RESPONSE TO THE FUKUSHIMA EVENT: STATUS AND INSIGTHS

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Round Table – Severe Accidents

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  - Plant protection concept
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- ELETRONUCLEAR (ETN) Fukushima Response Plan
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    - Hazard Protection
    - Core and Spent Fuel Pool Cooling Capacity
    - Severe Accident Mitigation
- Final Remarks

Fukushima Accident short descrition

- On 11 March 2011, a severe 9.0 magnitude earthquake struck Japan off the coast of Fukushima
  - significant damage to infrastruture of the region (roads, power lines, civil structures) ;
  - The NPPs at the Fukushima Daiichi site shut down as designed. The plants emergency Diesels supplied the power for safe shutdown.
- About 50 minutes later a huge tsunami with sea water level up to 14 m struck the coast of the same region
  - Widespread destruction of household, industry, roads, airport, harbor);
  - about 20.000 fatalities
  - At the Fukushima Daiichi nuclear plants site→tsunami sea water level far above the tsunami protection barrier leading to
    - flooding and heavy damage to the site,
    - flooding and loss of the Emergency Diesels resulting in total loss of AC power
    - damage and loss of function of the cooling water intake (loss main heat sink)

    resulting in core melt in 3 of the 6 Fukushima site reactors in the following hours /days and loss of the respective containments integrity due to H2 explosion.

Plant protection concept

- Nuclear power plants are designed to withstand internal and external events, (Design Basis Accidents), in accordance to national and/or international rules and standards;
  - The standards for protection against tsunami in Japan did not predict the possibility of a tsunami of that magnitude for the Fukushima site;
- Protection against very rare events, Beyond the Design Bases, is established in beyond design countermeasures
  - Set of procedures and equipment made available to attempt to avoid core melt in case of loss of the dedicated safety systems and if not possible to mitigate de consequences (protection of containment integrity).
- These countermeasures did not work for Fukushima because the Station was not prepared for an accident of that magnitude and severity
  - Long term total loss of AC power→plants in the dark, no instrument indications
  - Massive damage to the site and surroundings →problem to receive external support on time

International response to the accident

- Approach developed in Europe by the WENRA (Western Nuclear Regulators Association) .

  For Beyond Design events (very low probability) but high consequences

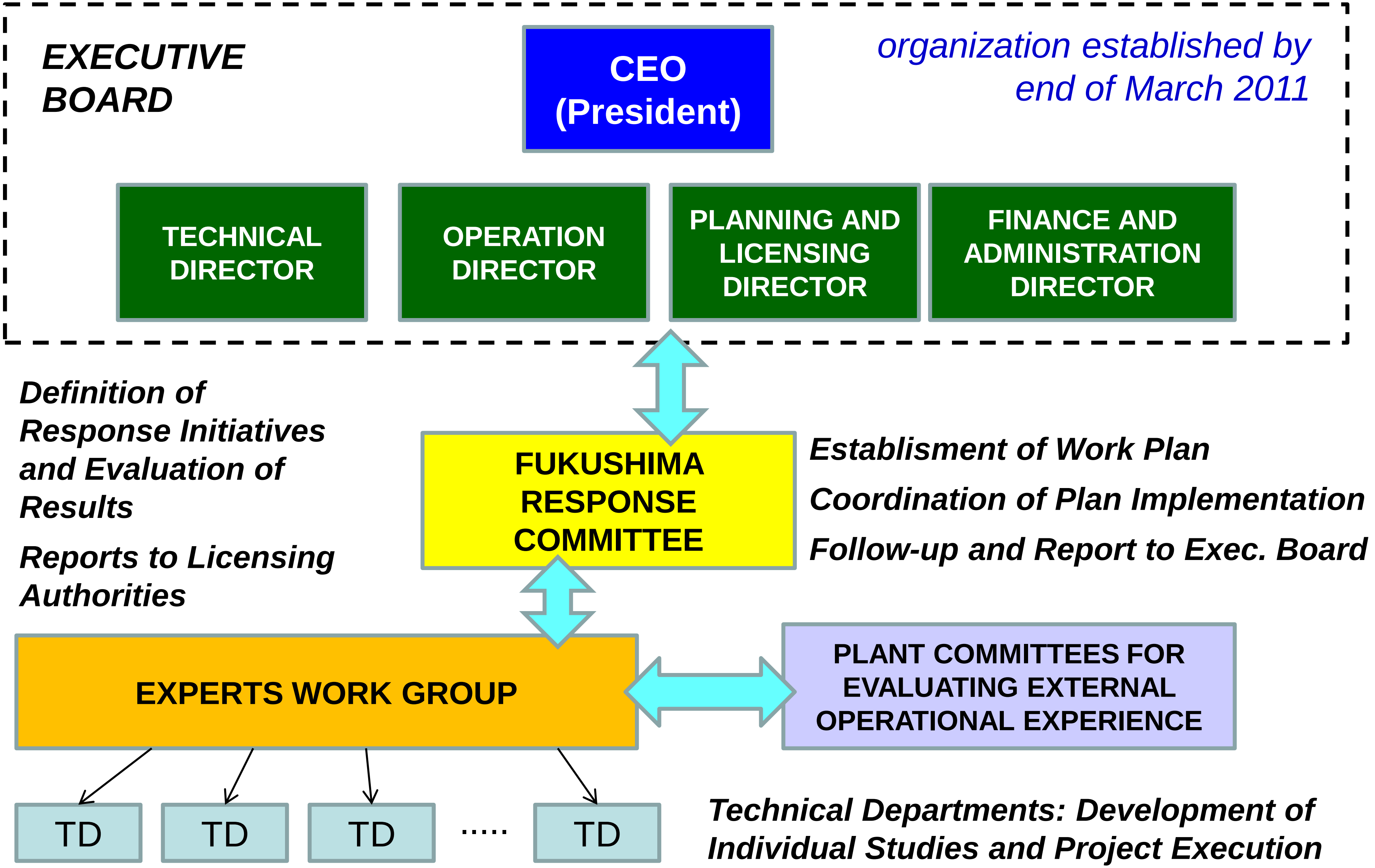
  - Deterministic approach→independent of the probability of occurance the response of a plant to conditions similar to the ones of the Fukushima accident
    - extended loss of all AC power
    - Loss of main heat sink
    - Deteriorated site infrastructure

