The Application of the Design Safety Requirements to the Passive SMART

Ji-Han Chun (Technical Coordination)
J.S. Song, H.O. Kang, and K.K. Kim

SMART Development

Technical Meeting on Challenges in the Application of the Design Safety Requirements for Nuclear Power Plants to Small and Medium Sized Reactors
4~8 September 2017, Vienna, Austria
Contents

- Introduction of Passive SMART
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  - Principal Technical Requirements
  - General Plant Design
  - Design of Specific Plant Systems
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Small Modular Reactors (SMR) offer Several Advantages
- Enable enhanced safety
  - Easier implementation of advanced safety features
  - Passive safety
- Suitable for small or isolated electrical grids
- Lower capital cost per unit
- Siting and co-generation flexibilities
- Short construction time

Potential Demand
- New Nuclear Countries: might be interested in starting with a SMR
- Replacement of Small Old Coal Power Plants
SMART System - integrated Modular Advanced ReacTor

365MWth Integral PWR
Electricity Generation, Desalination and/or District Heating

- Power: 365 MWt
- Water: 40,000 t/day
- Electricity: 100 MWe

Plant Data

- Electricity and Fresh Water Supply for a City of 100,000 Population
- Suitable for Small Grid Size or Localized Power System
Integral PWR SMART

- **365 MWt (~110 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
  - In-vessel Steam Generator
  - Canned Motor Pump

- **Inherent Safety**
  - Elimination of LB-LOCA by design
  - No core uncovery during SB-LOCA

- **Performance proved Fuel**
  - Standard 17x17 UO\(_2\) (< 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
Development of SMART

- **Standard Design Approval (July 4, 2012)**
  - 330MW
  - Hybrid Safety System (Active + Passive)
    - Active Safety Injection System
    - Active Containment Spray System
    - Passive Residual Heat Removal System
  - Basically Adopts Proven Technologies of Existing PWR
  - SMART-specific Technologies was Fully Validated

- **Enhancement of SMART Safety (2012~2016)**
  - Development of Full Passive System
    - Passive Safety Injection System
    - Passive Containment Cooling System
    - Passive Residual Heat Removal System
  - Validation Experiments for Passive Safety Injection System
SMART Pre-Project Engineering

- The 1st Step of ROK-KSA SMART Development Partnership
- Period of PPE: 3 years (Dec. 1, 2015 ~ Nov. 31, 2018)
- Task of PPE
  - Design of NSSS of 365MWt with Full Passive Safety System
  - Fuel Design
  - Balance of Plant Design
  - Design of Main Components
  - CPRSS Design
  - Preparation of Preliminary Safety Analysis Report
  - Human Capacity Build-up Program for K.A.CARE
  - Preparation for Construction of FOAK SMART Plant
## Design of Passive SMART (PPE)

<table>
<thead>
<tr>
<th>System</th>
<th>Hybrid SMART (SDA)</th>
<th>Passive SMART (PPE)</th>
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<tbody>
<tr>
<td>PRHRS</td>
<td>- passive, ≥36 hours w/o refill&lt;br&gt;- 50% x 4 trains : with single train failure</td>
<td>- passive, ≥72 hours w/o refill&lt;br&gt;- 33% x 4 trains : eliminate the single train failure by valve rearranging</td>
</tr>
<tr>
<td>* passive residual heat removal system</td>
<td></td>
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<tr>
<td>SIS</td>
<td>- active&lt;br&gt;- 100% x 4 trains&lt;br&gt;* electrically independent 2 trains, mechanically independent 4 trains</td>
<td>- passive, ≥72 hours w/o refill&lt;br&gt;- 33% x 4 trains (CMT &amp; SIT)&lt;br&gt;* electrically and mechanically independent 4 trains, gravity driven tanks (CMT &amp; SIT)</td>
</tr>
<tr>
<td>* safety injection system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Containment Pressure Protection</td>
<td>- active : CSS&lt;br&gt;- 100% x 2 trains&lt;br&gt;* CSS : containment spray system</td>
<td>- passive : CPRSS&lt;br&gt;* CPRSS : containment pressure and radioactivity suppression System</td>
</tr>
<tr>
<td>RCS Depressurization</td>
<td>- SDS&lt;br&gt;- 2 trains, controlled by operators&lt;br&gt;* SDS : safety depressurization system</td>
<td>- ADS&lt;br&gt;- 2 trains, automatically actuating valves under DBA&lt;br&gt;* ADS : automatic depressurization system</td>
</tr>
<tr>
<td>Emergency AC Power</td>
<td>- active, safety system&lt;br&gt;- 100% x 2 trains</td>
<td>- Not applicable&lt;br&gt;* non-safety DGs are equipped</td>
</tr>
</tbody>
</table>
Design of Passive SMART (PPE)
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- Application of the Design Safety Requirements to Passive SMART
  - Principal Technical Requirements
  - General Plant Design
  - Design of Specific Plant Systems
- Summary & Conclusion
Principal Technical Requirements

- SMART design ensures the regulations of Korea NSSC and applies Korean and International codes and standards
  - Prevention from Core Damage and Minimization of Radioactive Material Release into Public
  - Defense in Depth with Multiple Barriers and Multi Levels
Principal Technical Requirements

- SMART basically adopts proven technologies and fully validates SMART specific technologies
  - RPV Dynamics and Canned Motor Pump Tests
  - SG Tube Material Irradiation Test
  - FMHA Performance
  - Internal Pressurizer Performance and Level Measurement Test
  - RPV Flow Distribution Test
  - SG and PRHRS Heat Transfer Test ….

