US-APWR

6th Pre-Application Review Meeting
Small Break LOCA Methodology

March 22, 2007

Mitsubishi Heavy Industries, Ltd.

Meeting Attendees

Makoto Toyama (Responsible for Safety Analysis for US-APWR)
General Manager
Reactor Safety Engineering Department
Nuclear Energy Systems Engineering Center
Mitsubishi Heavy Industries, LTD.

Shigemitsu Umezawa (Responsible for LOCA methodology development)
Engineering Manager
Reactor Safety Engineering Department
Nuclear Energy Systems Engineering Center
Mitsubishi Heavy Industries, LTD.

Michitaka Kikuta (Responsible for LOCA Analysis for US-APWR) –Presenter–
Engineering Manager
Safeguard System Engineering Section
Nuclear Energy Systems Engineering Center
Mitsubishi Heavy Industries, LTD.

Objectives of Meeting

➤ **The purpose of the meeting is to:**

- ✓ Present information to the NRC on the scope of the proposed topical report on " Methodology for the US-APWR Small Break LOCA Analysis" to ensure the NRC's expectations for the topical report are met
- ✓ Provide an opportunity for the NRC to explain its process, schedule, expectations, and provide feedback to MHI

Presentation Summary

1. **Appendix-K version of M-RELAP5 code, modified version of RELAP5-3D, will be used for US-APWR small break LOCA analysis**
2. **US-APWR design features to be evaluated for applicability of code have been identified and discussed**
   - ✓ **New design**
     - Advanced Accumulator
   - ✓ **Improved design**
     - Direct Vessel Injection (DVI) for Safety Injection Pump
     - Neutron Reflector (NR)
     - Refueling Water Storage Pit (RWSP)
     - Model 100A Reactor Coolant Pump (RCP)
3. **Performance of M-RELAP5 code will be confirmed using small-break separate and integral effects test results**

US-APWR Plant Parameter Summary (1)

➢ Plant class of US-APWR

Features	US-APWR	US Current 4 Loop Plant
Core thermal output (MWt)	4,451	3,565
Number of loops, SGs and RCPs	4	4
Number of fuel assemblies	257	193
Fuel rod lattice	17 x 17	17 x 17
Active fuel length (ft)	14	12
Average linear heat rate (kW/ft)	4.6	5.7
Reactor coolant pump type	Centrifugal	Centrifugal
Design of steam generators	U-Tube	U-Tube
Refueling Water Storage Pit location	Inside CV	Outside CV

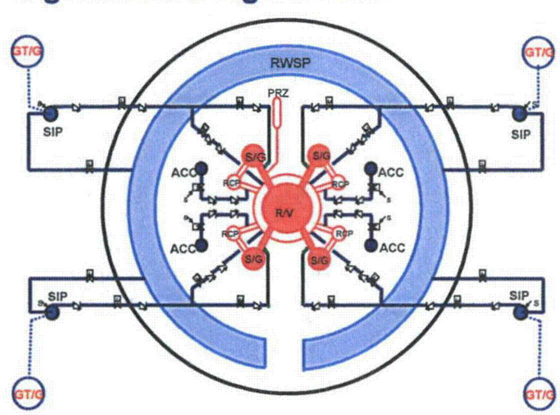
➢ US-APWR ECCS Component Configuration

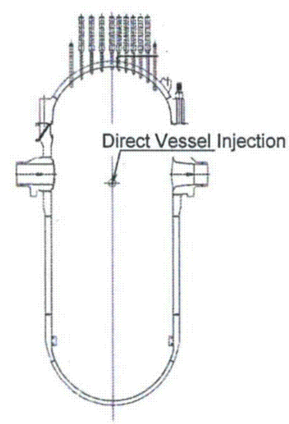
✓4 accumulators with flow damper (Advanced Accumulator)
✓4 safety injection pumps
✓Refueling Water Storage Pit (RWSP)

MITSUBISHI HEAVY INDUSTRIES, LTD. UAP-HF-07033-4

US-APWR Plant Parameter Summary (2)

- ➢ Four Advanced Accumulators: cold leg injection
- ➢ Four safety injection pumps: Direct Vessel Injection(DVI)
- ➢ DVI nozzle is located below elevation of centerline of hot-leg and cold-leg nozzles