    is to be verified;
  - Means are to be provided to allow the plant to survive to these conditions.
- This approach called “Stress Test” was adopted, with few modifications, internationally;

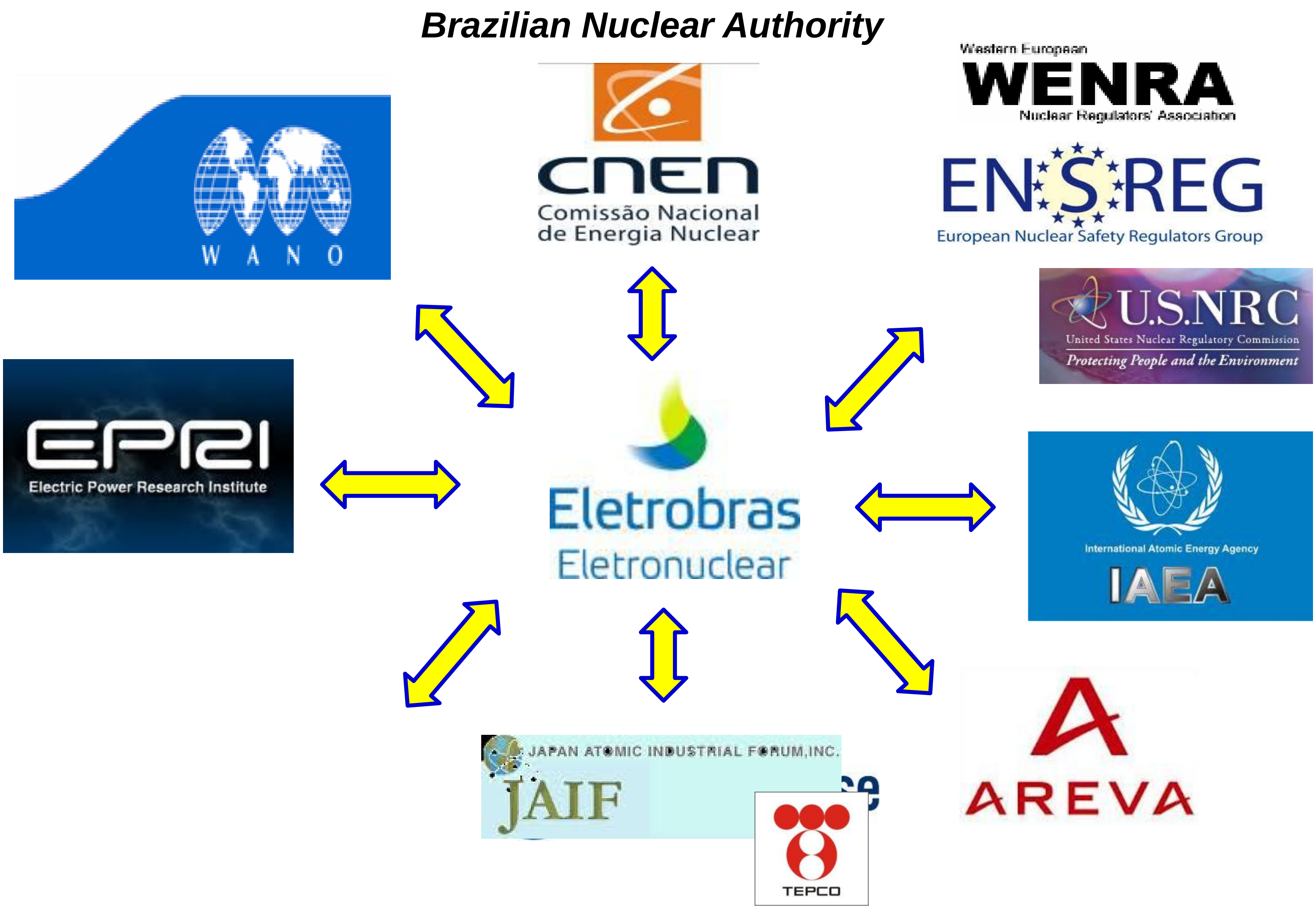
FUKUSHIMA EVENT: MAIN ETN ACTIONS AND SCHEDULE

