Expert review of seismic safety design of NPP

Part I : Seismic Hazard

Oona Scotti

Part II: Structural behavior

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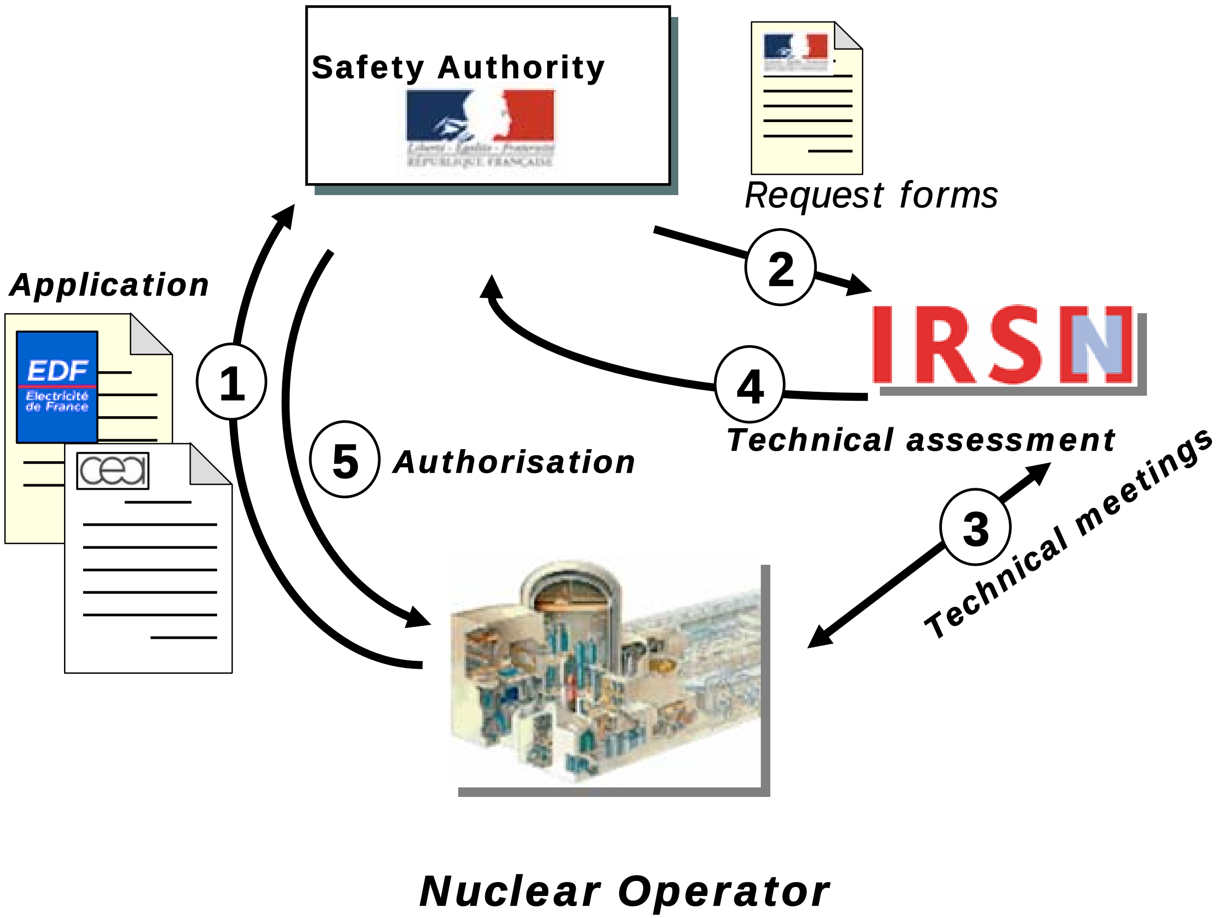
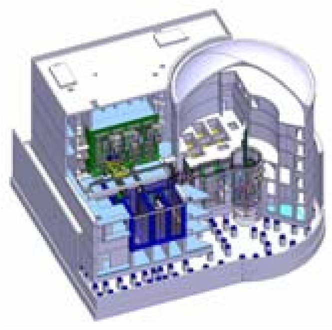
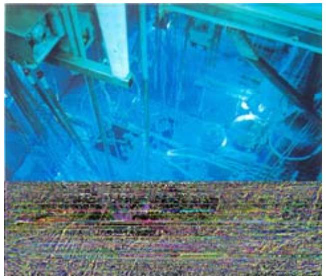
- Introduction (6 slides)
  - French Nuclear Safety/ Licensing procedure/ review process
  - Role of IRSN as TSO for Nuclear Safety Authorities
- Part I (11 slides) : Seismic Hazard Assessment (SHA)
  - French Deterministic regulation
  - IRSN review practice
- Part II (15 slides) : Seismic Structural behavior Assessment
  - Safety assessment principles for nuclear facilities
  - Seismic design of NPP
  - Seismic assessment of NPP

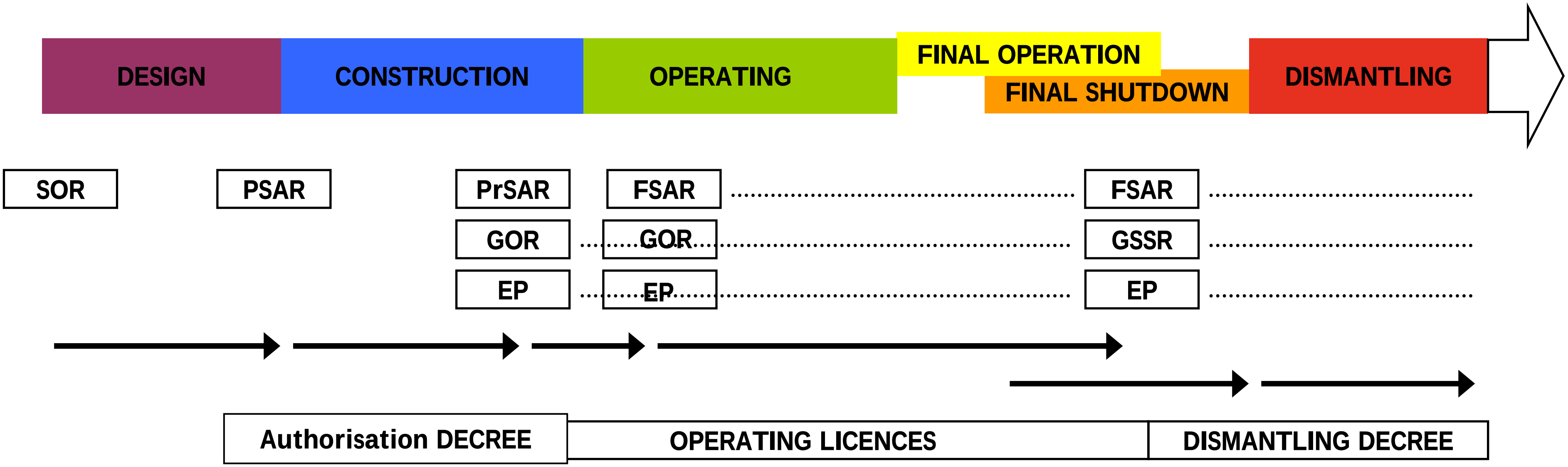
1. In France the fundamental principle of nuclear safety is the prime responsibility of the Operator (currently, EDF); only the Operator is able to undertake the actions which can maintain and/or enhance the plant safety. The Operator relies on the Constructor for undertaking these actions,
2. The Safety Authority (ASN) – a public authority - verifies that the Operator fully endorses his responsibility in compliance with the regulatory requirements,
3. The Safety Authority relies on the national TSO Organisation (IRSN) for expertise, advice and technical support.

