SMART
An Early Deployable Integral Reactor for Multi-purpose Applications
Contents

- SMR Perspectives
- Design & Safety Features of SMART
- Current (licensing) Status
- Summary

SMART: System-integrated Modular Advanced Reactor
Contents

- SMR Perspectives
- Design & Safety Features of SMART
- Current (licensing) Status
- Summary
SMR– Perspectives

- Small & Medium Reactors (SMR) offer Several Advantages
  - Enable enhanced safety features (robustness)
    - Easier implementation of passive safety features
  - Suitable for isolated or small electrical grids
  - Lower capital cost per unit
    - Small initial investment and short construction period reduces financial risks
    - Makes nuclear energy feasible for more utilities and energy suppliers
  - Multi-purpose application (co-generation flexibilities)
  - Just-in-time capacity addition, Short construction time
    - Enable gradual capacity increase to meet electric demand growth

- Many realizable SMR concepts proposed are based on the LWR technology and reflection of the past experiences
  - By eliminating the cause of accidents (initiators), instead of controlling accidents (ex. DBAs)
  - Integral PWR fits into these logical requirements
SMR– Perspectives

- **SMR Prospects**
  - Replacement for retiring fossil plants
    - reduces greenhouse gases
  - Non-electrical uses
    - desalination, process heat, etc
  - Multiple units permit generation with less impact by planned outages

- **User Expectations (Requirements)**
  - Proven Technology - Licensing Requirements and Conformance
  - Safety
  - Plant Performance and Applications
  - Economics and Financing
  - Proliferation Resistance and Physical Protection
  - Assurance of Supply
Economical Aspects (Competitiveness)

- No single SMR can compete with large NPP
  ⇒ Multi-modular units
- Design/Equipment Simplification
  ● Modular construction approach
  ● Easier to adopt passive features (elimination of active components)
- Shorter Construction Time
- Multiple Units per Plant
  ● Enable facilities/equipments sharing
  ● Reduces site-related costs
  ● Permit generation with less impact by planned outages
- Just-in-time Capacity Addition (Scalability)
  ● Enable gradual capacity increase to meet energy demand
Contents

- SMR Perspectives
- Design and Safety Features of SMART
- Current (licensing) Status
- Summary
Basic Concept of SMART

330MW\textsubscript{th} Integral PWR
Electricity Generation, Desalination and/or District Heating

- **Plant Data**
  - Power: 330 MWt
  - Water: 40,000 t/day
  - Electricity: 90 MWe

- **System-integrated Modular Advanced Reactor**

  - Electricity and Fresh Water Supply for a City of 100,000 Population
  - Suitable for Small Grid Size or Localized Power System
Application of SMART (1)

**Desalination System**

- **4 Units of MED-TVC to produce 40,000 ton/day + 90 Mwe**
- **Steam supplied through turbine extraction**
- **Steam Transformer - additional protection of possible radioactive contamination**

**Schematic Diagram of MED-TVC**

**Steam Transformer**
District Heating

- 147 Gcal/h of Heat Supply to Local Area Heating + 82 MWe
- Supply of Electricity and 85°C Hot Water for 100,000 Populations
  - Based on Korean Peak Electric Power and Heat Usages

Expected design point for 85 °C hot water
SMART
System-integrated Modular Advanced Reactor

Integral Design
- Integrated Primary System
- Inherent Safety: Passive Residual Heat Removal
- Advanced Digital Man-Machine Interface System

SMART
(System-integrated Modular Advanced Reactor)

- Enhanced Reactor Safety: No LBLOCA
- Flexible Applications: Electricity, Heat
- Early Deployment: Proven Technology

Loop Type PWR

Pressurizer
Canned Motor Pump
Helical Steam Generator
Core
Integral PWR – SMART

- **330 MWt (100 MWe) nominal output**
  - Small core (57 fuel assemblies) and source term
  - Unit output enough to support electricity, water and heat demand for population of 100,000

- **Integral PWR with no large RPV penetrations**
  - Less than 2” penetrations
  - In-vessel Pressurizer, Steam Generator and RCP (Canned Motor Pump)

- **Inherent Safety**
  - Elimination of LB-LOCA by design
  - No core uncovery during SB-LOCA
  - Large Coolant Inventory per MW
  - Low Power Density (~2/3 of Large PWR)

- **Performance proved Fuel**
  - Standard 17x17 UO₂ (< 5 w/o U_{235}) w/reduced height (2m)
  - Advanced Grid / IFM design
  - Peak Rod Burnup < 60 GWd/t
  - Performance proved @ operating PWRs