MAIN ACTIONS	SCHEDULE
FOLLOW UP OF INTERNATIONAL RELATED DEVELOPMENTS	From Fukushima event onwards
ESTABLISMENT OF A COORDINATING COMMITTEE FOR ALL FUKUSHIMA RELATED ACTIVITIES;	End of March 2011
RESPONSE TO BRAZILIAN REGULATOR REQUESTS;	From June 2011 onwards
DEVELOPMENT OF A FUKUSHIMA RESPONSE PLAN;	June to November of 2011(rev. 0)
RESPONSE TO WANO SOERS;	From April 2011onwards
PERFORMANCE OF STRESS TEST EVALUATION FOR ANGRA 1 AND 2	From June 2011 to March 2012
DEVELOPMENT OF FUKUSHIMA PLAN SHORT TERM MEDIUM TERM LONG TERM	 2011 – 2012 2012 – 2014 2014 – 2016

COMPANY ORGANIZATION TO RESPOND TO FUKUSHIMA



Full Integration with Nuclear Industry Initiatives



FUKUSHIMA RESPONSE PLAN: BACKGROUND AND BASES

BASES

The **ETN FUKUSHIMA Response Plan** followed basically the WENRA approach, which consisted of studies and projects covering,

- Evaluation of the completeness and adequacy of the Design Bases for protection against internal and external hazards(scope, design criteria and design implementation)
- Evaluation of the available **safety margins** in the design for coping with occurance of these events with magnitudes exceeding the Design Bases
- Identification and implementation of additional resources to allow core and spent fuel pool cooling in case of **failure of all the plant safety systems,** in particular for the case of extended loss of all AC power and loss of the ultimate heat sink
- Identification and implementation of resources and infrastructure for **mitigating the consequences of a severe accident**

ETN FUKUSHIMA RESPONSE PLAN: MAIN SAFETY GOALS

PE — PROTECTION FROM RISK EVENTS

15 initiatives

Focus:
Protection from events with the potential to induce multiple failures in safety systems

Objective:
Ensure that safety systems are preserved in case of extreme conditions associated with external or internal events, beyond the design basis.

RF — PROVISION OF COOLING CAPACITY

32 initiatives

Focus:
Reactor and Spent Fuel Pool cooling capacity in case of beyond design basis accidents

Objective:
Provide alternative possibilities for reactor and fuel pool cooling, for conditions beyond design basis

