Forum of the State Nuclear Safety Authorities of the Countries Operating WWER Type Reactors

Safety Enhancement of the Nuclear Power Plants with WWER–type Reactors in Response to Fukushima-Daiichi Accident

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on behalf of the Forum WWER

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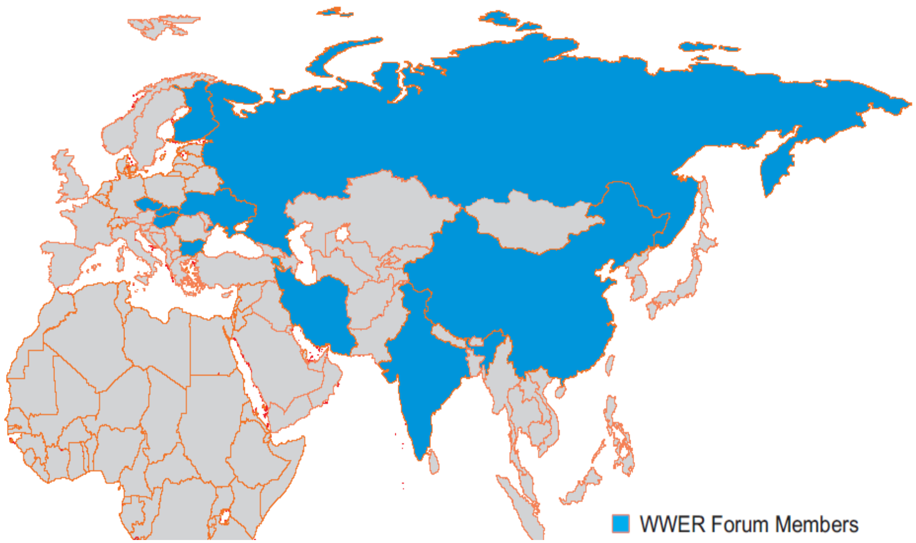
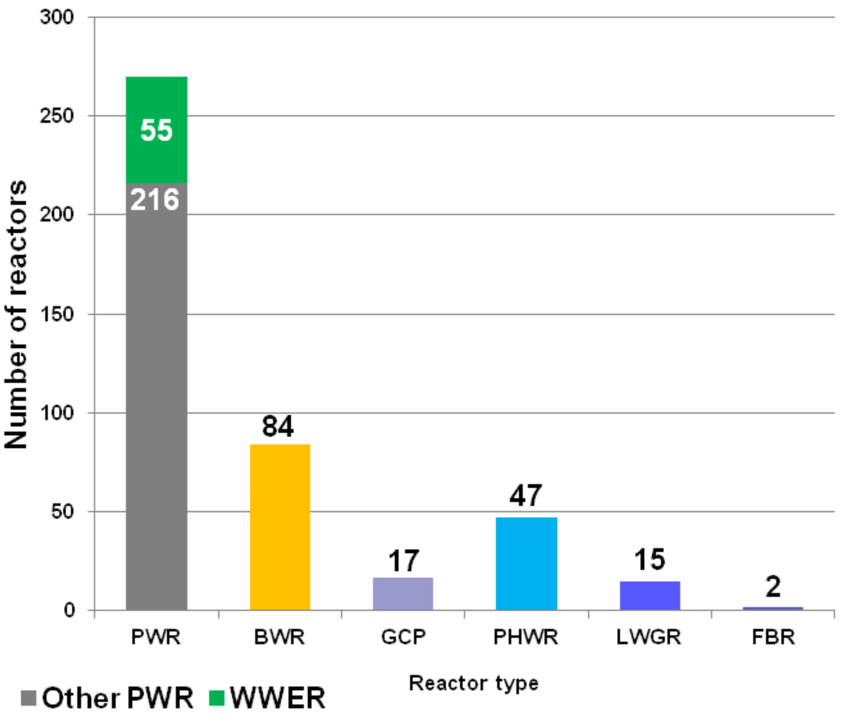
Key facts about WWER Forum



- WWER Forum established in 1993, 11 members and observers from GRS and IAEA
- Objectives:
  - to provide the network of chief nuclear safety regulators with WWER for exchanging experience
  - to discuss, harmonize and develop the common approach for relevant safety issues

