International Experts' Meeting on Assessment and Prognosis in Response to Nuclear or Radiological Emergency (IEM9)

Post-accident Monitoring in Pressurized Heavy Water Reactor NPPs

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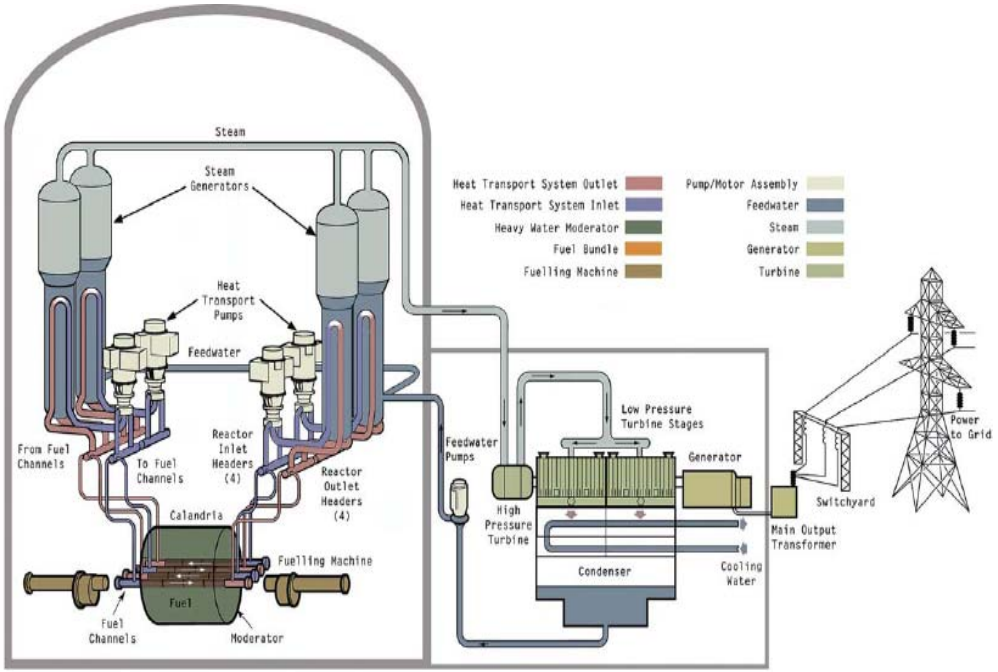
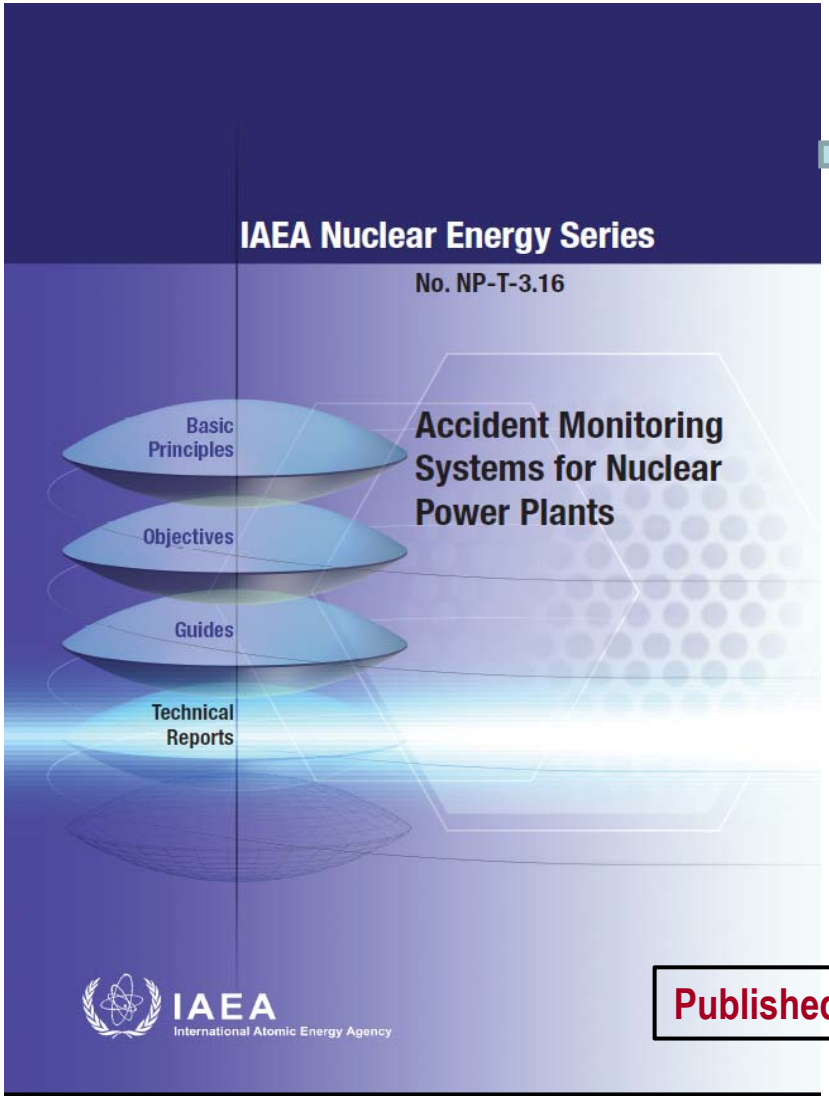


