Adapting NPP design to External Hazards

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ATMEA1 Project Manager

European Nuclear Young Generation Forum 2015
Adapting NPP design to external hazards

Outline

- ATMEA Company and ATMEA1 main features
- External Hazards
- ATMEA resistance to External Hazards
- Mitigation of Severe Accidents
- Conclusion
ATMEA Company and ATMEA1 main features

External Hazards

ATMEA resistance to External Hazards

Mitigation of Severe Accidents

Conclusion
Company name: ATMEA S.A.S.
Office Location: Paris La Defense
President & CEO: Andreas Goebel
Deputy CEO: Satoshi Utsumi
Establishment: November 2007
Capital: 126 Million Euros

Scope of activities:
Development, Marketing & Sales, Construction & Commissioning of 1100 MWe class Generation III+ ATMEA1 Nuclear Island

ATMEA Company

ATME1

A JOINT VENTURE
BETWEEN 2 WORLD
NUCLEAR LEADERS

50%

MITSUBISHI

50%

AREVA

forward-looking energy

1 NUCLEAR ISLAND DESIGNED

NYGF2015 in Paris
June 22nd to 26th of June, 2015
Achievements and Projects

Technical Dev.

Conceptual Design
- Definition of main features
- Project engineering manual
- Conceptual safety features

Basic Design
- Functional requirements
- Safety requirements
- General arrangement
- Core, System & Component design
- Standard Preliminary Safety Analysis Report

Generic Detail Design
- Defining the details of the plant and complete some of the confirmatory analysis
- Construction schedule development
- Civil design development

Licensing

ASN* Review
IAEA Review
CNSC* Review

Project initiation

Business (excerpt)


Conceptual / Basic Design
Generic Detail-Design
Project Preparation

Technology selection

Integrated-design based on proven technology
ATMEA 1 - Main Features

Reactor Type
- 3-Loop PWR

Electrical Output
- 1100 MWe class

Core
- 157 Fuel Assemblies

Steam Pressure
- More than 7 MPa

Safety Systems
- 3-Train reliable active system with passive features

Built-in Diversity
- Shutdown / cooling / I&C / power source for extreme conditions

Severe Accident Management
- Core catcher / Hydrogen re-combiners

Airplane Crash Protection
- Pre-stressed Concrete Containment Vessel with a liner

I&C
- Fully Digital

Reactor Building
1
Fuel Building
2
Safeguard Building
3
Emergency Power Source Building
4
Nuclear Auxiliary Building
5
Turbine Building
6
100% x 3-train reliable active safety systems combining passive safety features
Safety Design based on existing and proven technologies with increased redundancy and diversity

Front System (SIS, CSS)

Cooling Chain (CCWS, ESWS)

Power Supply (EPS, AAC)

SIS: Safety Injection System
CSS: Containment Spray System
IRWSP: In-containment Refueling Water Storage Pit

CCWS: Component Cooling Water System
ESWS: Essential Service Water System
UHS: Ultimate Heat Sink

EPS: Emergency Power Source
AAC: Alternative AC power source
2 diverse Heat Sinks

- Designed for an autonomy of 30 days
- Diverse 2nd Heat Sink to cope with loss of main Heat Sink

In very unlikely case of total loss of Heat Sinks.....

- Diverse access to water sources available on site
  - EFWS, IRWSP in Nuclear Island (NI)
  - Fire Fighting Tank outside NI

- 100% emergency feedwater system EFWS (in safeguard building)

- Diverse access to water sources available on site

- EFWS, IRWSP in Nuclear Island (NI)
- Fire Fighting Tank outside NI

- Main Heat Sink
- Diverse Heat Sink (Division X)

- 100% emergency feedwater system EFWS (in safeguard building)
- Fire Fighting Tank outside NI

- IRWSP : In-containment Refueling Water Storage Pit

够时间部署现场外的应急措施，即使在极不可能的全部热源丢失情况下。

Ex. Fire trucks

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Designed to resist to exceptional events and prevent damage to the environment

A. Reduce the probability of a severe accident with core meltdown
   - Physical separation, diversity, and redundancy of critical components

B. Protect population and environment in case of severe accident
   - Confined corium and radioactive products in the reactor (“core catcher”)

C. Protect against external hazards (e.g. airplane crash, flooding)
   - High structural resistance
External Hazards

- Earthquake
- (External) explosions wave
- Extreme meteorological conditions ((temperature, snow, rain, etc.))
- External flooding
- Air plane crashes (APC)
- Wind (hurricane) and tornado including missile
- Lightning and other extreme conditions
Earthquake considered in the design

- Ground Motion Response Spectra (GMRS) for safe shutdown earthquake (SSE) is based on RG 1.60 spectra with enhancement in higher frequency.