Key facts about WWER Forum

- WWER Forum combines regulators supervising:
  - 55 WWER Units in operation (~40 GWe)
  - 14 under construction
- Working methods: annual high level meetings supported by topical Working Groups



IAEA. Reference data series No. 2, Nuclear Power Reactors in the World (2013 Edition)

Targeted safety re-assessment (stress tests)

- All WWER-operating countries re-assessed NPP robustness against extreme external impacts as a short-term measure in response to Fukushima event:
  - EU WWER countries (Bulgaria, Czech Republic, Finland, Hungary, Slovak Republic) and Ukraine performed stress tests in compliance with ENSREG specifications and participated in respective peer review process;
  - Russian Federation performed stress tests in compliance with procedure similar to ENSREG specifications;
  - Armenia finished stress tests in 2014 (based on ENSREG specifications);
  - China and India performed comprehensive targeted safety re-assessment in a stand alone manner (in India the scope has been similar to EU stress tests)

Overview of safety statuses

- Stress-tests have not revealed any significant external hazards or their combinations that have not been considered in the initial design and/or in SARs/PSRs
- WWER plants are reliable to ensure safety functions:
  - **WWER-440**, very large design safety margins, robust components, high redundancy of safety systems, large water inventory in primary and secondary sides;
  - **WWER-1000** (Gen II), design and safety systems comparable to PWRs of the same generation
  - **WWER-1000/AES-92, AES-2006** (Gen. III+) new designs with enhanced inherited safety features, wide use of passive safety features
- Since their first start-up, all operating WWER plants have implemented a number of safety measures that have further increased reliability of the safety functions
- Additional measures have been implemented and planned after Fukushima accident

Safety functions

- Three main safety functions have to be provided for an extended time under all hazardous conditions
  - reactivity control
  - decay heat removal
  - containment of radioactive material

Both preventive and mitigative measures are to be provided at NPP to maintain mentioned above main safety functions.

Reactivity control

Original design features	**Further upgrades** **(SBO conditions)**
Gen II WWER designs (ref. WWER-1000)	
• scram (control rods) • high boron concentration HPIS (3x100%, 40 g/kg) • HPIS (3x100%, 16 g/kg)	• high boron concentration HPIS + small DG (boron water injection to primary circuit to *compensate LOCA through pump seals and prevent re-criticality on long term heat removal)*
New WWER designs	
• increased number and efficiency of the control rods ensure long term subcriticality at low temperatures (< 100 °C) • passive high concentration boron injection system	