- **Improved Core Operability**
  - Cycle length: 1,000 EFPD (~ 3 years)
  - Proven reactivity control measures
  - CRDM, Soluble Boron, BP
<table>
<thead>
<tr>
<th><strong>Type of Reactor</strong></th>
<th><strong>Integral PWR</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal Power</strong></td>
<td>330 MWth</td>
</tr>
<tr>
<td><strong>Electric Power</strong></td>
<td>100 MWe (in case of desalination: 90 MWe)</td>
</tr>
<tr>
<td><strong>Design Lifetime</strong></td>
<td>60 years</td>
</tr>
<tr>
<td><strong>Core Thermal Margin</strong></td>
<td>&gt; 15 %</td>
</tr>
<tr>
<td><strong>Fuel Type</strong></td>
<td>17x17 Square</td>
</tr>
<tr>
<td><strong>Effective Core Height</strong></td>
<td>2 m</td>
</tr>
<tr>
<td><strong>Fuel Material</strong></td>
<td>UO₂ Ceramic (&lt; 5 w/o)</td>
</tr>
<tr>
<td><strong>Number of Fuel Assembly</strong></td>
<td>57</td>
</tr>
<tr>
<td><strong>Refueling Period</strong></td>
<td>36 months</td>
</tr>
<tr>
<td><strong>Reactivity Control</strong></td>
<td>Control Rod Assembly, Soluble Boron</td>
</tr>
<tr>
<td><strong>Steam Generator</strong></td>
<td>Helically Coiled, Once-Through Type (8)</td>
</tr>
<tr>
<td><strong>Reactor Coolant Pump</strong></td>
<td>Glandless Canned Motor Pump (4)</td>
</tr>
<tr>
<td><strong>Control Rod Drive Mechanism</strong></td>
<td>Magnetic-Jack Type (25)</td>
</tr>
</tbody>
</table>
## System Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Thermal Power (MWth)</td>
<td>330</td>
</tr>
<tr>
<td>Design Pressure/Temperature (MPa/°C)</td>
<td>17/360</td>
</tr>
<tr>
<td>Operating Pressure (MPa)</td>
<td>15</td>
</tr>
<tr>
<td>SG Inlet Temperature (°C)</td>
<td>323</td>
</tr>
<tr>
<td>SG Outlet Temperature (°C)</td>
<td>295.7</td>
</tr>
<tr>
<td>Flow Rate (kg/sec)</td>
<td>2090</td>
</tr>
<tr>
<td>Steam Pressure (MPa)</td>
<td>5.2</td>
</tr>
<tr>
<td>Steam Temperature (°C)</td>
<td>298</td>
</tr>
<tr>
<td>Steam Superheating (°C)</td>
<td>30</td>
</tr>
<tr>
<td>SG Tube Material</td>
<td>Inconel 690</td>
</tr>
<tr>
<td>SG Tube I.D/O.D (mm)</td>
<td>12/17</td>
</tr>
<tr>
<td>Tube Plugging Margin (%)</td>
<td>10</td>
</tr>
</tbody>
</table>
Nuclear Steam Supply System

◆ General
  • Thermal/Electric Power: 330 MWt/100 MWe
  • Design Life Time: 60 Years

◆ Design Characteristics
  • Integrated Primary System
  • Passive Residual Heat Removal System
  • Simplified Safety Injection System
  • Long Refueling Cycle: 36 months
  • Full Digital MMIS Technology
Control & Protection (Digital MMIS)

- **Fully Digitalized I&C System : DSP Platform**
  - 4 Channel Safety/Protection System and Communication
  - 2 Channel Non-Safety System

- **Advanced Human–Interface Control Room**
  - Ecological Interface Design
  - Alarm Reduction
  - Elastic Tile Alarm
Balance of Plant

- **Electric System**
  - 100% x 2 Emergency DG & Alternate AC Power (Water-tight Bldg)
  - Emergency Battery to Vital Systems for 10 hrs

- **Containment Building**
  - Passive Auto-catalytic Hydrogen Recombiners (12)
  - Containment Spray System (2 Trains)
    - Water source from Sump integrated IRWST
  - Containment Isolation System
  - Aircraft Impact Proof

- **Auxiliary Building**
  - Quadrant Wrap-around
  - Fuel Storage Inside
  - Aircraft Impact Proof
  - Single Base-mat with Containment (Seismically Resistant)
Safety Consideration

- **Core Damage Frequency**
  - less than $10^{-6}$ / RY

- **Containment Failure Frequency**
  - less than $10^{-7}$ / RY

- **Operator Action Time**
  - at least 30 min.