IRSN's role in the Safety review process : e.g. seismic









SOR: Safety Option Report

GOR: General Operating Rules

EP: Emergency Plan

PSAR: Preliminary Safety Analysis Report

PrSAR: Provisional Safety Analysis Report

FSAR: Final Safety Analysis Report

IRSN - Institute for Radio-Protection and Nuclear Safety

- IRSN was created on 02/ 22/ 2002
- Annual budget about 300 M€, including:
  - ✓ Contractual activities (1/5th)
  - ✓ Expertise (2/5th)
  - ✓ Research (2/5th)
- More than 1500 people, 2/3 researchers and engineers
- Large involvement in international networks on safety
- scientific collaboration at national, European and international level
- IRSN has its own experimental capacity in different fields of endeavour of nuclear safety and radioprotection

The case of Seismic Safety re-assessment for power reactors (58 reactors/ 19 sites - submitted to a Safety review every 10 years)

Generalists:

- power reactors
- fuel cycle facilities
- experimental reactors
- waste

Specialists:

- mechanical engineering
- hydraulics, thermal eng.
- reactor control
- I&C
- severe accidents
- human factors
- neutronics
- seismic studies, etc.

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IRSN/DEI/SARG/BERSSIN

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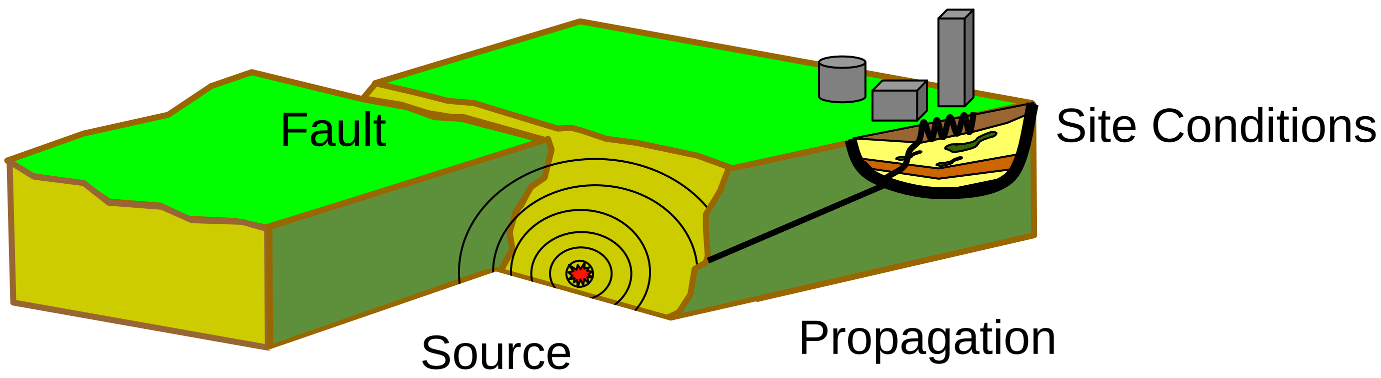
IRSN/DSR/SAMS/BACGS

Irrespectively of the methodology (determinsitic or probabilistic), seismic hazard assessment requires to identify and model the sources of seismic activity (e.g. faults) and to predict the seismic motion of such potential earthquakes at the site of interest.

➔ Key parameters

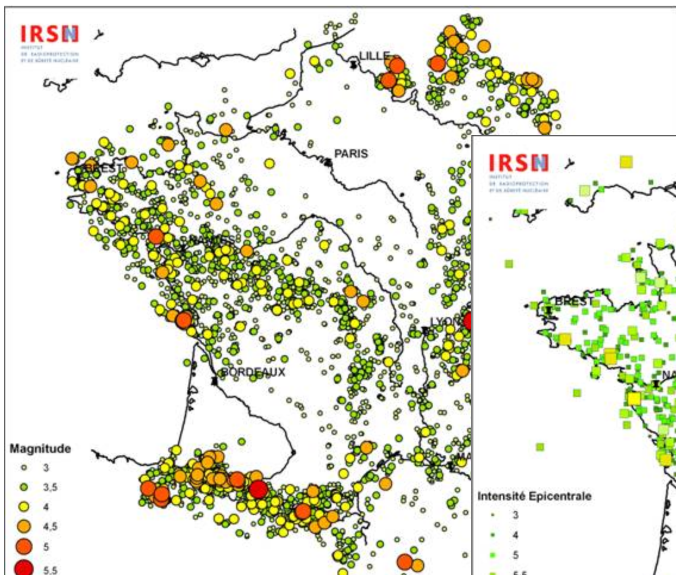
1. Magnitude/Depth of reference earthquake(s) – the Source,
2. Distance of the reference earthquake(s) from the NPP site ,
3. Geological site condition of the NPP site
4. Predicted ground motion at the NPP site
5. Characterization of the potentially active faults close to NPP
6. AND QUANTIFICATION OF RELATED UNCERTAINTIES



Defining the magnitude of reference earthquake(s)

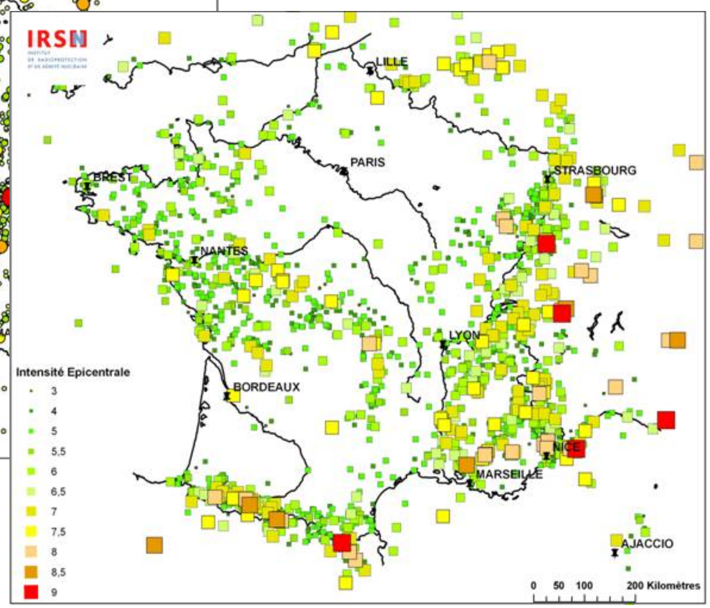
Magnitudes of earthquakes in most catalogues are known at best to +/- 0.2 units and most of the time only to +/- 0.5 units ➔ historical but also instrumental catalogues are often affected by subjective interpretations/model assumptions

Instrumental catalog



Covers last 50 years

Historical catalog



Covers last 1000 years

Need to have catalogues that account for multiple expert opinions.

