Regional Workshop on

Volcanic, Seismic and Tsunami Hazard Assesment Related to NPP siting Activities and Requirements

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“External Human Induced Events in Site Evaluation for NPP”

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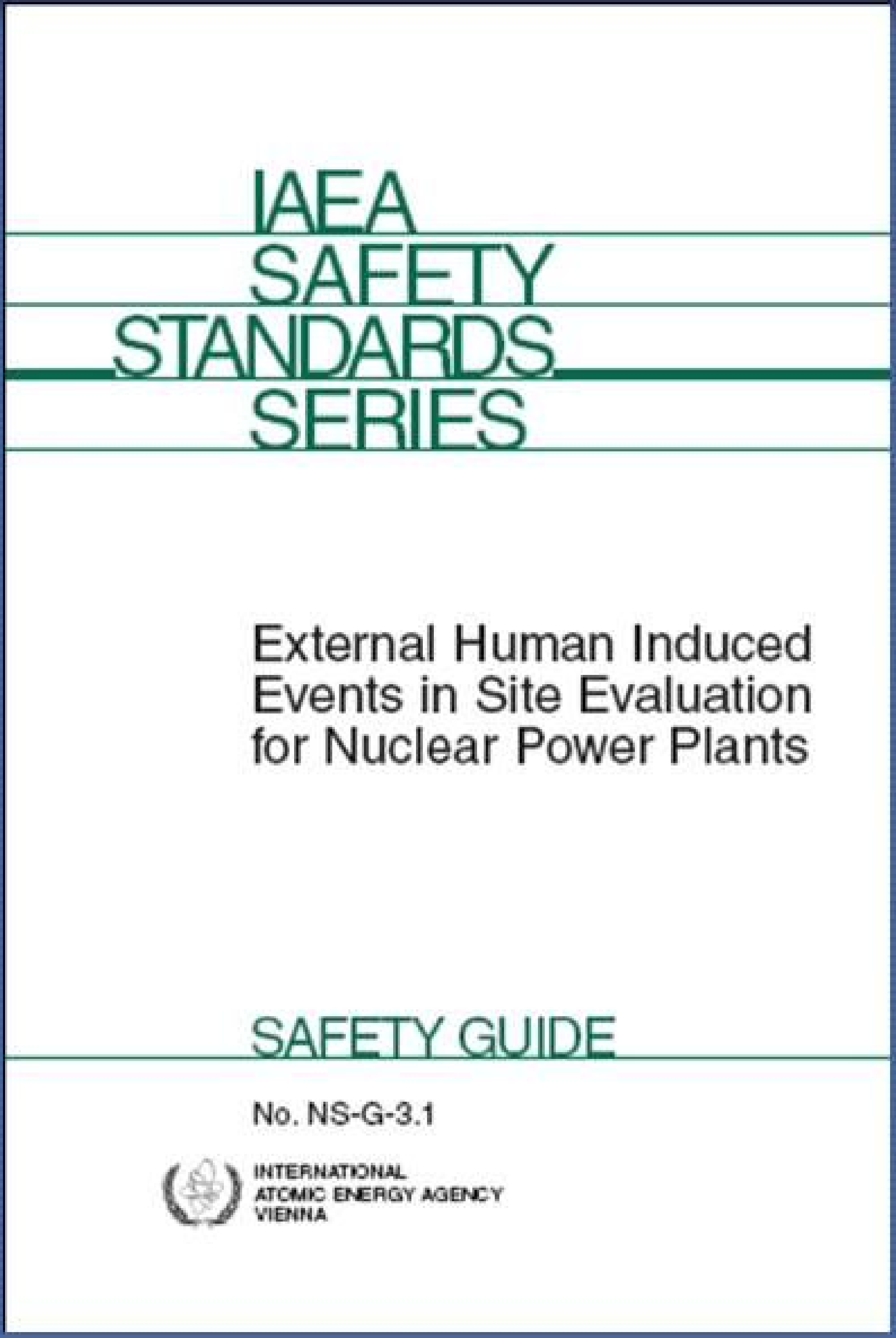
Background

- Facilities and human activities in the region in which a nuclear power plant is located may under some conditions affect its safety.
- The potential sources of human induced events external to the plant should be identified and the severity of the possible resulting hazard phenomena should be evaluated to derive the appropriate design bases for the plant.
- They should also be monitored and periodically assessed over the lifetime of the plant to ensure that consistency with the design assumptions is maintained.



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Scope

- The external human induced events are all of accidental origin,
- Physical protection of the plant against wilful actions by third parties are outside its scope,
- This SG may also be used for events that may originate within the boundaries of the site, but from sources not directly involved in the operational states of the NPP units,
- It concentrates on the definition of hazards for the site and on the general identification of major effects on the plant which are to be used in a design assessment framework,

Scope (ctd.)

- In the selection between a deterministic and a probabilistic approach for hazard evaluation, several issues are determinant:
  - availability of data for the site,
  - possibility of reliable extrapolation to lower excess values,
  - the design approach to be adopted,
  - the compatibility with national standards for hazard evaluation and design,
  - and public acceptance issues.
- The Safety Guide does not cover events resulting from the failure of artificial water retaining structures,

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General Approach to site Evaluation

- External human induced events that could affect safety should be investigated in the **site evaluation stage** for every nuclear power plant site ,
- It is required to examine first the region for facilities and human activities that have the potential, under certain conditions, to endanger the nuclear power plant over its entire lifetime ,
- Each **relevant potential source** is required to be identified and assessed to determine the potential interactions with personnel and plant items important to safety .

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Data collection and Investigations

- Type of potential source
- Identification of potential sources
- Collection of information
- Stationary sources
- Mobile sources
- Source display map

Type of Potential Sources

- The sources of external human induced events may be classified as:
  - Stationary sources :
    - location of the initiating mechanism (explosion centre, point of release of explosive or toxic gases) fixed (chemical plants, oil refineries, storage depots and other nuclear facilities at the same site).
  - Mobile sources :
    - location of the initiating mechanism not totally constrained, such as any means of transport for hazardous materials or potential projectiles (by road, rail, waterways, air, pipelines). In such cases, an accidental explosion or a release of hazardous material may occur anywhere along a road or other way or pipeline.

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Identification of Potential Sources

- Installations which handle, process or store potentially hazardous materials such as explosive, flammable, corrosive, toxic or radioactive materials should be identified ,
- Pipelines for hazardous materials ,
- Construction yards, mines and quarries which use and store explosives,
- Study on airports and their takeoff, landing and holding patterns, flight frequencies and types of aircraft,
- Conveyance of hazardous materials by sea or inland waterways,

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Identification of sources	Relevant features of the facilities and traffic	Initiating event
Stationary sources		
Oil refinery, chemical plant, storage depot, broadcasting network, mining or quarrying operations, forests, high energy materials rotating equipment	Quantity and nature of substances Flow sheet of process involving hazardous nuclear facilities Meteorological and topographical characteristics of the region Existing protective measures in the installation	Explosion, Fire, Release of flammable, explosive, asphyxiating, corrosive, toxic or radioactive substances Ground collapse, subsidence Projectiles Electromagnetic interference Eddy currents into the ground
Military facilities (permanent and temporary)	Types of activities Quantities of hazardous materials Features of hazardous activities	Projectile generation, Explosion Fire, Release of flammable, explosive, asphyxiating, corrosive, toxic or radioactive substances
Mobile sources		
Airport zone	**Aircraft movements and flight frequencies crashes, Runway characteristics** **Types and characteristics of aircraft**	**Abnormal flights leading to crashes**
Air traffic corridors and flight zones (military and civil)	**Flight frequencies, Types and characteristics of aircraft, Characteristics of air traffic, Corridors**	**Abnormal flights leading to crashes**
Railway trains and wagons, road vehicles, ships, barges, pipelines	Passage routes and frequency of passage Type and quantities of hazardous material associated [illegible]	Explosion, Fire Release of flammable, explosive, asphyxiating, corrosive, toxic or radioactive substances Blockage, contamination (such as from an oil spill)

Initiating event	Development of event	Impact on the plant
Explosion (deflagration, detonation)	Explosion pressure wave Projectiles Smoke, gas and dust produced in explosion can drift towards the plant Associated flames and fires	(1) (2) (3) (4) (5) (6) (7)
Fire (external)	Sparks can ignite other fires Smoke and combustion gas of fire can drift towards the plant Heat (thermal flux)	(3) (4) (5) (6)
Release of flammable, explosive, asphyxiating, corrosive, toxic or radioactive substances	Clouds or liquids can drift towards the plant and burn or explode into the plant, can also migrate into areas where operators or safety related equipment can be prevented from functioning	(1) (2) (3) (4) (5) (6)
Aircraft crashes or abnormal flights leading to crashes, collision of planes, projectiles , Vehicle impact	**Projectiles** **Fire** **Explosion of fuel tanks**	**(1) (2) (3) (4) (5) (6)**
Ground collapse	Interference with cooling water systems	(7) (8) (9)
Blockage or damage to cooling water intake structures	Interference with cooling water structures	(12)
Electromagnetic interference	Electromagnetic fields around electrical equipment	(10)
Eddy currents into ground	Electric potential into ground	(11)

Impact on the plant	Parameters	Consequences
(1) Pressure wave	Local overpressure at the plant as a function of time	Collapse or disruption
(2) Projectile	Mass, velocity, Shape, Size, type of material, Structural features, Impact angle	Penetration, perforatio spalling, collapse, vibra
(3) Heat	Maximum heat flux and duration	Impaired habitability
(4) Smoke and Dust	Composition, concentration and quantity as a function of time	Blockage of intake filte Impaired habitability
(5) Asphyxiating and toxic substances	Concentration and quantity as a function of time Toxicity and asphyxiating limits	Threat to human life an health, impaired habitability
(6) Corrosive and radioactive liquids, gases and aerosols	Concentration and quantity as a function of time Corrosive and radioactive limits Provenance (sea, land)	Threat to human life an health, impaired habitability
(6) Ground shaking	Response spectrum	Mechanical damage
(7) Flooding (or drought)	Level of water with time Velocity of impacting water	Damages to structures, systems and component
(8) Subsidence	Settlement, differential settl..	Collapse of structure
(9) Electromagnetic interference	Frequency band and energy	False signals
(11) Eddy currents into ground	Intensity and duration	Corrosion of undergro me

Collection of information

- Early enough to enable the potential sources of external human induced events in the region to be identified at the stage of site selection , to provide
  - data for design basis parameters (the site characterization stage) ,
  - a list of sources present in the region to be prepared and divided into different categories.
- The extent of the relevant region and thus the areas to be examined should be determined for each type of source.
- Usually such areas will extend a few kilometres from the site, but in some instances this distance may need to be greater.

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Screening and evaluation procedures

1. General procedure
2. Preliminary screening
3. Detailed evaluation
4. Design basis events and parameters

1. General procedure

- The information collected is initially used in a two step screening stage to eliminate those sources which should not be considered further, on the basis of distance (SDV) or probability (DBV).
- This preliminary screening may be carried out by the use of a ‘screening distance value’ and/or, where the available data permit, by evaluating the probability of occurrence of the event.
- For some sources, a simple deterministic study, based on information on the distance and characteristics of the source, may be sufficient to show that no significant interacting event can occur.
- It is often possible to select a screening distance value for a particular type of source beyond which the effects of such sources may be ignored.

1. General procedure (ctd)

- A second screening criterion is based on the probability of occurrence. The limiting value of the annual probability of occurrence of events with potential radiological consequences is called the screening probability level (SPL).
- This value is defined by the regulatory body in a coherent way. Initiating events with a probability of occurrence lower than this screening probability level should not be given further consideration, regardless of their consequences
- In general the design procedures for nuclear power plants are deterministic and therefore the design basis is assumed to provide the designer with a single point evaluation of the true probabilistic distribution of interacting effects on the plant.

1 General procedure (ctd)

- If the quality of the data is not reliable — accuracy, applicability, completeness or quantity — it is difficult to use a probabilistic approach to establish a design basis for a particular event or sequence of events or to eliminate them from consideration (by screening).
  - In such cases, a pragmatic approach on the basis of expert judgment should be taken in deciding which events or sequence of events should be considered in a detailed hazard evaluation.
- For each type of source or event not eliminated by the two step screening process, a more detailed evaluation should be made. Sufficiently detailed information to demonstrate the acceptability of the site in respect of external human induced events and to determine the relevant hazards should be collected.

Glossary

- Screening distance value (SDV) : distance from a facility beyond which, for screening purposes, potential sources of a particular type of external event can be ignored.
- Screening probability level (SPL) : a value of the annual probability of occurrence of a particular type of event below which, for screening purposes, such an event can be ignored
- Design basis probability value (DBPV): A value of the annual probability for a particular type of event to cause unacceptable radiological consequences. It is the ratio between the SPL and the CPV. The term is used in the detailed event screening process for site evaluation.

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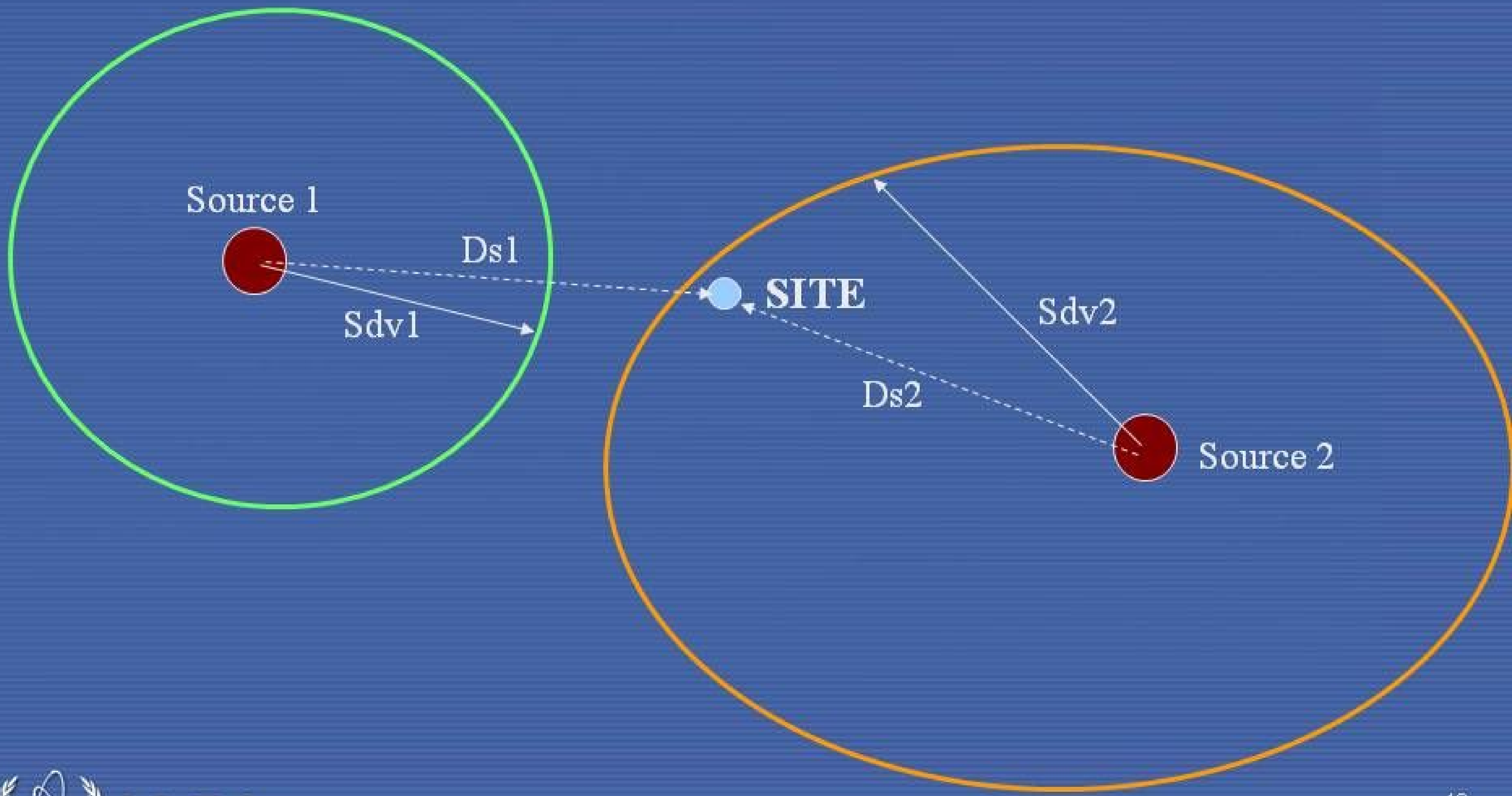
Screening Distance Value - SDV



2. Preliminary screening

- Identification of all stationary and mobile sources of potential external human induced events in the region and all possible initiating events for each source, a screening distance value (SDV) should be determined for each particular type of source (stationary and mobile) using a conservative approach
  - If the site is outside the SDV for the initiating event under consideration, no further action is necessary
  - If the site is not outside the SDV for the initiating event under consideration, the probability of occurrence of such an event should be determined and compared with the specified SPL

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2. Preliminary screening (ctd)

- In practice, it is highly recommended to take account :
  - The uncertainties in the estimation of the load intensity–probability curve.
  - The differences between the probability of the onset of the initiating event and the probability of interacting effects on the plant, after propagation of the effects from the source to the site.
  - The number of various possible sources of external human induced events whose individual estimated probability may be less than the SPL but whose total estimated probability (for all sources) may exceed it.

3. Detailed evaluation

- If the probability of occurrence of the initiating event under consideration is greater than the specified SPL value, a detailed evaluation should be made.
- An upper bound should be established denoted as the conditional probability value (CPV) that this event will cause unacceptable radiological consequences.
- A design basis probability value (DBPV) for the interacting event under consideration should then be determined by dividing the SPL by the CPV.
  - If probability of interacting event is less than DBPV, no further consideration should be given to that event
  - If probability is greater than DBPV, it should be evaluated to establish whether or not the effects of the interacting event on the plant can be reliably limited by preventing or mitigating them or by taking engineering or administrative measures

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4. Design basis and parameters

- If a probabilistic approach is applied to hazard evaluation, the design basis parameters for a particular interacting event should be those corresponding to the DBPV.
- For two or more external human induced interacting events of a given type whose probabilities are similar (to within about an order of magnitude) and for which the plant should be protected, the design basis event should be the event having the most severe radiological consequences.
- Events like aircraft crashes, chemical explosions … are discussed in greater detail in the guide because of their relevance to many possible nuclear power plant sites.
- Certain other events specific to a particular site should also be considered and a similar methodology should be adopted.

