US-APWR

5th Pre-Application Review Meeting
Severe Accident Treatment and Mitigation Overview

March 1, 2007

Mitsubishi Heavy Industries, Ltd.

Meeting Attendees

Makoto Toyama[(1)] (Responsible for Safety Analysis for US-APWR)
General Manager of Reactor Safety Engineering Department

Katsunori Kawai[(1)] (Coordinator of Safety Analysis for US-APWR)
Leader of Safety and Licensing Integration Group

Hiroshi Goda[(1)] (Representative of Severe Accident Analysis) –Presenter–
Engineer of Safety and Licensing Integration Group

Dr. John H. Bickel[(2)] (Technical Adviser for Severe Accident Analysis)

(1) Reactor Safety Engineering Department
Nuclear Energy Systems Engineering Center
Mitsubishi Heavy Industries, LTD.

(2) Talisman International, LLC.

Severe Accident Meeting Plan

- Two (2) meetings are planned to discuss severe accident related subjects
  1. Severe Accident Treatment and Mitigation Overview (this meeting)
     - ✓ Describe the US-APWR technical approach to address severe accidents
     - ✓ Describe the US-APWR design features credited for severe accident mitigation
     - ✓ Discussed separately from PRA topic to address NRC's interest in this subject
  2. Severe Accident Analysis Methodology (2nd meeting, planned to be held in June 2007)
     - ✓ Present the severe accident analysis methodology and the effectiveness of US-APWR design features
     - ✓ To further discuss the topic of the 1st meeting

Severe Accident Submittal Plan

- Severe accident related issues will be addressed as a part of Probabilistic Risk Assessment (PRA) and documented in Design Control Document (DCD) and PRA Report
- A Topical Report on severe accident issues is not anticipated at this stage

Objectives of Meeting

- Acquaint the NRC with MHI's general approach to address severe accidents
  - ✓ Technical approach
  - ✓ Design features for severe accident mitigation
- Obtain NRC's feedback
  - ✓ On MHI's approach
  - ✓ Any comments or questions on MHI's strategy
  - ✓ Planned changes to NRC guidance and requirements

Discussion Outline

1. Definition of severe accident
2. Motivation for addressing severe accidents
3. NRC policy and regulations for severe accident mitigation issues on new reactors
4. MHI interpretation of NRC requirements
5. Identification of severe accident phenomena to be addressed in US-APWR design
6. US-APWR design features for severe accident mitigation
7. Conclusions
8. Discussion

1. Definition of Severe Accident

- **Class of accidents beyond the design basis which result in core damage**
- **May occur if plant conditions significantly exceed the design basis limits, such as:**
  - Fuel or cladding melting
  - RCS pressure boundary stress
  - Containment pressure loads
  - Design basis radiological release

2. Motivation for SA Treatment

- **Position of severe accident treatment in the licensing process for a Design Certification**
  - ✓ Risks to the public are primarily due to severe accidents, as opposed to design bases accidents
  - ✓ Reduction of frequency and consequences of severe accidents directly reduces risks to the public
  - ✓ Severe accidents involve phenomena beyond the design basis
  - ✓ US-APWR design features address severe accident issues to enhance plant safety

3. NRC SA Policy and Regulations

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- NRC has issued policy statements and regulations regarding severe accident mitigation for new reactors
  - ✓ 50FR32138: Policy statement on severe accidents regarding future designs and existing plants
  - ✓ 10CFR52.47: Contents of applications, paragraph (a)(1)
  - ✓ 10CFR50.34: Contents of applications; technical information, paragraph (f) Additional TMI-related requirements
  - ✓ 10CFR50.44: Combustible gas control for nuclear power reactors, paragraph (c) Requirements for future water-cooled reactor applicants and licensees

4. MHI Interpretation of NRC Requirements

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- MHI's interpretation of NRC's severe accident policy statement and regulations:

(1) Demonstrate compliance with current Commission regulations including TMI requirements 10CFR50.34(f)