Decay heat removal

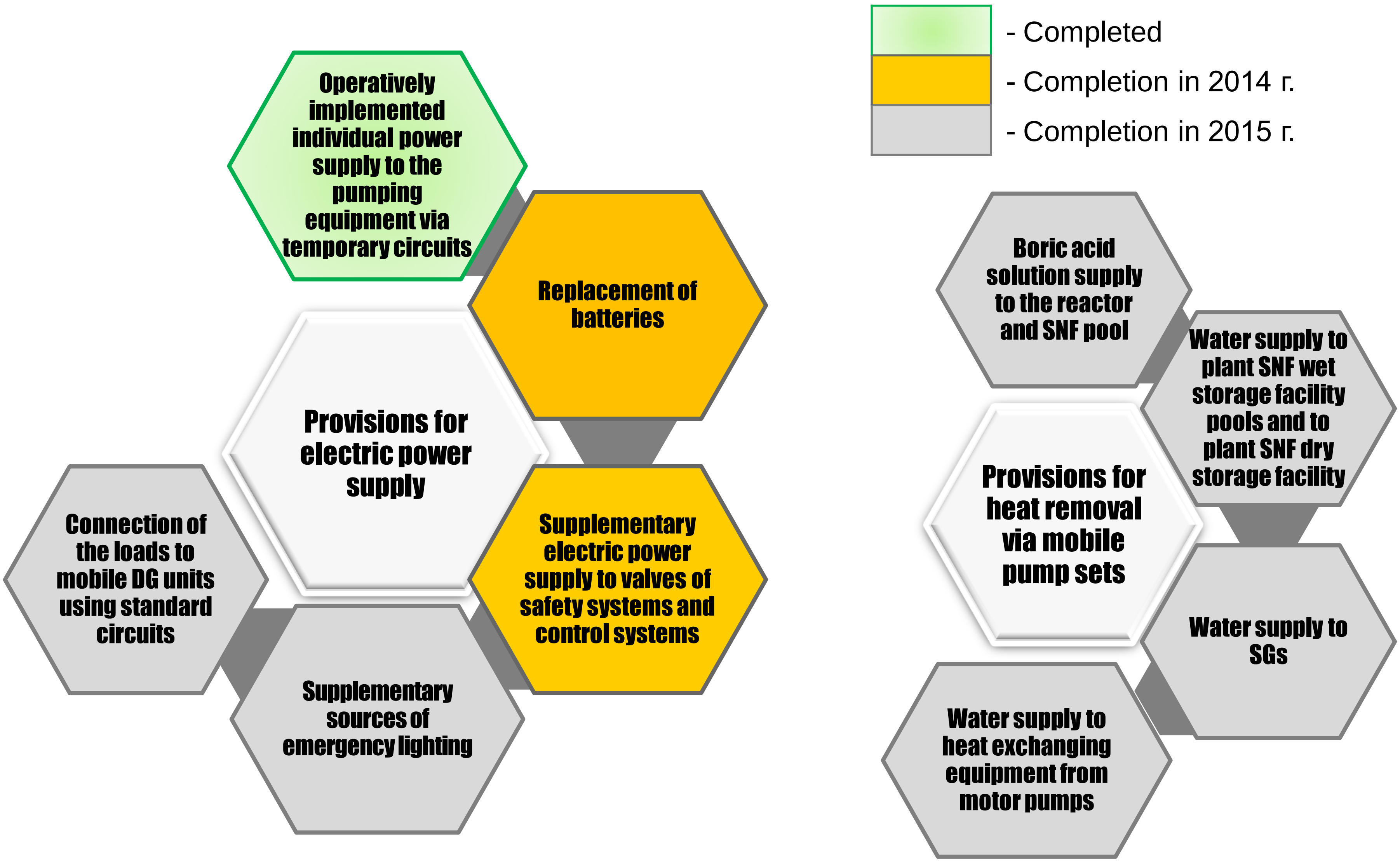
Original design features	Implemented measures	Further upgrades (SBO or/and UHS loss)
Gen II WWER designs		
• Primary heat removal by same system as in LB LOCA (3x100% ECCS) • Secondary heat removal (2x100% AFWS, 3x100% EFWS)	• Primary Feed & Bleed • Secondary Feed &Bleed • Super-emergency FWS using diesel driven pumps (WWER-440) • Passive SG make up (after pressure relief) from FW tank • SG make up from fire-fighting trucks	• SG make up from mobile sources
New WWER designs		
Passive core flooding system (2nd stage Hydro accumulators), additional closed-loop SG cooldown system (2x100%), passive secondary heat removal system (4x33%) , steam condensing by atmosphere (air flow)		

Decay heat removal *(spent fuel pools)*

Original design features	Implemented measures	Further upgrades (SBO or/and UHS loss)
Gen II WWER designs		
• Heat removal system (several trains) • Emergency heat removal using spray system (VVER-1000)	• SFP make-up from ECCS tanks (WWER-440)	• SFP make up or heat removal using mobile sources

Examples of the implemented measures

Implementation of measures to enhance Russian NPPs safety under SBO and Loss of UHS