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- Introduction
- General approach of site assessment in relation to external human induced events
- Data collection and investigations
- Screening and assessment procedures
- Aircraft crashes
- Release of hazardous fluids
- Explosions
- Other external human induced events : EMI,LOOP…

Different types of aircraft crash

- The potential for aircraft crashes should be considered in the early stages of the site evaluation process and it should be assessed over the entire lifetime of the plant.
- The potential will result from the contributions to the probability of occurrence of an aircraft crash of one or more of the following events:
  - *Type 1 event*: crash deriving from the general air traffic in the region.
  - *Type 2 event*: crash after takeoff or landing operation at a nearby airport.
  - *Type 3 event*: crash owing to air traffic in the main civil traffic corridors and the military flight zones.

Preliminary Screening

- In a preliminary evaluation, consideration should be given to potential sources for crashes in the site region within defined distances from the site. *The site is considered as a tract or circular area of 0.1–1 km^2 and the region as a circular area of 100–200 km in radius.*
- The first step is to determine the SDV.
- He is determined on the premise that any potential hazard beyond the screening distance is minor enough to be ignored, is developed from a deterministic and a probabilistic evaluation of a spectrum of aircraft hazards

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Preliminary Screening (ctd.)

- Evaluating the SDV needs the following informations:
  - distance from the nearest major airport to the site and the locations of landing
  - the types and frequency of air traffic;
  - the routes of air traffic corridors and the locations of air route crossings;
  - the distances from the plant to military installations such as military airports and bombing and firing practice ranges.
- The SDV may be estimated for Type 2 and Type 3 events only.

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Estimation of the SDV (example)

- For estimating the SDV, the following criteria can be adopted. The potential hazards arising from aircraft crashes are taken into account :
  - If airways or airport approaches pass within 4 km of the site;
  - If airports are located within 10 km of the site for all but the biggest airports;
  - For large airports, if the distance d in kilometer to the proposed site is :
    - less than 16 km and the number of projected yearly flight operations is greater than $500d^2$.
    - greater than 16 km, if the number of projected yearly flight operations is greater than $1000d^2$.
  - For military installations or air space usage such as practice bombing or firing ranges, which might pose a hazard to the site, the hazard will be considered if there are such installations within 30 km of the proposed site.

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Screening Probability Level Approach

- If the site is inside the SDV, the probabilistic approach should be used for screening purposes and if the probability is equal to or greater than the SPL, a detailed evaluation should proceed.
  - Type 1 events : probability should be evaluated, in particular in densely populated regions with several civil airports and thus more flights.
  - Type 2 events : probability of aircraft crashes in the vicinity of airports, both civil and military because it is usually higher .
  - Type 3 events : probability of crashes of civil aircraft near air traffic control corridors should be examined, but in general this probability is usually smaller than the specified SPL (for example, 10^{-7}/a). This is not necessarily true for military aircraft.

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Example of EPR project in UK

- In the UK, the airspace from ground level to approximately 66,000 ft is characterized as either Controlled Airspace (CAS) or Uncontrolled Airspace (UCAS) .
- CAS
  - Commercial, passenger-carrying aircraft ,
- UCAS
  - military, instructional or recreational flying .
- There are also prohibited to flights, restricted and danger areas, which include the immediate airspace around nuclear facilities.
- CAS is divided into five main types, those of particular relevance being Airways corridors forming the main routes connecting major airports, with a minimum height of 5000 ft (1.5 km), and Upper Airspace, which comprises the majority of UK airspace above 24,500 ft (7.5 km).
- Within CAS, all traffic is known to the Air Traffic Control system

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Low altitude airway
(24,500ft and below)
Map of the SE of ENGLAND

High altitude airway
(24,500ft and above)
Map of the SE of ENGLAND

Example of EPR project in UK (ctd)

- In general, the restricted zone around UK nuclear power stations is a circle of radius 2.0 nautical miles (3.7 km) and an altitude of 2000 ft (610 m), with exceptions being made for helicopters having permission to land at the station. It is common value.
- Commercial aircraft would be flying considerably higher than this, under instructions from Air Traffic Control.
- The restricted zone over most of the potential UK sites is in accordance with or in excess of the requirements for a restricted zone around UK nuclear power stations.
- Exception: for one potential site, the altitude of the restricted zone is reduced to 1500 ft to enable an instrument approach procedure at a nearby airport.

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Example of Statistics in FRANCE for aircraft crashes versus traffic

Commercial aircraft | **General aircraft** | **Military aircraft**

Commercial aircraft	General aircraft	Military aircraft
Flights per year: 1 000 000	Flights per year: 3 500 000	Flights per year: 600 000
Crash per flight : 10^{-6}	Crash per flight : 10^{-4}	Crash per flight : 10^{-5}
Airport : 80	Airport : 400	Airport : 40

Detailed Evaluation

- In this case, probability should be determined for each class of aircraft considered (small, medium and large civil and military aircraft) by using the aircraft crash statistics.
- The estimated probability of an aircraft crash affecting the plant may be determined in terms of crashes per year per unit area multiplied by an effective area for damage to safety items ,
- The size of the effective area depends on:
  - the average angle of the trajectory relative to the horizontal;
  - the plan areas of the relevant structures and their heights;
  - other areas relating to items important to safety;
  - and allowances to be made for the size of the aircraft and for skidding.

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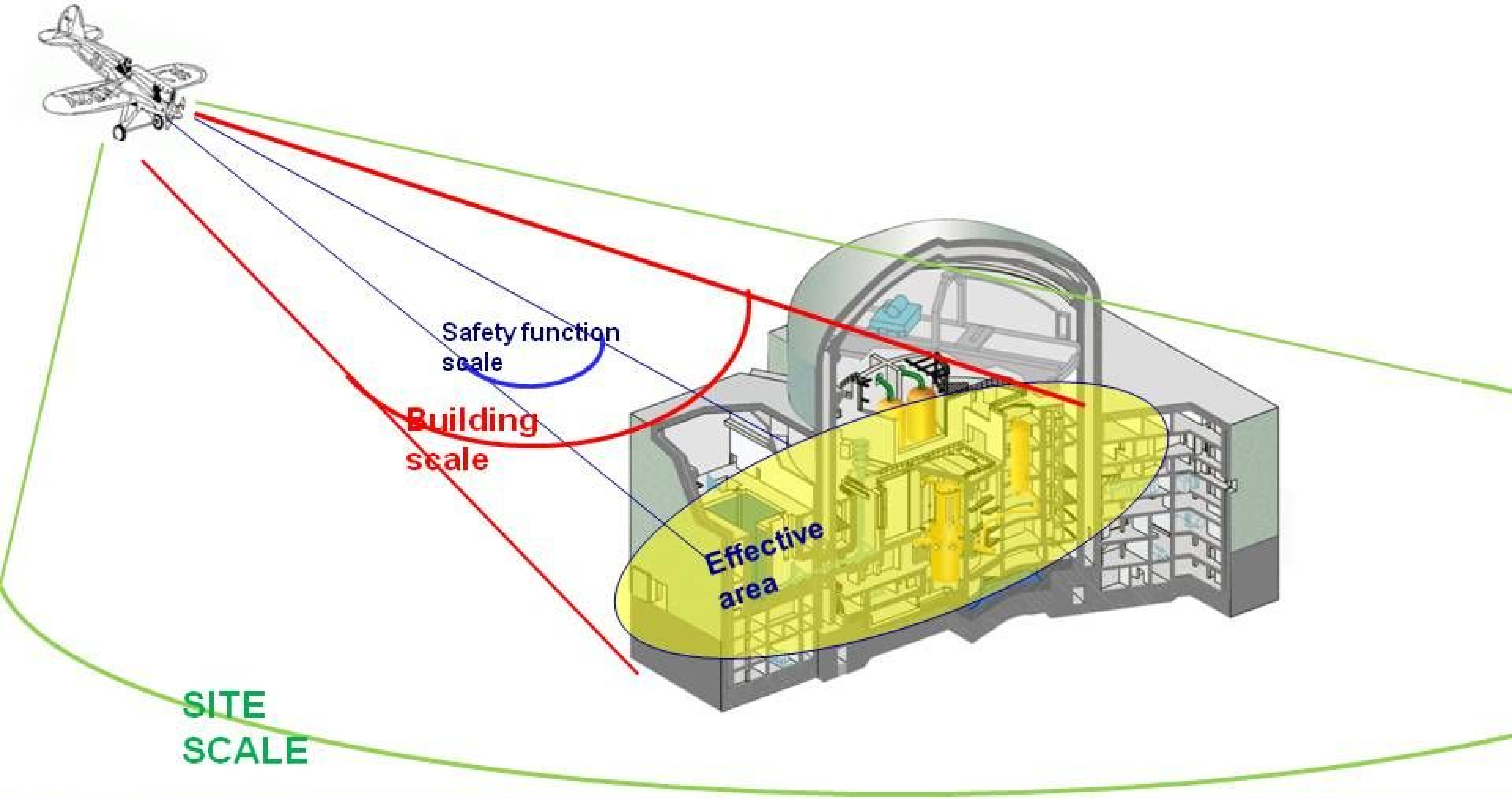
Effective area



National experience

- In general, figures of 10 000 m^2 to 40 000 m^2 have been used for the effective area.
- Some States have decided to design all nuclear power plants against aircraft crashes, having found a probability of about 10^{-6} per year for aircraft crashing on an area of 10 000 m^2 anywhere in the country.
- Consequently, a single idealized load function for a certain type of aircraft has been derived that is accepted as representative of aircraft crashes for design purposes in those States.
- In the calculation of these values, trajectory angles of 10° to 45° to the horizontal have been assumed.

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Rejection criteria for NPP Sitting in INDIA

Sl. No	Hazard	Rejection criteria and SDV, if applicable
1.	Earthquake	Site falling in seismic zone V as per BIS 1893
2.	Earthquake	Distance from capable fault < 5km
3.	Earthquake	Potential for soil liquefaction
4.	Earthquake/ Geological	Potential for slope instability which cannot be mitigated by engineering measures
5.	Earthquake/ Geological	Potential for ground collapse/subsidence/uplift which cannot be mitigated by engineering measures
6.	Geological	Possibility of formation of sand dunes
7.	Aircraft impact	Distance from small air fields < 5km
8.	Aircraft impact	Distance from major air ports < 8km
9.	Aircraft impact	Distance from military air fields < 15km
10.	Explosion	Distance from military installations storing ammunitions < 10km

Design Basis Probability Value

- DBPV is a value of the annual probability for a particular type of event to cause unacceptable radiological consequences. It is the product of the SPL times the CPV (conditional probability value) of loosing safety function.
- The following basic safety functions shall be satisfied:
  - Shutdown of the reactor and removal of decay heat,
  - Storage of spent fuel,
  - Treatment and containment of radioactive effluents.

Design Basis Probability Value (ctd.)

- The maximum probability of an unacceptable radiological release at the site boundary is fixed in accordance with the general protection objectives fixed by regulators, in relation to external hazards.
- General assurance is provided if the plant is protected against the aircraft crash that would be expected to produce the most severe consequences for the plant.
- The plant layout and particularly, the physical separation and the redundancy of items important to safety, especially for vulnerable parts of the plant should also be taken into consideration.

Hazard Evaluation

- Design basis events
  - For several types of aircraft, the probability of a crash at any given site may be equal to or greater than the DBPV (design basis probability value).
  - When the probability of an aircraft crash is equal to or exceeds the DBPV, the severity of the effects should be determined and a detailed analysis of the effects induced should be carried out, with consideration given to local structural effects

Technical Scope of the tests

- The actual of powerplants in Europa covers a large variety of situations. The technical scope has een defined considering the issues that have been highlighted by the events of Fukushima, including conbination of iniating events and failures.
- Initiating events conceivable at the site
  - Earthquake
  - Flooding
  - Other extreme natural events
- Consequential loss of safety functions
  - Loss of electric power, including Station Black Out (SBO)
  - Loss of the Ultimate Heat Sink (UHS)
  - A combination of both

APC Hazard Evaluation

- When the probability of an aircraft crash is equal to or exceeds the DBPV, the severity of the effects should be assessed.
- A detailed analysis of the effects induced should be carried out for the deterministic assumption of a reference aircraft crash that envelops a set of possible scenarios, with consideration given to :
  - local structural effects,
  - direct damage by primary and secondary missiles (perforation, spalling)
  - induced vibrations
  - effects caused by the fuel.

- FULL-SCALE TESTS

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Primary impact and secondary projectiles

- The evaluation of the effects of an aircraft crash should include analyses of the potential for structural failure due to shearing and bending forces, for perforation of the structure, for spalling of concrete within structures and for the propagation of shock waves that could affect items important to safety
- A crashing aircraft may break up into parts which become separate projectiles with their own trajectories and the effects of secondary projectiles should be considered.

Effects caused by aircraft fuel

- The following possible consequences of the release of fuel from a crashing aircraft should be taken into account:
  - burning of aircraft fuel outdoors causing damage to exterior plant components important to safety;
  - the explosion of part or all of the fuel outside buildings;
  - entry of combustion products into ventilation or air supply systems;
  - entry of fuel into buildings through normal openings, through holes caused by
  - the crash or as vapour or an aerosol through air intake ducts, leading to subsequent fires, explosions or side effects.

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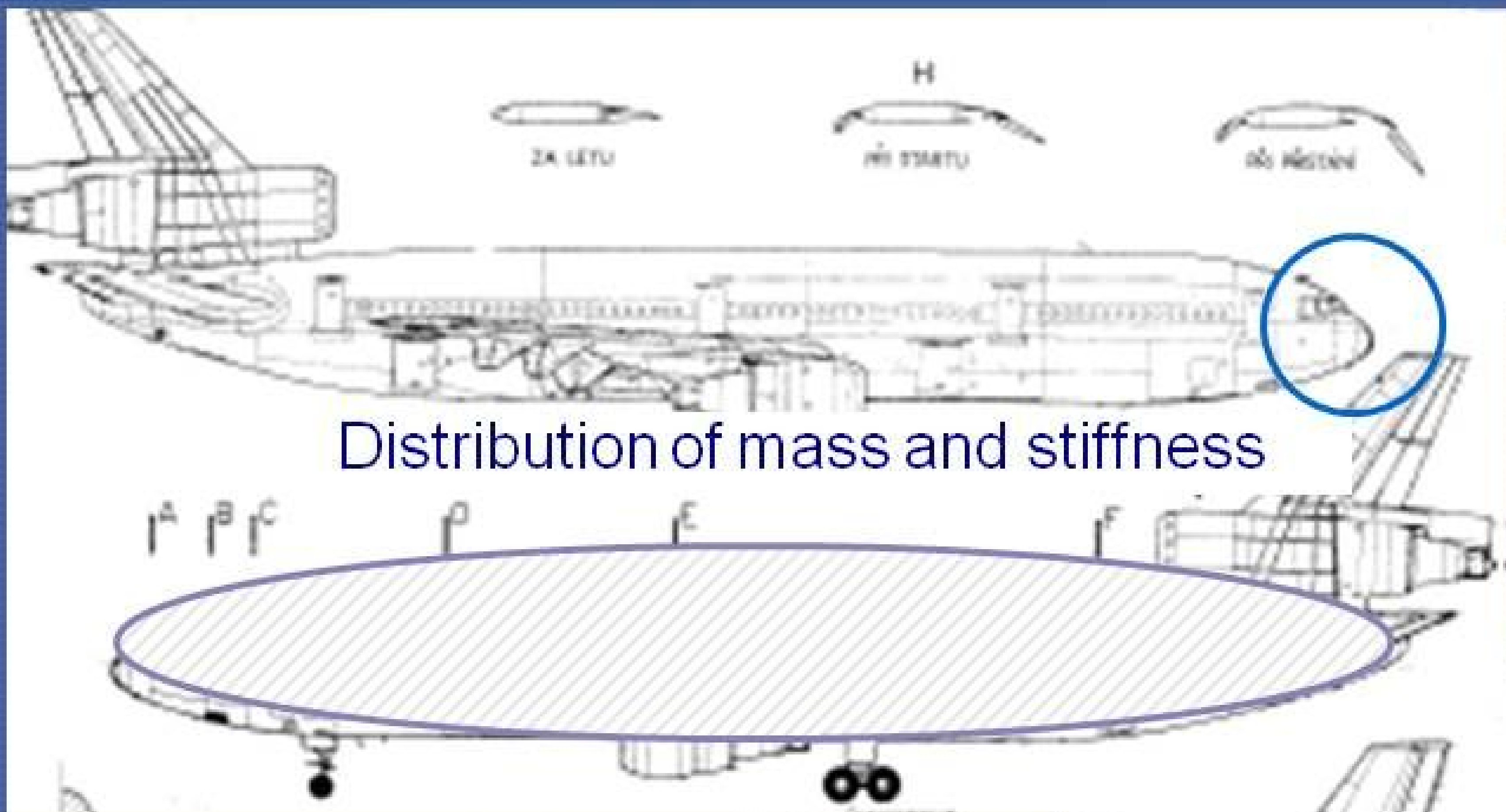
Design Parameters

- Distribution of mass and stiffness along the aircraft concerned (one or more),
- Nose shape,
- Area of impact,
- Velocity and angle of incidence when the structural evaluation includes detailed local analyses of the potential for structural failure due to shearing and bending forces, for spalling and scabbing of concrete within the structures, and for perforation of the structures.

- A load–time function, which may be independent of the specific aircraft and representative of a class of aircraft, with associated mass, velocity and application area when the structural evaluation includes only a preliminary screening of local effects in comparison with other design events, or for a generic evaluation of the induced vibration effects on structures and components.

