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# Some Findings from Thermal-Hydraulic Validation Tests for SMART Passive Safety System

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Hyun-Sik Park, Hwang Bae, Sung-Uk Ryu, Hyobong Ryu, Yong-Cheol Shin,
Kyoung-Ho Min, Sung-Jae Yi (hspark@kaeri.re.kr)

Thermal Hydraulics Safety Research Division
**Korea Atomic Energy Research Institute (KAERI)**

# Contents

# Introduction

- Standard Design Approval (SDA) for SMART
  - Certificated in July 2012 by the lead of KEPCO consortium & KAERI.
- Needs for Nuclear Safety Improvement after Fukushima
  - Domestic and international needs for nuclear safety improvement adopting passive systems after the Fukushima accident
  - Several efforts to improve the safety of SMART design
  - Passive Safety System (PSS) development program was launched for the SMART reactor. (2012-2015)
- Validation Tests for the SMART PSS Design
  - SMART-ITL (or FESTA) was constructed and its commissioning tests had been finished during 2012.
  - A set of Design Basis Accident scenarios was tested during 2013.
  - A test program to validate the performance of SMART PSS is scheduled to be performed using the existing SMART-ITL facility.

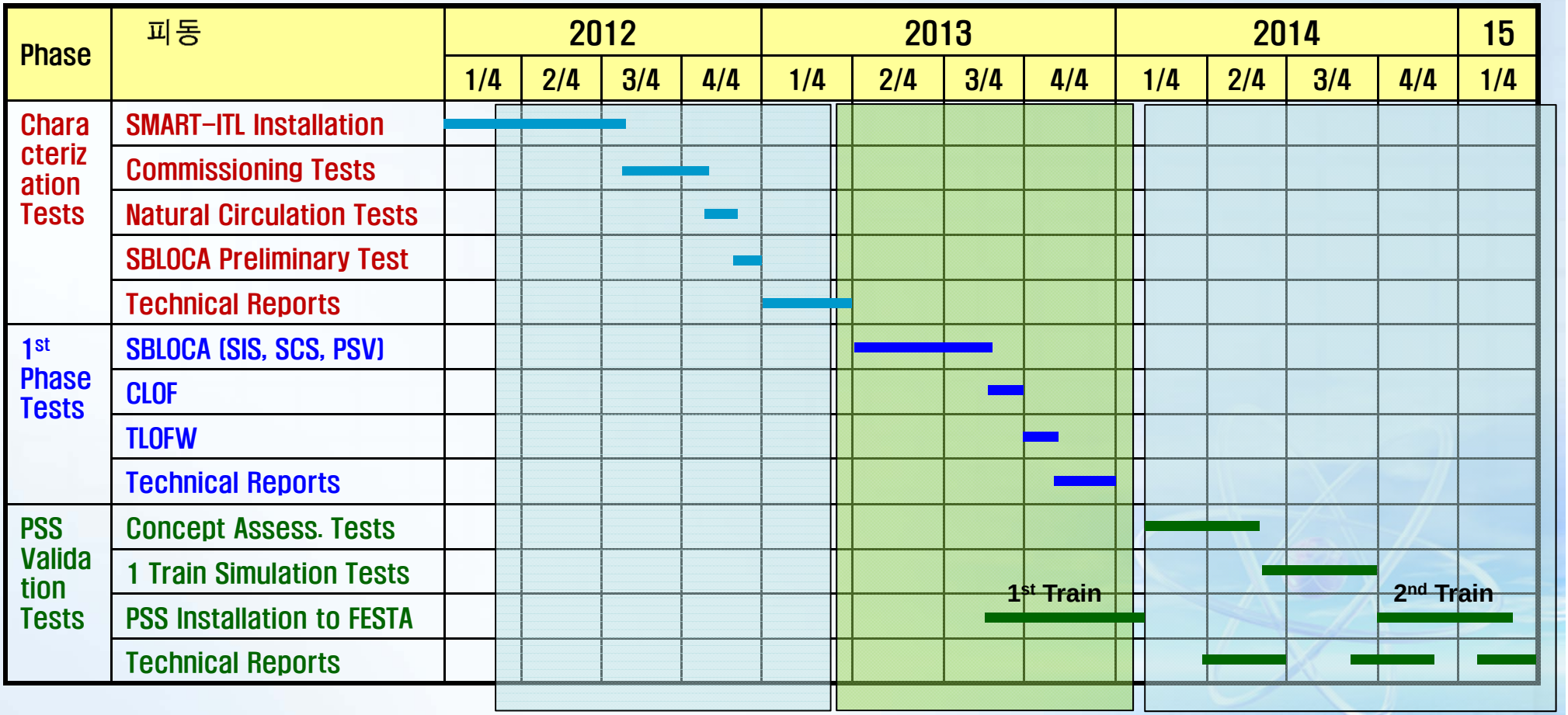
# SMART-ITL Program Status (1/2)