Introduction



- Provides a comprehensive overview of instrumentation for monitoring accident conditions in land based stationary nuclear power plants

- ✓ ANNEX II: POST-ACCIDENT MONITORING IN PRESSURIZED HEAVY WATER REACTOR NUCLEAR POWER PLANTS - CANDU 6

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Introduction

❑ CANDU 6 in Korea

❍ 4 Units in Operation

- Wolsong #1 - 1983
- Wolsong #2,3,4 – 1997, 1998, 1999

Shin-Hanul
2 units

Hanul
6 units

Shin-Wolsong
2 units

Wolsong
4 units

CANDU-6s

Shin-Kori
4 units

Kori
4 units

Hanbit
6 units

In Operation Under Construction

※ Source : KHNP, Jan 2014

CANDU 6s in Wolsong

Introduction

❑ PAM(Post-Accident Monitoring) in CANDU 6

❍ Goal = Provide information for Operators to:

- Assess plant conditions during and after an accident
- Confirm safety system's protective and mitigative actions
- Determine the appropriate operator actions to be performed, including initiation of the off-site emergency procedures

❍ How to achieve this goal ? - strategy

- PAM is not an independent system

Maximum use of Various instruments of Process, Safety, and Safety-related systems + **Additional Instruments**

MCR + SCA 

*SCA: Secondary Control Area

Introduction

❑ Functions of PAM Instruments in CANDU

❍ Provide information

- For verification of Rx shutdown, Rx heat removal, and radiation release barrier protection
- To MCR and SCA for monitoring and evaluation of accident by operators

❍ Provide annunciation

- To ensure the support of required operator actions
- To make an early warning of the accident progress

❍ Meet Regulatory Guide

- CSA N290.6, "Requirements for Monitoring and Display of CANDU Nuclear Power Plant Station in the Event of Accident"

⇨ **Equivalent to IEEE std. 497**
"Criteria for Accident monitoring Instrumentation for Nuclear Power Generating Stations"

Code and Standards

❑ Regulatory Requirements of Canada

❍ CSA N290.6 (1982, R2009):

- Design Standards endorsed by Canadian Regulator(CNSC: Canadian Nuclear Safety Commission, former AECB)
- Provides requirements for design, testing, and EQ for the display during an accident
- Includes parameter selection, design requirements, documentation, and QA, etc.