(2) Demonstrate technical resolution of the applicable unresolved safety issues (USI), and the medium and high-priority generic safety issues (GSI)

(3) Develop an appropriate PRA

(4) Submit DC application for staff review

5. Identification of SA Phenomena

➤ **Eight (8) severe accident issues identified for US-APWR**

(1) Hydrogen Mixing and Combustion
(2) Core Debris Coolability
(3) Steam Explosion (In- and Ex-vessel)
(4) High Pressure Melt Ejection and Direct Containment Heating
(5) Temperature Induced Steam Generator Tube Rupture
(6) Molten Core Concrete Interaction
(7) Early and Late Containment Overpressure failure
(8) Equipment Survivability

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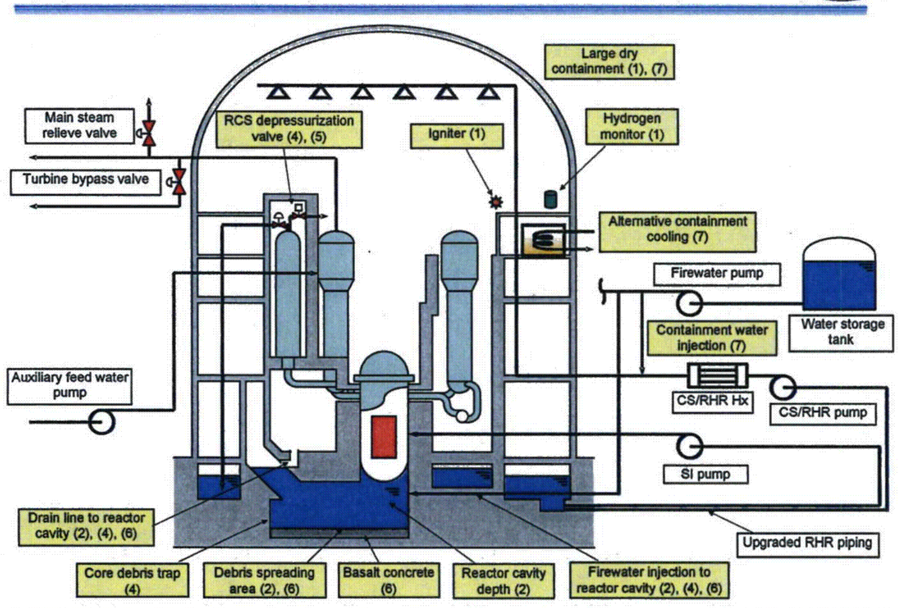
6. Design Features for SA Mitigation



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6. Design Features for SA Mitigation

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- **US-APWR Design Concept for Severe Accident Mitigation**
  - ✓ Wet reactor cavity for debris cooling
    - Provide reliable cavity flooding
    - Provide cavity floor area sufficient for debris spreading and quenching
    - Challenge by steam explosion can be limited and acceptable
  - ✓ In-vessel core retention is uncertain
    - Consider recovery of partially damaged core by late injection
    - Debris cooling by external vessel cooling is currently not credited
  - ✓ Component classification
    - Safety and non-safety grade components are used for severe accident mitigation

6. Design Features for SA Mitigation

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(1) Hydrogen Mixing and Combustion

- Enhance containment atmosphere mixing and avoid combustible gas accumulation
  - ✓ Large dry containment
    - Widely acknowledged having good ability for containment atmosphere mixing
    - Provide adequate strength to contain most hydrogen burns
- Control combustible gas to prevent deflagration/ detonation
  - ✓ Igniters
    - Proven technique for combustible gas control
    - Advantages such as no poisoning, good capability to control combustible gas (amount and speed), compact, easy to maintain, etc
    - MHI has experience to employ this device
  - ✓ Hydrogen monitor

6. Design Features for SA Mitigation

(2) Core Debris Coolability

- Flood reactor cavity with high reliability
  - ✓ Diverse reactor cavity flooding system
    - Drain line to reactor cavity
    - Firewater injection system to reactor cavity
- Enhance fragmentation for debris coolability
  - ✓ Appropriate reactor cavity depth
    - Enhance melt break-up and debris bed formation
- Enhance spreading on cavity floor for debris coolability
  - ✓ Sufficient reactor cavity floor area for debris spreading
    - Analytically demonstrate that the floor area is sufficient for debris cooling