CR — MITIGATION OF RADIOLOGICAL CONSEQUENCES

9 initiatives

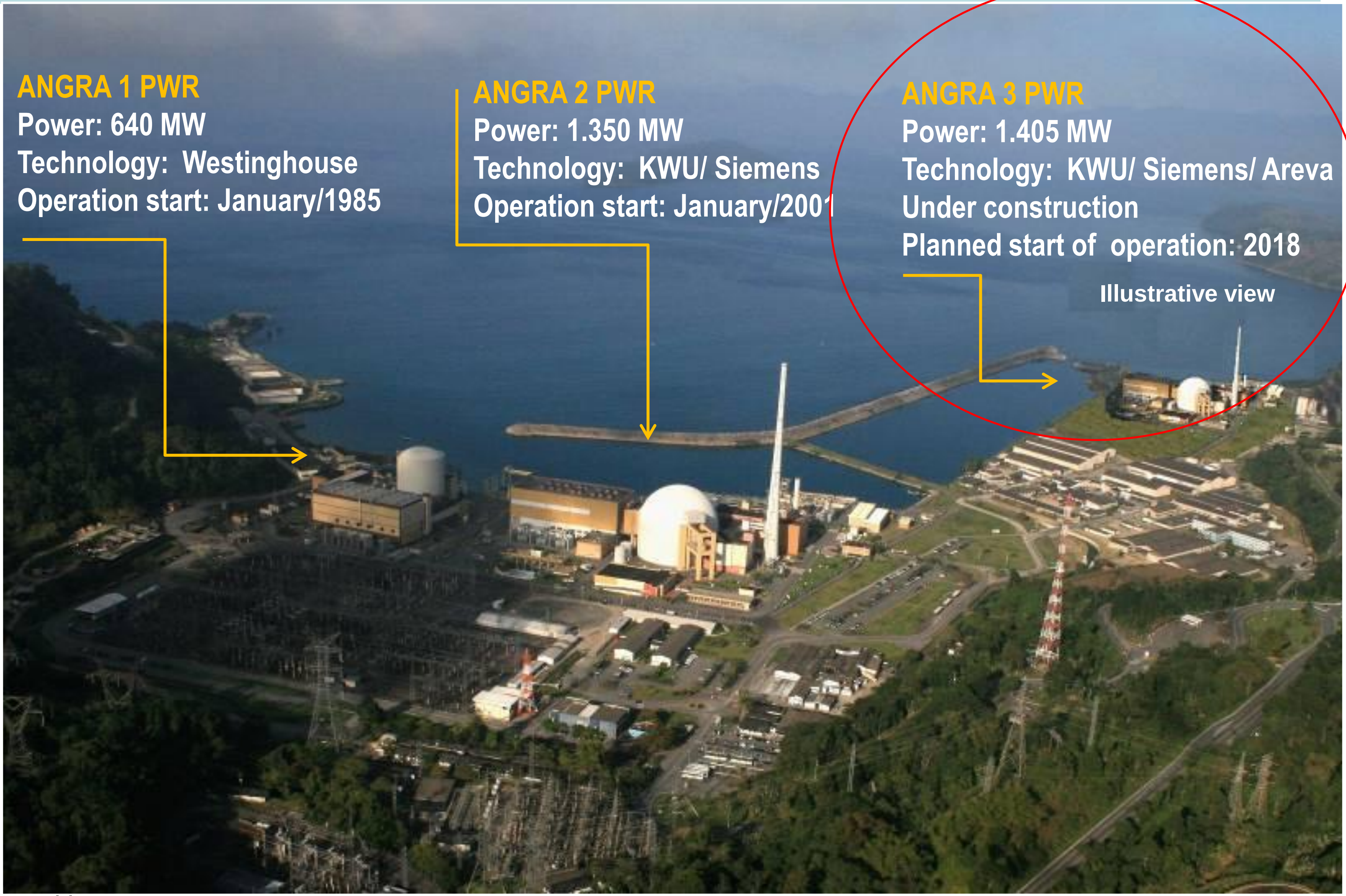
Focus:
Mitigation of radiological consequences in case of severe accidents

Objctive:
Provide means to minimize the risk of losing containment integrity and releases of radioactivity materials to the environment. Improvements on Emergency Planning

Time evolution of accidents – Defense in Depth

(in line with Stress Test approach)

ANGRA NUCLEAR POWER STATION SITE OVERVIEW



RESULTS OF THE EVALUATION OF RISK EVENTS

BASES

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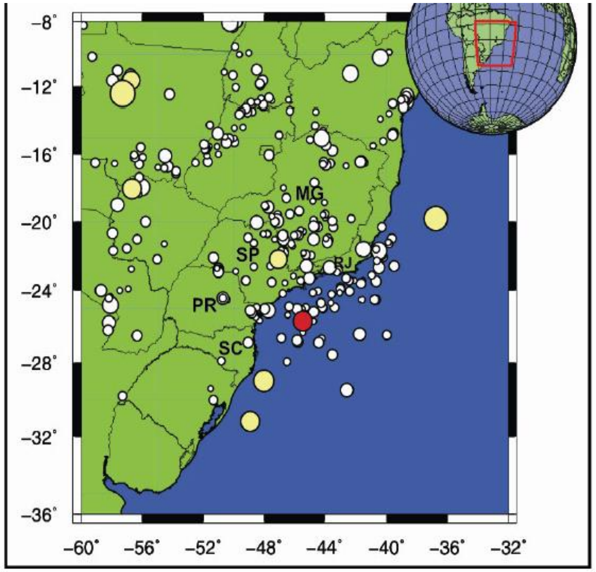
3. Reevaluation of Hazards

PE

Earthquakes



Mapa de sismicidade (círculos) com a localização do epicentro do tremor de terra (circulo vermelho). Os círculos amarelos representam sismos com magnitudes maiores ou iguais a 5,0 m_b. Os círculos são proporcionais a magnitude.