❍ RD-337: Design of New Nuclear Power Plants

- 7.9.1(General of I&C), 7.9.3 (Post-accident Instrumentation)
  - Requires to provide essential information during/following accidents

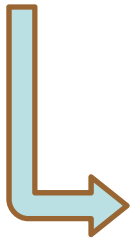
⇨ Korean RG 8.8 : "Instrumentation for Monitoring during and after an accident" — RG-1.97

Korean Standard KEPIC ENB-6330 : "Design of an Instrumentation System for Accident Monitoring" — IEEE std. 497

*EQ: Equipment Qualification

Design Bases

- What things should be basically considered to implement PAM ?
  - Initiating events/accidents to be monitored
  - Safety systems to protect or limit the accidents
  - Operator actions to be conducted during accident
  - Plant characteristics and associated parameters



Bases for

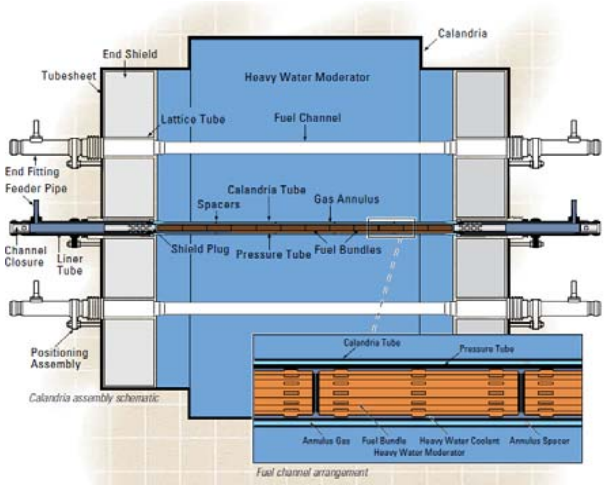
Parameter selection,
Design,
Testing,
Equipment Qualification,
Installation,
Display,
Location,
etc.

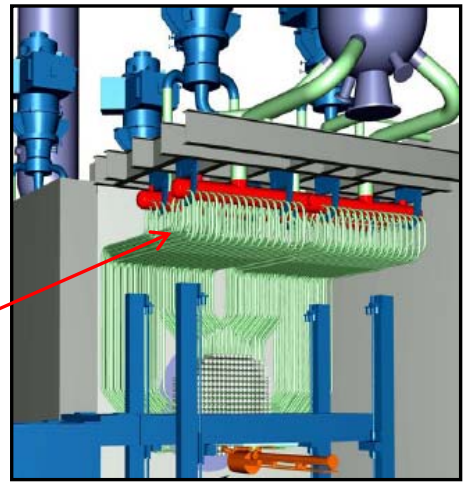
Design Bases

❑ DBA(Design Basis Accidents)

→ Events for which PAM is required

- LOCA + (Loss of Emerg. Core Cooling)
- Loss of FW(Feedwater)
- MSLB
- Loss of Class IV Electric Power
- DBE
- LOCA + SDE
- Single Fuel Channel Accident or small LOCA
  - Feeder Stagnation Break
  - Pressure Tube Rupture
  - Channel Flow Blockage
  - End Fitting Failure





Feeder Pipes

※ Source : AECL

*LOCA: Loss of Coolant Accident
*MSLB: Main Steam Line Break
*SDE: Site Design Earthquake
*DBE: Design Basis Earthquake

Design Bases

❑ Safety, Safety-related Systems credited in FSAR

→ System status to be monitored during accidents

- ❍ Shutdown System #1, #2 (SDS1, SDS2)
- ❍ Emergency Core Cooling System (ECCS)
- ❍ Containment System

Special Safety Systems

- ❍ Emergency Water Supply (EWS) System
- ❍ Emergency Power Supply (EPS) System
- ❍ Class I, II, III Power System
- ❍ Primary Heat Transport Systems (PHTS)
- ❍ Moderator Systems
- ❍ Feedwater Systems
- ❍ Instrument Air, Post-LOCA Instrument Air
- ❍ Post-Accident Air Sampling Monitor
- ❍ Etc.

