Drivers and approach for the design of the EPR™ reactor

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For new comers, selection process shall consider two main aspects:

- **Technology:**
  - based on proven design,
  - meeting highest international safety standards
  - already licensed

- **Project implementation and licensing support:**
  - Designer experience
  - Operator and Safety Authority assistance
EPR™ design objectives and principles
The EPR™ design was developed in accordance with the general safety objectives defined in:

- the Technical Guidelines issued by the French Safety Authority (ASN) highlighting the need for a significant improvement of the safety level of future plants at the design stage, compared to the safety level of existing plants
- the European Utility Requirements

which are both in line with IAEA Safety Standards

EPR™ design meets international high level safety requirements
EPR™ design philosophy is based on the following objectives related to the current generation of PWRs (Gen II):

- Improved redundancy and separation concept
- Reducing core damage frequency (CDF)
- Reducing large release frequency (LRF) (practically eliminated)
- Mitigation of severe accidents
- Protection of safety related systems from external events
- Fitting with an improved human-machine interface (HMI)
- Improving operation conditions and plant performances
  - Radiation protection
  - Waste management
  - Maintenance, availability and outage duration
  - Mitigation of human error risks (extending response time)
EPR™ - Built on large experience of the plants operated in France & Germany

- Developed with the support of French and German utilities
- Harmonized requirements of French Safety Authority and German experts, and from European Utilities (EUR)
- Evolutionary design based on experience from the most recent French and German PWRs
Gen III safety standards take into account the experience feedback of 3 major events

- **Three Miles Island (1979):** Core meltdown accident
  - Limit the risk of a Three Miles Island-type accident by decreasing the core damage frequency by a factor 10 compared to operating reactors (Gen II)

- **Chernobyl (1986):** Dispersal of radioactive material
  - Eliminate the risk of experiencing consequences on populations similar to the Chernobyl disaster (especially limiting long term consequences)

- **9/11 (2001):** Terrorist attack using a commercial aircraft
  - Ensure that a terrorist attack will not cause a severe accident in the context where more and more countries are considering accessing to the nuclear technology
3 main technical options chosen by AREVA to meet safety objectives

**Technical options for Gen II reactors**

- Reduce the probability of a severe accident with core meltdown
- Reduce the impact on the population in case of severe accident
- Reinforce the resistance to external attacks (e.g., commercial airplanes)

**AREVA technical options for EPR**

- Physical separation, Redundancy of critical components for maintenance and diversity
- Core catcher or equivalent
- APC\(^1\) resistant buildings and layout evolution

1. Airplane Crash Protection
The Design of the Safety Systems is based on Redundancy, Diversity and Complementarity

- **Diversity** (against Common Cause Failures)
- **Redundancy** (against single failure)
- **Complementarity** (between active and passive systems)

EPR is designed to resist to exceptional events and prevent damage to the surroundings
Protection against AirPlane Crash

Outer shell protection resistant to APC loads

Load cases
Military and commercial large airplane
Protection by geographical separation

EPR can resist to large commercial airplane crash
Severe accident mitigation

Short-term cooling

- The Core catcher protects the integrity of the containment basemat
  It is designed to passively stabilize molten core:
  - Passive valve opening
  - Gravity-driven overflow of water

Long-term cooling

- Long-term core cooling is provided by the containment spray

Complementarity of active and passive systems for severe accident management
Prevention of high energy events

Pressurizer safety valves

- The EPR design includes additional dedicated primary depressurization valves to prevent Core melting at high system pressure

H2 recombiners

- Minimize H2 concentration: Large reactor building with interlinked compartments
- Passive Autocatalytic recombiners to reduce Hydrogen quantity

No high pressure core melt – No hydrogen detonation
Evaluation of UK EPR design was conducted by IAEA using the Draft safety assessment requirements:


Based on this review, it is concluded that:

- EPR™ design conforms to the applicable IAEA fundamental safety principles
- the safety case presented in a level of detail which allowed assessing in most cases that the IAEA Requirements have been addressed

EPR design fulfills IAEA requirements
7 high level « new reactors safety objectives » published in 2010

- O1: Normal operation, abnormal events and prevention of accidents
- O2: Accidents without core melt
- O3: Accidents with core melt
- O4: Independence between all levels of defence-in-depth
- O5: Safety and security interfaces
- O6: Radiation protection and waste management
- O7: Leadership and management for safety

Some of these objectives (O2, O3, O4 and O5) were subsequently detailed through « position papers » discussed in 2011 – 2012 and compiled in a « booklet » issued on April 30, 2013