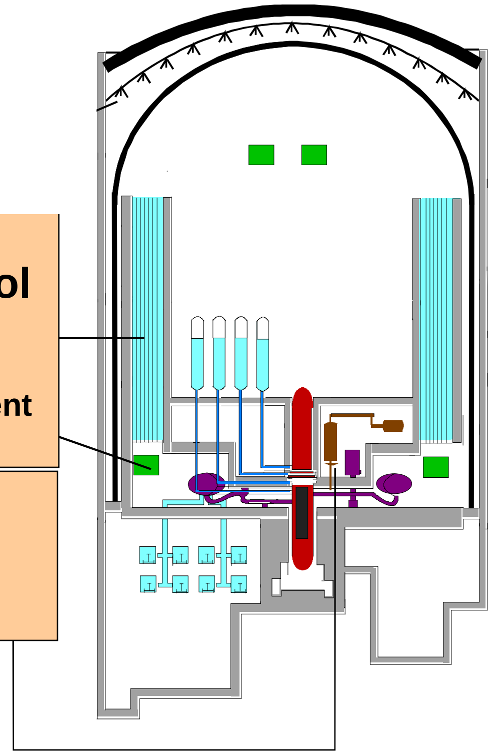
Containment of the radioactive material

Original design features	Implemented measures	Further upgrades
Gen II WWER designs		
• large containment with spray system • containment with bubble condenser (WWER-440) *Severe accident management tools were not considered in the original plant design*	• special system for large primary to secondary leak management • hydrogen management • containment filtered venting • containment vacuum breaker (WWER-440) • RPV ex-vessel cooling (WWER-440)	
New WWER designs		
Double containment, Annulus passive filtering system, Passive containment heat removal system, Containment hydrogen monitoring and catalytic recombination systems, Core catcher with passive heat removal		

Examples of the implemented measures (Loviisa NPP)

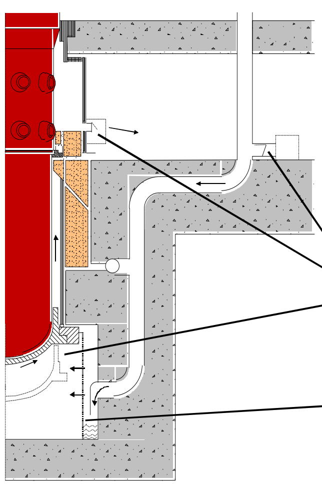
3. Hydrogen control
- Ice condenser doors
- Recombiners
- Glow plug improvement

1. Primary system depressurisation



4. Containment pressure control
- External spray

5. Containment isolation
- Manual actuation as back-up
- Monitoring of leak-tightness
- Leakage control



2. Melt retention within pressure vessel
- Inlet valves
- Steam outlet
- Lowering the neutron shield
- Debris removal

6. Severe accidents instrumentation & control

AC & DC power as support for safety function

Original design features	Implemented measures	Further upgrades (SBO conditions)
Gen II WWER units		
• emergency power supply system (3x100% or 4x100%) • common-unit DGs at site	• increase of the battery capacity, optimizations of the consumers list • interconnection between on-site power supply sources • various off-site power supply options (dedicated lined etc.)	• Mobile power sources (small portable DGs, powerful mobile DG station – already implemented at most of plants) • Improving reliability of fixed on-site power supply (diverse cooling of DGs)
New WWER designs		
4x100% EDGs + 2x100% common DGs; 24 hours battery backup for safety functions; No need for AC power for decay heat removals		