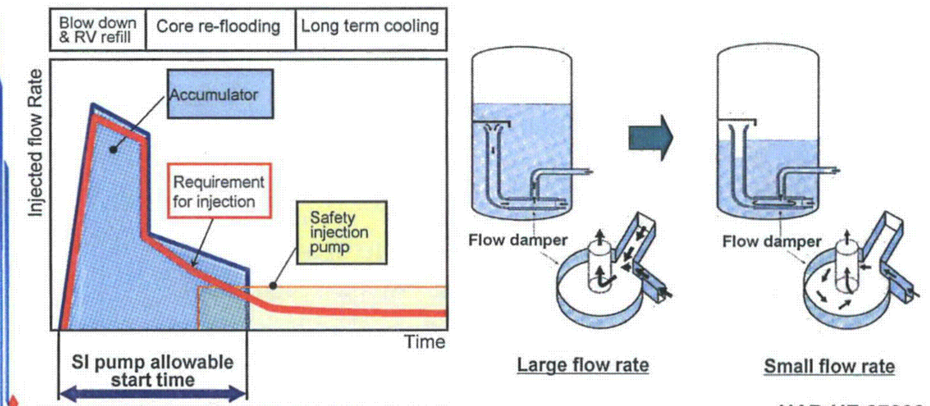




MITSUBISHI HEAVY INDUSTRIES, LTD. UAP-HF-07033-5

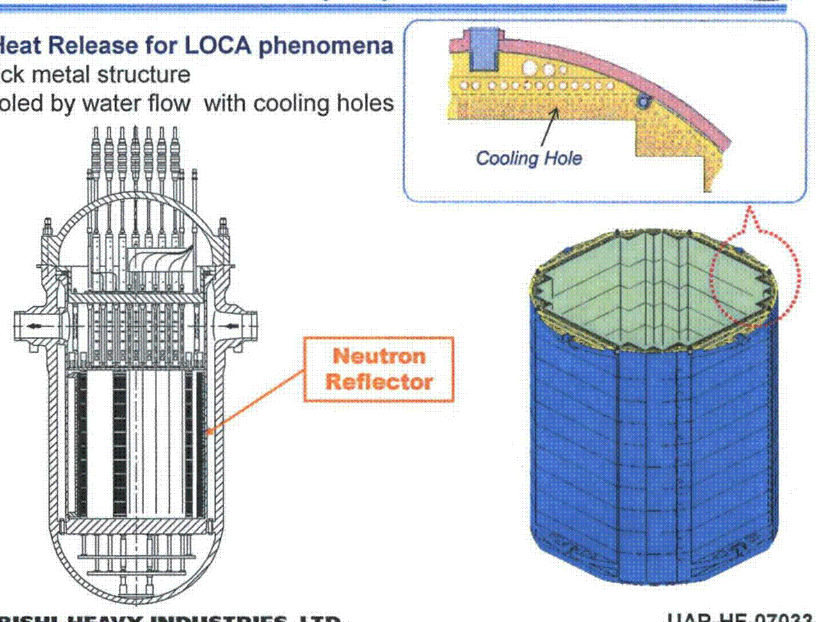
New Features of US-APWR
Advanced Accumulator

- Automatic switching of injection flow rate by flow damper
- Integrated function of low head injection system
- Long-lasting injection of ACC allows additional time for safety injection pump to start



New Features of US-APWR
Neutron Reflector (NR)

- Metal Heat Release for LOCA phenomena
  - ✓ Thick metal structure
  - ✓ Cooled by water flow with cooling holes



Appendix-K version of M-RELAP5 code

US-APWR

- M-RELAP5 code is modified version of RELAP5-3D which has multi-dimensional thermal hydraulic and kinetic modeling capability
- MHI will use one-dimensional modeling with M-RELAP5 for US-APWR small break LOCA analysis
- This is equivalent to RELAP5/MOD3.2
- M-RELAP5 will incorporate 10CFR50.46 Appendix-K requirements
- M-RELAP5 will be applied to LOCA analysis with break size less than 1.0ft^2

Appendix-K compliant models (1)

US-APWR

- **Models to be incorporated into M-RELAP5 code**

  A. Source of Heat during LOCA
  - Fission Product Decay : ANS-1971 x 1.2 decay curve
  - Metal-Water Reaction Rate: Baker-Just correlation (not steam limited)

  B. Swelling and Rupture of the Cladding and Fuel Rod Thermal Parameters
  - ZIRLO™ high temperature creep model and burst model will be incorporated
  - Influence of cladding swell on core flow blockage will be incorporated