Design parameters



Nose shape,

Distribution of mass and stiffness

Velocity
Angle of incidence

Area of impact,

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Case study :
Methodology used for airplane crash in EPR project

EPR design approach

- The initial approach for protection against an aircraft crash is deterministic and is based on specific scenarios applied to different groups of aircraft. Protection against aircraft impact is achieved by the design of the safety classified buildings or by physical separation of redundant systems.
- The EPR site structures which house equipment required for reactor safety and prevention of core meltdown are protected against an aircraft impact.
- For the EPR, the general aim of significant safety improvement compared with earlier NPPs has resulted in a decision to consider the consequences of an aircraft crash (military and commercial), independently of the probability of occurrence of such an event. Protection of the plant is achieved either by geographical separation of redundant systems or by the provision of a physical barrier referred to as the aircraft shell.

Military aviation

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

- Total protection is provided for the buildings that are likely to contain nuclear fuel.
- The protection is provided by the aircraft shell which protects the reactor building and the fuel building.
- Protection for the buildings housing back-up systems is provided either by protecting them with an aircraft shell, or by providing sufficient physical separation of redundant systems.

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

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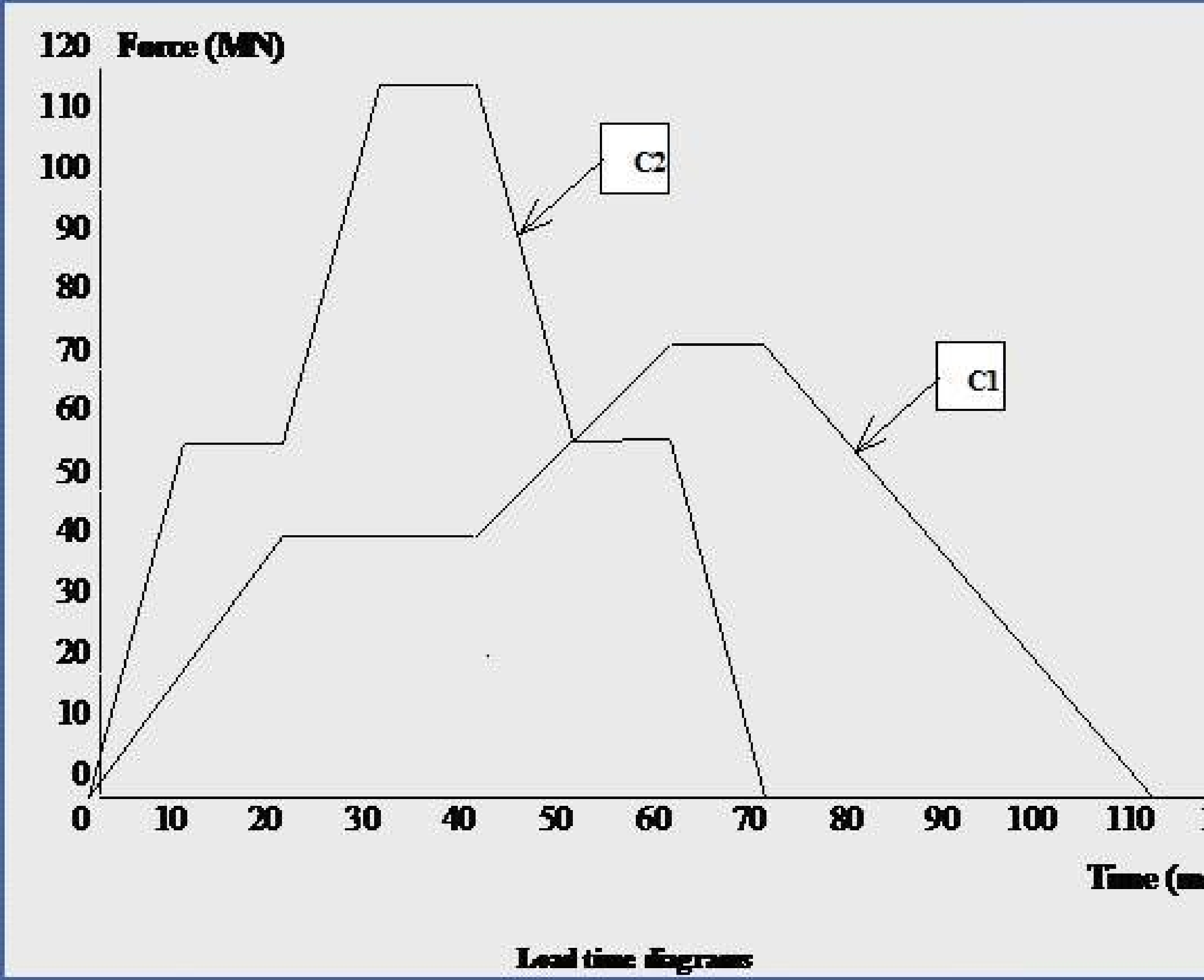
Military Air Plane Loading (APC)

- The purpose of these load diagrams (C1 and C2) 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



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.

Light civil aviation

- For buildings not protected by the aircraft shell, a verification is performed of the resistance to a light civil aircraft crash: this applies to the Nuclear Auxiliary Building, divisions 1 and 4 of the Safeguard buildings, and part of the Waste Treatment building. The margins existing for this load case are estimated

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Light aircraft loading curves

Lear Jet 23 : $12 m^2$ (M = 5 700 kg)

- Cessna 210 : $4 m^2$ (M = 1 500 kg)

Impact velocity 100 m/s

Hard missile (Cessna 210 engine) :
0.5 m^2 (M = 200 kg)

Perforation formula EDF-CEA

$(rV_2 / f_c)_{juste\ perforation} = 1.89 (rH^2/M)^{4/3}$

EPR aicraft protection

- 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.

EPR aircraft protection (ctd)

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

EPR aircraft protection (ctd.)

- Military aviation 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 an aircraft shell. This applies to the reactor building , electrical and safegard 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 safety classified and non-redundant equipment in the buildings protected by the aircraft shell: this mainly concerns the control room.

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MALICIOUS ACTIVITY in EPR project

- In the UK, it is the responsibility of the Office for Civil Nuclear Security (OCNS) to define worst-case scenarios for malicious activity.
- The OCNS establishes and documents a Design Basis Threat (DBT), which defines the hostile activities and capability that could be faced by civil nuclear facilities.
- The DBT is regularly reviewed, to ensure that it remains up-to-date. Details of the DBT cannot be published since it is classified as Secret.
- Discussions between EDF/Areva and OCNS are taking place separately to confirm that the EPR design adequately addresses the DBT.

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MALICIOUS ACTIVITY in EPR project (ctd)

- Malicious activity (in the form of sabotage) is identified as one of the hazards to be considered for any future European LWR, although the outcome will not be published for security reasons.
- Aircraft crash is identified as a hazard to be considered in the design.
- Standard LWR designs may or may not include aircraft crash protection but, for those that do not explicitly include it, the design must allow protection against light or military aircraft to be incorporated for all sensitive parts of the plant.
- Although aircraft crash may be malicious (as with the destruction of the World Trade Center in 2001) the plant consequences will be the same as for a worst-case accidental aircraft impact.
- In the case of the design of EPR, a deterministic approach has been adopted which enables the installation to withstand a range of aircraft crashes up to that of a large civil airliner.

No. 09-030 February 17, 2009

NRC ISSUES FINAL RULE ON NEW REACTOR AIRCRAFT IMPACT ASSESSMENTS

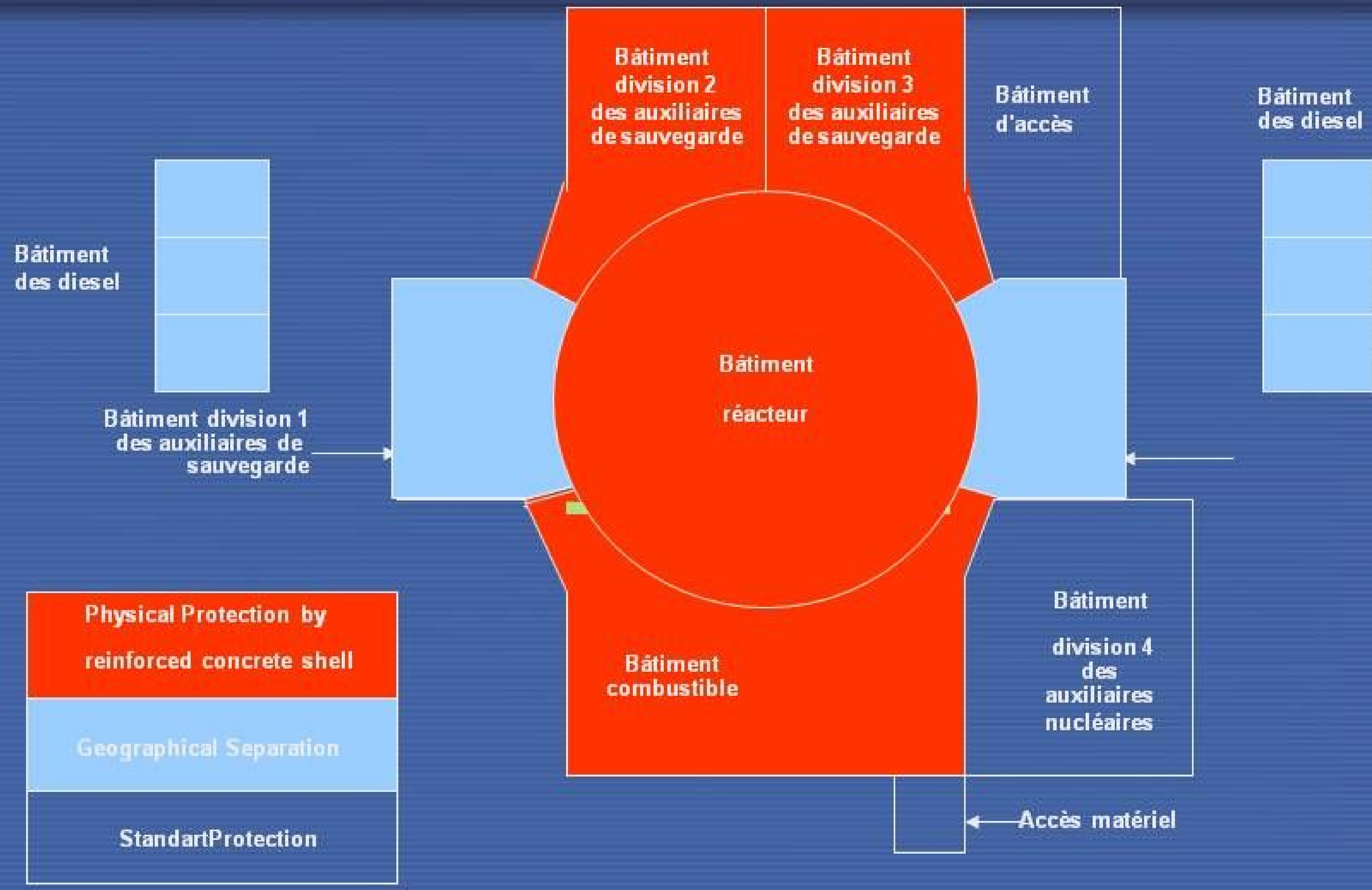
Nuclear power plants are designed under very stringent requirements to assure they can safely shut down following "design-basis events" such as large fires, floods, earthquakes and hurricanes, as well as improbable equipment malfunctions including pipe breaks. These requirements include having two redundant systems to accomplish each safety function. The rul treats large commercial aircraft crashes as "beyond-design-basis events."

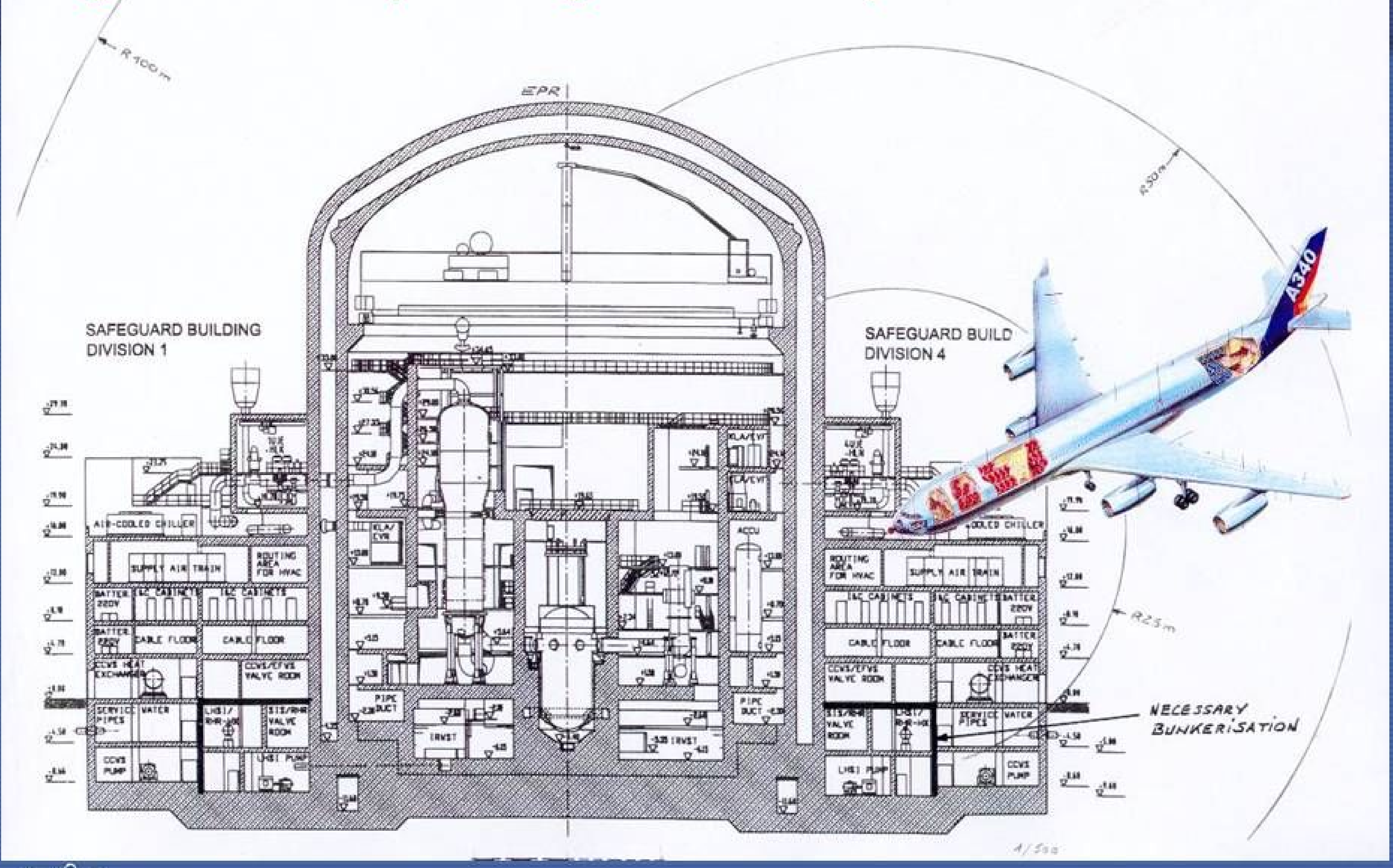
The NRC has already taken several steps to improve security at existing nuclear power lants, including adopting a rule in March 2007 that requires both existing and potential new eactors to defend against a more realistic threat. The agency also issued a February 2002 Orde equiring all existing nuclear power plants to develop and adopt mitigative strategies to cope vith large fires and explosions from any cause, including beyond-design-basis aircraft impacts. The NRC voted in December 2008 to codify these requirements in a separate rule for all existing nd future nuclear power plants.