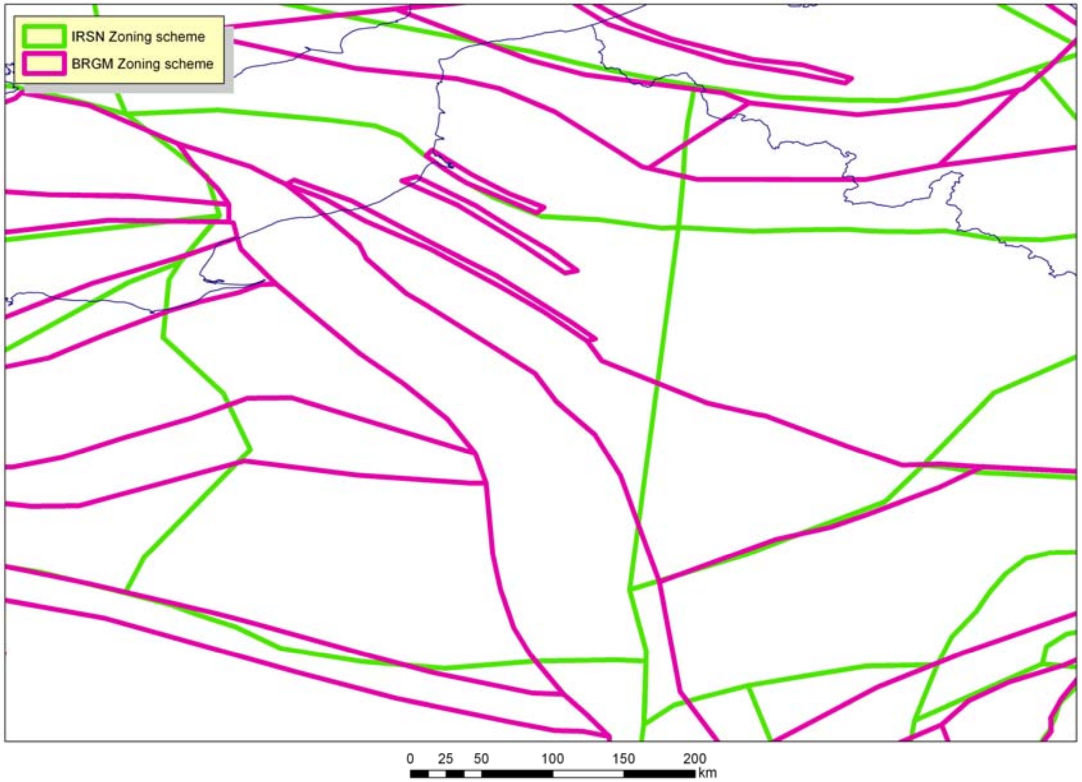
Ex. France:
BRGM (French Geol Service), EDF and IRSN have been involved in the SISFRANCE WG for a continous review/critique of the historical data since the 1980s ➔ consensual historical data catalogue

However each institute produces its own historical magnitude catalogue!!

IRSN has developed a method to account for uncertainty in historical magnitude catalogues

Defining seismic source zones (SSZ)

Distance of reference event can vary by up to 100% depending on SSZ definition.



Need for comprehensive up-to-date seismotectonic studies

Need to account for multiple expert opinions: CEA - EDF-AREVA .. each rely on their own SSZ

IRSN performs a careful review of the criteria used by each operator to define the seismotectonic limits and evaluates their relevance in the face of uncertainty

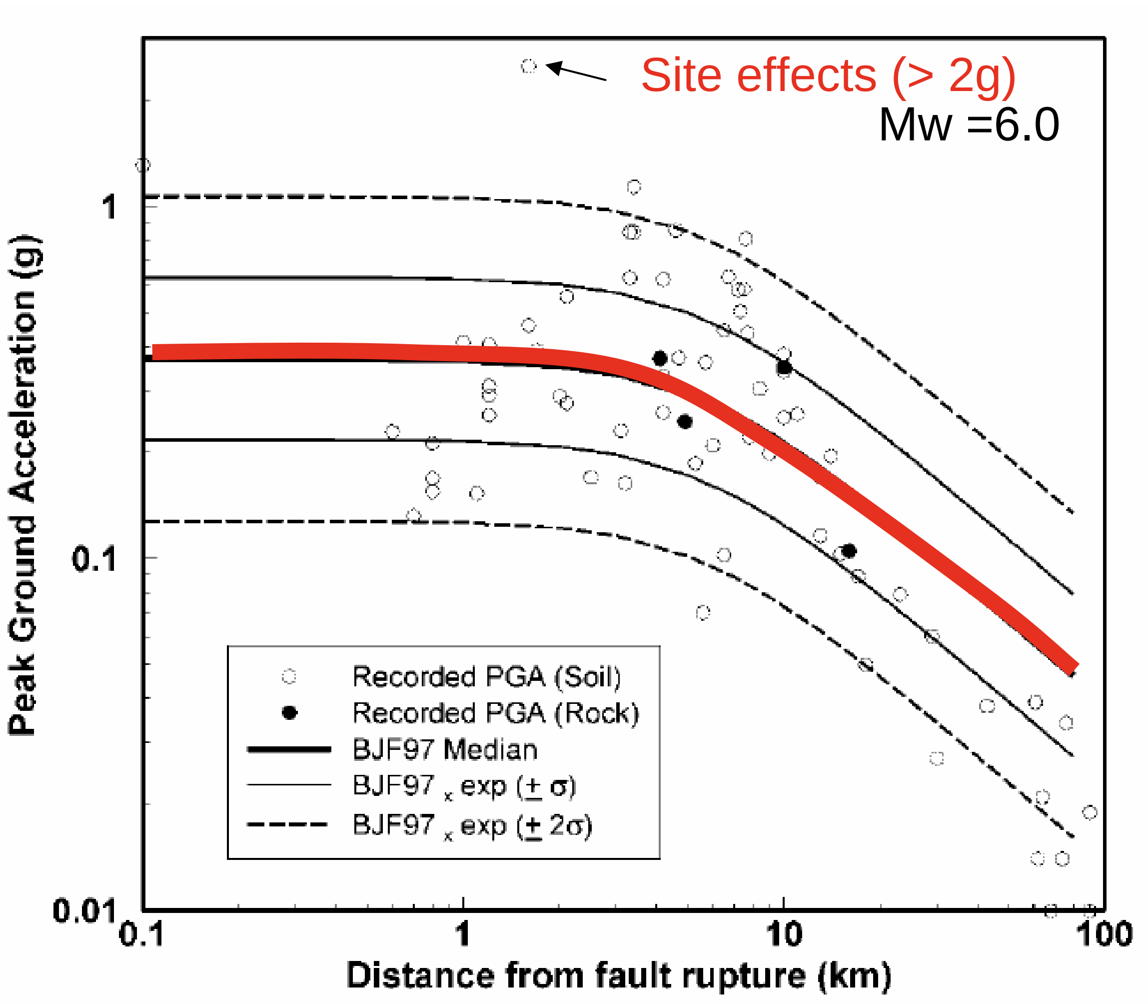
SSZ 1: supported by « **static » criteria** (geophysical anomalies in the crust revealed by gravimetric or magnetic maps),

SSZ 2: take into account **« dynamic criteria »** (orientation of main faults relative to maximum horizontal stress direction, seismic rate)

Expected Ground motion

Defining Expected ground motion

Main tool➔Empirical Ground Motion Prediction Equations (GMPE)



Need for a comprehensive sesimological study /strong ground motion database/detailed knowledge of recording station geotechnical conditions

-

Careful review of the criteria used to accept or refute a GMPE

-

Need to account for multiple expert opinions

In France the deterministic regulation imposes a single GMPE and considers only the median value

<u>Defining geological site conditions</u>

Particular attention to sites affected by so-called « site-effects »

- Need for site-specific data (earthquake recordings)

- Need for elaborate modeling tools (in the absence of recorded data)