Low seismicity site

Largest earthquake 5.2 m_b at 250 km (PGA 0.002g at site)

Design PGA 0.10g ($p< 10^{-4}$/yr)

Heavy Rains and Landslides

Slopes very steep around the site

Residual and colluvial soils

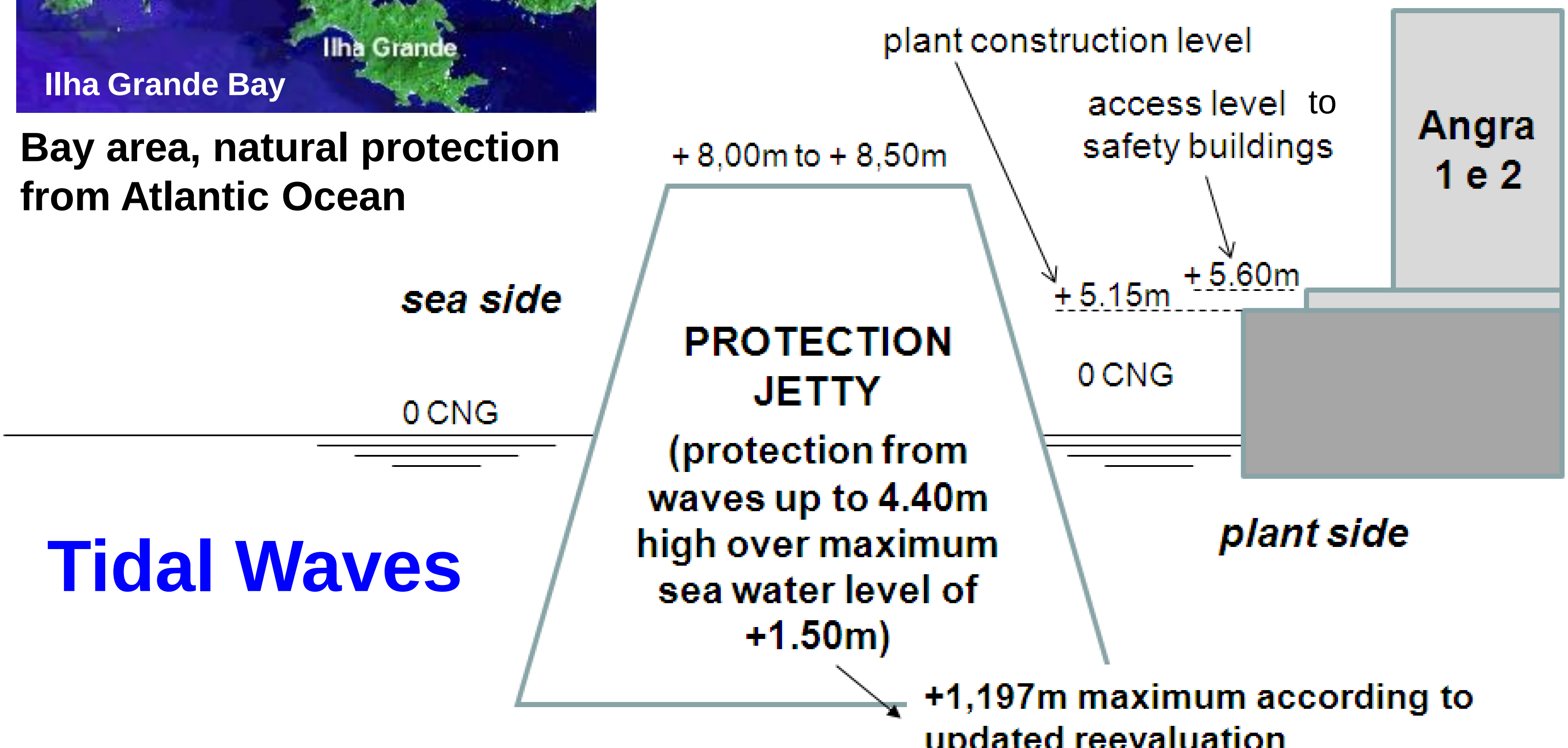
High rainfall rates

Station protected by slope stabilization works and slope monitoring system

3. Reevaluation of Hazards PE

Bay area, natural protection from Atlantic Ocean

Favorable geological characteristics of the South Atlantic coast. No record of tsunamis.