- The peak ground acceleration (PGA) of GMRS is 0.3 g.

Horizontal Direction

Vertical Direction

Note: spectra for damping 0.5, 2, 5, 7, 10% from top to bottom.
Low risk site (probability is less than $10^{-7}$) for gas cloud explosion should be selected in principle.

The impact of gas cloud explosion load is applied on the air intake/exhaust structures of:

- Safety-related diesel generators,
- Gas turbine generators,
- HVACs.
Standard extreme meteorological conditions (temperature, snow, rain, etc.) are based on EPRI Utility Requirement Document.

These values will be confirmed or re-assessed once a site is chosen.

<table>
<thead>
<tr>
<th>Ambient Design Temperatures</th>
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</thead>
<tbody>
<tr>
<td>5% Exceedance Values</td>
</tr>
<tr>
<td>Maximum</td>
</tr>
<tr>
<td>Minimum</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>1% Exceedance Values for Building and HVAC Design</th>
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<tbody>
<tr>
<td>Maximum</td>
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<tr>
<td>Minimum</td>
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</table>

<table>
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<tr>
<th>0% Exceedance Values for capability check of HVAC</th>
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<tbody>
<tr>
<td>Maximum</td>
</tr>
<tr>
<td>Minimum</td>
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<table>
<thead>
<tr>
<th>Heat sink temperature</th>
</tr>
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<tbody>
<tr>
<td>Maximum</td>
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<table>
<thead>
<tr>
<th>Rain and snow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum precipitation height</td>
</tr>
<tr>
<td>Maximum snow load</td>
</tr>
</tbody>
</table>
Time history of airplane crash load is based on defined crash conditions associated with specific commercial/military airplanes.

The time history is based on consensus among selected members consist of ATMEA, AREVA and MHI.

The loads will adapted based on the applicable regulation in the selected country.
Extreme Wind and Tornado

Wind (hurricane) and tornado (including missile) parameters are based on ASCE/SEI 7-05 and RG 1.76 rev.1.

<table>
<thead>
<tr>
<th>Wind</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum speed (design figure)</td>
<td>249 km/h</td>
</tr>
<tr>
<td>Extreme wind speed (tornado)</td>
<td>103 m/s</td>
</tr>
<tr>
<td>Atmospheric pressure drop (tornado)</td>
<td>83 mb</td>
</tr>
<tr>
<td>Rate of pressure change (tornado)</td>
<td>37 mb/s</td>
</tr>
</tbody>
</table>

Missiles generated by extreme wind (tornado) are based on RG 1.76 rev.1.

<table>
<thead>
<tr>
<th>Projectile</th>
<th>Dimensions (m)</th>
<th>Weight (kg)</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>5 x 2 x 1.30</td>
<td>1,800</td>
<td>Horizontal: 41</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Or vertical: 28</td>
</tr>
<tr>
<td>Pipe</td>
<td>Diameter: 0.17</td>
<td>130</td>
<td>Horizontal: 41</td>
</tr>
<tr>
<td></td>
<td>Length: 4.6</td>
<td></td>
<td>Or vertical: 28</td>
</tr>
<tr>
<td>Sphere</td>
<td>Diameter: 0.25</td>
<td>0.0669</td>
<td>7.9</td>
</tr>
</tbody>
</table>
Outline

- ATMEA Company and ATMEA1 main features
- External Hazards
- ATMEA resistance to External Hazards
- Mitigation of Severe Accidents
- Conclusion
Design to withstand External Hazards

- Earthquake
- Wind (hurricane) and tornado including missile
- Extreme meteorological conditions (temperature, snow, rain, and so on)
- Extreme flooding
- Airplane crash
- (External) explosion wave
- Lightning
- Other extreme conditions (including fire)