Need for a comprehensive microseismic/geotechnical study

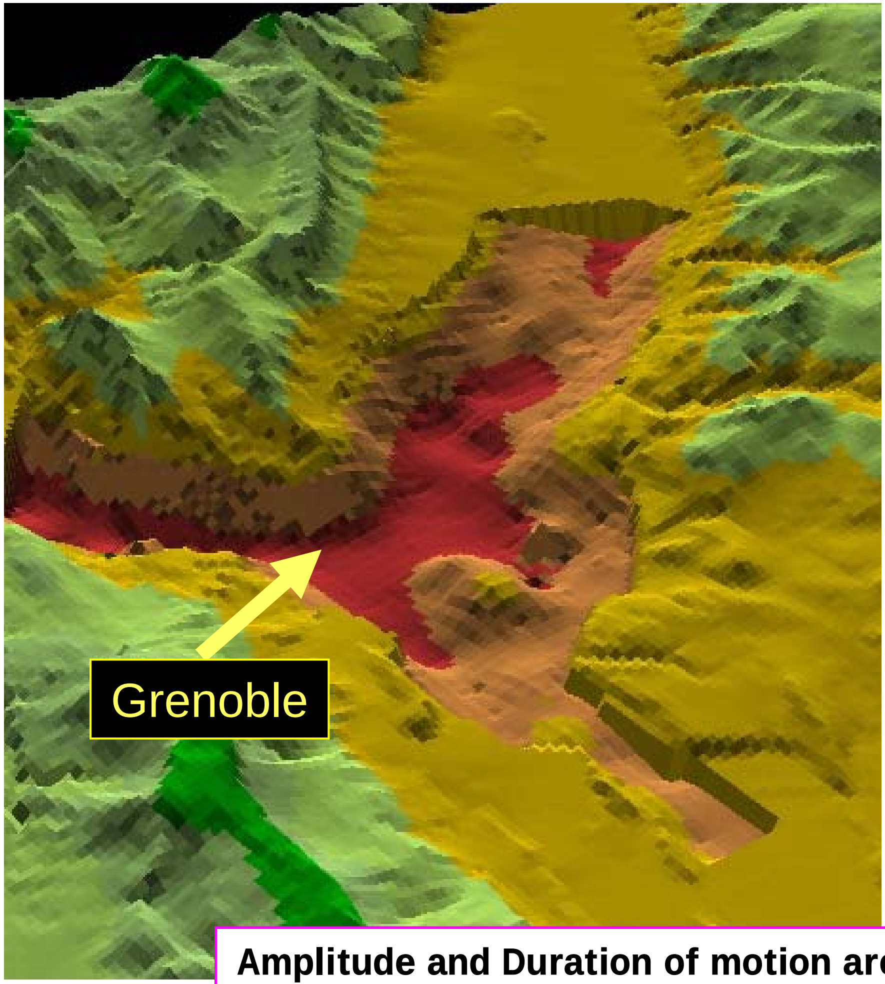
-

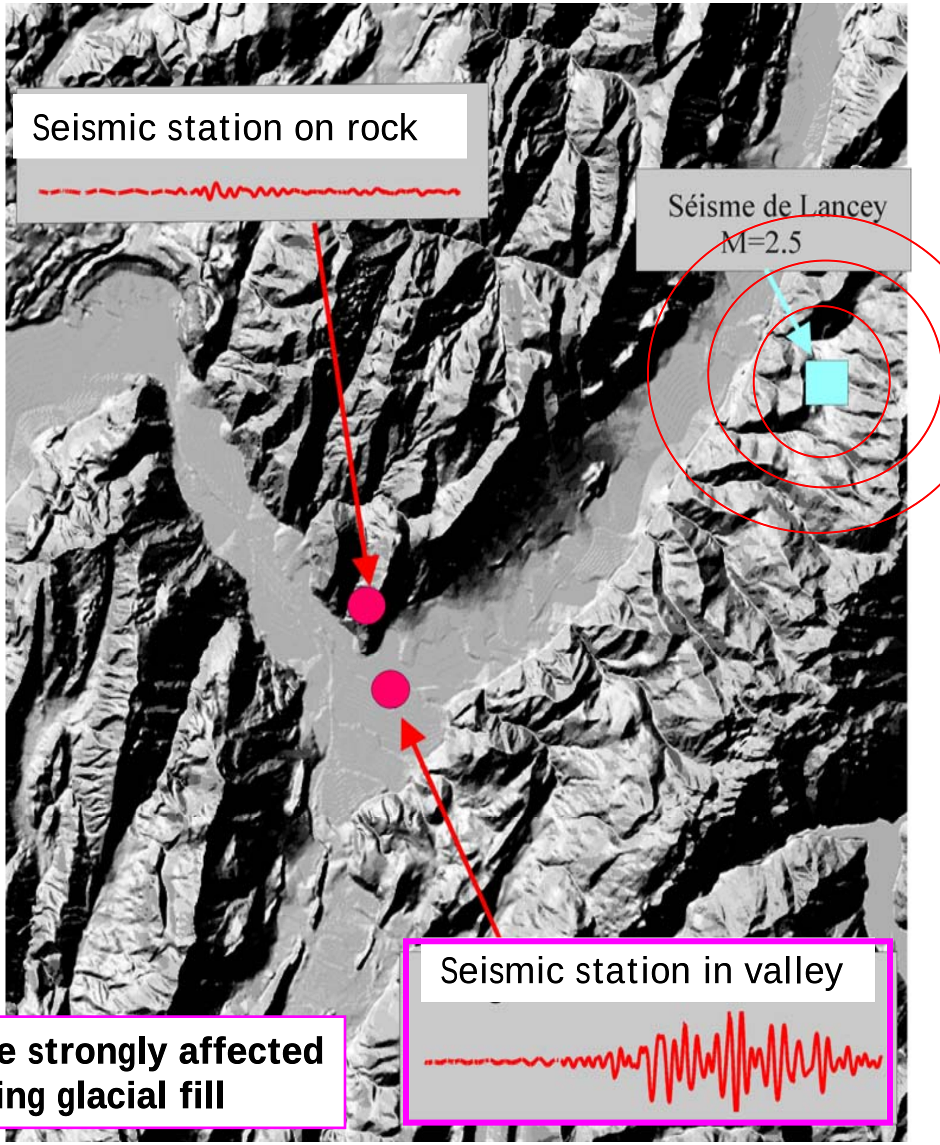
Careful review of the criteria used to define the geological models

-

Need to account for multiple expert opinions: IRSN develops its own tools and performs sensitivity tests

Example: Site-effects (Glacial sediment-filled valley)





Amplitude and Duration of motion are strongly affected by the presence of the underlying glacial fill

Framework for IRSN's seismic hazard analysis

In the 1970's : - beginning of the French Nuclear research program
- and first NPP for energy production built since 1975

First regulation devoted to the SHA: « French Safety Rule » 1981

1997- 2000 revision motivated by the improvement in

Characterization of active faults

Estimation of the magnitude of historical events

GMPE based on numerous recent accelerometric data recorded in Europe

REX onthe importance of Site effects following important earthquakes (Mexico 1985, Loma-Prieta 1989, Northridge 1994, Kobe 1995 …)

New safety rule, named RFS 2001-01 adopted in 2001

Main steps of the Safety Rule (RFS 2001-01): deterministic approach

Step 1
Magnitude
Distance

- Define source zones, or faults
- Define the « Reference » event (s) (RE)
- Define the energy (Magnitude), and the location of these events (Distance, depth)

$(\text{Location, Magnitude})_{\text{R.E.}}$ ⟷ Uncertainties

"Safety Margins"

Step 2
MPHE
SSE

- « M.H.P.E. (MaximumHistoricallyProbableEarthquake) = Reference Earthquake shifted close to the site
- « S.S.E. » Magnitude = MHPE Magnitude +0.5 units (equivalent to the Safe Shutdown EQ)

Main steps of the Safety Rule (RFS 2001-01): deterministic approach

Step 3
Site conditions

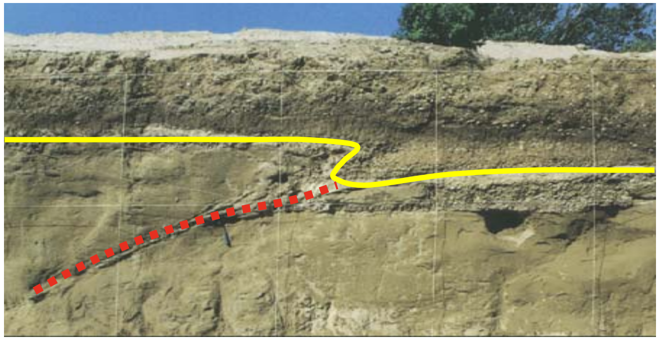
RFS 2001

- Define the site geology (rock ? Soil ?)
- Geometry (topography, basin,1D, 2D, 3D ?)