- **Capacity for Station Blackout**
  - EDG(2), AAC, Battery

- **Severe Accident Mitigation Capability**
  - In-Vessel Retention, ERVC, PARS, Containment Spray System

- **Seismic Design**
  - 0.3g SSE
CDF Contributor (Full Power Internal Events)

%SLOCA, 35.3
%RVR, 17.2

%TLOCCW, 4.0
%GTRN, 4.4
%SGTR, 6.2
%LOFW, 7.7
%LSSB, 7.9
%ATWS, 11.4
%RCPE, 2.2
%ISLOCA, 1.0
%LOCCW, 0.0
%SGHR, 0.6
%SLBU, 0.2
%LODC, 0.0
%LOOP, 1.7
%LOKV, 0.1
%LODC, 0.0
%LOCCW, 0.0
Safety Features

- **Inherent Safety**
  - No Large Break: vessel penetration < 2 inch
  - Large Primary Coolant Inventory per MW
  - Low Power Density (~2/3)
  - Large PZR Volume for Transient Mitigation
  - Low Vessel Fluence (1.1 x 10^{14} n/cm^2)
  - Large Internal Cooling Source (Sump-integrated IRWST)

- **Engineered Safety Features**
  - Passive Residual Heat Removal System (50% x 4 train)
    - Natural Circulation
    - Replenishable Heat Sink (Emergency Cooling Tank)
  - Safety Injection System (100% x 4 train)
    - Direct Vessel Injection from IRWST
  - Shutdown Cooling System (100% x 2 Train)
  - Containment Spray System (2 Train)

- **Severe Accident Management**
  - In-Vessel Retention and ERVC
  - Passive Hydrogen Control (PARs)
Safety Systems of SMART

- Passive Residual Heat Removal System (4 trains)
- Safety Injection System (4 trains)
- Shutdown Cooling System (2 trains)
- Containment Spray System
- Emergency Diesel Generator (2)
- Alternate AC
- Hydrogen Control
  - Passive auto-catalytic recombiner (12)
- Counter Measure : Severe Accident
  - Large inventory of reactor coolant
  - Large containment volume
Passive Residual Heat Removal System

- passively removes the residual heat from the secondary side of SG through natural circulation (10 m height difference btw SG and Hx)
- cools down the temperature of RCS to 200℃ within 36 hours through removing the core decay heat and the sensible heat of reactor coolant after the reactor tripped from any power level
**SMART is secured** against Station Blackout

- 2 Water-tight EDG and AAC insures Emergency Power Supply
- If EDG/AAC fails, Fully Passive (No Electricity) PRHRS insures Safe Shutdown (PRHRS Heat Sink can be Replenished)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>EDG/AAC</th>
<th>PRHRS</th>
<th>Grace Time*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yes</td>
<td>All 4 Trains</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>No</td>
<td>All 4 Trains</td>
<td>20 Days**</td>
</tr>
<tr>
<td>3</td>
<td>No</td>
<td>2 Trains</td>
<td>10 Days**</td>
</tr>
<tr>
<td>4</td>
<td>No</td>
<td>No</td>
<td>2.6 Days</td>
</tr>
</tbody>
</table>

* Grace Time : the Time allowed for Operator’s Action before Core Damage
** No Replenishment of PRHRS Heat Sink Assumed

**Hydrogen Control**

- PAR (12) passively removes Hydrogen in Containment, if any
- Large containment volume
  - Max. hydrogen contents assuming 100% fuel clad oxidation < 7 %
    : Hydrogen explosion does not occur
## Post Fukushima Action Items

<table>
<thead>
<tr>
<th>No.</th>
<th>Action Items</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Automatic RX Shutdown @Earthquake &gt;0.18g</td>
<td>To be resolved @SSAR</td>
</tr>
<tr>
<td>2</td>
<td>Strengthen Aseismic Design for MCR Panel</td>
<td>Done</td>
</tr>
<tr>
<td>3</td>
<td>Provide Water-tight Door &amp; Drain Pump</td>
<td>To be resolved @SSAR</td>
</tr>
<tr>
<td>4</td>
<td>Secure Mobile Generator and Battery</td>
<td>To be resolved @SSAR</td>
</tr>
<tr>
<td>5</td>
<td>Improve Alternate EDG Design Criteria</td>
<td>To be resolved @PSAR</td>
</tr>
<tr>
<td>6</td>
<td>Fix-up Extra Transformer Anchor Bolt</td>
<td>To be resolved @PSAR</td>
</tr>
<tr>
<td>7</td>
<td>Prepare Measure to Cool-down SFP</td>
<td>To be resolved @SSAR</td>
</tr>
<tr>
<td>8</td>
<td>Prepare Anti-Flood &amp; Recovery for Final Heat Removal</td>
<td>To be resolved @PSAR</td>
</tr>
<tr>
<td>9</td>
<td>Provide Passive Autocatalytic Recombiner</td>
<td>Done</td>
</tr>
<tr>
<td>10</td>
<td>Provide Depress. or Purge on RX. Bldg</td>
<td>N/A for SMART</td>
</tr>
<tr>
<td>11</td>
<td>Provide External Injection Path on SI</td>
<td>To be resolved @SSAR</td>
</tr>
</tbody>
</table>
Contents

- SMR Perspectives
- Design & Safety Features of SMART
- Current (Licensing) Status
- Summary
Technology Validation & Standard Design Approval