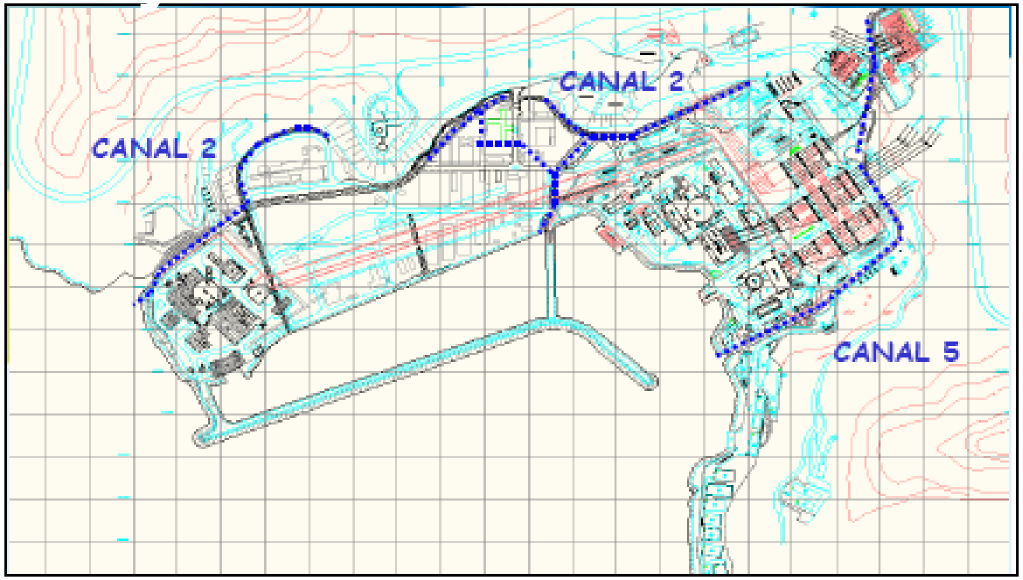


Tidal Waves

3. Reevaluation of Hazards

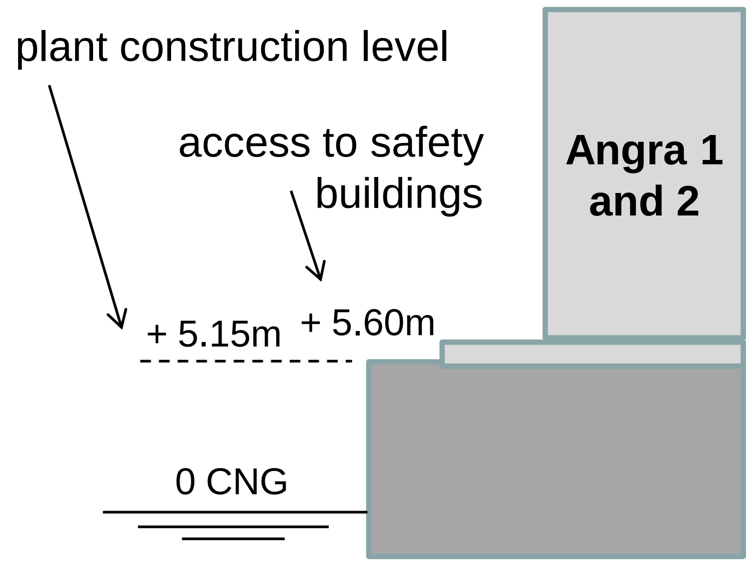
PE

Flooding



Design Flooding level calculated considering rainfall of 10,000 years recurrence time (311 mm/hr)

Reevaluation considering obstruction of circulating water discharge and drainage channels by lanslides;



Results of the evaluation of the safety margins

BASES

The ETN FUKUSHIMA Response Plan followed basically the WENRA approach, which consisted of studies and projects covering,

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- **Evaluation of the available safety margins in the design for coping with occurance of these events with magnitudes exceeding the Design Bases** PE
- Identification and implementation of additional resources to allow core and spent fuel pool cooling in case of failure of all the plant safety systems, in particular for the case of extended loss of all AC power and loss of the ultimate heat sink
- Identification and implementation of resources and infrastructure for mitigating the consequences of a severe accident

3. Reevaluation of Hazards PE

- **Verification and enlargement of safety margins**
- **Earthquake**
  - From walkdowns performed (AREVA, Consultant): after some fixes, an estimation of the margins indicates that plants can withstand PGAs of the order of 0.25 g for Angra 1 and 0.35 g for Angra 2 (uncertainty of ~0.05g);
  - Values to be confirmed from full scope Seismic Margin Evaluation; definition of methodology and start evaluation in second semester of 2013
- **Landslides**
  - Studies considering heavy rains and seismic induced landslides concluded; extreme case of full rupture of slope covering material evaluated.
  - Switchyard and discharge channels may be affected however no impact on Plants buildings;
  - **Recommendation for enlargement of slope drainage system and reinforcement of same barriers.**

3. Reevaluation of Hazards PE

Verification and enlargement of safety margins

- **Tidal waves**
  - Reevaluation of jetty stability, considering extreme meteorological conditions, to be concluded until end of 2013;
  - Expected indication of reinforcement measures; implementation until 2016;
- **Site flooding**
  - Reevaluation of flooding level under more severe conditions concluded (rainfall rate higher than 10,000 years rainfall, blockage of site drainage channels and circulating water discharge tunnel due to landslides and continued operation of circulating pumps);
  - **Current design flooding level includes sufficient safety margin; no plant changes necessary**.

3. Reevaluation of Hazards PE

Verification and enlargement of safety margins

- **Tornadoes**
  - Tornadoes were not originally considered for Angra 1 and 2 due to low probability (~10-7/y);
  - Tornado hazard study developed for Angra 3;
  - Impact on Angra 1 and 2 under evaluation; affected components and recommended protective measures until the end of 2013; implementation until 2016;

Conclusions for PE :

- ○ Design basis for external hazards confirmed;
- ○ Opportunity for enlarging safety margins;
- ○ Additional protective measures under definition for implementation in 2 to 3 years.