- **장치 구축 및 시운전** (~2012)
  - **시운전** ~ 2012. 10
  - **주요 특성 시험 (정상상태**, NC **운전)** ~ 2012. 11
  - SBLOCA **예비 시험** ~ 2012. 12
- **1단계 시험** (2013~ ) PSS **시험 연계 수행**
  - PIRT **기반 설계기준사고** (SBLOCA, SLB **등)**
  - PRHRS **성능 및** IPWR **관련 현상 모의 시험**
- **피동안전계통 검증시험** (2013~15)
  - 2013~14**년**: 2**계열 구축 및** 1**계열 모의시험**
  - 2015**년**: **전 계열 구축 및 성능 검증시험**
- **산업체 요구 시험** (2016~ )
  - SMART **건설에 따른** SMART **인허가 지원 시험**
  - **일체형 원자로의 열수력 특성 시험 (국제 협력)**

**FESTA:** 단기 활용 계획

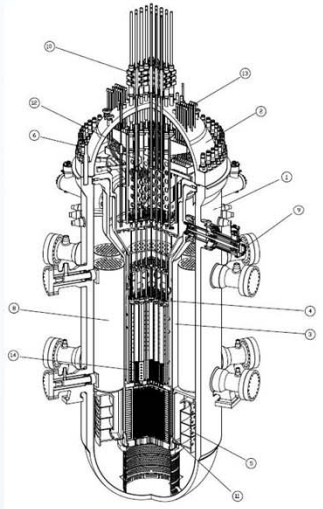
# SMART-ITL Program Status (2/2)

## ❑ 시험 일정: 2012~2014년도



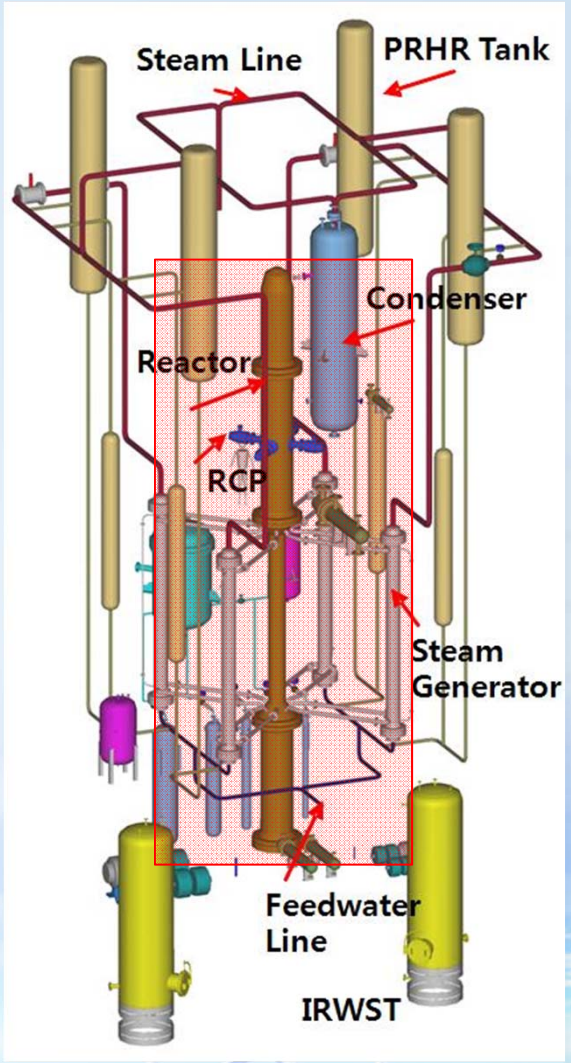
# SMART-ITL Overview (1/2)