- **2009**
  - Separate Effect Tests
  - Design Tools & Methods
  - Integral Effect Tests (VISTA)

- **2010**
  - Licensing Support

- **2011**
  - Key Safety & Performance Validation
  - Standard Design, Licensing Q&A
  - SSAR, CDM, EOG

- **2012~2017**
  - Pre-Application Review
  - Regulatory Review
  - Pre-Application SDA Application
  - Standard Design Approval

**FOAKE Plant Construction**

- **Plan Preparation Underway**
- **Construction**

**SMART-ITL**

- Integral System Confirmation Tests
Current Status

- **Technology Validation**
  - Separate Effect Tests: 20 tests completed
  - Integral Effect Tests: small scale SBLOCA tests completed

- **Standard Design**
  - CDM, SSAR, EOG and related documents were submitted for the application of Standard Design Approval: Dec. 2010

- **Licensing**
  - Pre-application Review (by KINS): 2010
  - SDA Licensing Review (by KINS): 2011
  - Standard Design Approval (Target): End of 2011
Licensing Milestone toward SDA

- **Pre-Application Review**: completed (2010)
  - System Description, Preliminary Safety Analysis Reports, Tools & Methods, Validation Test Plan, etc. (~ 800 Q&A’s)

- **Application of Standard Design Approval** (Dec. 2010~)
  - Certified Design Material, SSAR, EOG and related documents, and 22 Technical Reports were submitted.
  - **Document Conformance Evaluation** (Feb. 2011)
    - 190 comments demanding supplementary / additional materials
  - **1st Round Questionnaire** (April, 2011)
    - 932 Q&A’s
  - **2nd Round Questionnaire** (July, 2011)
    - 470 Q&A’s
  - **Nuclear Safety Committee Review**: Nov. 2011
  - **(target) Standard Design Approval**: End of 2011
Project Organization – SMART SDA

Government

KAERI

KEPCO Consortium

SMART Development

Technology Validation

NSSS Design

Fuel Design

BOP Design

Component Design

- Technology Validation: $60M
- Standard Design: $85M
Partnership for the SMART Project

- **KEPCO Consortium**
  - Project Management, Funding, Marketing Evaluation
  - Leads the feasibility study on the construction of a FOAKE plant
    - site survey, social acceptance, economics, etc

- **KAERI**
  - Korea Atomic Energy Research Institute

- **KEPCO Consortium**
  - Daewoo Engineering
  - Heavy Industries
  - SAMCHANG
  -Energy
  - posco
  - Daewoo Engineering
Contents

- Introduction
- History and Status of the SMART Project
- Design Features
- Safety of the SMART
- Summary
Deployment Consideration

- Domestic Construction Plan of Reference Plant
  - Construction Planning (2012)
  - Site Survey (2013~2015)
  - Construction of Reference Plant (2015~2019 : FOAK)

- Design Improvement for Construction (2012~2014)
  - Application of Fukushima Daiichi Action Plans
    - Prepare Automatic Reactor Shutdown @ Earthquake (> 0.18g)
    - Enforce Seismic and Tsunami Criteria
    - Prepare External Injection Path on the Safety Injection Line
    - Improve Cooling Performance of Spent Fuel Pool
    - Prepare Mobile Generation Facility & Connection Points
  - Optimization of BOP System
    - Arrangement & Layout
Construction

- **Footprint**
  - 300 x 300 m for Electricity System
  - 300 x 200 m for Desalination System

- **Boundaries**
  - EAB : Circle of R300 m
  - EPZ : 1.5 km
  - LPZ : 2 km

- **Construction Period**
  - 3 years (n-th plant)

- **Economics (as of 2007)**
  - Construction Cost : $5,000 ~ $6,000/kWe
  - Levelized Generation Cost : ~ 6.1 ¢/kWh
Summary

- SMR can provide Flexible Solutions to energy, water & environmental issues

- Certified SMART Design will be available for commercial deployment

- SMART is a viable option for early deployment of SMR
  - Enhanced safety and operability by advanced design features
  - Low licensing risks by using proven and validated technologies
  - Flexible applications for both electricity and heat supply
  - KEPCO consortium with wide NPP experiences strengthens the viability of SMART
Thank you for attention!
SMART
System-integrated Modular Advanced ReacTor

Integral PWR – SMART

- **330 MWt (100 MWe) nominal output**
  - Small core (57 fuel assemblies) and source term
  - Unit output enough to support electricity, water and heat demand for population of 100,000

- **Integral PWR with no large RPV penetrations**
  - Less than 2” penetrations
  - In-vessel Pressurizer, Steam Generator and RCP (Canned Motor Pump)

- **Inherent Safety**
  - Elimination of LB-LOCA by design
  - No core uncovery during SB-LOCA
  - Large Coolant Inventory per MW
  - Low Power Density (~2/3 of Large PWR)