Safety Support Systems
+
Other Process Systems

Safety-related Systems

Design Bases

❑ Operator Actions to be performed in DBAs

➢ Basis & Rationale for PAM Parameter Selection & Grouping

❖ Operator Actions during DBAs

- ❍ Start EWS & EPS in LOCA/SDE or DBE
- ❍ Secure Heat Sink (ECCS, SG, Moderator)
- ❍ Open MSSVs(Main Steam Safety Valves) in MSLB
- ❍ Depressurize Containment
- ❍ Conduct cool-down by SG, Maintain SG level
- ❍ Close Instrument Air to R/B
- ❍ Change EWS Makeup Mode to Recirculation Mode
- ❍ Etc.

*R/B: Reactor Building

Design Bases

❑ Plant Characteristics under Accident

➢ Distinguishing Safety-related Properties of NPP that can be inferred from PAM variables

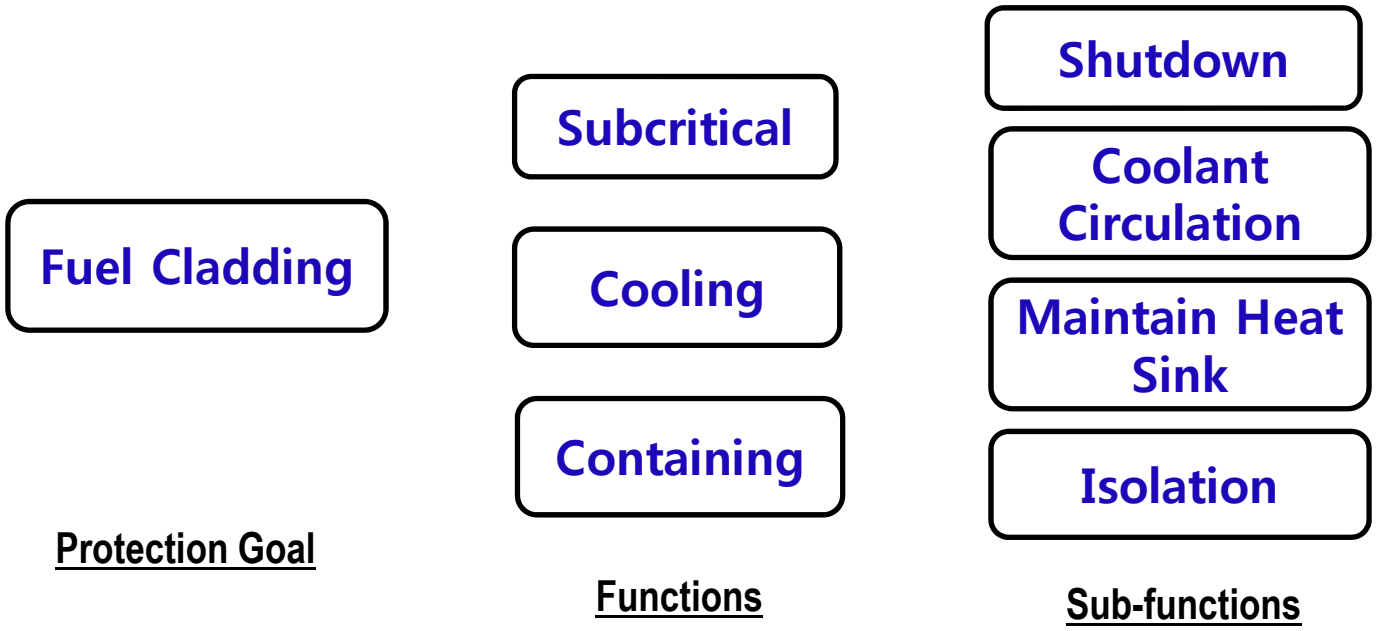
- ❖ Fission Reactivity
  - ❍ Neutron Flux Level, Log Rate, SDS-1,2 Status
- ❖ PHTS Integrity & Inventory
  - ❍ Temperature, Level, Pressure, LRV Status, D_2O Storage Tank Level
- ❖ Heat Sink source by SG
  - ❍ SG level, MSSV, FW flow, Deaerator Level
- ❖ Containment Integrity
  - ❍ Containment Press & Radioactivity
- ❖ Moderator Inventory

*__LRV__: Liquid Relief Valve

PAM Parameters

❑ What parameters to be measured for PAM ?