Examples of the implemented measures

6 kV Mobile DG
in Novovoronezh NPP

Mobile DG in
Kozloduy NPP

400 V Mobile DG
in Tianwan NPP

Advanced systems in new WWER plants

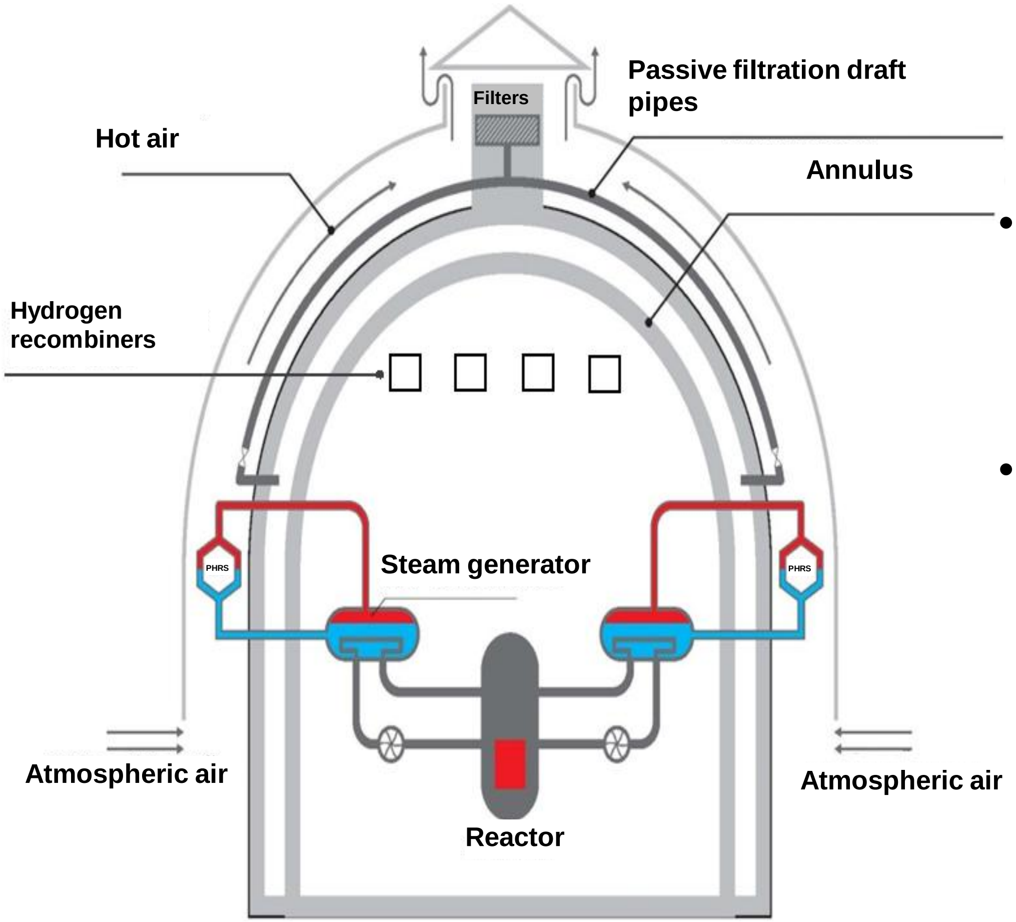
New WWERs have adequate built in systems to withstand prolonged SBO as well as loss of UHS:

- long term cooling of the reactor core without AC power, and
- long term decay heat removal that is not relying on primary ultimate heat sink

Safety systems (extended passive HAs + passive heat removal system) allow to avoid core damage even in case of Large Break LOCA in coincidence with SBO.

Generation 3+ features operability has been demonstrated during comissioning of Kudankulam NPP in India.

Passive decay heat removal from SGs (Kudankulam NPP, India)



- The system consists of four independent (4x33%) loops for natural circulation of the secondary coolant
- Each loop has air ducts for passive removing of decay heat to the atmosphere, and direct-action passive devices that control the air flow rate

Other Post-Fukushima activity

Strengthening protectability against external events of natural and man-made origin

- New analyses: Additional site seismicity analyses of NPP sites, Margin analyses for external impacts, External events PSAs, Seismic fragility analyses, Evaluation of site accessibility in case of extreme events etc.

Additional measures are based on the results of the analysis:

- Reinforcement of NPPs civil structures (safety related and some other – such as fire stations), qualification of safety related equipment, unfixturing of equipment and piping;
- Improvement protection against extreme natural phenomena (such as high sea level);
- Introduction of reactor scram by seismic signals