- **Performance proved Fuel**
  - Standard 17x17 UO₂ (< 5 w/o U_{235}) w/reduced height (2m)
  - Advanced Grid / IFM design
  - Peak Rod Burnup < 60 GWd/t
  - Performance proved @ operating PWRs

- **Improved Core Operability**
  - Cycle length: 1,000 EFPD (~ 3 years)
  - Proven reactivity control measures
    - CRDM, Soluble Boron, BP
Fuel & Core

- **Fuel**
  - Proven 17 x 17 UO2 Ceramic Fuel with Reduced Height (2m)
  - Peak Rod Burn-up < 60GWD/MTU

- **Core**
  - 57 Fuel Assemblies
  - Fuel Cycle Length : 3 years
  - Availability Factor : 95%

- **Reactivity Control**
  - Magnetic-Jack type CRDM
  - Soluble Boron
  - Burnable Poison

- 60 years of on-site Spent Fuel Storage
Reactor Vessel Assembly

- **Primary Components in RPV**
  - 8 helical once-through SGs
  - 4 canned motor pumps
  - Internal steam pressurizer
  - 25 magnetic jack type CRDMs

- **RPV**
  - Max 6.5m (D) x 18.5m (H)
  - Material: SA508 Grade 3, Class 1
RPV and Internals

SMART
System-integrated Modular Advanced Reactor

Flow Skirt
Upper Guide Structure
Core Support Barrel
CRDM (25)
PSV Nozzle
ICI Nozzle
ICI Support Structure

In-vessel Steam Pressurizer

Flow Mixing Header Assembly
Helically-coiled Steam Generator (8)

Canned Motor Pump (4)
Component Cooling
Sealing Can
Shaft
Cooler
Stator
Impeller Flywheel
Diffuser
Cooler Rotor
Stator
## Nozzles

<table>
<thead>
<tr>
<th>Items</th>
<th>Ea</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP Nozzles</td>
<td>4</td>
</tr>
<tr>
<td>Feed Water Nozzles</td>
<td>8</td>
</tr>
<tr>
<td>Steam Nozzles</td>
<td>8</td>
</tr>
<tr>
<td>Safety Injection Nozzles</td>
<td>4*</td>
</tr>
<tr>
<td>Shutdown Cooling Nozzles</td>
<td>4*</td>
</tr>
<tr>
<td>Chemical Volume Control System Nozzles</td>
<td>2*</td>
</tr>
<tr>
<td>Ex-Core Detector Nozzles</td>
<td>2*</td>
</tr>
<tr>
<td>Reactor Coolant Ventilation Nozzles</td>
<td>1*</td>
</tr>
</tbody>
</table>

* Nozzle IDs are < 2.0 inch

**Nozzles on RPV**
## Reactor Closure Head Assembly

<table>
<thead>
<tr>
<th>Name (Item)</th>
<th>No</th>
<th>Name (Item)</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRDM Nozzle</td>
<td>25</td>
<td>PZR Level Gauge Nozzle</td>
<td>3</td>
</tr>
<tr>
<td>PZR Heater Nozzle</td>
<td>10</td>
<td>PZR Temp. Gauge Nozzle</td>
<td>2</td>
</tr>
<tr>
<td>PZR Safety Valve Nozzle</td>
<td>2</td>
<td>PZR Press. Gauge Nozzle</td>
<td>4</td>
</tr>
<tr>
<td>SDS Nozzle</td>
<td>2</td>
<td>Ex-Core Detector Nozzle</td>
<td>4</td>
</tr>
<tr>
<td>PZR Spray Nozzle</td>
<td>4</td>
<td>PZR Sampling Nozzle</td>
<td>1</td>
</tr>
<tr>
<td>ICI Nozzle</td>
<td>29</td>
<td>PZR Ventilation Nozzle</td>
<td>1</td>
</tr>
<tr>
<td>RV Level Gauge Nozzle</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Diagram of Reactor Closure Head Assembly]

**Key Components:**
- CRDM Nozzle
- ICI Nozzle
- RV Upper Flange
- ICI Guide Tube Structure
Pressurizer

- **In-Vessel Pressurizer**
  - **Pressurizer Space**
    - Closure head and upper region of UGS
    - Not a separate equipment (hardware)
  - **Pressure Control : by Electric heater**
    - Steam & coolant mixture
  - **Insulation**
    - External Insulation on the Closure Head
    - Wet Thermal Insulation
Major Component Design

---

Steam Generator
- Helically coiled once-through HEX
- Produce Super-heated steam (30 ℃)
- Tube material: Alloy 690
- Tube inspection (ISI)

Reactor Coolant Pump
- Canned motor pumps
- Horizontally mounted on RV wall
- Monitoring
  - Rotational Speed: Flow-rate
  - Acoustic & Vibration
  - Temperature (Coil, Coolant)
  - Motor Overload
Digital MMIS