Step 4

RFS 2001

Characterizing potentially active faults
Need for Paleoseismological study



Courthézon - Fault

Step 5
GMPE

Compute the mean response spectra (SSE, paleoevent)
Using an GMPE, or a SITE-SPECIFIC STUDY

Consider a Minimal PGA Level of 0,1g

RFS 2001

The Safety Rules does not explicitly mention a method for the exploration of uncertainty, **however**, IRSN expects seismic hazard levels to be very dependent on how uncertainties are handeled concerning:

1. Data
2. Models
3. Methodologies

IRSN expects from the Operators an explicit quantification of the uncertainty at each step of the seismic hazard computation, be it deterministic or probabilistic

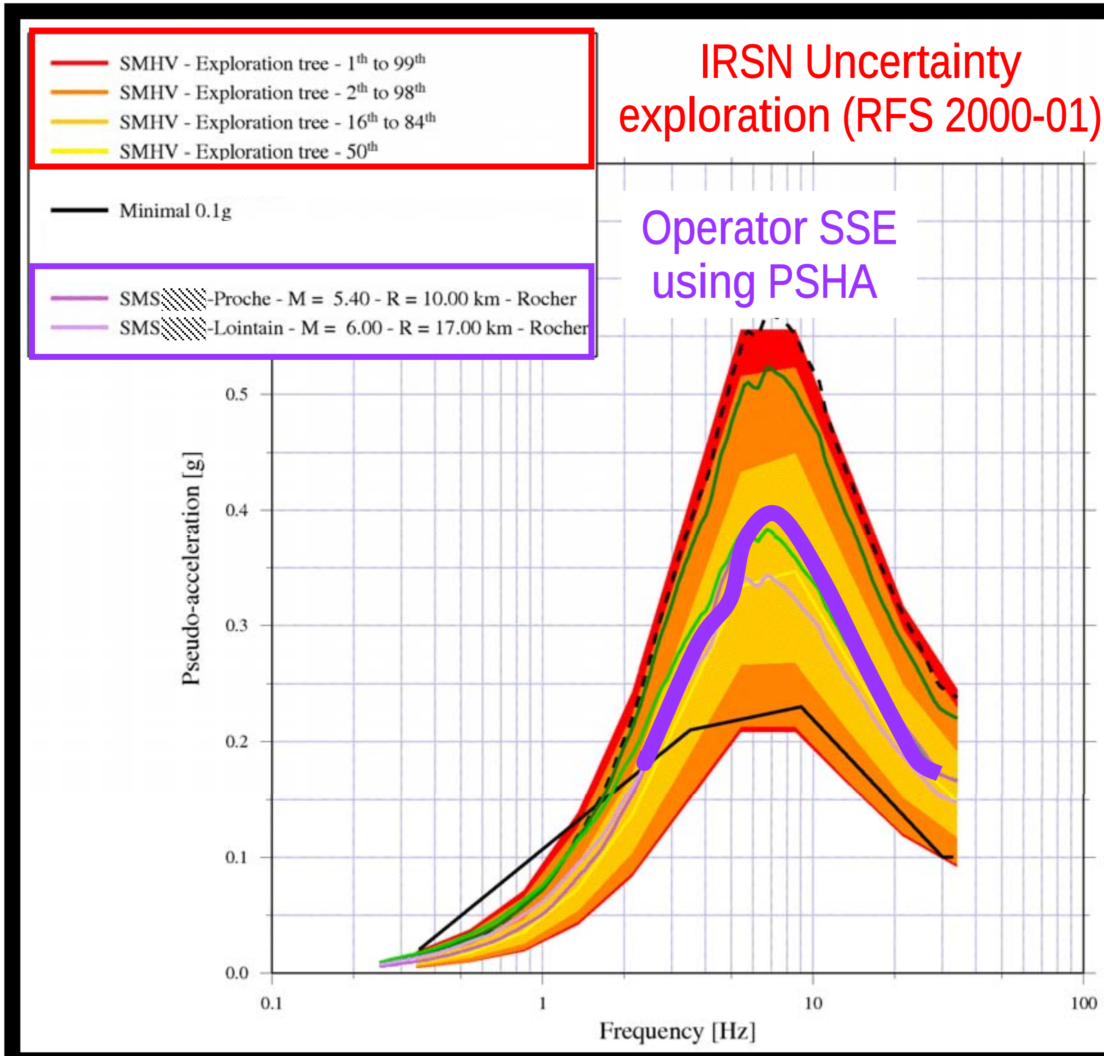
IRSN is continously updating its own methodology to asses uncertainty - Example based on the deterministic methodology

IRSN's deterministic methodology allows to quantify uncertainties (Mag., Dist and source zoning schemes) in compliance with RFS.

According to IRSN uncertainty exploration, the SSE proposed by the Operator is closer to a median MHPE RFS scenario (NB The SSE spectra presented in the Operator's Safety Report was derived from a PSHA study).

IRSN considered the Operator's evaluation to be insufficient with respect to the MHPE uncertainty

IMPACT
The operator asked their consultant to re-evaluate their seismic hazard levels



IRSN

Given the actual level of knowledge on the data and models, seismic hazard can only be estimated with significant uncertainty.

Independently of the method, uncertainty needs to be propagated

The uncertainty analysis can help evaluating whether the spectra retained by an applicant is penalizing enough with respect to the uncertainties.

Thank you for your attention

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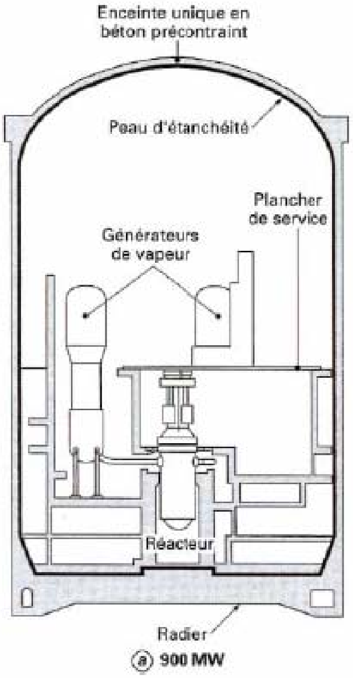
- Part II (15 slides) : Seismic Structural behavior Assessment
    - Safety assessment principles for nuclear facilities
  - Seismic design of NPP
  - Seismic assessment of NPP