ACTIONS FOR ENHANCEMENT OF THE COOLING CAPACITY FOR BDBA

The ETN FUKUSHIMA Response Plan followed basically the WENRA approach, which consisted of studies and projects covering,

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- **Identification and implementation of additional resources to allow core and spent fuel pool cooling in case of failure of all the plant safety systems, in particular for the case of extended loss of all AC power and loss of the ultimate heat sink** RF
- Identification and implementation of resources and infrastructure for mitigating the consequences of a severe accident

Assumptions for Safety Evaluation

Event Initial Conditions (from Fukushima event)

- Loss of Offsite and Onsite Power and Loss of Ultimate Heat Sink
- no possibility of external support within 72h after the accident onset;

Plant in Power Operation

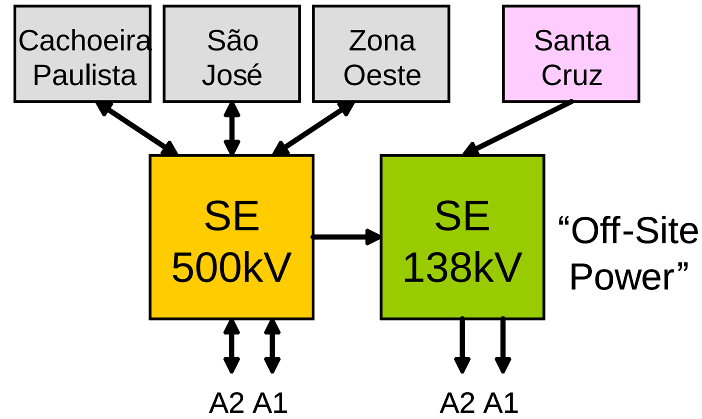
- 100% reactor power;

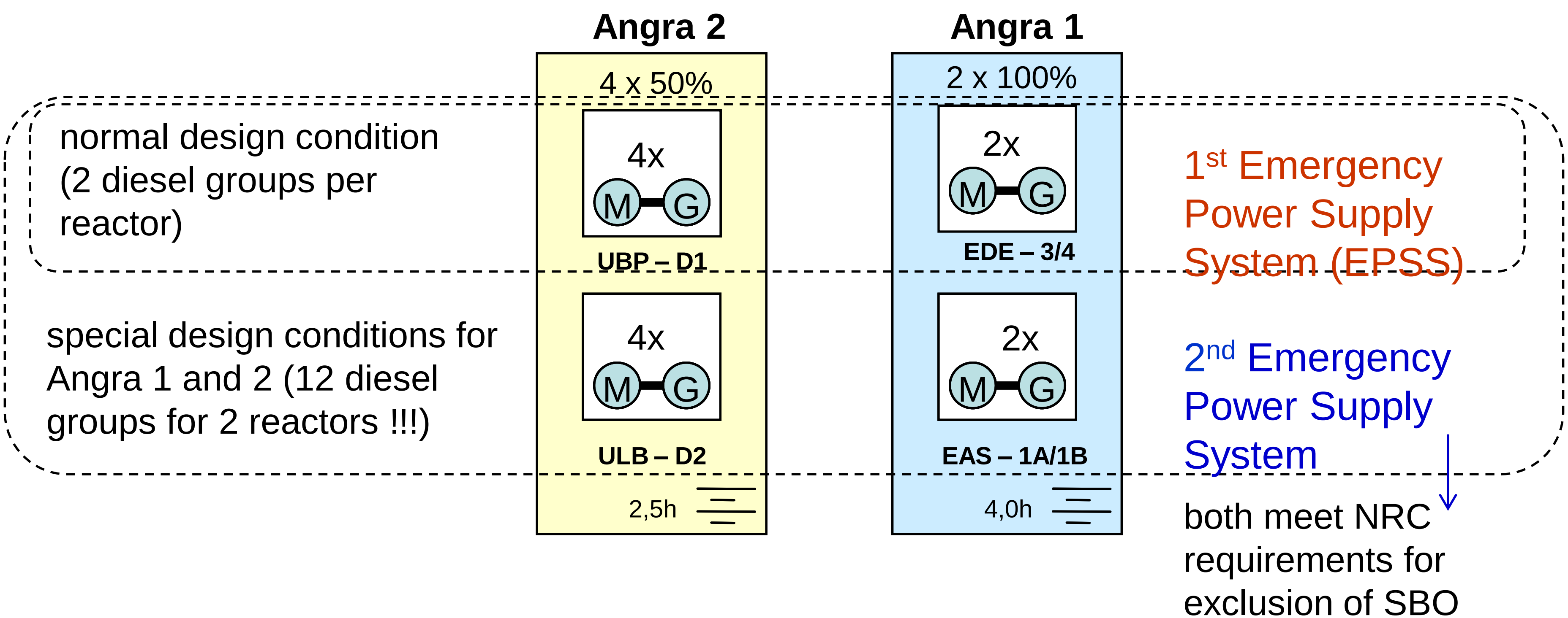
Plant at Refueling (worst condition for fuel pool temperature)

- full core transferred to fuel pool;
- full utilization of fuel pool storage racks;

Plants Emergency Power Supply Systems (EPSS)

Angra 1 and Angra 2 have very robust EPSS with Main and SBO EDGs. Normally SBO would be ruled out.