- Fully Digitalized I&C System: DSP Platform
  - 4 Channel Safety/Protection System and Communication
  - 2 Channel Non-Safety System

- Advanced Human-Interface Control Room
  - Ecological Interface Design
  - Alarm Reduction
  - Elastic Tile Alarm
Balance of Plant

Schematic Diagram of the Secondary System
Reactor Containment Building

- Pre-Stressed Concrete Lined with Carbon Steel Plate
- Maintains structural integrity of cavity in severe accident
- Aircraft Crash
  ✓ Requirements are under legislative process in Korea
  ✓ SMART: designed to have reinforced CV and Aux. Bldg against Aircraft Crash

Containment Building
- Design Pressure: 35 psig
- Design Temperature: 240°F
## Post Fukushima Action Items

<table>
<thead>
<tr>
<th>Post Fukushima Action Items</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aseismic Structural Integrity</strong></td>
<td>SSAR Revise Done</td>
</tr>
<tr>
<td>• Automatic Reactor Shutdown System @&gt;0.18g Earthquake</td>
<td></td>
</tr>
<tr>
<td>• Plant Safety System Seismic Design: 0.3g SSE</td>
<td></td>
</tr>
<tr>
<td><strong>Tsunami Protection</strong></td>
<td>@Construction SSAR Revise</td>
</tr>
<tr>
<td>• Designed Site Elevation &gt; 10m</td>
<td></td>
</tr>
<tr>
<td>• Water-tight Doors and Drain Pumps for Emergency Power Sources and Safety Related Equipments (EDG, AAC, Battery, SFSP Cooling System, Circulation Water Intake System…)</td>
<td></td>
</tr>
<tr>
<td><strong>Additional Emergency Power Source and Heat Sink</strong></td>
<td>SSAR Revise @Construction</td>
</tr>
<tr>
<td>• Install Mobile Emergency Diesel Generator/Battery per each plant site</td>
<td></td>
</tr>
<tr>
<td>• External Cooling Water Supply Lines to SFSP (+Mobile Water Supply)</td>
<td></td>
</tr>
<tr>
<td>• Enhance AAC Design Requirements @ Multiple Units Failure (Capacity, Cooling Mechanism, Fuel Storage)</td>
<td></td>
</tr>
<tr>
<td><strong>Severe Accident Mitigation</strong></td>
<td>Done</td>
</tr>
<tr>
<td>• Installation of Passive Auto-Catalytic Recombiners (PAR) and Real-time Hydrogen Monitors</td>
<td></td>
</tr>
<tr>
<td>• Containment Depressurization/Exhaust System @Severe Accident</td>
<td></td>
</tr>
<tr>
<td>• Additional Installation of External Emergency Cooling Water Injection Lines for both Primary/Secondary Systems and Safety Parameter Monitoring System</td>
<td></td>
</tr>
<tr>
<td>• Enhance Operator Training Program @ Severe Accident Scenarios</td>
<td></td>
</tr>
<tr>
<td><strong>Others</strong></td>
<td>@Construction</td>
</tr>
<tr>
<td>• Enhancement of Emergency Preparedness (Additional Storage of Potassium Iodide, Gas Masks, Filters, RMonitors, RPSuit…)</td>
<td></td>
</tr>
<tr>
<td>• Revise Emergency Action Level of Radiation Emergency Plan reflecting earthquake and/or tsunami level</td>
<td></td>
</tr>
</tbody>
</table>
SMART basically adopts Proven Technologies of Existing PWR

SMART-specific Technologies are being fully Validated

- Experimental Validation of SMART-specific Design Performance and Safety
  - Total of 22 Validation Experiments were Selected based on
    - PIRT (Phenomena Identification and Ranking Table)
    - Experts Opinions from Regulation, Industries, Institutes and Universities
  - Experimental Validation envelop Fuel/Core, TH/Safety, Mechanics/Components and Digital I&C
- Software Validation of Key Design Tools and Methods (11)
  - Core Physics, Core Thermal-Hydraulics, Safety Analysis, ....
Technology Validation Program

Technology Validation

Safety Tests
- Core SET
  - Freon CHF
  - Water CHF
- Safety SET
  - Safety Injection
  - Helical SG Heat Transfer
  - Condensation HX Heat Transfer
- Integral Effect Tests
  - VISTA SBLOCA
  - SMART-ITL
- Digital MMIS Safety System
  - Control Unit Platform
  - Communication Switch
  - Integral Safety System

Tools & Methods
- Code Devel/V&V
  - Safety: TASS/SMR-S
  - Core TH: MATRA-S
  - Core Protec./Monitor.
- Design Methodology
  - DNBR Analysis
  - Accident Analysis (SBLOCA, LOFA, …)
  - Integral Rx Dynamics