MAIN TYPES OF NUCLEAR FACILITIES

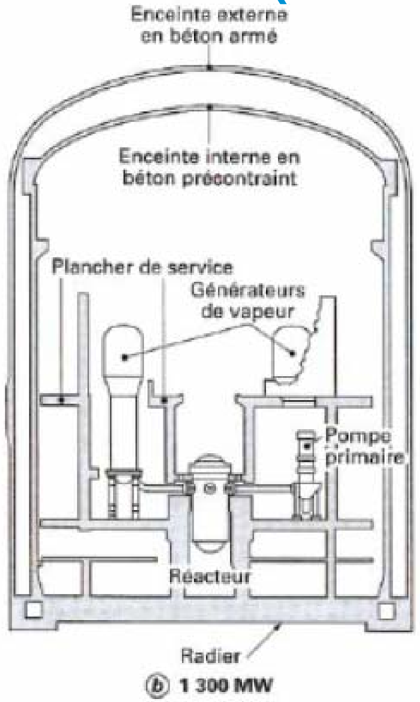
•**LABORATORIES & PROCESS PLANTS, TEST REACTORS, WASTE STORAGES …**
= "prototype" (peculiar safety requirements)

• **NPP (PWR), STANDARD DESIGNED (French practice)**
= "industrial product" (common safety requirements)

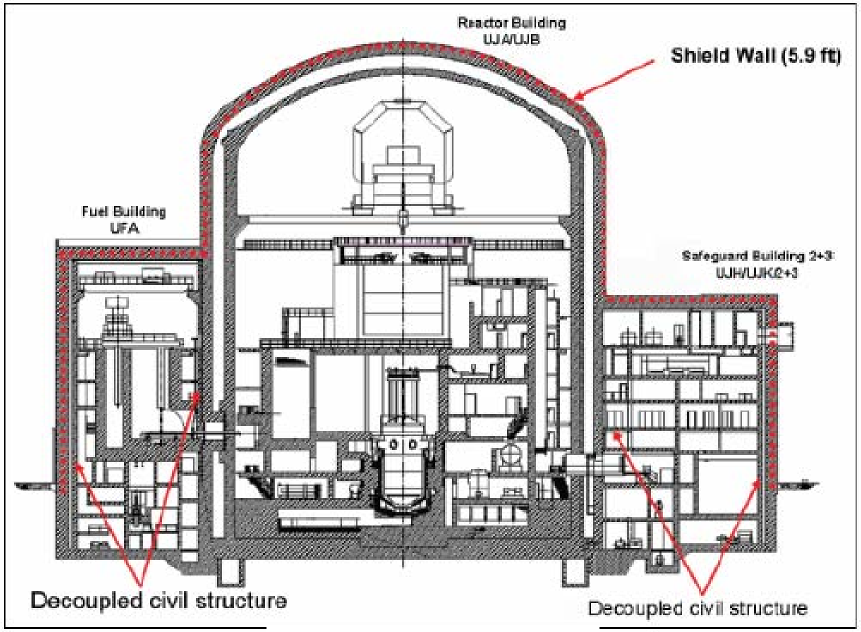
34 units 900 MW (1977-1987)



20 units 1300 MW (1984-1993)
4 units 1500 MW (1996-1999)



1 unit 1700 MW (construction in progress)



EPR

SAFETY STAKES

OBJECTIVE of nuclear buildings civil engineering, with regard to the risks to be assessed by the IRSN (TSO) :

MAINTENANCE OF THE NUCLEAR PLANT IN A SAFE STATE

- **THROUGHOUT ITS LIFETIME, INCLUDING THE PHASE OF DISMANTLING**
- **IN NORMAL SITUATIONS (OPERATION), IN INCIDENTAL AND ACCIDENTAL SITUATIONS**

→ **SEISMIC HAZARD (= DESIGN BASIS EARTHQUAKE)**

THE CONTENTS OF THE TERM "SAFE NUCLEAR PLANT" ARE EXPRESSED IN ACCEPTABLE CONSEQUENCES FOR THE ENVIRONMENT

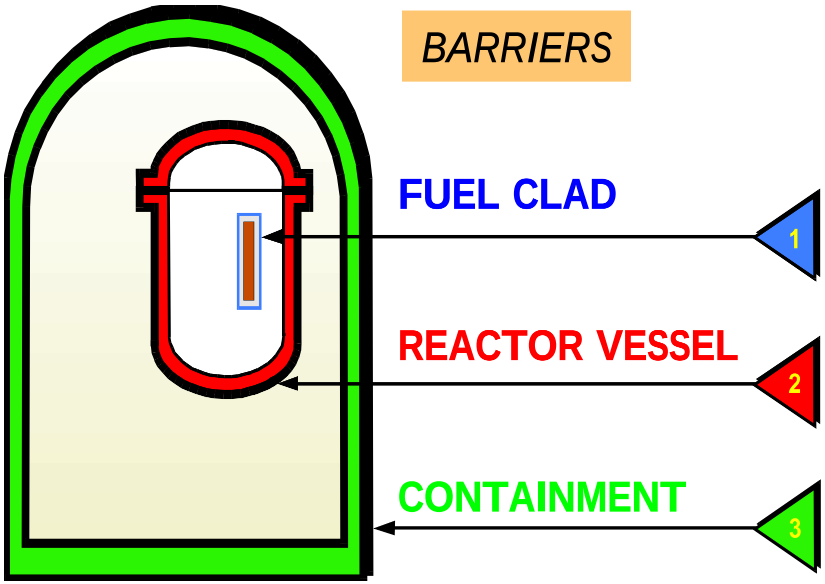
NUCLEAR BUILDINGS MUST GUARANTEE SAFETY- RELATED FUNCTIONS

THE CONTAINMENT OF NUCLEAR MATERIALS AT NUCLEAR FACILITIES IS ENSURED BY MEANS OF

- STEPS OF DEPRESSIONS IN THE ROOMS, FROM "cold" zones TO "hot" zones (DYNAMIC CONTAINMENT = VENTILATION)

- THE WALLS OF THE BUILDING (STATIC CONTAINMENT).

- **THE EXTERNAL STRUCTURES (RAFT, WALLS, COVER SLABS, REACTOR CONTAINMENT) CONSTITUTE THE "3rd BARRIER".**
- **The INTEGRITY OF THIS BARRIER (i.e. its capacity to ensure static containment) MUST BE ENSURED IN ALL SITUATIONS (especially during earthquakes)**



SEISMIC REGULATION (France)

Seismic hazard:
zoning based on historical seismic events

« BASIC » RISK

Standard seismic rules
(Eurocode 8)

Seismic hazard:
process based on
a seismotectonic analysis

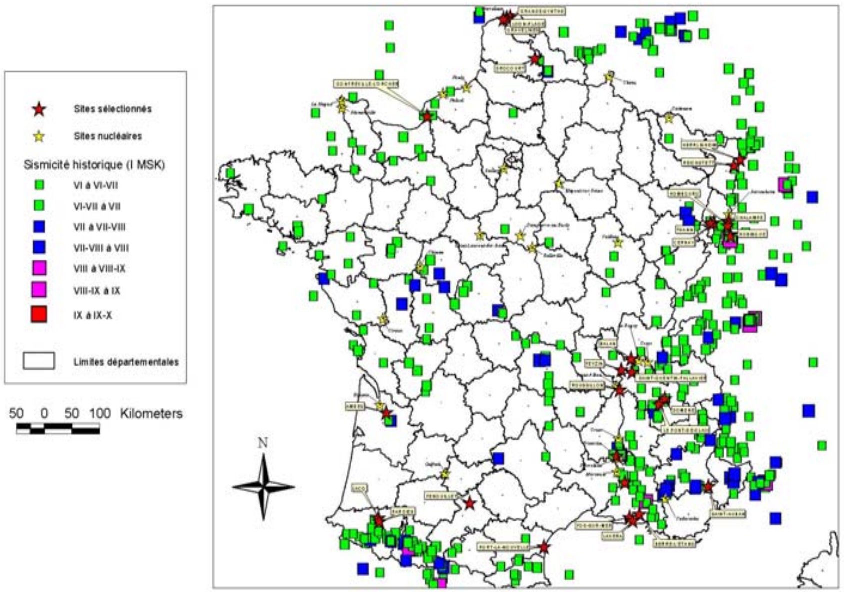
« SPECIAL RISK »