- SMART (nuclear reactor)
  - SMART: 330 MWth integral type reactor
  - Single RPV contains all of the major components
- SMART-ITL (T-H test facility)
  - An IET facility for the SMART design
    - Length, Time : 1/1
    - Area, Volume, Power, Flowrate : 1/49
    - Prototypic P & T conditions



SMART

**Volume Scaling Methodology (1/1-height, 1/7-diameter)**

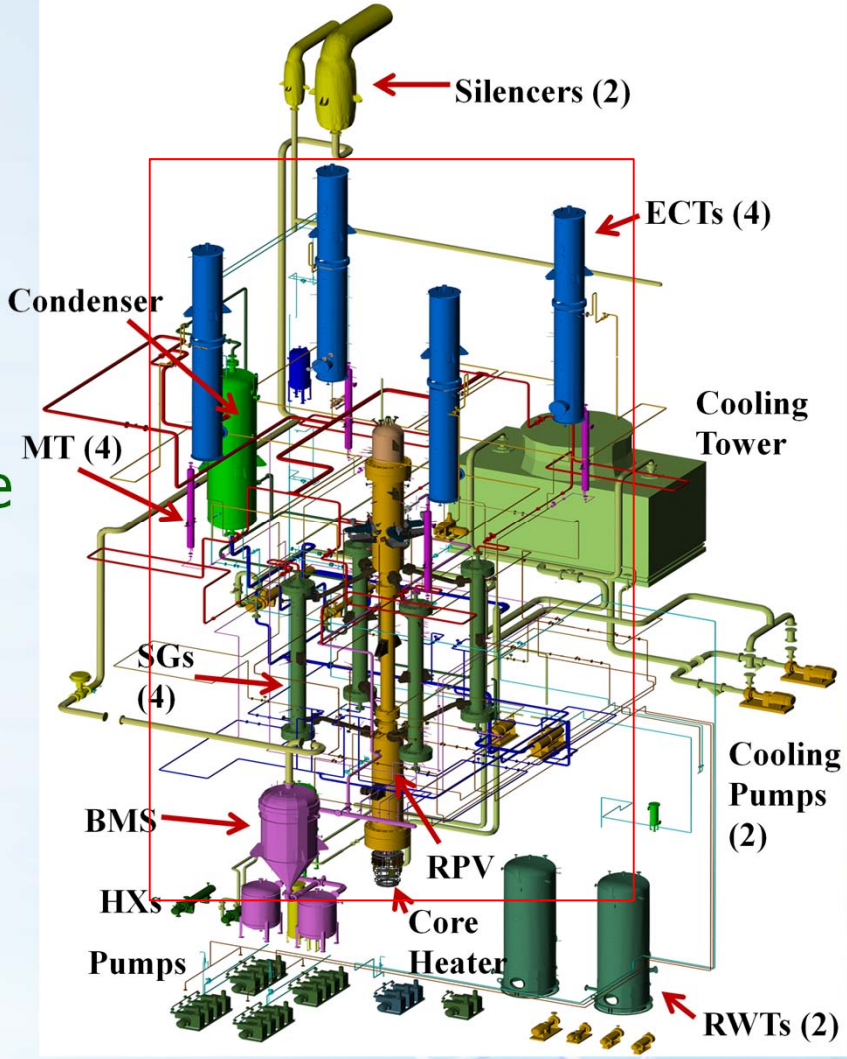



SMART-ITL

# SMART-ITL Overview (2/2)

## ❑ Design Characteristics

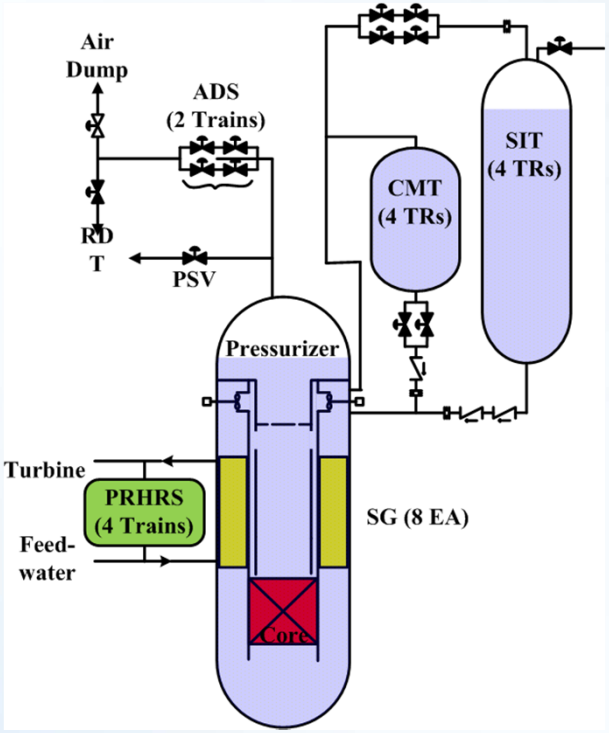
- ❍ Design pressure & temp.
  - ⏩ 180 bar, 370°C
- ❍ Maximum core heater power
  - ⏩ 2.0 MW (30% of scaled full power)
- ❍ External SGs for proper instrumentation and easy maintenance
- ❍ SG & PRHRS : 4 Trains
- ❍ Major Components
  - ⏩ Primary/Secondary systems
  - ⏩ PRHRS, SIS/SCS, Auxiliary systems
  - ⏩ Break system, Break measuring system