Building structural integrity
System (including component and piping) structural integrity
HVAC (inlet and outlet) structural integrity
HVAC performance
Specific adaptations depending on the site conditions
Seismic Design

- Symmetric layout of safety related buildings to avoid twist deformation of buildings under earthquake loadings

- Large rectangular basemat (Fuel Building, Reactor building, Safeguard building) to improve seismic stability

- Thickened outer walls against seismic shear force

- Japanese design and construction experiences against earthquake were fully implemented in ATMEA1 design
**Baseline**

- Ground level is set as high enough to avoid consequences from a Tsunami

**Additionally:**

- Electrical equipment and I&C equipment are located in upper floors
- All safety related buildings including Essential Service Water Building are protected with water-tight walls and doors
ATME A1 buildings are protected:

- By shielding (APC wall): Reactor, Fuel and Safeguard buildings
- By physical separation: Essential Pumping Station buildings

Ensures that:

- The reactor core remains cooled, the containment remains intact
- Spent fuel cooling and spent fuel pool integrity are maintained
- No-offsite countermeasures necessary
For external explosions wave, tornado and extreme meteorological conditions (snow, rain), air intake and outlet parts have the following structure.

Minimal level of protection:
- Measures for protection against weather conditions (snow, rain, wind).
- Explosion wave protection damper (EPW).
- Isolation damper for general isolation of HVAC.
Requirements for extreme external hazard conditions:

- Bring and maintain Reactor in **safe shutdown condition**
- **Prevent** core melt in reactor vessel
- **Limit** radiological consequences should a core melt occur in reactor vessel (defense-in-depth approach)
- **Prevent** spent fuel uncovering and criticality in spent fuel pool

European/French requirements

- **Prevent** fuel melt in both the SFP and the reactor
- Address RCS closed states (Power states and Shutdown states)
- Address RCS opened states (Shutdown states)
The consequences of postulated beyond-design-basis external events that are most impactful to reactor safety are:

- loss of power (LOOP + all EDGs lost) and
- loss of the main access to the ultimate heat sink

**PROTECTION against Extreme external hazards**

With 7 days* autonomy of:

- Permanently-installed:
  - Diverse UHS2 for Division X cooling chain
  - Diverse AAC to supply power to Division X and one safety division

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* 7 days assumption is to be assessed with site-specificities
Review of regulatory statements

ATMEA1 response to extreme external hazards follows latest international regulatory consensus

- ASN* (France): review of ATMEA1 safety options
  - Safety options of ATMEA1 demonstrate its robustness to extreme events
- CNSC* (Canada)
  - “For a new NPP design, as a countermeasure against such extreme events, it is expected that the use of installed equipment and resources or passive design features to maintain or restore core cooling, containment cooling, and spent fuel cooling for a prolonged period of time (e.g. 72 hours)”
- MDEP* Common position paper (Jan 2013)
  - Most safety functions of NPPs depend on alternating current (AC) power, hence high reliability of AC power supply is essential. This high reliability is expected to be achieved through an adequate combination of redundancy and diversity. Ensuring adequate protection of the AC power supply against rare and severe external hazards is a lesson from the Fukushima Dai-ichi accident. Regarding emergency power supply, diverse, electrically adequately isolated AC power sources needs to be required as a part of Defence-in-Depth concept of the plant.
  - The Defence-in-Depth approach needs to be applied also to the ultimate heat sink. The design of new nuclear power plants needs to provide diverse means to provide reactor and spent fuel cooling. The use of a secondary ultimate cooling water system is an example of diverse means to provide reactor and spent fuel cooling for decay heat removal in case of unavailability of the primary ultimate heat sink.