- ➢ Variables to identify condition of protection barriers from rad. release in DBAs, i.e. (1)fuel cladding, (2)PHTS, (3) containment.
- ➢ Multiple & Diverse Measurements for monitoring the integrity of the barriers



PAM Parameters

Category / Plant Char.	Parameters	Purposes / Related Events	Display Location
Reactivity	Reactor Power Rate of Reactor Power	Rx Shutdown Verification / LOCA (+ SDE)	MCR, SCA
PHTS Integrity	Reactor Outlet Header Temp. & Press. Core Diff. Press. Header Diff. Temp. Reactor Inlet Header Temp. LRV(Liquid Relief Valve) Status	Heat Removal Verification / LOCA, DBE, SDE	MCR, SCA SCA MCR MCR MCR
PHTS Inventory	Pressurizer Level D_2O Storage Tank Level	RCS Leak Verification / Small LOCA	MCR, SCA MCR
SG Heat Sink	Steam Generator Press. & Level MSSV Status Deaerator Level Feed Water Flow	Heat Removal Verification, Performance Monitoring / LOCA, SDE, MSLB	MCR, SCA MCR MCR MCR
ECCS Functioning	ECC Recirculation Flow & Temp ECC Sump Level ECC Pump Status	Heat Removal Verification, Performance Monitoring / LOCA, SDE	MCR, SCA