Statements of WENRA

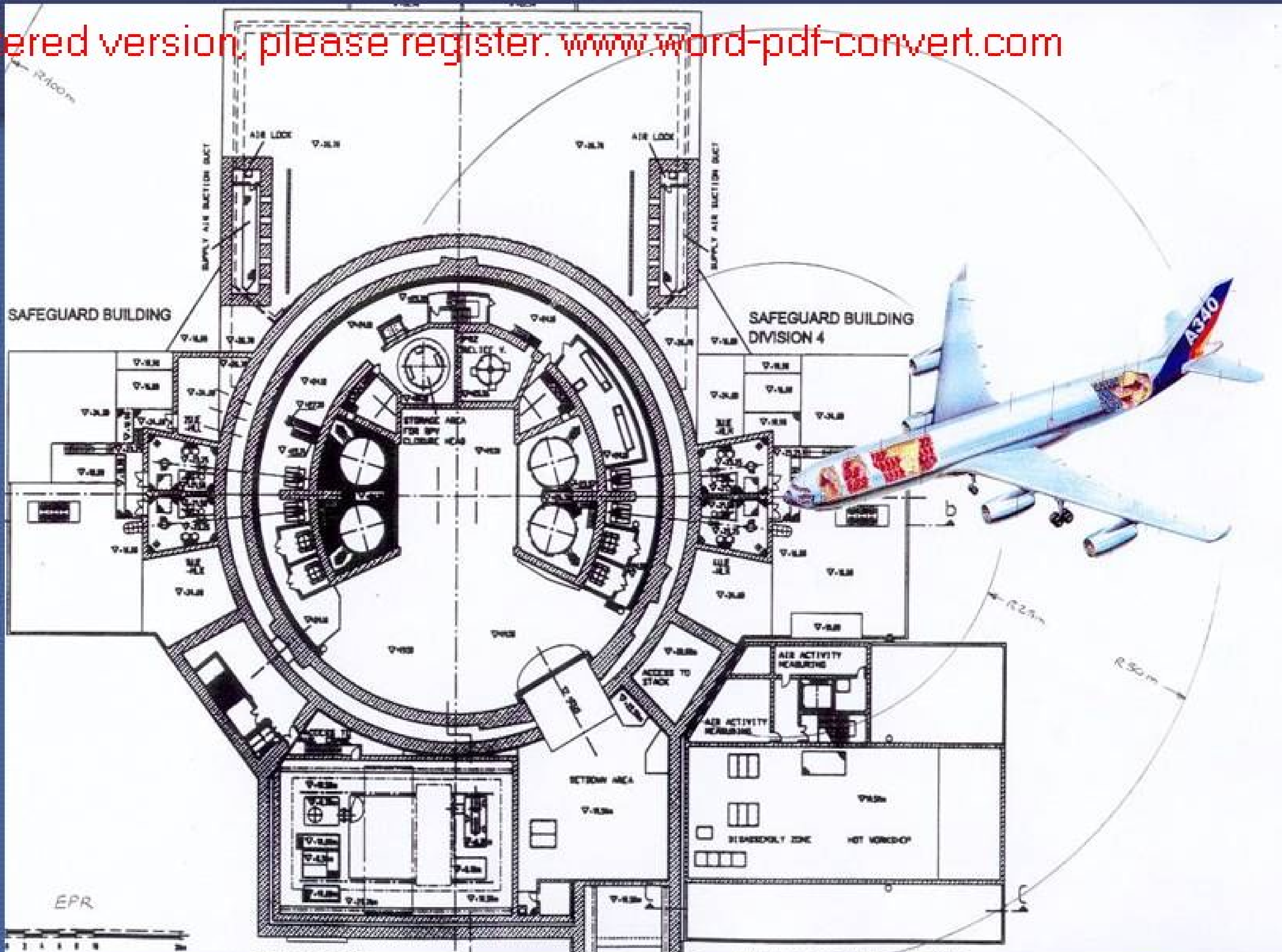
- Considering safety and security interfaces (O5)
- According to the purposes of ensuring that safety measures and security measures are designed and implemented in an integrated manner and of seeking synergies between safety and security enhancements, the following area for improvement can be highlighted:
- · Aircraft crash protection against large civil airplanes

APC Protection on EPR





EPR (airplane & nuclear island = same scale)



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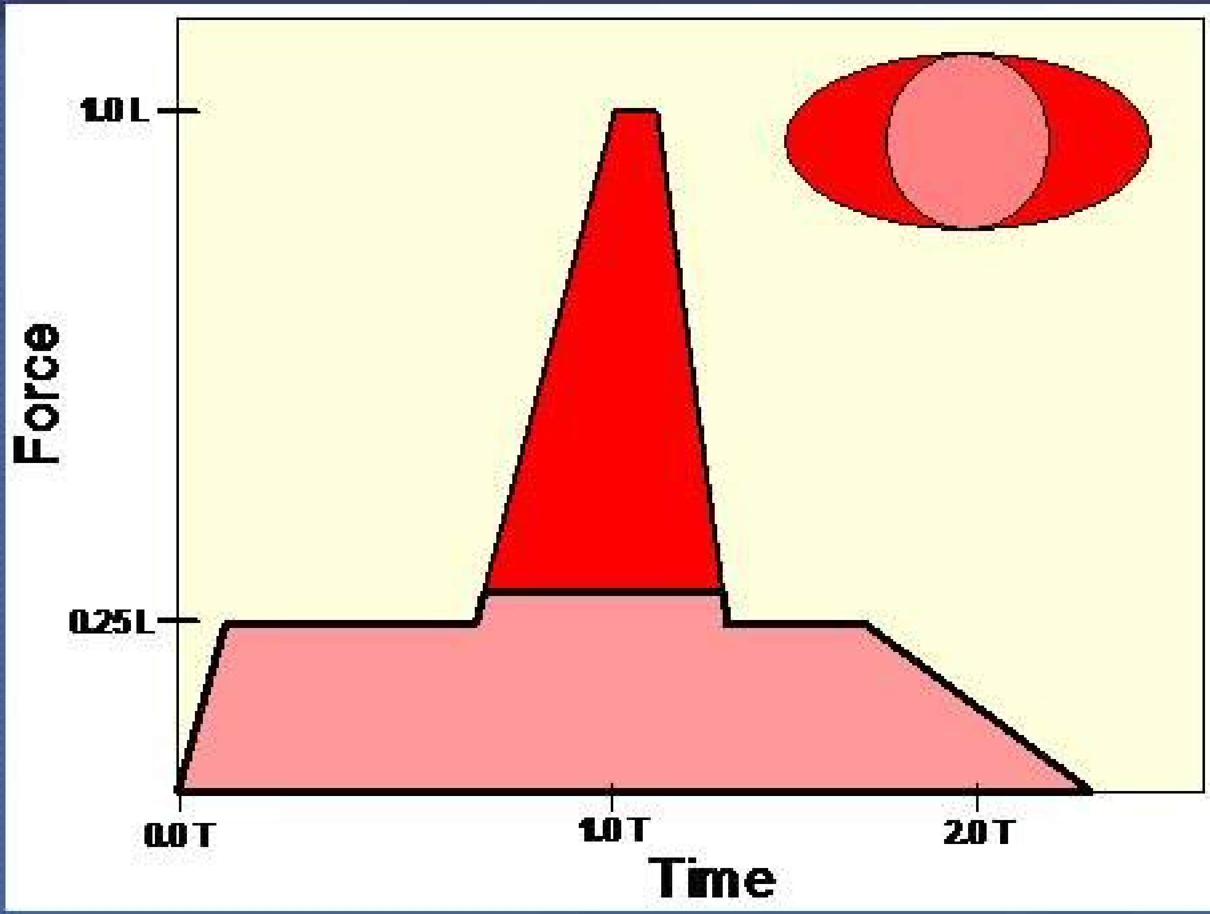
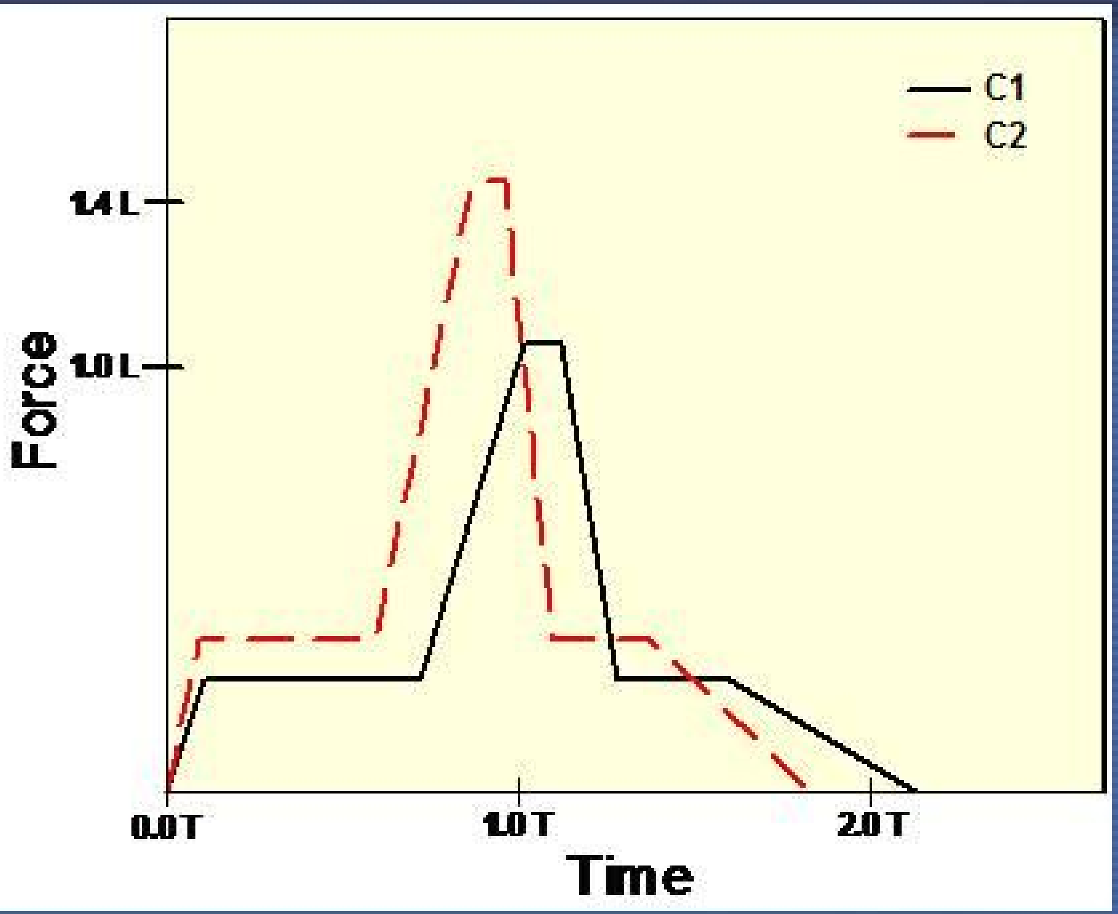
EPR (airplane & nuclear island = same scale)

Beyond design load Functions





Load-time function C1
and related load area

Load-time functions C1 and C2

L2/L1 ≈ 1.4 T2/T1 ≈ 0.85

Load-time functions (normalised amplitudes due to confidentiality reasons)

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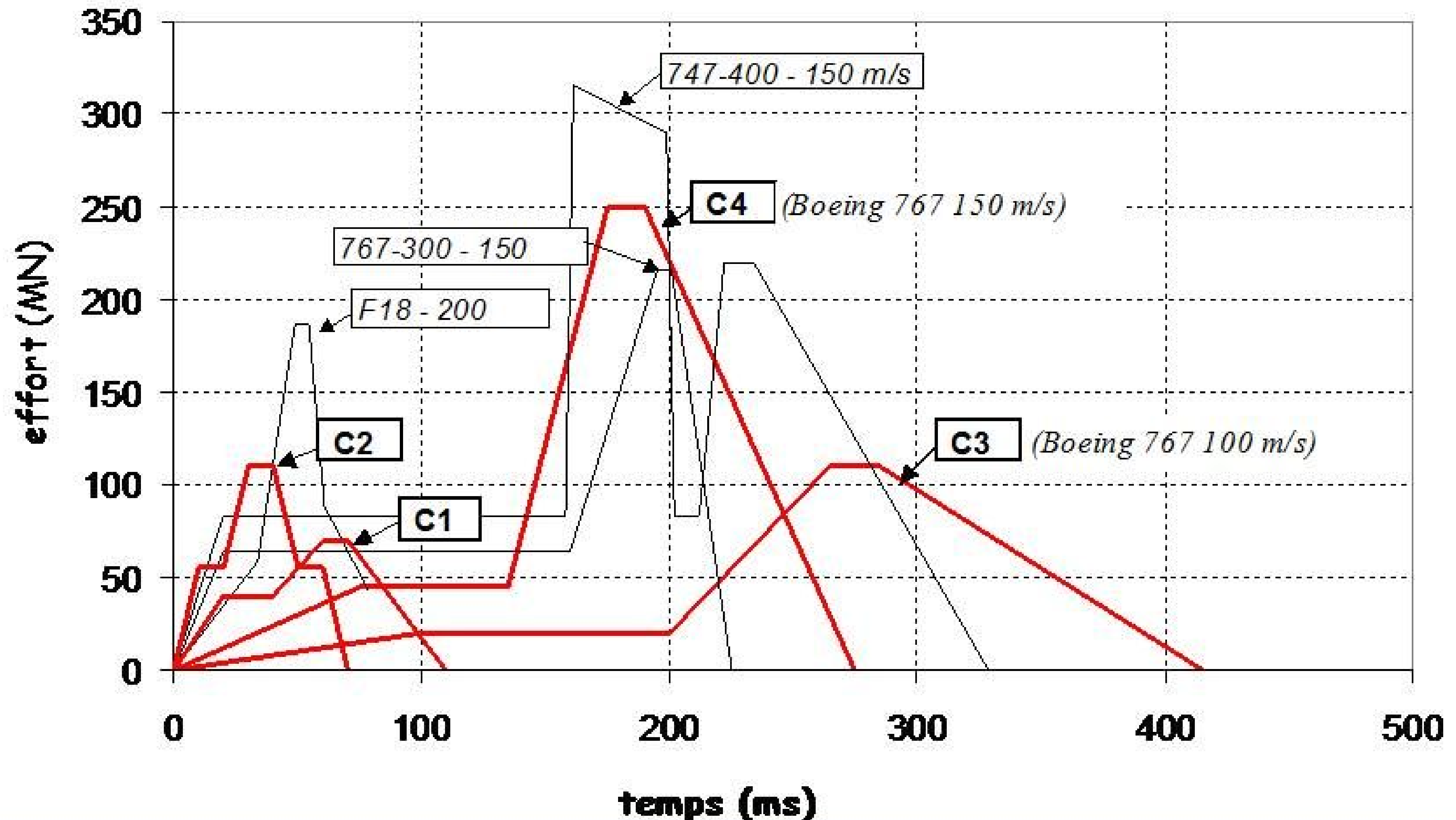
Comparison between different loading curves



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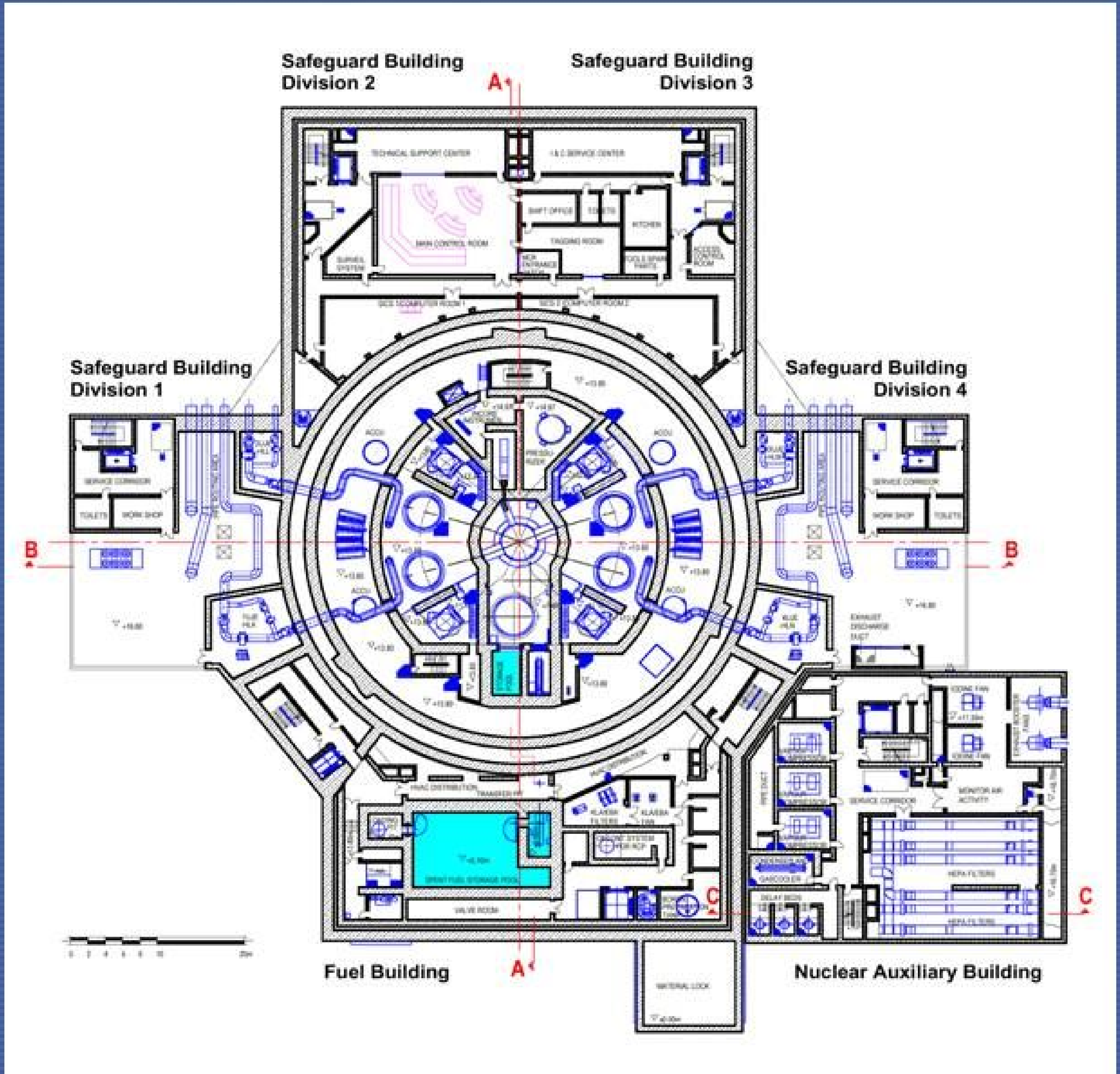
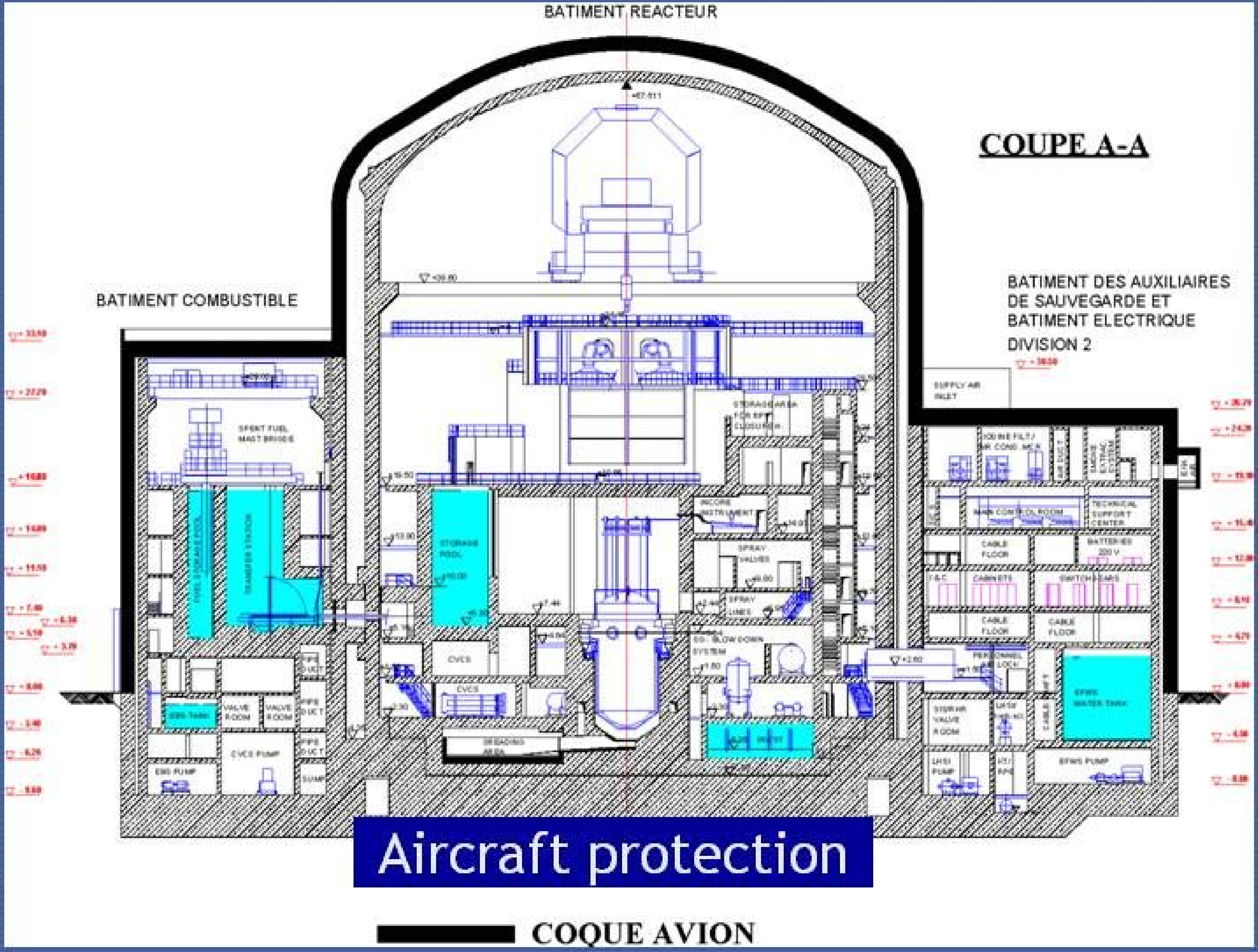
Protection against Air Plane Crash



Protection against Air Plane Crash (Cntd)



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Particularities of commercial aircraft

- Shock is softer than the one military airplane
- Impact surface 10 times higher
- Interaction target/ missile
    - Necessity of nonlinear calculations taking account for 3D effects
- Sensitivity studies are essential (for cliff-effects examination)
- Secondary effects are dominating due to the fuel (see the WTC attack) and due to the high level of induced vibrations comparable to seismic vibrations.
- The design of civil structures is still governed by C1 and C2 except for one particular structure (Electrical buliding)

Secondary effects of commercial aircraft crash

Fire

- Limitation of external openings on protected parts
- Design hypothesis for external walls (normes KTA)
  - « fire ball » hypothesis : « lethal » diameter 90m, 1200°C, duration 2mn,
  - external fire hypothesis : duration 1/2h, 800°C on the concerned buildings
- Examination of this hypothesis on mechanical behaviour of structures to be performed
- The results of examinations are classified !!