Consideration is made of the major lessons learned from the Fukushima Daichi accidents, especially concerning the design of new NPPs, and how they are covered by the new reactor safety objectives and related « positions »

These high level objectives are in line with IAEA Fundamental Safety Principles

The EPR reactor fully complies with WENRA objectives for New Power Reactors
Robustness of the EPR to a Fukushima like event

- The EPR resistance to a Fukushima situation was assessed in the frame of the Stress Tests requested by the Safety Authorities in Europe (France, Finland and UK).
- The Fukushima load cases have been taken as input in this assessment.
  - **Earthquake**: ~ 0.5 to 0.6 g peak ground acceleration at site
    - **Loss of Offsite Power (LOOP)**
      - Safety systems, including EDGs, would resist this earthquake
  - **Tsunami / flooding**: Flooding of the platform
    - **Loss of Ultimate Heat Sink (LUHS) + Loss of diesels and batteries**
      - Safety classified buildings remain water tight

EPR™ reactor would have withstood the Fukushima scenario (earthquake and subsequent tsunami)
Conclusion

- The EPR™ Reactor is an evolution of mature French and German reactors, incorporating proven technologies as well as innovations validated through R&D programs.

- The Safety features of the EPR™ Reactor integrate the lessons learned from the past. They have been deemed necessary and sufficient by the safety authorities of advanced nuclear countries as fulfilling the most stringent GEN III safety objectives, until March 2011.

- The robustness of the EPR™ reactor design against Fukushima event was analyzed and confirmed by the complementary safety evaluations (stress tests) performed by the European Regulators.

The strengthened design of EPR™ reactor offers improved protection against extreme situations.
Designer experience and support to embarking countries
AREVA experience designing and building PWRs

**Generation I**
- 1 PWR
  - 1 unit, France

**Generation II**
- 77 PWR (up-to 1400 MWe)
  - 54 units, France
  - 10 units, Germany
  - 15 units, export
- 7 PWR (1300 to 1500 MWe)
  - 4 units, France
  - 3 units, Germany

**Generation III**
- 4 PWR under construction (1600+ MWe)
  - 1 unit, Finland
  - 1 unit, France
  - 2 units, China

- 1950
- 1970
- 1988
- 2010

1 model
6 models
N4, KONVOI
EPR™ Reactor

102 NPP built, of which 87 PWRs feeding innovation and providing certainty
Main Steps of the EPR™ Development & Licensing

- 1989 Cooperation agreement between Framatome and Siemens
- 1991 EDF and German utilities decide to join their development work
- 1998 End of Basic Design
- 2000 Technical Guidelines for the next generation of PWRs are finalized by French and German TSOs (IRSN + GRS) and approved by the French “Groupe Permanent Réacteurs” (Standing advisory group to the French Regulatory Body)
- Until 2003 Continuation of Engineering work on specific scope of work
- 2005 Construction License for Olkiluoto 3, Finland
- 2007 Construction License for Flamanville 3, France; EPR design submitted to Generic Design Assessment in the UK
- 2008 US NRC accepts EPR design application for review
Main Steps of the EPR™ Development & Licensing

And more recently

► **2009** Construction license for Taishan 1 & 2, China

► **2012** in the UK

- Design Acceptance Confirmation (DAC) from the Office of Nuclear Regulation (ONR) and Statement of Design Acceptability (SoDA) from the Environment Agency awarded on December 13, 2012
- Nuclear Site License (NSL) has been granted on November 26, 2012 to NNB Generation Company to build a new nuclear power station at Hinkley Point in Somerset

► **2012** in the US

- Phase 2 (safety evaluation) and Phase 3 (review of the safety evaluation by the Advisory Committee on Reactor Safeguards) have been completed
- Phase 4 (final rulemaking for certification) planned for mid 2015
Key factors for the success of a project

- Licensing framework = basis for design acceptance
- Licensing process = basis for project time schedule
- Licensing stakeholders = basis for mutual understanding and dialogue
Licensing framework as the basis for design acceptance

- The design must comply with mandatory documents (Acts, Decrees):
  - Good knowledge of the regulatory framework is required: regulatory pyramid, mandatory laws and requirements, codes and standards, national norms identified in mandatory documents
  - To minimise risks, non-compliance with mandatory regulations and/or codes and standards should be identified as early as possible
  - A list of codes and standards should be developed

- A good understanding of the Regulator’s requirements is needed by the Owner and Supplier
  - Early dialogue with the Regulator will help to prevent any misunderstandings or misinterpretation of requirements
Licensing process as the basis for project time schedule

- The licensing process is sometimes complex and is likely to involve a certain number of procedures in parallel, e.g. the ‘Building Act’ and the ‘Atomic Act’