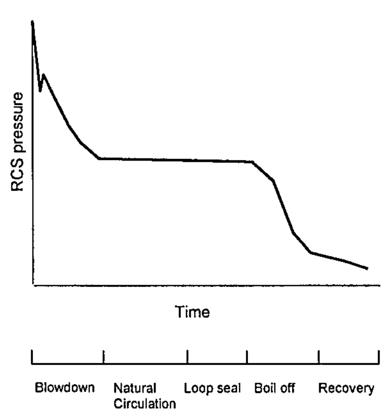
Appendix-K compliant models (2)

➢Models to be incorporated into M-RELAP5 code

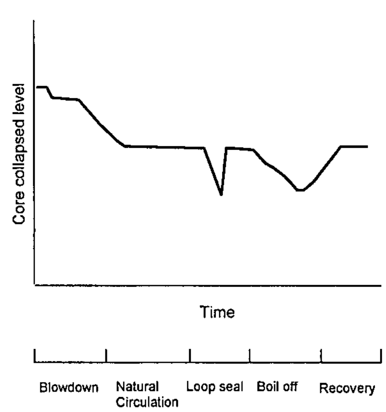
C. Blowdown Phenomena

- Discharge Model:
  - Henry-Fauske Model (Quality<0.1) and Moody model (Quality>0.1)
- Critical Heat Flux and Post-Critical Heat Flux:
  - Prevention of return to nucleate and transition boiling heat transfer modes for initial blowdown phase

Small Break LOCA Scenario



RCS pressure during small break LOCA
(Cold leg break case)



Core collapsed level during small break LOCA
(Cold leg break case)

Small Break LOCA PIRT (1)

➢ Small Break LOCA PIRT* for US-APWR design features

Process	Phenomena	Ranking				
		Blow down	Natural circulation	Loop seal	Boil-off	Recovery
Accumulator: •Injection Flow rate	Resistance coefficient changes according to accumulator water level, thereby affects the injection flow rate	N/A	N/A	N/A	N/A	H
Direct Vessel Injection: •condensation	Potential to affect condensation phenomena in downcomer	N/A	L	L	M	L
RWSP in the CV: •safety injection water temperature	SI water temperature will rise following a break	N/A	L	L	L	L

*PIRT : Phenomena Identification and Ranking Table

(H: High, M: Medium, L: Low)

Small Break LOCA PIRT (2)

➢ Small Break LOCA PIRT for US-APWR design features

Process	Phenomena	Ranking				
		Blow down	Natural circulation	Loop seal	Boil-off	Recovery
Neutron Reflector: •metal heat release	Heat release may affect core mixture level	L	L	L	L	L
•core bypass flow	NR flow rate may affect core flow rate	L	L	L	L	L
100A RCP: •two-phase performance	Two-phase performance may affect core flow rate	L	L	L	L	L

(H: High, M: Medium, L: Low)

Small Break LOCA PIRT (3)

➢ **Small Break LOCA PIRT high-ranked phenomena considered for code performance evaluation**

Process	Phenomena	Ranking				
		Blow down	Natural circulation	Loop seal	Boil-off	Recovery
Core: •Two-phase mixture level	Mixture level directly affects heat transfer in uncovered portion of core	M	M	H	H	H
Steam generator: •Water holdup inlet plenum	Water holdup in steam generator inlet plenum affects core level through static water head	L	M	H	L	L
•Water holdup in uphill side U-tubes	Water holdup in U-tube affects core level through static water head	L	M	H	L	L

(H: High, M: Medium, L: Low)

New Features of US-APWR Advanced Accumulator

➢ Phenomena Identification and Ranking

✓ Injection Flow Rate

- Resistance coefficient changes according to accumulator water level, thereby affects the injection flow rate
- Ranked "N/A" for early periods and "Low" only for the recovery period
- Ranked "High" for recovery period for medium size break

➢ Code Applicability

✓ Empirical correlations are incorporated into M-RELAP5 to model Advanced Accumulator characteristics

New Features of US-APWR Direct Vessel Injection (DVI)

➢ Phenomena Identification and Ranking

✓ Condensation phenomena

- Potential to affect condensation phenomena in downcomer
- Condensation phenomena ranked as "Low", because DVI would be initiated when downcomer water level is high, "Medium" when downcomer water level is low

➢ Code Applicability

✓ Modeling of injection region

- M-RELAP5 is able to model DVI injection region with "Branch Component"

MITSUBISHI HEAVY INDUSTRIES, LTD. UAP-HF-07033-16

New Features of US-APWR Refueling Water Storage Pit (RWSP)