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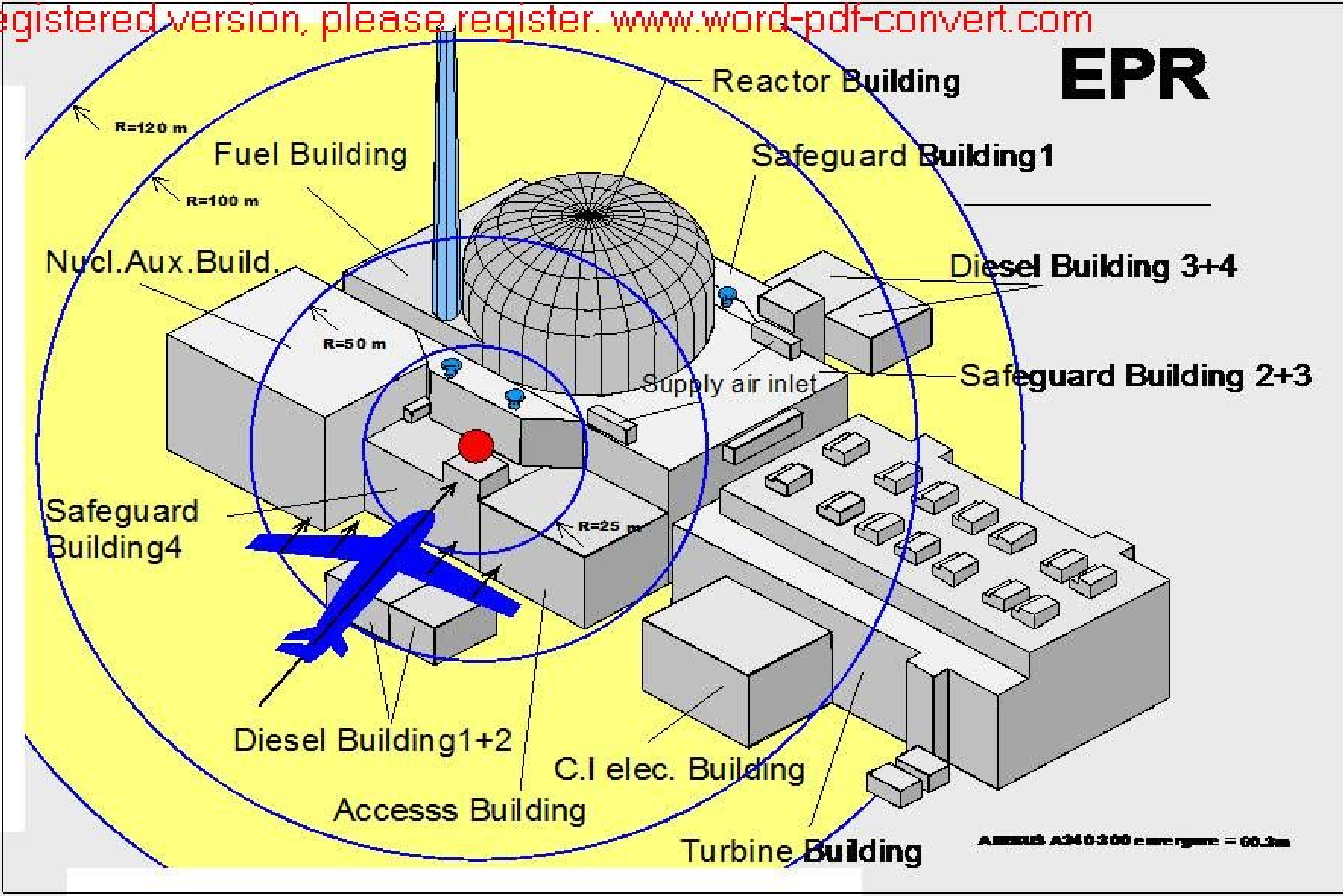
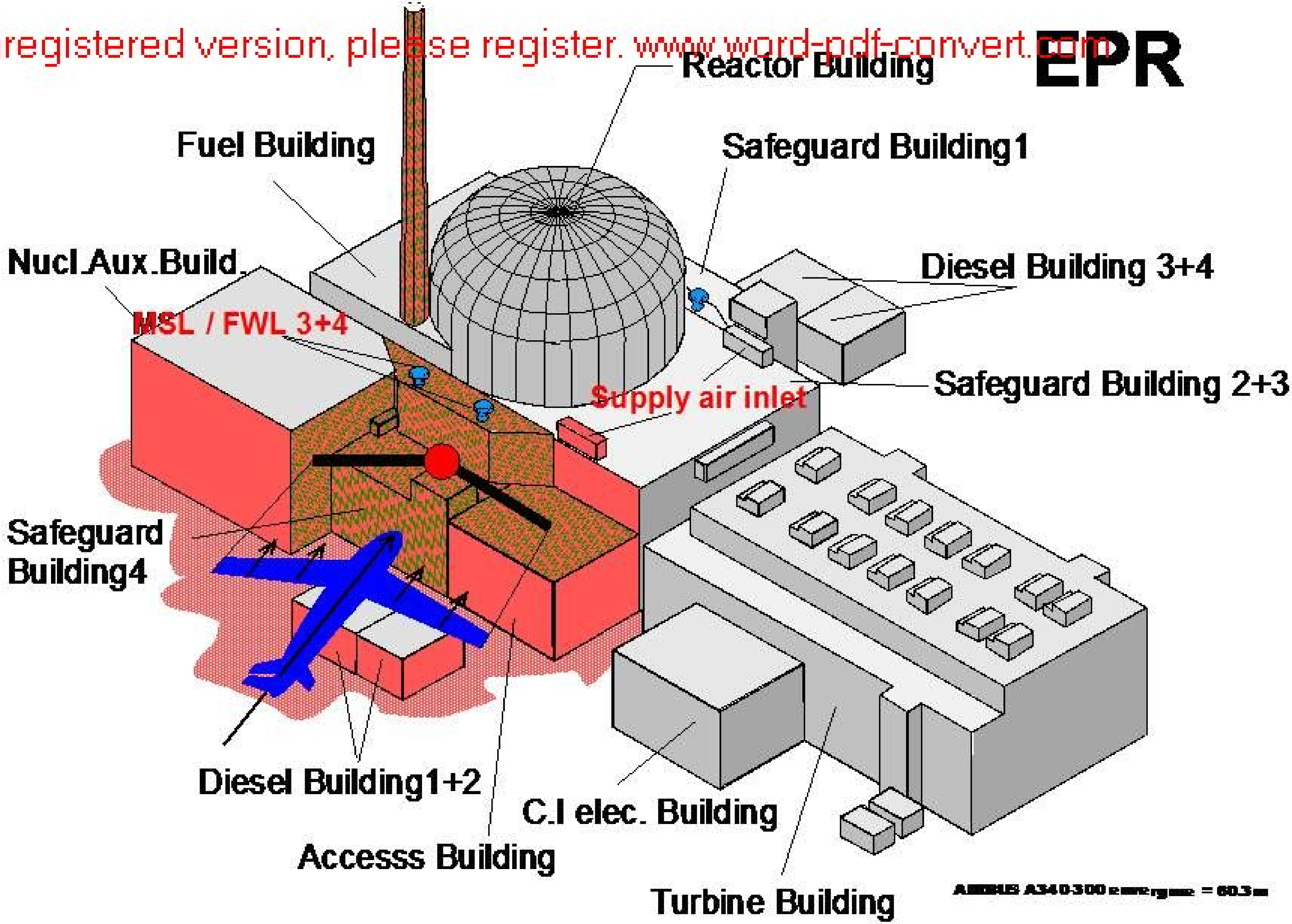
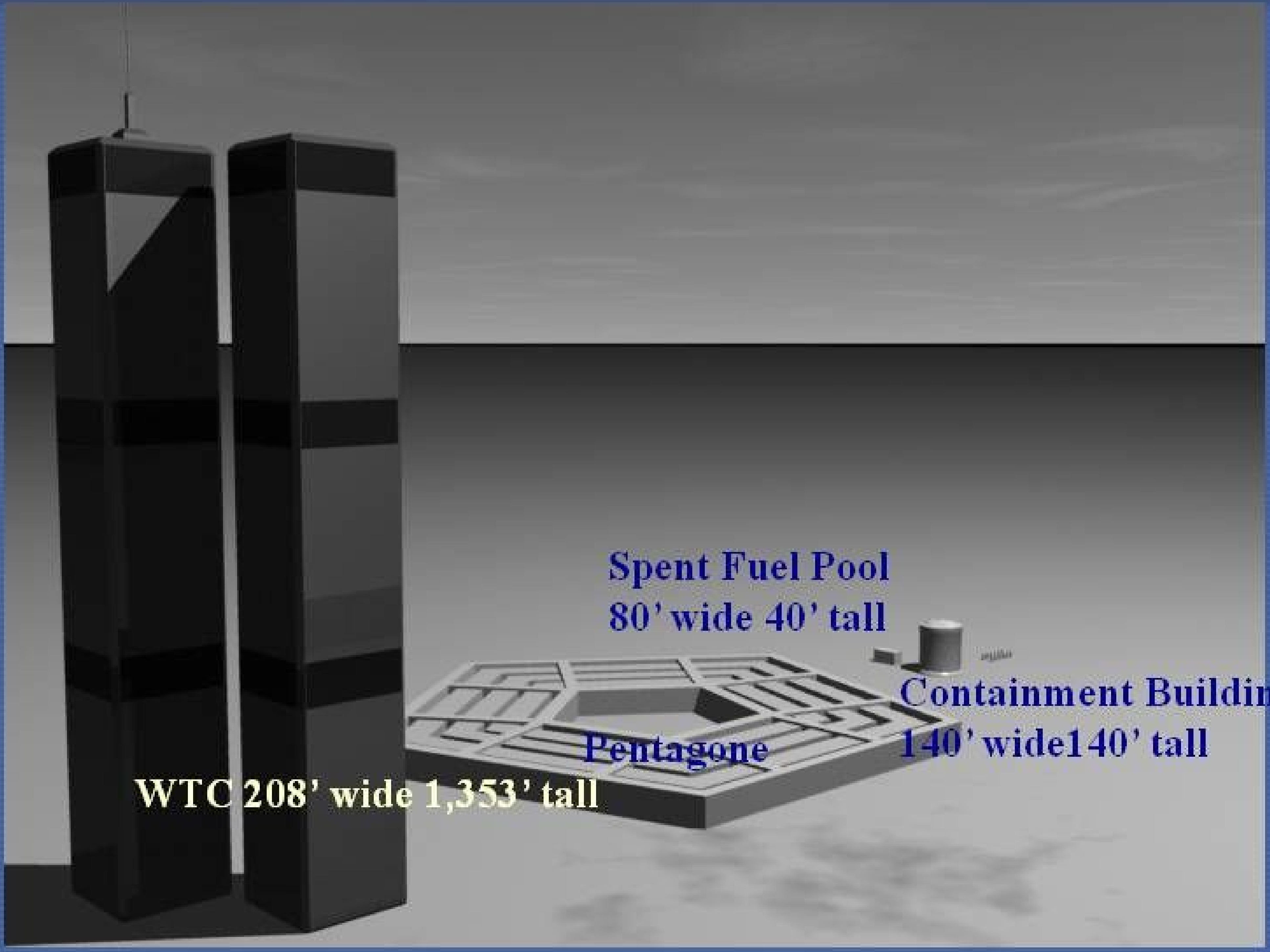

EPR
Reactor Building
R=120 m
R=100 m
Fuel Building
Safeguard Building1
Nucl.Aux.Build.
Diesel Building 3+4
R=50 m
Safeguard Building 2+3
Supply air inlet
R=25 m
Safeguard Building4
Diesel Building1+2
C.I elec. Building
Accesss Building
Turbine Building

EPR


Reactor Building
Fuel Building
Safeguard Building1
Nucl.Aux.Build.
Diesel Building 3+4
MSL / FWL 3+4
Safeguard Building 2+3
Supply air inlet
Safeguard
Building4
Diesel Building1+2
C.I elec. Building
Accesss Building
Turbine Building

Just to give an idea of the problem …



Simulation of the fuel fireball from a hypothetical commercial airliner crash on a generic nuclear power plant

*WOLFGANG LUTHER, W. CHRISTOPH MÜLLER**
GRS, FORSCHUNGS INSTITUTE, GARCHING, GERMANY

▪

A well-documented experiment on hard target impact of an airplane is available: the SANDIA Phantom experiment performed in 1988, when a Phantom F-4 fighter was projected on a rocket sled against a concrete block and literally crushed to pieces.

Lessons from Sandia experiment

- As a result of the impact a debris cloud of substantial size (~60m diameter) is formed. The volumetric ratio of structural material and fuel stimulant (water) is 1:1 and a substantial part of the debris clouds consists of water droplets.
- The size of the cloud can only be explained by the fact that small size water droplets experience a reduced drag when traveling in the wake of larger structural particles.
- Based on this only experiment with hard target and a small fighter plane it is assumed that hard target impact of a large commercial aircraft will be similar: a large cloud is expected consisting of structural debris and a large amount of fuel, as the ratio structural material/fuel is much higher for commercial airliners.

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- One of the potential consequences of the impact is the occurrence of a fireball, large enough to engulf the entire NPP. The knowledge about fireballs from air crashes is rather poor since it is only based on footage shot by chance.
- From careful physical and chemical examinations using first principles, it can be concluded that the physics and chemistry of the kerosene fireball are similar to BLEVE fireballs in gas tank accidents which have been studied during the last decades. The knowledge from these analyses can be applied to air crash fireball analysis.
- BLEVE means "Boiling Liquid Expanding Vapor Explosion". This is a type of explosion that can occur when a vessel containing a pressurized liquid is ruptured. A BLEVE can occur in a vessel that stores a substance that is usually a gas at atmospheric pressure but is a liquid when pressurized

- In order to obtain an adequate understanding of the potential hazards to a NPP engulfed by a fireball a detailed analysis of the fireball is necessary. It is only by a detailed analysis that the effect of the NPP structures on the evolution of the fireball can be derived.
- Though the safety-relevant parts of the NPP are strong concrete structures, according to IAEA regulations the hypothesized entry of combustion products into ventilation or air supply systems and the entry of fuel into buildings through normal openings have to be analyzed in detail. This requires local transient values of the safety-relevant fireball parameters.
- With the NPP being a very large structure an adequately detailed simulation requires substantial computing power.