Evaluation of Loss of Main Heat Sink - BDBA conditions

Improbable event - protected water intake structures

- water intake structures protected from open sea waves (Ilha Grande Bay) and by jetty 8.0 m high above average seawater level;
- very low probability of water intake blockage to the extent of impairing minimum flow for residual heat removal;

Available alternative Heat Sink

- Passive cooling of SGs with water from the FFWS () (5,000 m^3 reservoir, located at an elevation of 110 m above the site level - not seismically designed)

Fuel Pool Temperature Increase after Loss of Cooling

Unit	Plant condition	Time until start boiling	Time until fuel element exposure
Angra 1	Power Operation	18 h	190 h
	Refueling (*)	9 h	63 h
Angra 2	Power Operation	23 h	155 h
	Refueling (*)	5 h	35 h

(*) limit condition, full core unloaded and full occupation of pool racks

BDBA Backfits

RF

Additional measures for restoring AC power supply:

<u>Power lost in one Plant</u>

- manual connection of emergency power busbars of Angra 1 and Angra 2 (use of large installed DG reserve capacity);

- recovery of Emergency Power System Diesels of Angra 1 by second cooling alternative in case of failure of Service Water;

<u>Power lost in both Plants</u> (Input from Stress Tests)

- mobile diesel generators for emergency supply of essential systems and components (1,800 kVA in Angra 1 and 1,000 kVA in Angra 2);

- mobile diesel generators for recharging batteries (250 kVA for Angra 1 and for Angra 2)

Planned Implementation : 2014 / 2015

BDBA Backfits

RF

Additional measures for Reactor and Fuel Pool Cooling:

• mobile compressor for operating Angra 1 MS-valves;

• mobile diesel engine driven pumps for feeding SGs (27 kg/s and 75 m head, two pumps for each plant);

• mobile diesel engine driven pumps for refilling AF Tank in Angra 1 and DW Pools in Angra 2 (20 kg/s and 20 m head, two pumps for each plant);

• design and construction of additional 4,000 m3 seismic FFWS reservoir, located on the elevation 70 m above site level, connected to the plant by seismic designed piping;

• autonomous mobile cooling unit for fuel pool cooling in Angra 1;

• possibility of fuel pool cooling and residual heat removal connecting FFWS to the RHR heat exchanger in Angra 2

Planned implementation 2014 / 2016

ADDITIONAL ACTIONS FOR MITIGATION OF SEVERE ACCIDENTS

The ETN FUKUSHIMA Response Plan followed basically the WENRA approach, which consisted of studies and projects covering,

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CR

5. Mitigation of Accident Consequences CR

Containment Protection concept/equipment in case of Severe Accident (SA):

Concept : “Depressurization of Primary Circuit to avoid RPV failure at high pressure, control of H2, control of Containment pressure, and core cooling with available Plant systems and mobile equipment, all integrated into SAMG to manage the accident”

- Depressurization: Pzr valve station adapted for F&B with dedicated I&C and DC power up to 6 hours (already installed in Angra 2)
- H2 control : passive H2 catalytic recombiners already purchased for Angra 1 and Angra 2 (installation until 2015)
- Containment pressure control: filtered venting under technical evaluation for Angra 1 and commercial clarification for Angra 2 (until 2016);

5. Mitigation of Accident Consequences

CR

Containment Protection concept/equipment in case of Severe Accident (SA):

Severe Accident Management Guidelines (SAMG):

• WOG SAMGs are in the process of validation and integration with the Emergency planning procedures and training in Angra 1 (planned for mid 2014); .

• AREVA SAMGs are being developed for Angra 2 (planned for the end of 2014);

Other improvements in the infrastructure for emergency planning are being planned and performed.

Final conclusions/remarks

- The work performed to date indicates that the Angra Plants have a solid Design Basis and substantial margins in case of BDB events;
- Based on the reevaluation of the Site hazards under extreme conditions complementary protection measures have been identified for implementation;
- Evaluation of the response of the Plant to the extreme BDB conditions of total loss of power and of main heat sink led to the development of backfits, basically power supply between Plants, additional mobile equipment and alternative seismically protected heat sink;
- Mitigative hardware measures for Containment protection in case of Severe Accidents were considered to be of high value in atempting to avoid large releases and will be implemented;
- The design phase for the above measures is underway and implementation is planned to occur mostly in 2014 – 2016.