- Safety Analysis is conducted both with deterministic and probabilistic methodologies

- Provision for construction and operation take account of proven engineering and regulatory practices with over the last 50 years of reactor design and licensing for commercial NPP in Korea
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General Plant Design

- **Plant States**
  - Categories (10CFR50, NUREG0800)
    - Normal Operation
    - AOOs (Anticipated Operational Occurrences)
    - Design Basis Accidents
    - Design Extension Conditions

- **Initiating Events**
  - AOO
    - Those conditions of normal operation that are expected to occur one or more times during the life of the nuclear power plant
    - Fuel Cladding Integrity
      - Minimum DNBR > DNBR Limit
      - PLHGR < LHR Limit
    - System Integrity
      - System Maximum Pressure < 110% of Design Pressure
General Plant Design

- **Initiating Events**
  - **Postulated Accident**
    - Unanticipated occurrence (i.e., they are postulated but not expected to occur during the life of the NPP)
    - System Integrity
      - Maintain Coolable Core Geometry
      - System Maximum Pressure < 110% of Design Pressure
    - Radiological Release: Dose Limit < 10 CFR 100.11 Limit

- **Design Extension Conditions**
  - **New Accident Management Plan (NSSC)**
    - Management for Prevention and Mitigation of Severe Accident
    - Probability Safety Analysis
    - The sum of accident frequencies that the release of the radioactive material Cs-137 to the environment exceeds 100 TBq should be less than once per 1 million reactor-yr
Safety System

- Implementation of the principles for diversity, redundancy, and independency among systems and components against common cause failure.

- Single failure criteria are applied in the safety analysis for conservatism
  - Emergency Core Cooling: $33\% \times 4$ of PSIS for Single Failure
  - Residual Heat Removal: $33\% \times 4$ of PRHRS for Single Failure
  - Emergency Core Reactivity control: Considering N-1 Banks of CRDM in Safety Analysis for Conservatism

- Fail Safe Design Concepts
  - Dropping CRDM after Loss of Electric Power
  - Valve with Fail-Open or Fail-Close Concept
General Plant Design

- **SSCs classification**
  - NSSC No. 2016-10 (Regulation on Safety Classification and Applicable codes and Standards for Nuclear Reactor Facilities)
    - 10 CFR 50.55
  - Reactor Coolant Pressure Boundary Components
    - KEPIC MN, ASME Code Section III
  - Application of RTNSS
General Plant Design

- Technical Specification (Ch 16 of SAR)
  - Safety Limits
  - Limiting Settings for Safety Systems
  - Set of Operational Limit and Conditions
  - Control System Constraints and Procedural Constraints on Process Variables and Other Important Parameters
  - Requirements for Surveillance, Maintenance, Testing and Inspection of the Plant to Ensure SSCs Functions
General Plant Design

- **Qualification and Reliability**
  - Requirements for EQ is Based on
    - IEEE Standard IEEE-323
    - American IEEE Standard IEEE-627
  - Safety systems are periodically inspected and tested to confirm their operation. (Quality and Reliability Assurance, Ch 17 of SAR)

- **Human Factors**: Full-Scope Dynamic Mockup (FSDM) for MCR

- **Other Design Considerations**
  - No Common Safety Systems to Cause Failure in Multi-Units
  - Physical Security Systems: 10 CFR Parts 73, 73.55

- **Safety Analysis**
  - Deterministic Safety Analysis Using Limiting Accident Conditions
  - Probability Safety Analysis: Event Classification, Identification of Weak Point of Design, Using in RTNSS...
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Design of Specific Plant Systems

- Reactor Core
  - Proven 17 x 17 UO$_2$ Ceramic Fuel
  - 57 Fuel Assemblies
  - Reactivity Control
    - Control Rod Driven Mechanism
    - Soluble Boron
    - Burnable Poison
  - Sufficient Margin
    - Satisfied within Specified Acceptable Fuel Design Limit (SAFDL) during DBA
      - Maintain Coolable Geometry
Design of Specific Plant Systems

- Reactor Coolant Systems
  - Integral Primary System with No Large RPV Penetrations
    - Elimination of LBLOCA
  - Canned Motor Pump without RCP Seal
    - Elimination of SBLOCA from Seal Failure
  - Pressurizer Safety Valves Installed on Top of RHA connected to IRWST
    - Overpressure Protection of Reactor Coolant Boundary
  - Chemical and Volume Control System
    - Maintain Required Volume of Water in RCS
    - Remove Noble Gas and Add Chemicals for Primary Coolant Chemical Control
Design of Specific Plant Systems