"SEVESO" RISK FACILITIES

NUCLEAR RISK FACILITIES

Seismic motion:
RFS 2001-01

Design rules
(civil engineering):
Guide ASN 2/01



Seveso site

Nuclear site

In France, 200 nuclear facilities

SAFETY RULES AND TECHNICAL DESIGN (France)

1 - FUNDAMENTAL SAFETY RULES (R.F.S): regulatory general rules for NPP and nuclear facilities

- **CALCULATION OF SEISMIC MOTION : RFS 2001-01**
- **SEISMIC DESIGN OF CIVIL WORKS : Guide ASN 2/01**

« *The purpose of this guide is to define the earthquake-proof design of civil engineering structures for nuclear installations, not covering long term storage of radioactive waste, using site data. Acceptable methods for the following are covered:*

- determining the earthquake-proof response for these structures; considering their interaction with equipment that they contain, and to evaluate mechanical stress associated with the earthquake-proof response, which is to be used for structural engineering.*

- determining earthquake movements to be considered for designing equipment. »

2 – DESIGN AND CONSTRUCTION RULES: created by operators

- **IN ACCORDANCE WITH RFS (Fundamental Safety Rules),**
- **IN ADDITION TO TECHNICAL DESIGN STANDARDS :**

For civil engineering - EDF : RCC-G (PWR), ETC-C (EPR)
- AREVA : SG 0101 (Nuclear plants)

PRESENTATION of GUIDE ASN 2/01 (french regulatory guide)

Guide ASN 2/01 applies to all new nuclear facilities seismic design (excepted long term storage of radioactive waste facilities)

- explains the link between design process and safety analysis of the facility concerning the seismic risk

- **behavior requirements of the structures,**
- **concomitant and induced situations,**

- **recalls the principles of the earthquake engineering design**

- **indicates the seismic motion caracteristics for the seismic design (DBE)**

- specifies acceptable calculation methods for the seismic behavior analysis of nuclear buildings and some other kinds of civil works (dykes, underground tunnels, retaining walls, tanks …),

- clarifies the use of the calculated efforts for the design;

- **lists the documents to be provided for the TSO safety assessment (appendix 4).**

SAFETY REQUIREMENTS & SEISMIC BEHAVIOR

OBJECTIVE = to ensure the safety-related functions

= to define :

- the operating conditions and the combinations of associated actions

- the safety functions ⇒ safety requirements applied to civil works ⇒ behavior requirements for structures ⇒ design criteria

= to check :

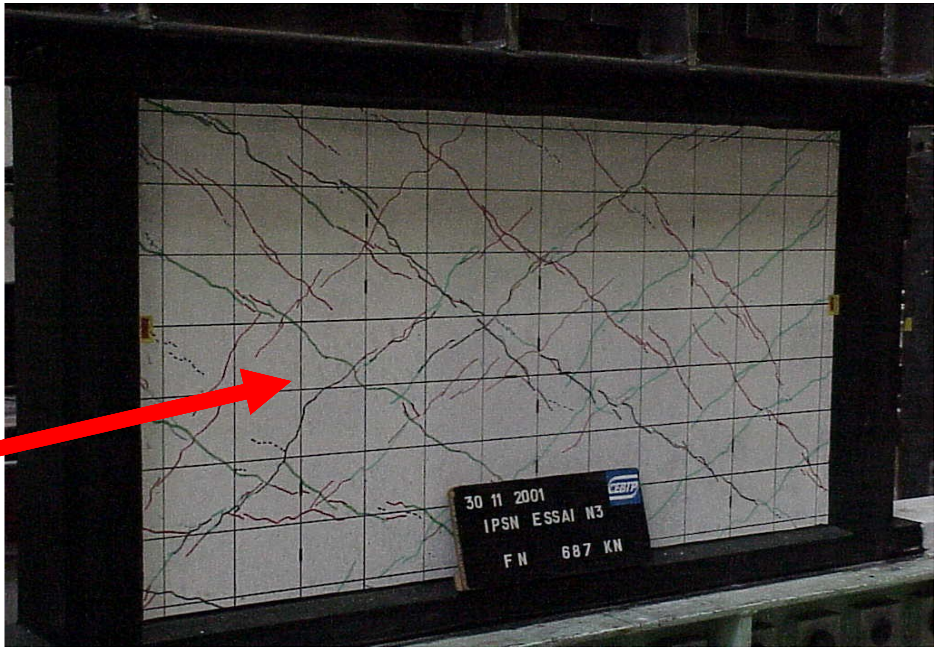
- the design methods

- the seismic responses,

- the compliance with design criteria

A wall after an earthquake :

resistance, tightness, biological shielding …?



SAFETY REQUIREMENTS & SEISMIC BEHAVIOR

Safety functions	Civil works safety requirements
Tightness	• containment • retention • « closed and covered »
Protection against radiations	• stability of biological shields • compliance of cracking with the allowed dose rate
Protection against internal / external hazards	• stability • (containment…)
Maintenance of subcriticality	• conservation of the geometry, localization
Supporting of the equipment	• limited deformation • resistance of the anchoring device
No interference between close buildings	• stability • control of displacements

SAFETY REQUIREMENTS & SEISMIC BEHAVIOR

SEVERITY

REQUIREMENTS FOR RESISTANCE

Overall stability (of the building)
Local stability (of the structural elements)
Supporting (of the equipment).

+ REQUIREMENT OF NO-INTERFERENCE
(close buildings)

SEVERITY

REQUIREMENTS FOR TIGHTNESS

« Closed and covered »
Retention.
Containment.

SAFETY REQUIREMENTS & SEISMIC BEHAVIOR

Requirements for resistance (reinforced concrete)