  It is therefore recommended to:
  - Ensure understanding (Owner and Supplier) of the process at bid stage
  - Define in the bid the approach of the Reference Plant with regard to licensing (guideline with regard to licensing criteria)
  - Work in partnership during project implementation for the management of the licensing and permitting process and associated documentation, e.g. establish shared roadmap for review and approval
Licensing stakeholders as the basis for mutual understanding and dialogue

- Early and regular contacts between Supplier, Owner and Regulator are required to ensure:
  - Safety criteria are clear and known, including identification of critical safety issues
  - Licensing / regulatory system and requirements are understood by Supplier and Owner
  - Regulatory approvals needed during the project (hold points) are known and understood by Supplier and Owner

- The Owner and Supplier are partners before the Regulator

- Several authorities may be involved in licensing and permitting process
The EPR is:

- Presently under construction in 3 countries
- The only reactor licensed (or under licensing process) by 5 independent regulators
AREVA is engaged in several Licensing processes based on the same original design.

The different Regulatory frameworks lead to differences between projects.

Key objective is to combine into a reference design a consistent and optimum set of technical features based on experience feedback from on-going EPR projects, bids, licensing or other initiatives, in order to:

- Improve quality by stabilized continuous industrial processes
- Facilitate Licensing
- Minimize risks for all parties during Project implementation
- More generally, take into account the Lessons Learnt from the experience
- Facilitate EPR Projects engineering activities through:
  - Replication of a sound and optimized design to the maximum extent possible
  - Focus on project-specific adaptation studies
- Introduce scale effects which should be favorable on the quality (equipment manufacturing)
The AREVA NP Lessons Learned Process

General Objectives of Lessons Learned

- Share **common practices** across the business (standard EPR, project management…) in order to reach **excellence in project execution** (in terms of time and cost).
- Leverage the significant variations happening today to **benefit future projects**.

Key points of the lessons learned process

- **To capture issues** that we encounter at the time of the realization of our activities
- **To understand the causal factors** that have led to the difficulties
- **To give a clear description** and identify a **point of contact** for future investigations
- **To propose action plans** to solve these difficulties and to avoid that the situation represents itself
- **To capitalize these new knowledge in a worldwide database** (all 3 regions of plants sector) at disposal of the other BU and the future projects
- **Make available** for future users
The usual practice is to adapt the reference model to the project characteristics following this rule:

- No modification should impact Safety Levels

The typical required adaptations are the following ones:

- Specific country regulation (nuclear or non nuclear)
- Site characteristics (soil and site general arrangement, heat sink capabilities, grid code -including frequency-, …)
- Operator choices
- Compliance with an adequate waste strategy (country dependant)

Lessons learned from previous projects are implemented in new projects
Sharing information and experience on design reviews and construction oversight in order to

- leverage the technical evaluations completed by each of the participating regulators
- leverage the resources and knowledge of the national regulatory authorities
- develop consistency between regulators and/or to understand differences
- develop joint assessment on specific subjects

• Make safety assessments more robust and increase the safety level of EPR™

Members of EPR WG are regulators from:

• Canada,
• China,
• Finland (chair),
• France (co-chair),
• United Kingdom,
• United States
• Sweden
MDEP EPR Working Group - Activities

- General meetings on the status of each EPR project
  - discussions on the status of design review, construction
  - goal to identify new items for in depth discussions in the group

- Specific subgroups for
  - instrumentation and control
  - probabilistic risk assessment
  - accidents and transients
  - severe accidents

- Observed and Joint inspection efforts
  - Main coolant lines manufacturing, I&C design processes

- Issue specific ad hoc meetings, teleconferences
  - Internal hazards, radiation protection, human factors, grouted tendons, technical specifications, spent fuel cask loading device
The value of French experience: A strong and historical partnership

Since the early 70’s, EDF and AREVA have joined their force to design and built the 58 reactors of the French fleet (Construction Program)

A successful team worldwide: South Africa, China (Daya Bay, Ling Ao, Taishan) backed by a common engineering structure (Sofinél)

Strong cooperation on existing EPR projects and offers

- Cooperation on EPR Design, since the beginning of the project
- Diverse R&D programs
- Optimization of experience feedback and continuous improvement processes (FA3/Taishan)
- AREVA participation on Hinkley Point Project (forging & pre-studies contracts...)

Safety culture and safety management are key in the process (along with quality management and project management)

Preparation for the next projects => EPR optimization

This model can be applied with other countries in the frame of the new nuclear construction programs
We are here to help and support you!

Thank you for your attention