- A simulation tool is available which is capable to perform simulations of large fireballs with the release of Version 5 of the Fire Dynamic Simulator (FDS) from NIST in 2007 on sufficiently large computing grids. These fireball simulations can be performed also by any other CFD (Computational Fluid dynamics) code in which the relevant models have been implemented.
- To demonstrate the applicability of FDS to nuclear safety analysis a simulation of the impact of a 90 to fireball on a generic NPP was performed.
- The results show that FDS release Version 5 is an adequate tool to analysis the effect of a fireball on a NPP, even if the largest possible amount of kerosene involved in the crash is assumed


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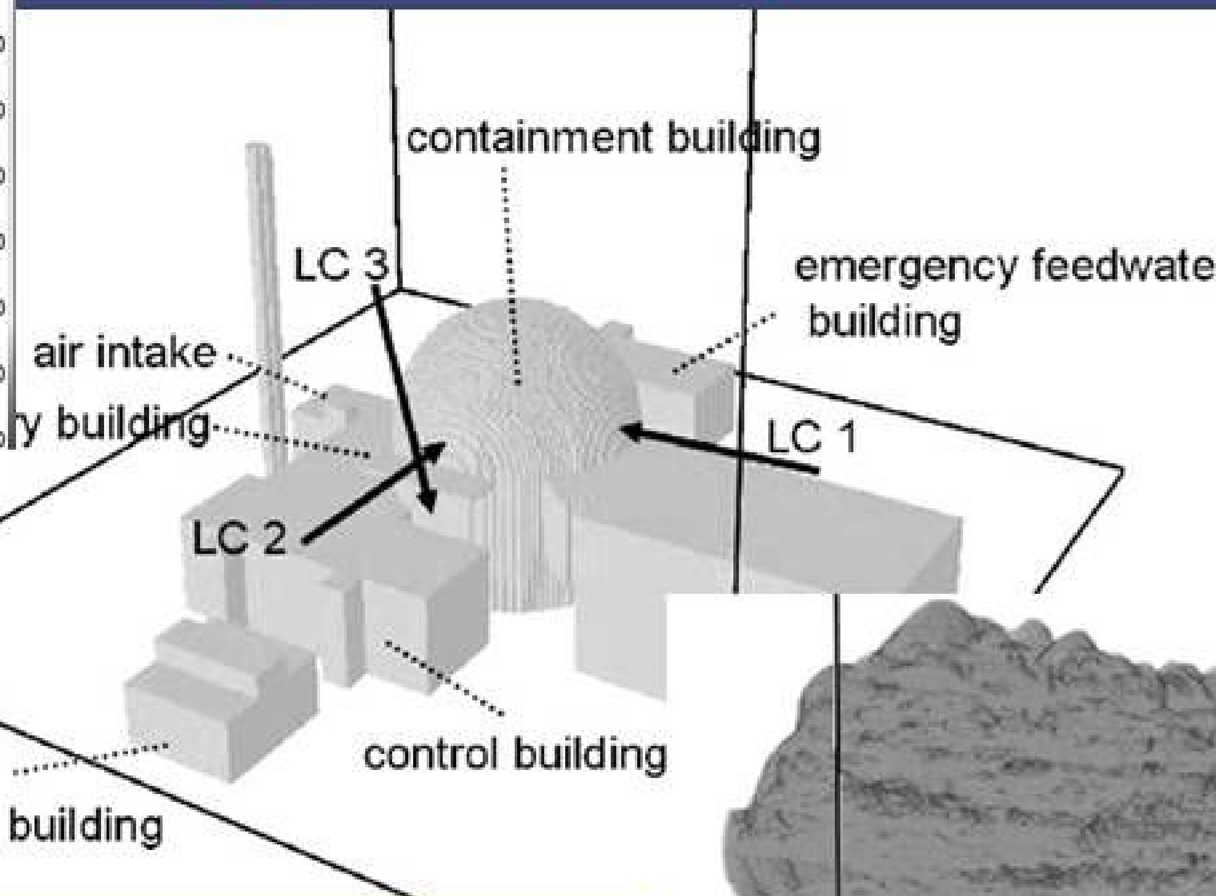
containment building
LC 3
emergency feedwater building
air intake
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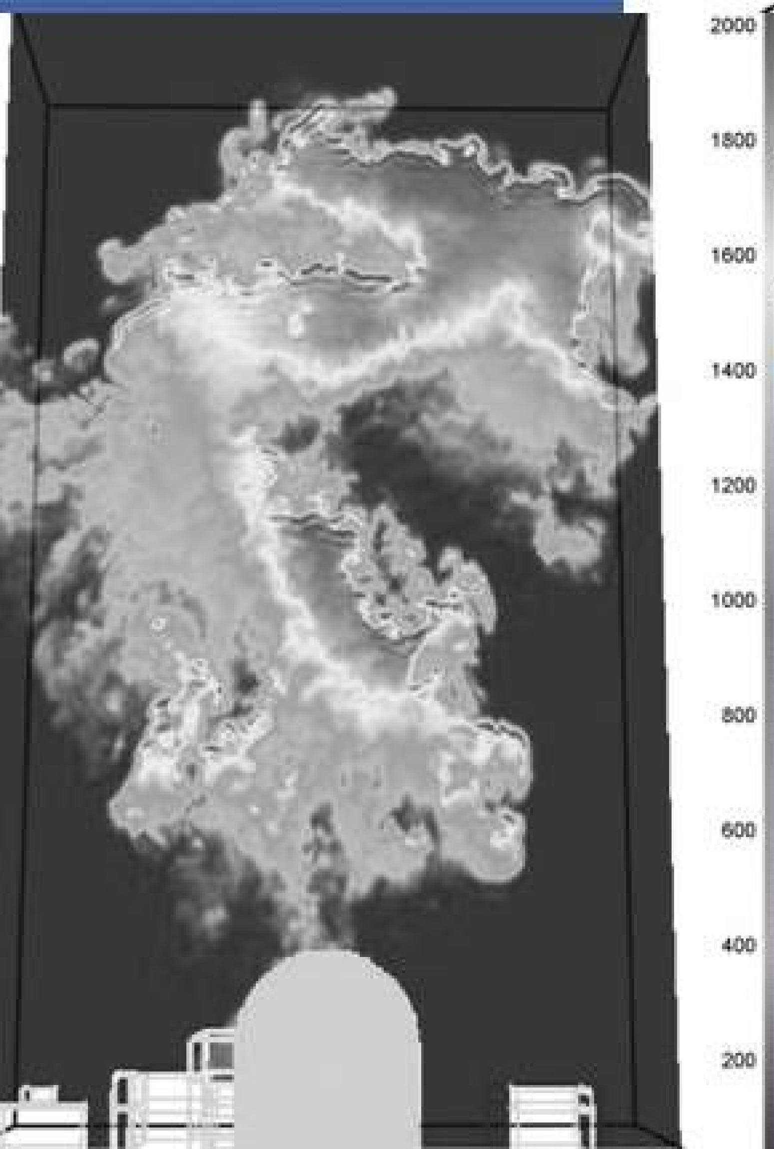
LC 1
LC 2
control building
el building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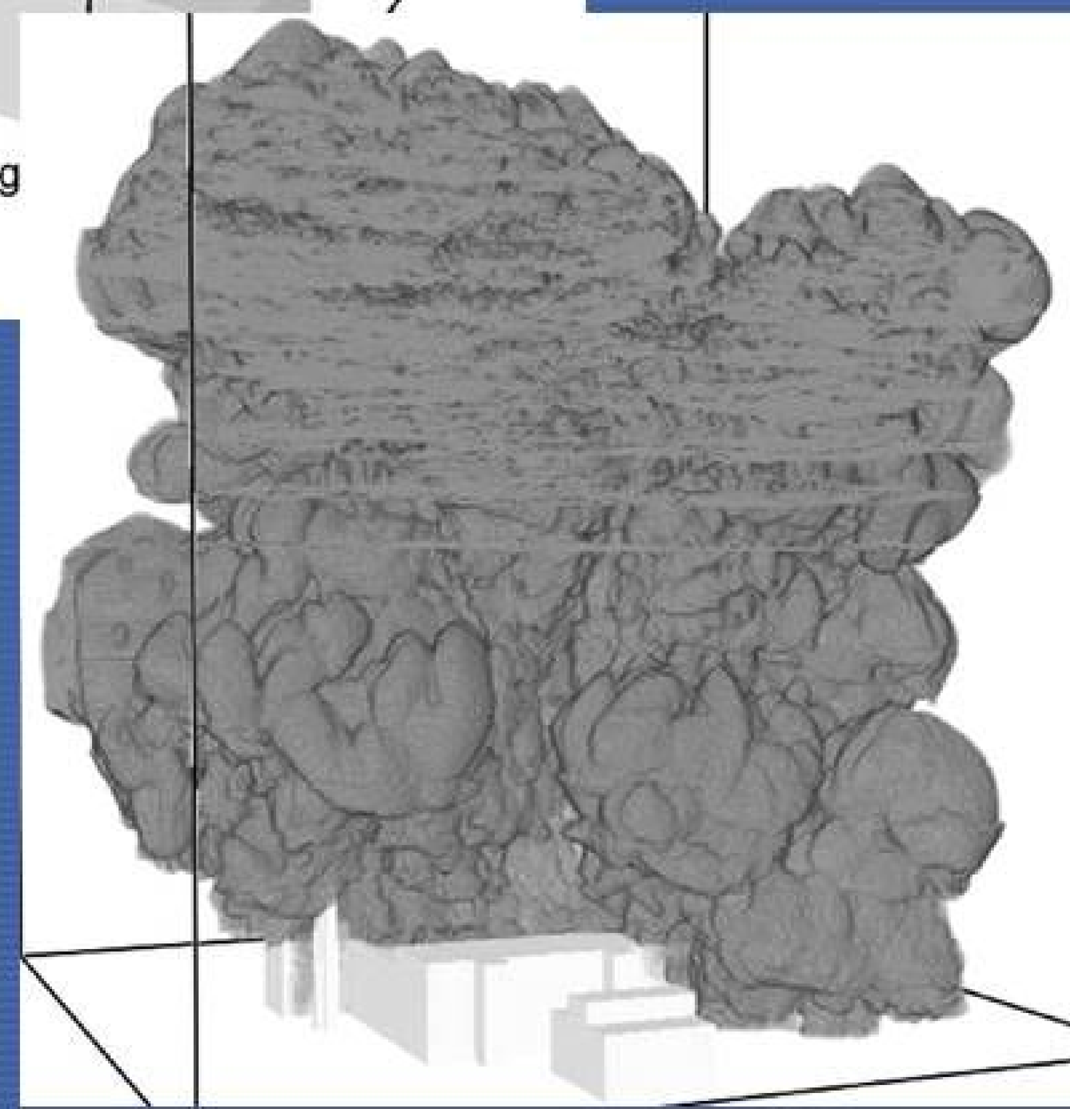

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General

- Flammable gases and vapours can form explosive clouds and can enter ventilation system intakes and burn or explode,
- Asphyxiant, corrosive, radioactive and/or toxic gases can threaten human life and impair crucial safety functions,
- The propagation phenomena can be considered as generic from one event to another,
- Secondary effects like toxic, corrosive and asphyxiant effects are to be considered in the design stage .

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Preliminary Screening for Hazardous Liquids

- Identify all activities and facilities involving the processing, handling, storage or transport of flammable, toxic or corrosive liquids within the SDV.
- The SDV selected will depend on a number of factors：
  - physical properties of the substance,
  - regional topography
  - type and extent of industrialization.
- If the potential hazard within the SDV to items important to safety arising from these activities and facilities is less than that due to similar materials to be stored on the site and against which protection has been provided, then no further investigation should be carried out.
- Otherwise the potential hazards due to off-site activities should be evaluated .

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Hazard Evaluation for Hazardous Liquids

Design basis event

- The location and size of, and the flow paths to and from, any pool formed by hazardous liquids should be determined and the associated hazards to the nuclear power plant should be assessed.
- It may be possible to prevent the flow of liquid towards the nuclear power plant by means of engineered structures such as earthworks.
- For a fixed source, such a barrier may be constructed in its immediate vicinity and the hazard to the nuclear power plant would thereby be reduced.

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Design basis parameters

The Design basis parameters and properties that should be established for protection of the nuclear power plant against hazardous liquids are as follows:

- amount of liquid,
- surface area of the pool,
- chemical composition,
- concentration (corrosion potential),
- partial pressure of vapours,
- boiling temperature,
- ignition temperature,
- toxicity.

Gases, Vapours and Aerosols

- Gases, vapours and aerosols from volatile liquids or liquefied gases may, upon release, form a cloud and drift. The drifting cloud may affect the nuclear power plant in the following two ways:
  - When the cloud remains external to the plant , it is considered as other external human induced events considered in this Safety Guide (fires, explosions..).
  - The cloud can permeate plant buildings, posing a hazard to personnel and items important to safety, particularly for a cloud of toxic, asphyxiant or explosive gas. It can affect the habitability of the control room and other important plant areas.
- The most practical method of defence is to ensure protection from the potential source by means of distance .

Preliminary Screening for Gases, Vapours and Aerosols

- Particular attention should be paid to the following sources:
  - chemical plants,
  - refineries,
  - above ground and underground storage systems,
  - pipelines for volatile liquids, gases and liquefied gases,
  - transport routes and their associated potential sources external to the SDV on which hazardous clouds may be generated.
- The preliminary evaluation is intended to screen out those facilities and activities to which no further consideration should be given.
- The criteria should be conservative and simple in their application (ex: assumption that the maximum inventories of the plant and the storage area are involved)

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Preliminary Screening for Gases, Vapours and Aerosols (ctd)

- A conservative and simple method should be adopted for mobile sources within the SDV .
- The maximum amount of hazardous material that may reach the point of the greatest potential hazard to the nuclear power plant for a given transport system should be determined, and this amount should be assumed to be present for any incident that may occur.
- Particular care should be exercised in the consideration of explosive clouds.
- The evaluation should be progressively refined to yield the probability of occurrence of an interacting event (frequency of passage of hazardous shipments and probability of an accident during such a passage).
- The potential sources that are not eliminated by this initial screening process should be given consideration in the detailed evaluation.

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- Introduction
- General approach of site assessment in relation to external human induced events
- Data collection and investigations
- Screening and assessment procedures
- Aircraft crashes
- Release of hazardous fluids
- Explosions
- Other external human induced events .
- Administrative aspects

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Explosions

- Explosion = any chemical reaction between solids, liquids, vapours or gases which may cause a substantial rise in pressure, possibly owing to impulse loads, drag loads, fire or heat.
- An explosion can take the form of :
  - a deflagration, which generates moderate pressures, heat or fire, or
  - a detonation, which generates high near field pressures and associated drag loading but usually without significant thermal effects.
- Given their low combined probability, external hazards associated with industrial environment or transport routes are not combined with other external hazards such as earthquakes.

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Explosions (ctd)

- Deflagration or a detonation in air is depending on the concentration of the chemical vapour or gas.
- At concentrations 2 to 3 times the deflagration limit, detonation can occur,
- The deflagration limit and therefore the related effects are in general related to the burning velocity.
- For a gas cloud, there is evidence that the maximum burning velocity (relative to the non-burning gases) increases with the size of the gas cloud.

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Deflagration effects

- For deflagrations in free air and in the absence of significant turbulence, the chemical reaction will create a peak around 0.3 bar (30 kPa) in the incident wave.
- With a moderate amount of confinement and for a saturated hydrocarbon such as butane, the burn velocity will be higher and deflagration overpressures of 1 bar are obtainable.
- If more reactive fuels such as ethylene are present in the maximum free field conditions pressures may rise to 5 bar or more.
- A deflagration wave can become a detonation wave, due to turbulence or partial confinement (for example, multiple reflection), affecting only a limited volume. In this case, an overpressure of between 0.2 and 20 bar may be generated in the surrounding space.

Detonation effects

- In a detonation of solid substances and/or a partial detonation of a fuel–air gas or vapour mixture:
  - the reaction is shock induced,
  - will travel at velocities higher than the speed of sound
  - and will produce high peak overpressures.
- With high explosives (such as trinitrotoluene (TNT)) the pressure peaks in the near field may be of the order of 1000 bar (100 MPa).
- At standoff ranges of interest, the overpressure will probably be less than 0.5 bar. Engineering relationships should be used for determining the correlation between the pressure peak, the explosive yield and the distance from the explosion.

Evaluation of explosive potential

- In evaluating the potential for explosions, all potential sources lying within the SDV should be taken into consideration
- This process should permit the evaluation, for each identified source, of the following parameters:
  - The nature and maximum amount of the material that may simultaneously explode,
  - The distance and orientation from the explosion centre to the site,

  where the explosive mass is usually expressed in terms of TNT equivalent mass for generic explosive substances.

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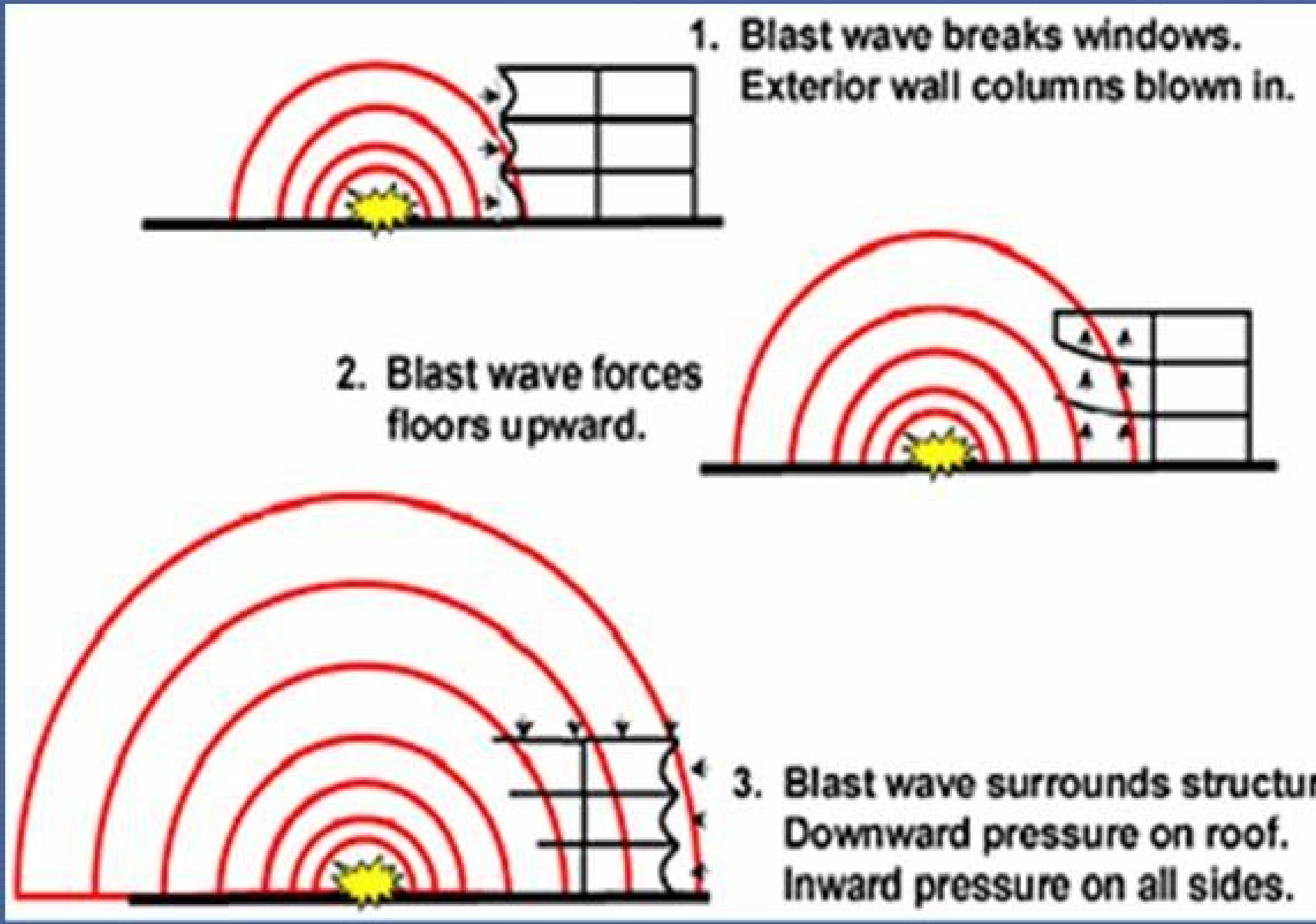
Mechanical effects

- An explosion will cause a pressure wave to propagate away from the source, in which the shock front moves with supersonic velocity.
- The pressure at any fixed point in the free field is designated as side-on or incident overpressure.
- Upon reflection of the pressure wave by interacting obstacles, the overpressure may increase several times and is designated as reflected overpressure.



