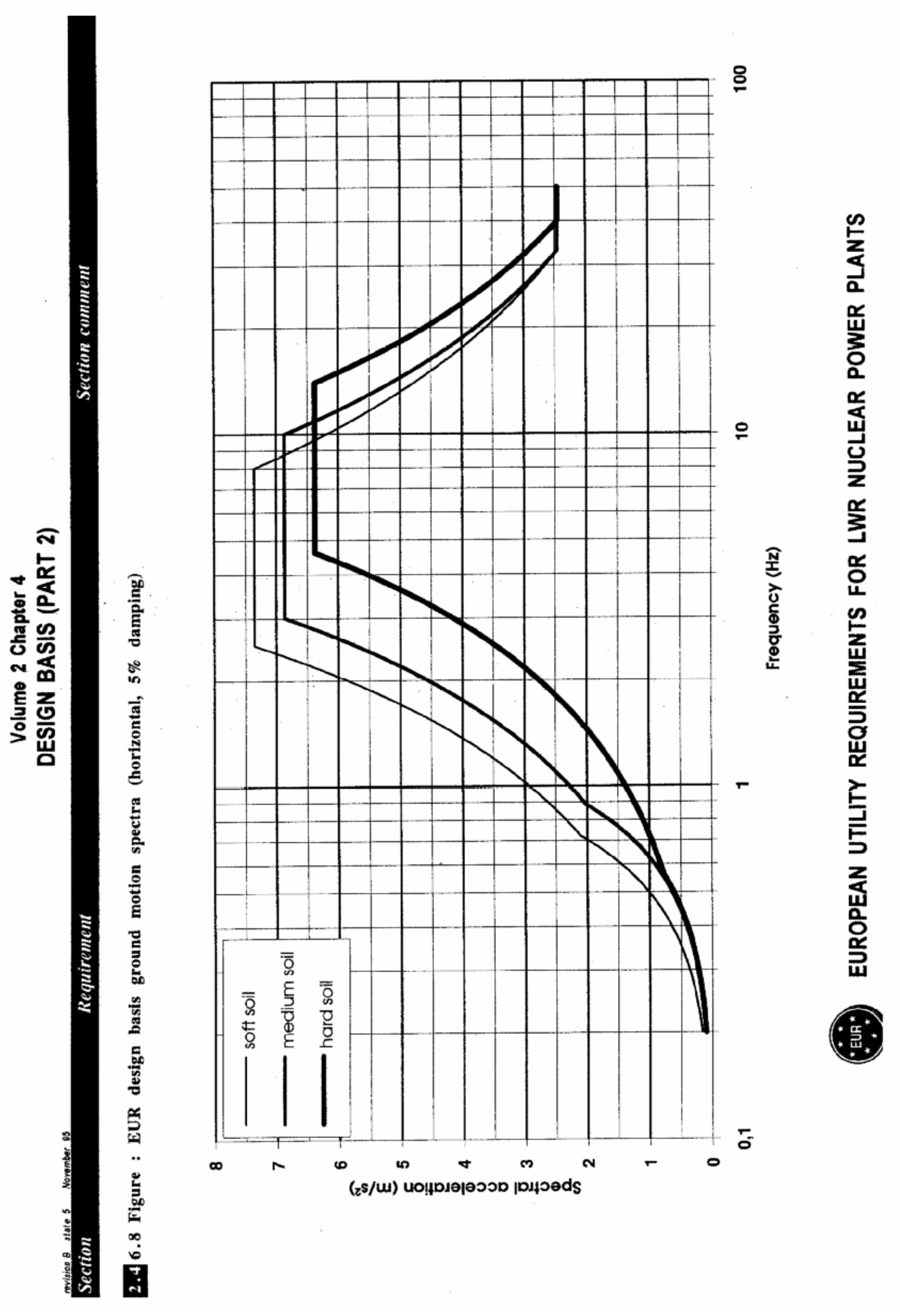
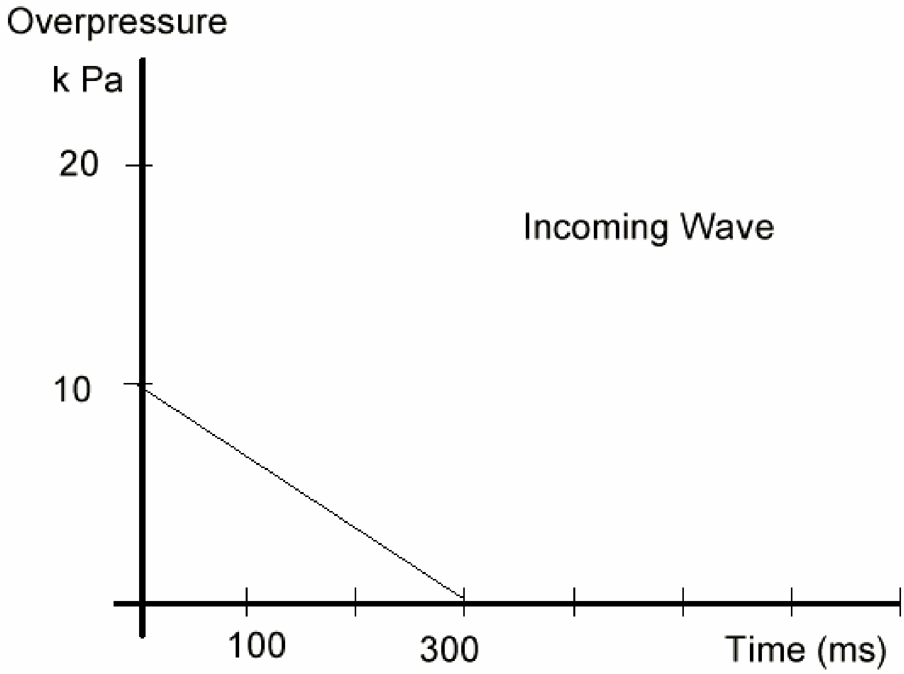


FIG 2: INSPECTION EARTHQUAKE– DIAGRAM TO ESTABLISH MEASURES AFTER EARTHQUAKE

$a_{hf\ max}$ = max. horizontal acceleration in the free field

Inspection Earthquake
Diagram to establish measures after earthquake

FIG 3: STANDARD LOAD-TIME FUNCTION FOR EXPLOSION PRESSURE WAVE



Standard load-time function for Explosion Pressure Wave

N.B.: the 15 ms rising duration of the wave edge is not shown on the graph.