Examples of the implemented measures

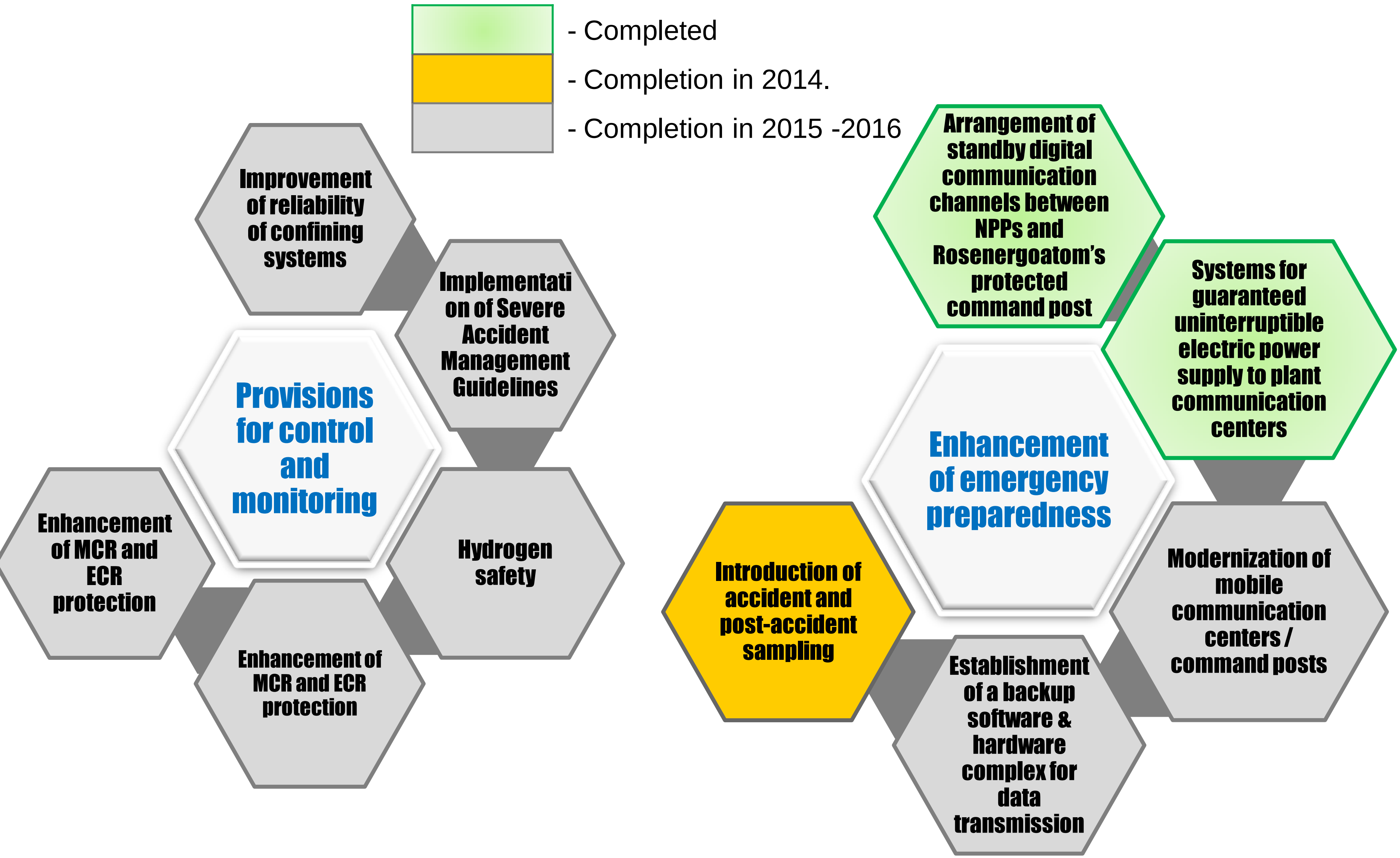
Flash boards on border gates of key building – Tianwan NPP, China

Other Post-Fukushima activity

Accident preparedness (including severe accident preparedness aspects)

- Additional research studies on severe accident phenomena;
- Level 2 PSAs development and updating;
- Development and implementation of SAMGs. Appropriate emergency drills;
- Hydrogen safety. Controlled filtered release ;
- Emergency I&C (including radiation and post accident monitoring systems);
- Enhancement of MCR and ECR protection. Communication devices;
- Improvement of the technical features and infrastructure to respond effectively to accidents (including severe accidents) that may affect multiple units for extended periods.

Implementation of measures to enhance Russian NPPs safety under severe accidents



Other Post-Fukushima activity

Effectiveness of Regulatory bodies

- Stress-tests results and safety improvement plans are reported to public. Also safety improvement information are publically available;
- Enforcement current national regulations (to address Fukushima lessons such as design basis extensions requirements, severe accident management provisions etc.). This activity is coordinated with IAEA Safety Standards revision;
- Operators are obliged by RBs to provide on regular basis reports to on the progress of implementation of safety measures;
- Regulatory body inspection plans are adjusted to monitor the progress of implementation of Post-Fukushima safety measures;
- Various formats are used for international information exchange on post-Fukushima activity.

Conclusions

- Fleet of WWER units has a robust inherent design features which have been further substantially improved during last two decades. Additional actions have been implemented or planned after Fukushima event.
- Fukushima accident provides insights for further safety strengthening of existing WWER plants and for extending the scope of issues to be addressed in new designs.
- Extended measures should be continually taken to encourage all countries to improve their compliance with IAEA standards and follow transparency and openness principles.
- Significant progress in the post-Fukushima measures implementation achieved in all WWER countries.