<table>
<thead>
<tr>
<th>Mitigation of Radiological Consequences of Significant Releases</th>
<th>Off-site emergency response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mitigation of Fuel Melt Consequences</strong></td>
<td>Severe Accident features to either practically eliminate or prevent and mitigate accident scenario</td>
</tr>
<tr>
<td>Design Extension Condition (DEC) B</td>
<td></td>
</tr>
<tr>
<td><strong>Prevention of Fuel Melt</strong></td>
<td>Onsite means to address specific regulatory and site-specific requirements</td>
</tr>
<tr>
<td>Extreme External Hazards</td>
<td>Extended protection of installed equipment against extreme external hazards</td>
</tr>
<tr>
<td><strong>External Threats (APC…)</strong></td>
<td>Protection by shielding and segregation</td>
</tr>
<tr>
<td>DEC A</td>
<td></td>
</tr>
<tr>
<td><strong>Control of Incidents /Accidents</strong></td>
<td>Design features:</td>
</tr>
<tr>
<td>Design basis accident Anticipated operational Occurrence</td>
<td>- Diversified AAC</td>
</tr>
<tr>
<td></td>
<td>- Diversified UHS2</td>
</tr>
<tr>
<td><strong>Normal Operation</strong></td>
<td>Design features:</td>
</tr>
<tr>
<td></td>
<td>Reactor protection system,</td>
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<td></td>
<td>Safety systems,</td>
</tr>
<tr>
<td></td>
<td>Accident procedures,</td>
</tr>
<tr>
<td></td>
<td>Conservative design and high quality of construction</td>
</tr>
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Severe Accident Design Targets

ATMEA

- uses improved safety features to (further) decrease the probability of entering into severe accident conditions (lower CDF/CMF)

- takes additional measures at the design stage to decrease the consequences of a severe accident, independent of the achieved extremely low probability,

- The target of the SA measures is to preserve the integrity of the containment as an ultimate fission product barrier

- The radiological consequences of a SA shall remain limited to the immediate vicinity of the plant (no evacuation, no long-term restrictions on food consumption)
Severe Accident

- SA occurs as a result of a sustained loss of adequate core cooling, due to multiple failures of the plant safety-grade emergency cooling systems.

- Initial phase:
  - Oxidation of fuel cladding
  - Release of radioactive fission products into the containment,
  - Melting of core components due to progressive core uncovery
  - Loss of the 1st and 2nd safety barriers: Fuel Cladding and Reactor Coolant System

- Detection:
  - Core outlet temperature: >650°C
  - or, if not available: radiation rate
Severe Accident Chronology

- Core uncover, release of volatile and medium volatile fission products
- Zr oxidation (exothermal): Generation of hydrogen
- Dissolution of fuel 1800°C/2600°C. Formation of temporary molten pools, $\text{UO}_2$ melting starts at 2600°C/2800°C:
- Relocation of molten corium and debris into water filled lower head, dry out
- Heating of the vessel, failure by thermal ablation or creep. Release of corium into the reactor pit

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Severe Accident Mitigation

In SA, Containment integrity is kept in the long term ➔ No significant release to the atmosphere

<table>
<thead>
<tr>
<th>Entry in severe accident conditions</th>
<th>Primary side heat-up</th>
<th>RPV failure at low pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dedicated SA batteries</strong></td>
<td><strong>Dedicated depressurization system</strong></td>
<td><strong>Core catcher</strong></td>
</tr>
<tr>
<td>Feed necessary monitoring systems and key valves, ensures MCR habitability</td>
<td>Prevent high pressure core melt</td>
<td>Spread corium and prevent basemat degradation</td>
</tr>
</tbody>
</table>

Release of hydrogen, pressure increase in containment

<table>
<thead>
<tr>
<th>Hydrogen recombiners</th>
<th>Pressure resistant containment And annulus for confinement</th>
<th>Severe accident heat removal system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevent hydrogen explosions passively (Auto catalytic recombiners)</td>
<td>Prevent radiological releases</td>
<td>Cool the corium on the long-term</td>
</tr>
</tbody>
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ATMEA 1: Designed to cope with Extreme External Hazards

ATMEA Design: Strong Defense in depth Approach
- Separation of defense lines
- Redundancy of the safety systems
- Diversity (4th train is diversified, including its heat sink (UHS2))

ATMEA Design is adapted to cope with Stringent External Hazards
- Civil structure
- System design
- Physical separation

Margin to cope with beyond design conditions
- Consider multiple failure sequences from the design phase
- Core Damage Frequency $2;3^{\text{E}}-7$ and LRF $9,9^{\text{E}}-9$

Severe accidents with core melt are considered in the design
- Countermeasures outside the site, limited in space and time
- No permanent re-housing
- No long term restriction for the consumption of food
Thank you for your kind attention

Please visit us at http://www.atmea-sas.com/

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