- **Reactor Coolant Systems**
  - **Passive Residual Heat Removal System**
    - Remove the RCS heat (residual and sensible heat) to achieve and maintain the safe shutdown condition mainly for non-LOCA design basis events.
    - The temperature of the RCS shall be lower than that of safe shutdown condition within 36 hours after an accident occurrence and maintain this state until at least 72 hours after accidents even without the aid of operator or AC power.
    - Safety class: 2
    - Seismic category: I
    - Electric class: class 1E / valves
Design of Specific Plant Systems

- **Reactor Coolant Systems**
  - **Passive Safety Injection System**
    - Safety injection using gravity to prevent core uncovery in case of a loss-of-coolant accident (LOCA) by CMTs & SITs
    - Independent 4 trains: CMT, SIT, PBL, SIL, Valves, Instruments
    - The RCS water level shall be maintained above top of core for a minimum of 72 hours after LOCA even without AC power or operator action.
    - Safety class: 1(CMT), 2(SIT)
    - Seismic category: I
    - Electric class: class 1E / valves
Design of Specific Plant Systems

- **Reactor Coolant Systems**
  - **Automatic Depressurization System**
    - Depressurization of RCS for SBLOCA
    - Depressurization of RCS for TLOSHR (Total Loss of Secondary Heat Removal)
      - Feed : PSIS
      - Bleed : ADS
    - Independent 2 trains : Lines, Valves, Sparger, Instruments
    - Safety class : 1~2
    - Seismic category : I
    - Electric class : class 1E / valves
Design of Specific Plant Systems

- **Containment Structure and System**
  - **Containment Pressure and Radioactivity Suppression System**
    - Suppression of Pressure/Temperature and Radioactive Material Release in Containment for a minimum of 72 hours after DBA even without AC power or operator action.
    - CPRSS Lid, LCA, Pressure Relief Line, Sparger, IRWST, IRWST Vent Line, Iodine Filter, ECTHS (HX, Steam & Return Line, Valve)
    - Safety class : 2
    - Seismic category : I
    - Electric class : class 1E / valves
  - **Structural Integrity** : AIA, H₂ Combustion
  - **Containm. Isolation Sys.** : Automatic and Leaktight Closure of Valves for All Penetrations
Design of Specific Plant Systems

- **Instrumentation and Control System**
  - **Provision of Instrumentation**
    - PAMI (Post-Accident Monitoring Instrumentation) : Monitoring Instruments, Equipment, and Systems Providing Automatic Action During Accidents
    - RG 1.97 “Instrumentation for Light-Water-Cooled Nuclear Power Plant to Assess Plant and Environs Condition During and Following an Accident”
  - **Control System**
    - Regulating System : Control Reactor Power, Control Rod and Reactor Power Cutback System
    - Process Control System : Control Pressure and Level of Pressurizer
    - Secondary Control System : Control Feedwater Flow, Steam Bypass and Turbine System
    - Software Quality Assurance : 10 CFR Part 50
Design of Specific Plant Systems

- **Instrumentation and Control System**
  - **Protection System**
    - RPS (Reactor Protection System)
      - Automatic Initiation of Reactor Trip
      - Automatic Actuation of ESFAS (Engineered Safety Features Actuation System)
    - 4 Channels of Safety Related Equipment
  - **Software Program Manual**
Design of Specific Plant Systems

- **Power Conversion System**
  - **Main Steam and Feedwater System**
    - 8 Helical Once-through Steam Generators
    - 4 trains
      - Main Steam Isolation Valves, Feedwater Isolation Valves
  - **Turbine Generator**
    - Controlled by Turbine Control and Safety System
      - Overspeed Protection, Speed and Load Control, Turbine Trip by Closing the Turbine Stop Valves and Control Valves

- **Treatment of Radioactive Effluents and Radioactive Waste**
  - **Liquid Waste Management System**
  - **Gaseous Waste Management System**
  - **Solid Waste Management System**
  - **Area Radiation Monitoring and Sampling System**
Design of Specific Plant Systems

- Radiation Protection
  - Design of Radiation Protection
    - Limitation of Radiological Exposure to Plant Personnel and General Public with Korean Regulations
    - Provisions of Room Shielding, Personal Plant Shielding, Ventilation Features, Airborne Radioactivity Monitoring, Radiation Shielding to Protect General Public
  - Area Radiation Monitoring and Sampling System
    - Measurement, Record, Control for Release of Radioactive Materials
      - Routine Operational Radiation Release
      - Equipment or Component Failure
      - System Malfunction and Misoperation
      - Potential Radiological Hazards to Plant Personnel or to the Public
Design of Specific Plant Systems

- Emergency Power Supply
  - Safety Systems: Four Independent Channels of Class 1E 125V Battery Systems
  - Non-safety Systems: Two Non-Class 1E Onsite Standby Diesel Generator

- Auxiliary Systems
  - Fuel Handling System
  - Essential Service Water System
  - Compressed Air System
  - Chemical and Volume Control System
  - HVAC System
  - Fire Protection System
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Summary & Conclusion

- Full Passive SMART is being Designed for Construction in Kingdom of Saudi Arabia

- Design Safety Requirements Proposed by IAEA are Fully Applied in the Design of Passive SMART
Thank You for Attention