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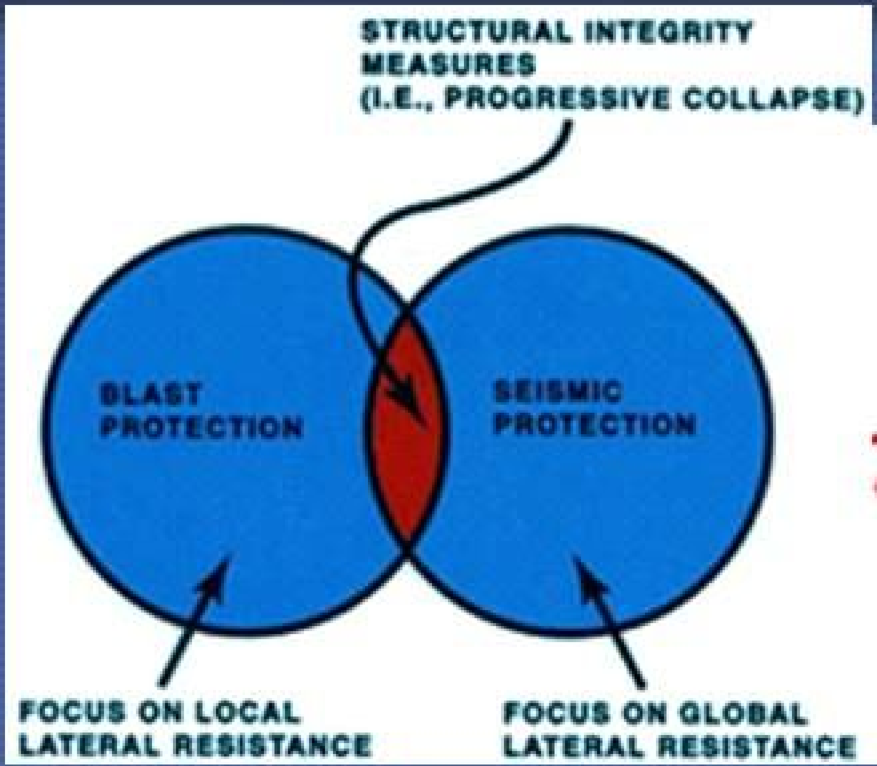
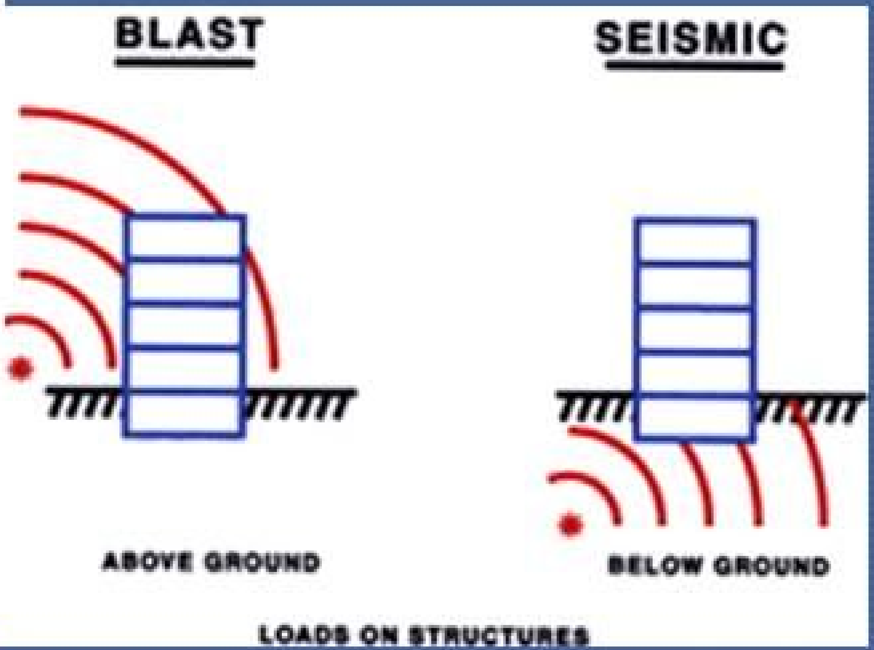
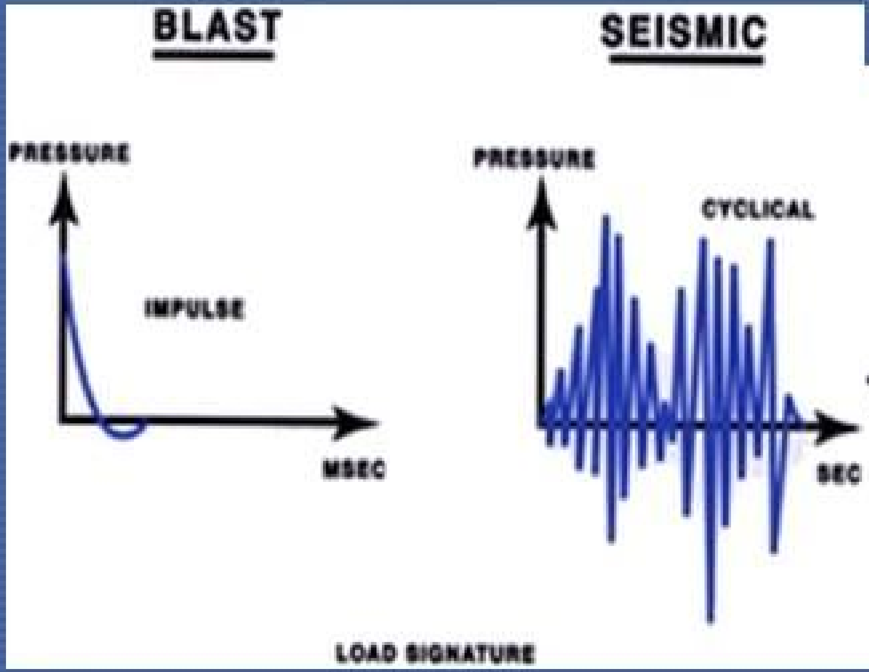
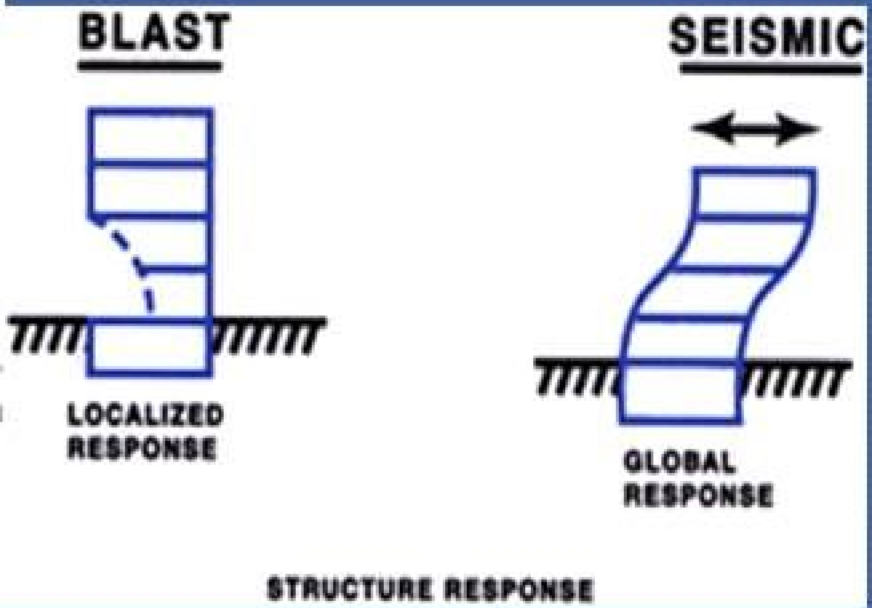
Comparison between seismic and blast effects









Blast effects

Peak overpressure	Maximum wind speed	Effect on structures	Effect on the human body
70 mb	61 km/h	Window glass shatters	Light injuries from fragments occur
140	113	Moderate damage to houses and severe damage to roofs, windows and doors blown out	People injured by flying glass and debris
210	164	Residential structures collapse	Serious injuries are common, fatalities may occur
305	263	Most buildings collapse	Injuries are universal, fatalities are widespread
690	473	Reinforced concrete buildings are severely damaged or demolished	Most people are killed
1380	808	Heavily built concrete buildings are severely damaged or demolished	Fatalities approach 100%

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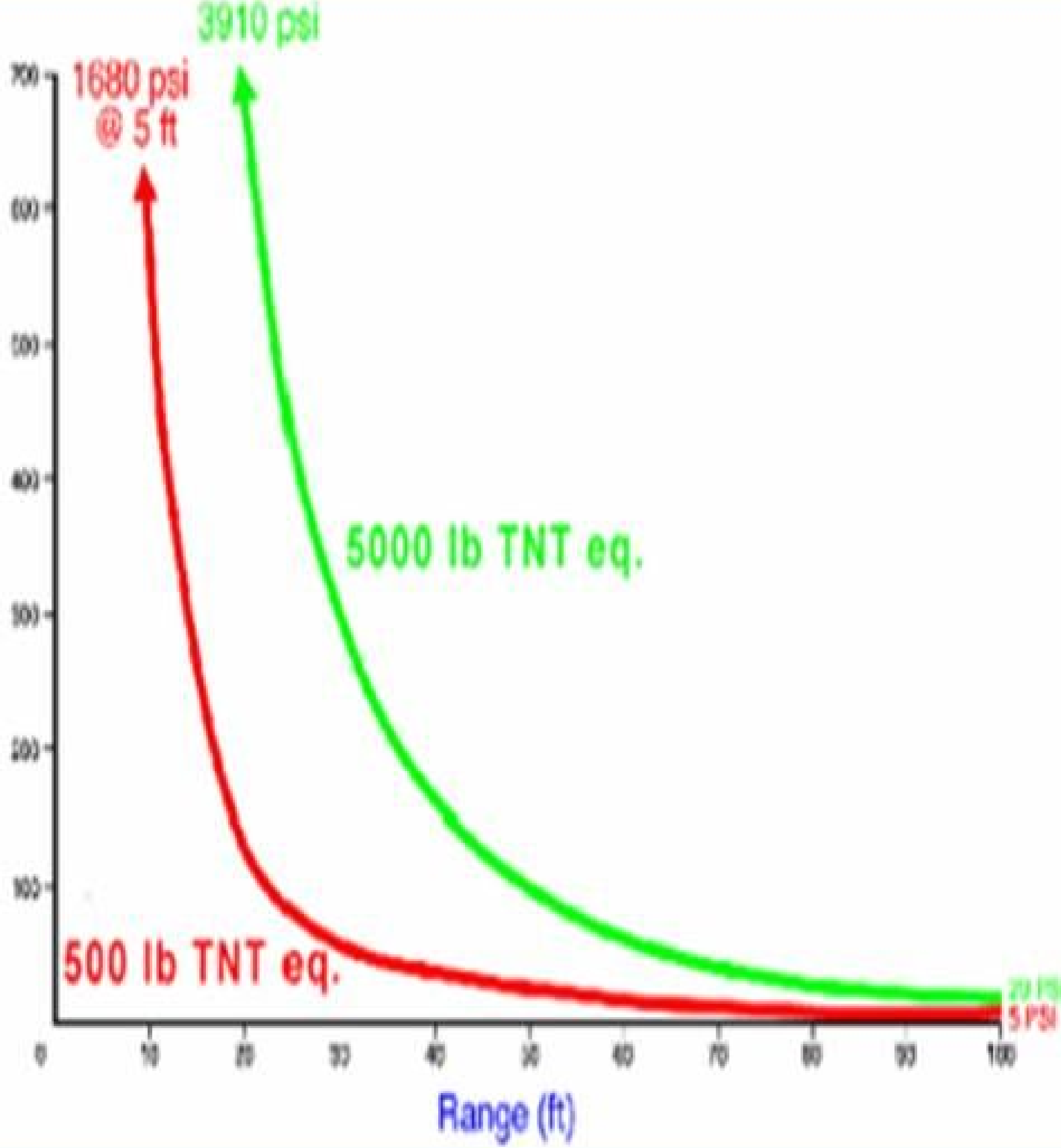
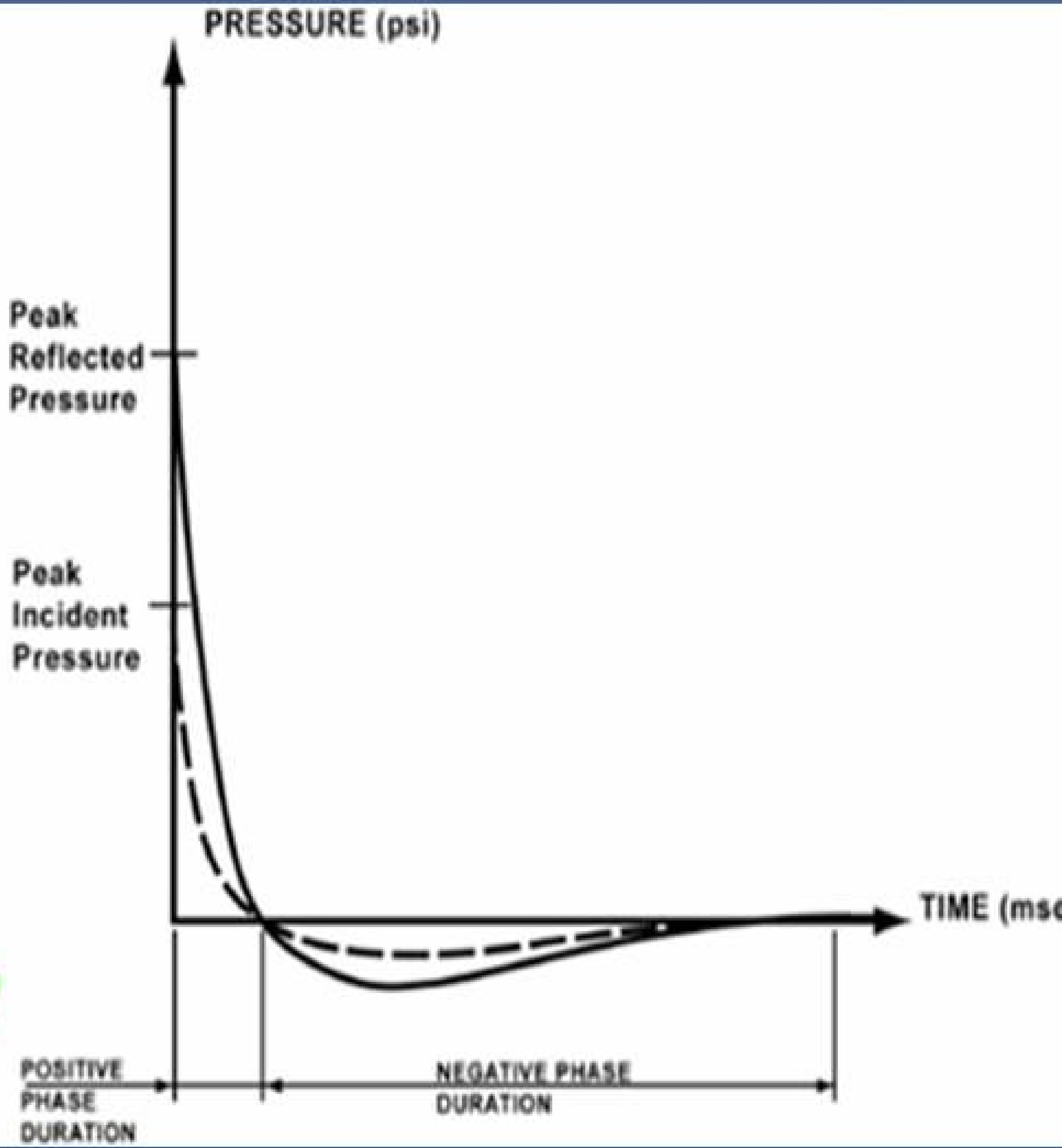
Air-blast pressures as a function of weapon size and distance and as a function of time





Industrial risks in EPR project

- 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.
- The design cases to be used are defined in Technical Guidelines :