Performance Tests
- Fuel Assembly
  - Out-of-Pile Mech./Hydr.
- RPV TH
  - RPV Flow Distribution
  - Flow Mixing Header Ass.
  - Integral Steam PZR
  - PZR Level Measurement
- Components
  - RCP Hydrodynamics
  - RPV Internals Dynamics
  - SG Tube Irradiation
  - Helical SG ISI
  - In-core Instrumentation

V&V

Technical Reports

Standard SAR

Standard Design Approval

Design Data

Standard Design
High Temperature & High Pressure T/H Integral Tests

VISTA- ITL
- Experimental Validation of SBLOCA Phenomena
- Height Ratio = 1:2.8, Area Ratio = 1:470,
  Operating Parameter Ratio : 1:1
- Single Loop

SMART- ITL
- Experimental Validation of Integral Performance and Safety
- Height Ratio = 1:1, Area Ratio = 1:49,
  Operating Parameter Ratio = 1:1
- Four Loops
Technology Validation Program– Core & Fuel

Subchannel Code V&V
- MATRA-S code
  - Subchannel integral balance eq.
  - Heat/mass transfer kinetics
  - Implicit, marching scheme
- MATRA-S code validation
  - Flow & enthalpy distribution tests
  - Inlet jetting test
- Subchannel relocational tests

CHF Correlation System V&V
- TH Field Analysis: MATRA-S
- Optimization of Mixing Coefficient
- Local Parameter CHF Correlation
- Limit DNBR
- 95/95 tolerance limit
- Statistical DNBR Design

Fast-run DNBR Code V&V
- 5-channel analysis model
- Characteristics
  - 4-channel model for SMART core
  - Non-iterative marching scheme
  - Local parameter CHF correlation factor
  - Modular programming
- Applications
  - STDNB module in SCOPS
  - Transient DNBR analysis module

Model Validation

DNBR Model

CHF Correlation System V&V

Fast-run DNBR Code V&V

Core Protection/Monitoring System V&V

Fuel Component Test
Tests for Component Selection
- Spacer Grid Impact Test
- Top/Bottom Nozzle Structure Test
- Debris Filtering Test
- Fuel Rod Characteristics Tests
- Control Rod Component Tests

Fuel Performance Tests

Core Thermal-Hydraulic Tools and Methods

DNBR Code Analysis

Model Validation

Fast-run DNBR Code V&V

Core Protection/Monitoring System V&V

Fuel Component Test
Tests for Component Selection
- Spacer Grid Impact Test
- Top/Bottom Nozzle Structure Test
- Debris Filtering Test
- Fuel Rod Characteristics Tests
- Control Rod Component Tests

Fuel Performance Tests

Core Thermal-Hydraulic Tools and Methods

CHF Correlation System V&V

Fast-run DNBR Code V&V

Core Protection/Monitoring System V&V

Fuel Component Test
Tests for Component Selection
- Spacer Grid Impact Test
- Top/Bottom Nozzle Structure Test
- Debris Filtering Test
- Fuel Rod Characteristics Tests
- Control Rod Component Tests

Fuel Performance Tests

Core Thermal-Hydraulic Tools and Methods

CHF Correlation System V&V

Fast-run DNBR Code V&V

Core Protection/Monitoring System V&V

Fuel Component Test
Tests for Component Selection
- Spacer Grid Impact Test
- Top/Bottom Nozzle Structure Test
- Debris Filtering Test
- Fuel Rod Characteristics Tests
- Control Rod Component Tests

Fuel Performance Tests

Core Thermal-Hydraulic Tools and Methods

CHF Correlation System V&V

Fast-run DNBR Code V&V

Core Protection/Monitoring System V&V

Fuel Component Test
Tests for Component Selection
- Spacer Grid Impact Test
- Top/Bottom Nozzle Structure Test
- Debris Filtering Test
- Fuel Rod Characteristics Tests
- Control Rod Component Tests

Fuel Performance Tests

Core Thermal-Hydraulic Tools and Methods

CHF Correlation System V&V

Fast-run DNBR Code V&V

Core Protection/Monitoring System V&V

Fuel Component Test
Tests for Component Selection
- Spacer Grid Impact Test
- Top/Bottom Nozzle Structure Test
- Debris Filtering Test
- Fuel Rod Characteristics Tests
- Control Rod Component Tests

Fuel Performance Tests

Core Thermal-Hydraulic Tools and Methods

CHF Correlation System V&V

Fast-run DNBR Code V&V

Core Protection/Monitoring System V&V

Fuel Component Test
Tests for Component Selection
- Spacer Grid Impact Test
- Top/Bottom Nozzle Structure Test
- Debris Filtering Test
- Fuel Rod Characteristics Tests
- Control Rod Component Tests