➢ Phenomena Identification and Ranking

✓ Safety injection water temperature

- Following a break, RWSP water temperature will rise, because ECCS switchover from an external refueling water storage tank is not employed
- Ranked as "Low", because the temperature rise would be small

➢ Code Applicability

✓ M-RELAP5 is able to model safety injection water temperature as boundary condition

MITSUBISHI HEAVY INDUSTRIES, LTD. UAP-HF-07033-17

New Features of US-APWR
Neutron Reflector (NR)

➢ Phenomena Identification and Ranking

- ✓ Metal Heat Release from NR and bypass flow through NR cooling holes may affect core mixture level
- ✓ Ranked as "Low", because the metal heat release would be small at high temperature during small LOCA
- ✓ Ranked as "Low", because the NR flow rate is small compared to core flow rate

➢ Code Applicability

- ✓ M-RELAP5 is able to model NR as separate channel with heat structure

New Features of US-APWR
Model 100A RCP

➢ Phenomena Identification and Ranking

- ✓ Pump two-phase performance is ranked:

  "Low" because RCPs trip on "Safety Injection Initiation Signal" early in transient

➢ Code Applicability

- ✓ Pump two-phase performance obtained by Westinghouse 1/3 scale test data will be used for M-RELAP5 calculation

M-RELAP5 Small Break Model Performance (1)

- **M-RELAP5 Modeling for small break LOCA will consider the following phenomena**
  - ✓ Core mixture Level
  - ✓ SG primary side water holdup
- **Separate and Integral effects test results for high and medium ranked phenomena will be compared with M-RELAP5 calculations**
- **Appendix-K requirements provide overall conservatism**

M-RELAP5 Small Break Model Performance (2)

- **Core mixture level**
  - ✓ **Core mixture level directly affects peak cladding temperature (PCT)**
  - ✓ **Code modeling confirmation**
    - M-RELAP5 interfacial friction model will be confirmed to reproduce ORNL Void Profile test results

M-RELAP5 Small Break Model Performance (3)

US-APWR

- **SG primary side water holdup**
  - ✓ **Water holdup(CCFL) at the inlet of SG plenum and U-tubes affects core level behavior**
  - ✓ **Code modeling confirmation**
    - M-RELAP5 CCFL model will be confirmed to reproduce UPTF full-scale SG plenum CCFL test results (tentative)
    - M-RELAP5 CCFL model will be confirmed to reproduce Dukler Air-Water Flooding test results

MITSUBISHI HEAVY INDUSTRIES, LTD. UAP-HF-07033-22

M-RELAP5 Small Break Model Performance (4)

US-APWR

- **Confirmation of integral system behavior based on integral test results**
  - ✓ **M-RELAP5 calculated results will be compared with experimental test data for:**
    - **ROSA-IV/LSTF small break LOCA test (SB-CL-18)**
    - **Additional Tests to be determined**
  - ✓ **M-RELAP5 performance including core mixture level and CCFL in the steam generators will be assessed for the small break LOCA transient**

MITSUBISHI HEAVY INDUSTRIES, LTD. UAP-HF-07033-23

Others
Fuel Rod Model (FINE*)

- **US-APWR fuel type (UO_2 pellet, 17x17, ZIRLO™ cladding) is same as used for conventional Westinghouse PWRs**
- **ZIRLO™ cladding model will be incorporated into M-RELAP5**
- **Fuel thermal conductivity degradation is adjusted as a function of burnup using the same model as in fuel design code "FINE"**
  - ✓ Fuel initial temperature and uncertainty (stored energy) will be calculated by fuel design code

* FINE will be discussed in the fuel topical report to be submitted in May 2007

Contents of Topical Report

- **Methodology**
  - ✓ Code description
    - Basis for M-RELAP5 Code
    - Appendix-K modeling
    - US-APWR design modeling
- **Code performance**
  - ✓ Comparison with separate/integral effects test results
- **Sample Calculation for US-APWR**
- **Appendices**
  - ✓ US-APWR small break LOCA PIRT
  - ✓ M-RELAP5/RELAP5-3D Code and Model Differences

Summary

- Appendix-K version of M-RELAP5 will be used for US-APWR small break LOCA analysis
- US-APWR design features needing evaluation have been identified and M-RELAP5 modeling capability will be confirmed
- Performance of M-RELAP5 code will be confirmed using small-break separate and integral effects test results
- Topical Report on small LOCA methodology for US-APWR will be submitted by the end of July, 2007