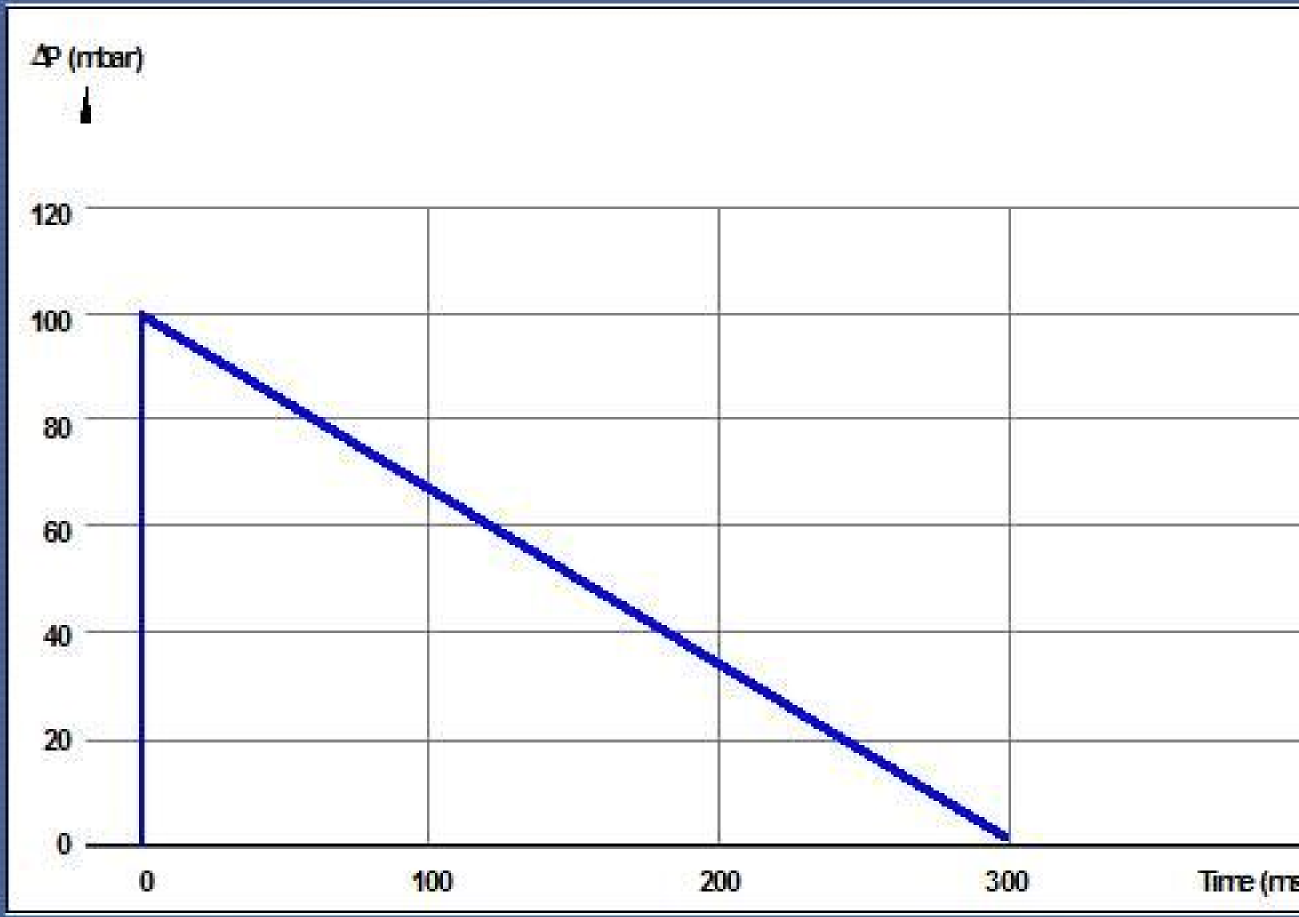
"With regard to external explosions, design of the next generation of nuclear power plants must take into consideration, as a standard load over time, a triangular shaped pressure wave with a vertical leading edge and a maximum over-pressure of 100 mbar and a duration of 300 ms. This means that, given 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".

Design basis on EPR

- The design takes into consideration the external explosion risk based on Technical Guideline.
- 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 :
  - Reactor Building (BR)
  - Fuel Building (BK)
  - Safeguard buildings (BAS)
  - Diesel-Generator Buildings (DB)
  - Pumping Station
  - Nuclear Auxiliaries Building (BAN)
  - Effluent-Treatment Building (BTE)

Design value for EPR NPP

- 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.
- 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



Design parameters (ctd)

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.
    - No reflection will be considered for other buildings
- The duration of overpressure on the vertical walls is expected to be at least equal to half of the incident overpressure wave.
- 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.

Other external human induced events

- General
- Fires
- Ship collision
- Electromagnetic interference
- Loss of off-site power

Fires

- A survey should be made at and around the site to identify potential sources of fire, such as *forests, peat, storage areas for low volatility flammable materials (especially hydrocarbon storage tanks), wood or plastics, factories* that produce or store such materials, their transport lines, and vegetation.
- The area to be examined for the possible occurrence of fires that may affect items important to safety should have a radius equal to the SDV for this type of hazard. This radius is some 1–2 km from the nuclear power plant.
- The precautions taken to protect the nuclear power plant against internal fires also offer some protection against external fires and should be taken into account in evaluating the effects of external fires on the plant.
- Fires may be caused by an event such as an aircraft crash or a chemical explosion.

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Fires (ctd.)

- The protection provided against fire hazards at the source of the fire should also be taken into account (automatic sprinkler systems or permanent local fire fighters).
- The main fire related hazard to the nuclear power plant site is the burning of parts of the plant and the resulting damage (structural collapse..).
- Smoke and toxic gases may affect plant operators and certain plant systems.
- Particular attention should be paid to sources causing possible common mode failures:
  - For instance, the off-site emergency power supply could be interrupted by fire, while the emergency diesel generators may fail to function owing to smoke being drawn into their air intakes.

Fires (ctd)

- Parameters and properties that define the magnitude of a fire are:
  - the maximum heat flux,
  - the magnitude of hazards from burning fragments and smoke,
  - the duration of the fire.
- It should be taken into consideration that the heat flux is inversely proportional to the distance from the fire, although other factors may affect this relationship.

Ship Collision

- Ship collision may constitute a particular hazard to the water intake structures of a nuclear power plant.
- If the ship collision probability is found to be greater than the SPL, a detailed analysis should be conducted to assess the consequences of such an impact.
  - The simulation of uncontrolled drifting of ships and recreational boats (especially sailing vessels) should be conducted, according to the direction of dominant winds and currents.
  - The collision of large ships in normal cruising can usually be screened out by the implementation of administrative measures and safeguards.
- Important parameters are the same as for aircraft crash

Electromagnetic Interference

- Electromagnetic interference can affect the functionality of electronic devices.
- It can be initiated by both
  - on-site (high voltage switchgear, cellular phones, laptops, electronic devices)
  - off-site sources (radio interference, the telephone network).
- The presence of telephone exchange installations close to the site could give rise to specific provisions for the design stage, but usually such high frequency waves do not represent exclusion criteria for sites since :
  - specific engineering measures for the qualification of equipment should be taken
  - administrative procedures should be adopted on site .
- In the site evaluation stage, potential sources of interference should be identified and quantified (for example, intensity, frequency) and monitored over the lifetime of the plant.

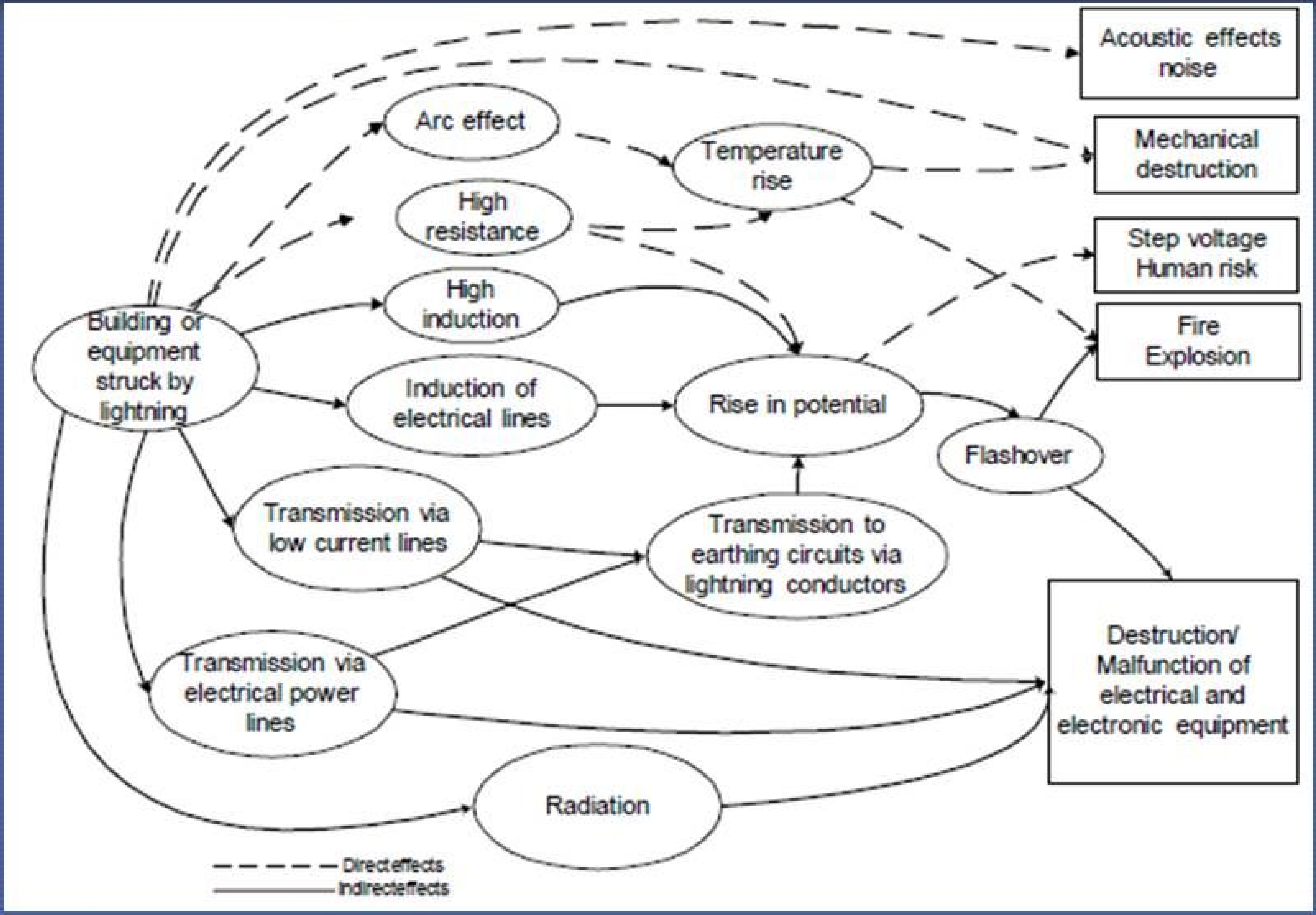
Lightning and electromagnetic interference

- The severity of lightning strike is defined as the density of lightning strikes on the ground expressed as the number of strikes/km2/year.
- Lightning is a climatic event, whose probability of occurrence is high relative to other external hazards i.e. it is of the order of magnitude of category 2 operating conditions
- The electromagnetic environment of power stations is defined according in the IEC 61000-6-5 Standard. The electromagnetic interference induced by lightning hazard is considered as the sizing case for protection requirements.

Effects of lightning

- The direct effects of lightning are thermal, mechanical or electrical (step change in voltage and electrification of objects/equipment). The magnitude of these effects is a function of the energy of the lightning strike.
- The indirect effects on equipment are due
  - to the direct electromagnetic radiation of the lightning ;
  - overvoltages generated, by conduction or induction, in the cables and lines and which may disrupt operation.
- The source of the electromagnetic field is the current of the return arc of the lightning discharge and, in particular, the steepness of the wave front.

Consequences of lightning



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Design measures

- Good protection against the direct effects of lightning involves the control of the attraction and discharge of the lightning current. This protective device is made up of three main parts:
  - Attraction devices (meshed cage or lightning conductor);
  - The lightning conductor designed to discharge the lightning current to the ground;
  - The earthing system designed to dissipate the lightning current in the ground.

Loss of Off-site Power Supplies (LOOP)

- The loss of off-site power supplies is more likely to occur during a period 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 fulfill the required functions.
- The other F1 and F2 classified equipment, which are required in periods of Extreme Demand in other operating conditions, must be available after the LOOP.
- The postulated loss of off-site power is assumed to be due to loss of grid and not an on site equipment failure.

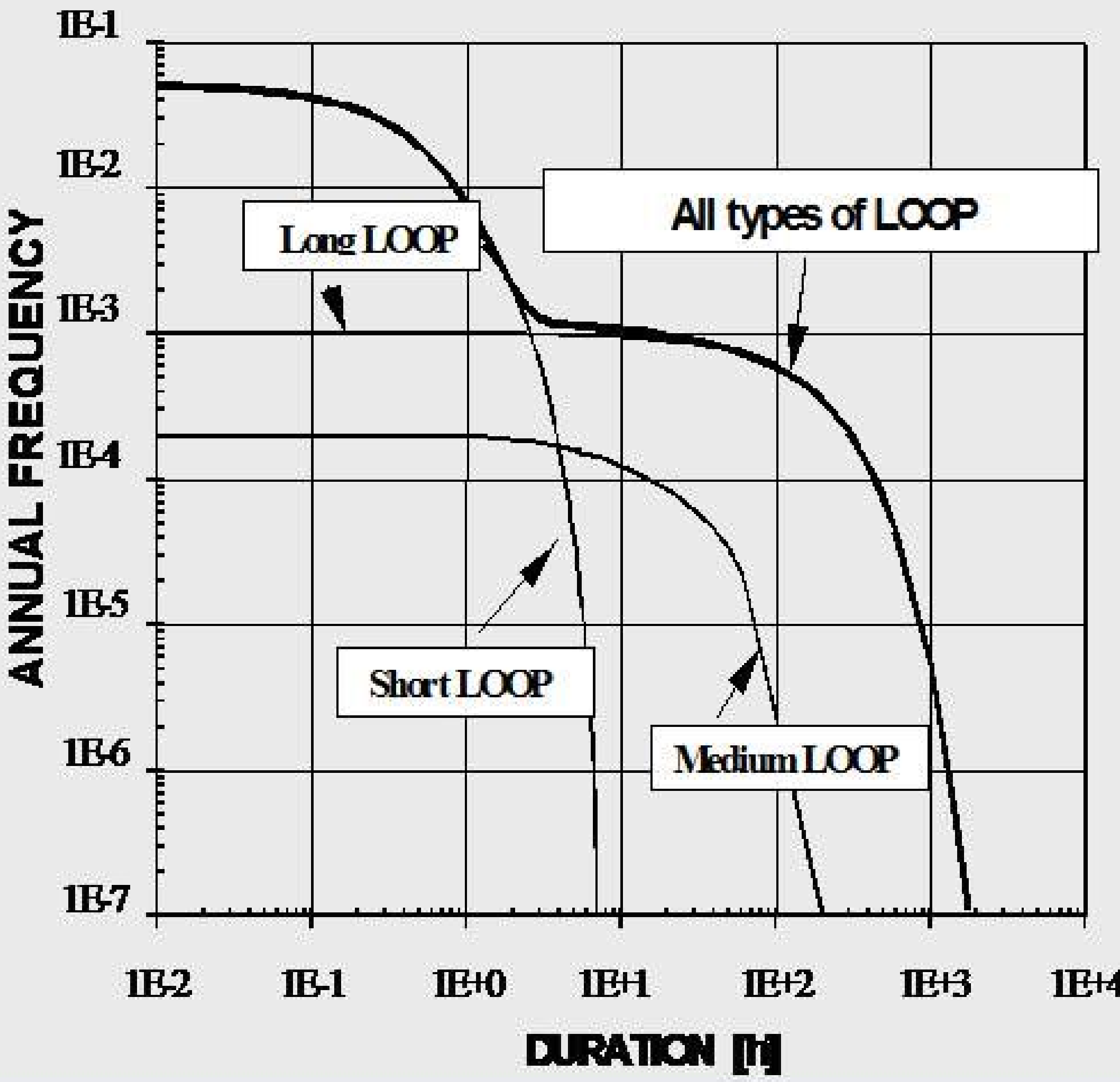
Standard design conditions for loss of off-site power (LOOP)

EVENT	MEAN TIME FOR GRID RECOVERY (τ)	ANNUAL FREQUENCY		COMMENT
		DATA	ERROR FACTOR	
Short time LOOP	0,5 h	$5 \cdot 10^{-2}$	3	Short time LOOP corresponds to most frequent grid failures, with a short recovery time.
Medium time LOOP	24 h	$2 \cdot 10^{-4}$	3	Medium time LOOP corresponds to switchgear accidents, being a common cause for both normal and auxiliary line power supply failure.
Long time LOOP	192 h	$1 \cdot 10^{-3}$	3	Long time LOOP is composed of less frequent grid faults between the plant and the transformer and of line accidents due to climatic causes in the vicinity of the plant, both associated with a long recovery time.

These figures are based on French grid data used for the 1 300 MW plants-PSA. The LOOP initiating event is made-up of different types of failures. They are combined into 3 categories, each one being characterised by a specific mean time for grid recovery.

Standard design conditions for LOOP : annual frequency versus failure duration

LOOP duration	ANNUAL FREQUENCY FOR LOOP			
	Type of grid failure			Total
	Short	Medium	Long	
0	5,0E-2	2,0E-4	1,0E-3	5,1E-2
0,5	1,8E-2	2,0E-4	1,0E-3	2,0E-2
1	6,8E-3	1,9E-4	9,9E-4	8,0E-3
2	9,2E-4	1,8E-4	9,9E-4	2,1E-3
3	1,2E-4	1,8E-4	9,8E-4	1,3E-3
6	3,1E-7	1,6E-4	9,7E-4	1,1E-3
12	≈ 0	1,2E-4	9,4E-4	1,1E-3
18	0	9,4E-5	9,1E-4	1,0E-3
24	0	7,4E-5	8,8E-4	9,6E-4
48	0	2,7E-5	7,8E-4	8,1E-4
160	0	2,5E-7	4,3E-4	4,3E-4
320	0	≈ 0	1,9E-4	1,9E-4
720	0	0	2,4E-5	2,4E-5
1000	0	0	5,5E-6	5,5E-6



Consideration of the Loss of external power supplies (LOOP)

- The loss of external power supplies is more likely to occur during a period 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.
- 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,

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Thank you for your attention

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