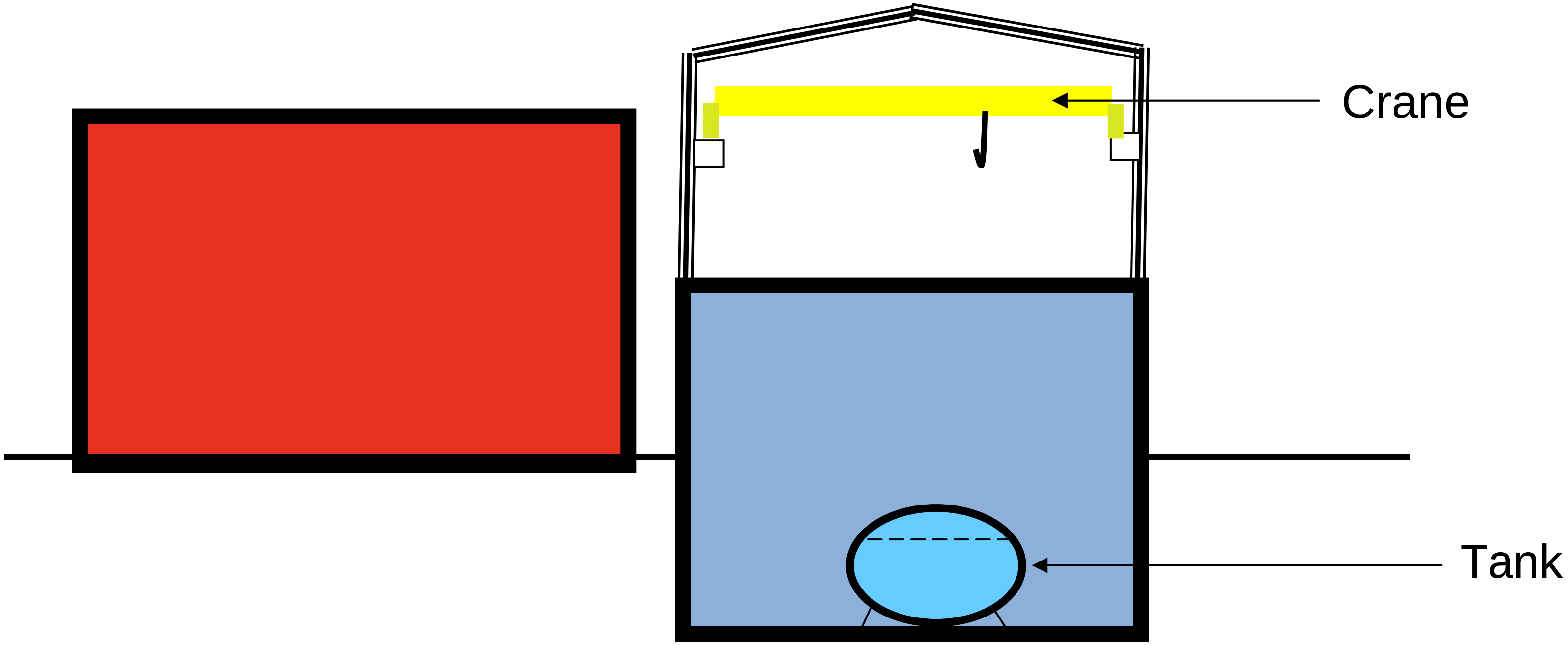
Safety requirements	Structural elements	Behavior requirements	Design criteria
Overall stability	• building • part of the building	limited overall displacement limited uplift of the foundation	geometrical unlinearities allowed stresses and strains of the ground
Stability of structural elements	• raft • walls, posts • slabs, beams	acceptable cracking limited displacements and deformations	linear field design code criteria
Supporting of equipment	• raft • walls, posts • Slabs, beams	limited deformations limited cracking	linear field design code criteria (limit of cracking)

SAFETY REQUIREMENTS & SEISMIC BEHAVIOR
Requirements for tightness (reinforced concrete)

Safety requirements	Structural elements	Behavior requirements	Design criteria
Closed and covered	• raft • walls • slabs	acceptable cracking limitation of displacements and deformations	linear field design code criteria
Retention	• raft • walls • slabs	limitation of deformations limitation of cracking	linear field design code criteria (limit of cracking)
containment	• Reactor containment • raft • walls • slabs	residual compression stress complementary devices (liner, prestressing tendons….)	linear field design code criteria (operating service and limit of cracking)

Containment is a function which the civil engineering cannot provide by its own

SPECIAL TECHNICAL ISSUES TO BE ASSESSED, INFLUENCING SEISMIC MOTIONS FOR NUCLEAR BUILDINGS



- **soil/structure interaction (SSI)**
- **fluid/structure interaction (tanks),**
- **structures coupling (metallic frame/crane)**

FILE TO BE PROVIDED BY THE OPERATOR

- SAFETY REQUIREMENTS FOR CIVIL ENGINEERING
- BASIC DATA FOR BUILDINGS AND EQUIPMENTS DESIGN :
  - GENERAL LAYOUTS AND DESCRIPTION OF THE STRUCTURES,
  - GROUND CARACTERISTICS, CLIMATIC CONDITIONS,
  - INTERNAL AND EXTERNAL HAZARDS,
  - SEISMIC MOTION (following RFS 2001-01)
- DESIGN METHODOLOGY (in accordance with ASN Guide 2/01)
- SEISMIC CALCULATIONS OF THE STRUCTURES
- GENERAL & DETAIL CONSTRUCTION DRAWINGS

ASSESSMENT PROCESS OF THE TECHNICAL FILE PROVIDED BY THE OPERATOR

- general safety requirements assessment : TSO safety experts

- seismic hazard assessment : TSO seismologists

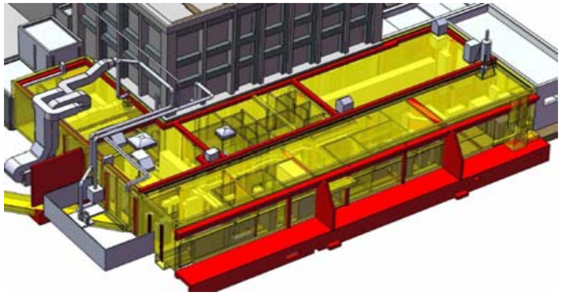
- behavior requirements seismic design assessment : TSO civil engineering experts

ANALYSIS AND CHECKING OF THE BASIC DATA, DESIGN RULES, CALCULATIONS HYPOTHESIS, CALCULATIONS METHODS, SEISMIC RESPONSES RESULTS AND BEHAVIOR OF THE STRUCTURAL ELEMENTS

AIMS :

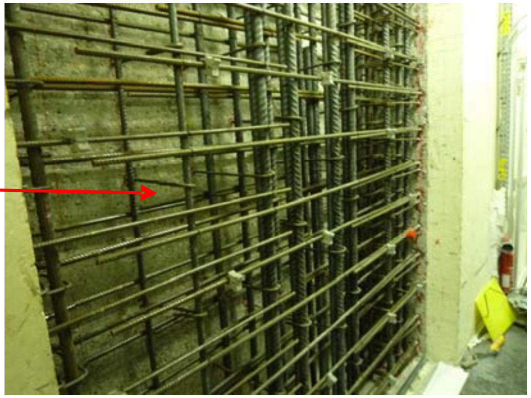
- TO IDENTIFY PECULIAR DESIGN FEATURES, DISCREPANCIES BETWEEN DESIGN AND EARTHQUAKE ENGINEERING PRINCIPLES,
- TO UNDERSTAND THE TRANSFER OF SEISMIC EFFORTS AND THE STRUCTURAL BEHAVIOR OF THE BUILDINGS
- IF NECESSARY, TO CARRY OUT CONTRADICTORY CALCULATIONS
- TO CHECK SEISMIC DESIGN IN REGARD WITH SAFETY REQUIREMENTS

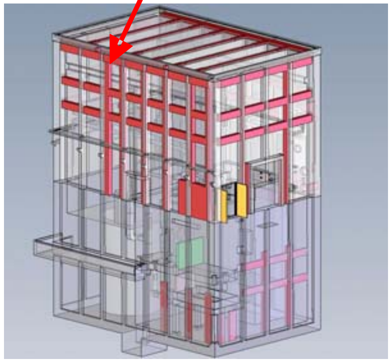
SEISMIC STRENGTHENING OF EXISTING NUCLEAR BUILDINGS **(RESEARCH REACTOR CABRI – Cadarache, France)**

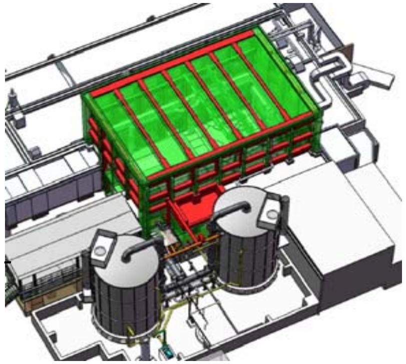


strengthening of the auxiliary buildings

Works
consist on strengthening walls, piles, beams and on girdling the superstructure of the reactor building with reinforced concrete tie-beams.







strengthening of the reactor building

Thank you for your attention

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