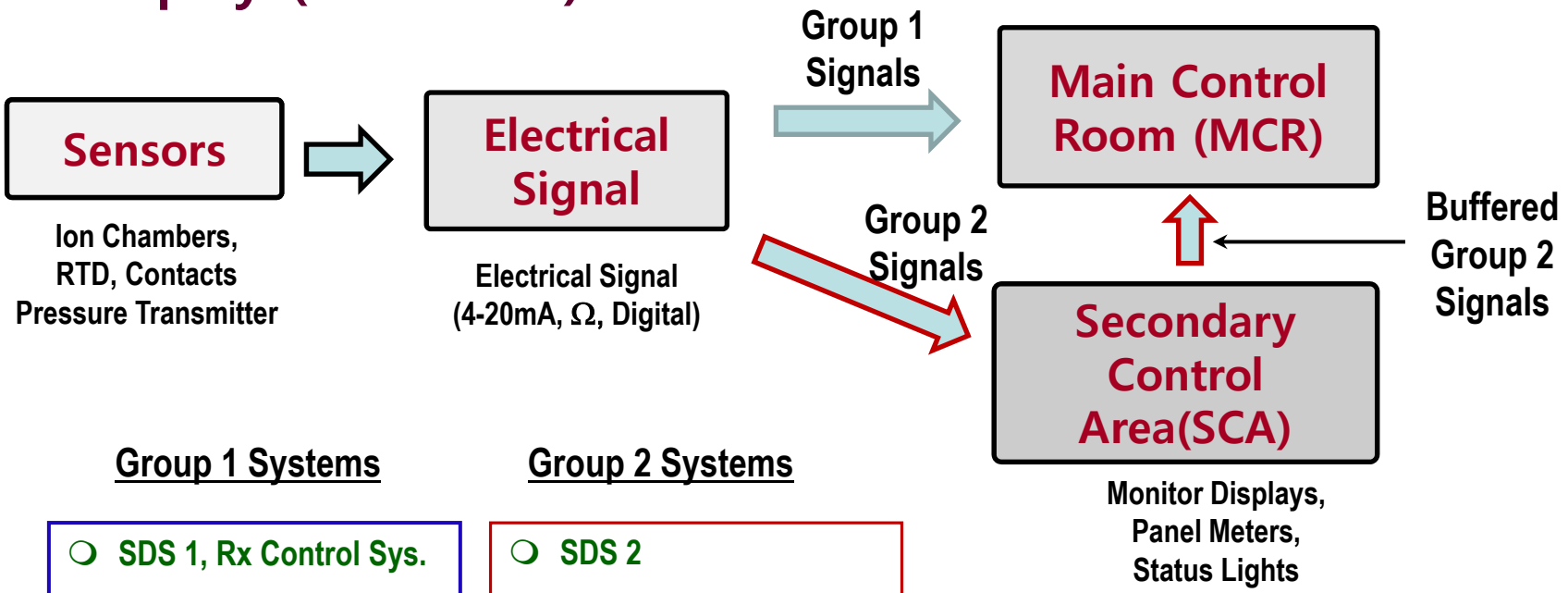
PAM Parameters

Parameter Category	Parameters	Purposes / Related Events	Display Location
Containment Integrity	Reactor Building Isolation Valve Status Reactor Building Press., Temp. & Activity H2 Igniter Status Dousing Tank Level	Release Barrier Verification, Performance Monitoring / LOCA, MSLB, SDE	MCR, SCA
Moderator Condition	Moderator Temperature Moderator Level	Heat Removal Verification / LOCA	MCR, SCA MCR
Safety Support System Status	Post-LOCA Instrument Air Sys. Status Emergency Power Supply Bus Voltage Emergency Water Sys. Pump Status Emergency Water Sys. Pump Flow	Performance Monitoring / LOCA, SDE, DBE	MCR, SCA SCA MCR,SCA SCA
Shutdown Cooling	Pump Suction/Discharge Press. Heat Exchanger Inlet/Outlet Temp.	Heat Removal Verification / LOCA	MCR
Stack Release Radioactivity	Particulate, Iodine-131, Noble Gas	Release Barrier Verification / LOCA	MCR

PAM Performance

❑ Components of PAM Instruments

➢ Sensors, Transmission Devices(Signal Buffers), Displays(Indicators)



Group 1 Systems

- SDS 1, Rx Control Sys.
- PHTS, Steam and Feedwater Sys., Shutdown Cooling Sys., Moderator
- ECCS
- MCR

Group 2 Systems

- SDS 2
- Emergency Water Supply System, Emergency Power Supply System
- Containment Sys.
- SCA

PAM Performance

- **Seismic Qualification**
  - SDS1, SDS2, Containment System, SCA, ECCS(Part), EWS, EPS, etc. (All Group-2, Some Group-1)
  - Qualified to DBE (ref. CSA-N289.x)
- **Environmental Qualification**
  - Demonstrate functionality during/after accident (ref. IEEE std. 323, CSA-N290.13)
- **Reliability**
  - Availability >99.0% required in CSA-N290.6-82
  - Periodic testing, On-power testing
- **Redundancy**
- **Grouping and Separation**
  - Independence & Diversity
  - Consistent with two group approach in safety functions

PAM Operation

❑ Normal Operation

- ➢ Compare two redundant indication of each parameter to check the proper functioning of instruments

❑ Accident Operation

- ➢ Operators use PAM indications to follow EOP(Emergency Operating Procedure) in MCR
- ➢ SCA is used when MCR is not habitable

Summary

❑ Main Features of PAM in CANDU 6

- ➢ Maximum use of Safety and Process System instruments, displays and indicators
- ➢ Two Grouping Approach for Diversity against common mode failures
- ➢ MCR and SCA for Post-accident Monitoring
- ➢ Parameter Selection based on DBAs, Operator actions, Safety-related Systems
- ➢ DBAs includes multiple events (ex, LOCA + Loss of ECCS)

Thank You !