Fuel Performance Tests

Core Thermal-Hydraulic Tools and Methods

CHF Correlation System V&V

Fast-run DNBR Code V&V

Core Protection/Monitoring System V&V

Fuel Component Test
Tests for Component Selection
- Spacer Grid Impact Test
- Top/Bottom Nozzle Structure Test
- Debris Filtering Test
- Fuel Rod Characteristics Tests
- Control Rod Component Tests

Fuel Performance Tests

Core Thermal-Hydraulic Tools and Methods
Thermal-Hydraulic Performance Tests

- **FMHA Performance Test**
  - Scale Ratio: 1/5
  - SG Outlet – Core Inlet Simulation
  - Condition: ATM, 60°C
  - Test Matrix
    - 1 or 2 Section SG Breakdown Test
    - FMHA Outlet Flow Hole Optimization

- **Internal Pressurizer/Level Meas. Test**
  - Scale Ratio: 1/6
  - PZR Internal Structure Simulation
  - Condition: 15MPa, Saturation Temperature
  - Test Matrix
    - Normal Condition
    - In-surge/Out-surge
    - Level Measurement Test

- **SG and PRHRS Hx Heat Transfer Test**
  - Scale Ratio Height/Volume: 1/2.8, 1/473
  - Single Loop Simulation
  - Operating Condition (Power/Pressure): 100% / 15MPa

- **Safety Injection Bypass Test**
  - Scale Ratio: 1/5
  - Operating Condition: < 4MPa, Saturated Temp.

**Reactor Pressure Vessel Assembly Flow Distribution Test**

**Safety Certification Tests**

- **Design Certification for SMART Hydraulic System**
  - 1/5 Scaling
  - SG Outlet – Core Inlet Simulation
  - Condition: ATM, 60°C
  - Test Matrix
    - 1 or 2 Section SG Breakdown Test
    - FMHA Outlet Flow Hole Optimization

- **PZR Internal Structure Simulation**
  - 1/6 Scaling
  - Condition: 15MPa, Saturation Temperature
  - Test Matrix
    - Normal Condition
    - In-surge/Out-surge
    - Level Measurement Test

- **Tube Modeling Test**
  - Condition: Normal and Transient

- **Scale Ratio Height/Volume**:
  - 1/2.8, 1/473

- **Single Loop Simulation**
  - Operating Condition (Power/Pressure): 100% / 15MPa

- **PRHRS Makeup Tank**
  - Scale Ratio: 1/49
  - Design Concept: 4 Loop, 4 Train Secondary side
  - Operating Condition (Power/Pressure):
    - < 30% Power, 15MPa

- **Tube Modeling Test**
  - Condition: Normal and Transient

- **Scale Ratio Height/Volume**:
  - 1/2.8, 1/473

- **Operating Condition (Power/Pressure)**:
  - 100% / 15MPa

- **Separate Effect Test**
  - Scale Ratio: 1/5
  - Operating Condition: < 4MPa, Saturated Temp.

- **Operating Condition** (Power/Pressure):
  - < 30% Power, 15MPa

**Tube Modeling Test**

- Scale Ratio: 1/5
- Operating Condition: < 4MPa, Saturated Temp.

**Operating Condition**

- Power/Pressure:
  - < 30% Power, 15MPa

**Scale Ratio Height/Volume**

- 1/2.8, 1/473

**Normal and Transient**

**Single Loop Simulation**

**Operating Condition (Power/Pressure)**

- 100% / 15MPa

**Scale Ratio Height/Volume**

- 1/2.8, 1/473

**Operating Condition** (Power/Pressure):

- < 30% Power, 15MPa
Mechanics & Components

- Reactor Coolant Pump Performance Test
- Verification of Structural Dynamic Analysis Method
- Verification of Hydraulic Load Analysis Method
- SMART Steam Generator Winded With Helical Tubes
- Neutron Irradiation in HANARO
- HANARO and Capsule Including Alloy 690 Test Specimen for Neutron Irradiation
- 0.4T CT Tensile Test Specimen
- 0.4T Compact Tension Test Specimen
- Smart Steam Generator Winded With Helical Tubes
- Alloy 690 Test Specimen
- SG Tube Material (A690) Irradiation Test

RPV Dynamics & Canned Motor Pump Tests

SMART System-integrated Modular Advanced Reactor
Component Maintenance

**Insertion Test of ICI (In-Core Instrument)**
- ICI sensor Spec.
  - Dia.: 10.7 mm
  - Length: 18 m

**Real Path of In-Core Instrument**

**Insert Force Analysis of ICI**

**Eddy Current Sensor Spec.**
- Detector Dia.: 10.5 mm
- Length: 40 m

**Insert Force Analysis of Eddy Current Sensor**

**ISI (In-Service Inspection) Test Using Eddy Current Sensor**

**ISI Test Mock-up for Steam Generator**

---

**Top-mounted In-core Instrumentation**

**Helical SG In-service Inspection**