6. Design Features for SA Mitigation

(3) Steam Explosion

(In-vessel)

- ✓ Probabilistic consideration from previous research
  - Very low probability of alpha-mode failure, such as 10^{-4} (NUREG-1524) is widely recognized
  - Evaluate applicability of NUREG-1524 conclusions to US-APWR
  - Specific mitigation features are not anticipated at this time

(Ex-vessel)

- ✓ Analytical consideration
  - Examine previous studies for occurrence probability, boundary conditions, etc (for example NUREG-1150)
  - If appropriate, evaluate containment loads and integrity. Demonstrate that the failure probability is acceptable
  - Specific mitigation features are not anticipated at this time

6. Design Features for SA Mitigation

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(4) High Pressure Melt Ejection (HPME) and Direct Containment Heating (DCH)

- ➢ Reduce RCS pressure to avoid HPME and DCH
  - ✓ RCS depressurization valve
    - HPME and DCH are negligible if RCS pressure is low
    - Provide dedicated valves for severe accident
- ➢ Enhance core debris cooling by cavity water
  - ✓ Diverse reactor cavity flooding system
    - Drain line to reactor cavity and firewater injection system
- ➢ Reduce amount of core debris going out from cavity to containment atmosphere
  - ✓ Core debris trap
    - Enhanced capturing of ejected molten core in cavity

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6. Design Features for SA Mitigation

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(5) Temperature Induced Steam Generator Tube Rupture (TISGTR)

- ➢ Evaluate applicability of existing data on TISGTR to US-APWR
  - ✓ TISGTR competes with hot leg creep rupture, surge line creep rupture and vessel melt-through
  - ✓ Previous analyses have shown TISGTR to be the least likely failure mode by a large margin
- ➢ Reduce RCS pressure to further reduce likelihood of TISGTR
  - ✓ RCS depressurization valve
    - Creep rupture more likely at high temperature and pressure
    - Provide dedicated valves for severe accident

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6. Design Features for SA Mitigation

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(6) Molten Core Concrete Interaction (MCCI)

- Enhance ex-vessel debris coolability as discussed under (2) Core Debris Coolability
- Protect containment boundary
  - ✓ Basalt concrete reactor cavity floor
    - Protection against challenge of containment liner due to short term MCCI during debris spreading and quenching

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6. Design Features for SA Mitigation

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(7) Long Term Containment Overpressure

- Provide sufficient capability to withstand pressure and temperature
  - ✓ Large dry containment
    - Provide sufficient strength to delay long term overpressure failure at elevated temperature due to generation of steam or non-condensible gases
- Provide containment cooling for decay heat removal
  - ✓ Alternative containment cooling
    - Utilize containment recirculation cooling unit
    - Supply CCW to the cooling unit and enhance condensation of surrounding vapor
  - ✓ Water injection to spray header by firewater pump
    - Delay containment failure (no cooling)

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6. Design Features for SA Mitigation

(8) Equipment Survivability

- Assure containment maintains structural integrity under most hydrogen burn conditions
  - ✓ Analytical demonstration of equipment capability
    - Analytically demonstrate that the combustible gas control maintains containment conditions within the capability of needed equipment inside containment

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7. Conclusions

- DCD and PRA report will cover the complete scope of severe accident assessment
- US-APWR design features consider severe accident challenges and satisfy regulatory requirements
- US-APWR design features for severe accident mitigation rely on known methods and principles
- Severe accident analysis methodology and the effectiveness of US-APWR design features will be discussed in future interactions with NRC

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8. Discussion

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- Are there any NRC comments or questions on MHI severe accident mitigation strategies?
- Are there any planned changes to NRC requirements and guidance?
- Are changes planned to DG-1145 relative to severe accidents and PRA?

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