- ❍ Instruments : ~ 1,200
  - ⏩ Pressures, temperatures, flow rates, mass, power, etc.



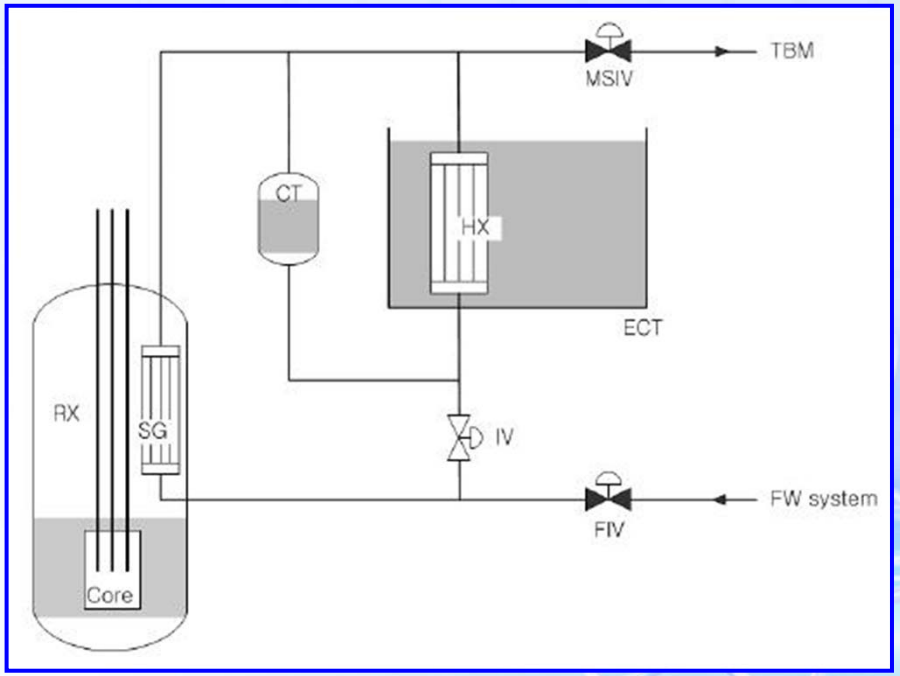

SMART-ITL Schematics

# SMART Passive Safety System (1/4)

- The SMART PSS design
  - Passive Residual Heat Removal System (PRHRS) – 4 Trains
  - Passive Safety Injection System (PSIS) – 4 Trains & 2 ADSs
  - Passive Containment Cooling System (PCCS) – under development




SMART PSS (1 Train)




SMART PRHRS (1 Train)

# SMART Passive Safety System (2/4)

- The SMART PSIS design
  - 4 Core Makeup Tanks (CMTs)
  - 4 Safety Injection Tanks (SITs)
  - 2-stage Automatic Depressurization Systems (ADSs)
  - Pressure-balanced lines
    - To RCP discharge
  - Injection lines
    - To Safety injection line
- Operation
  - No active pumps
  - Gravity force due to $\Delta H$
- Considered Scenario
  - SBLOCA & SLB

Schematics of SMART PSIS (1 Train)

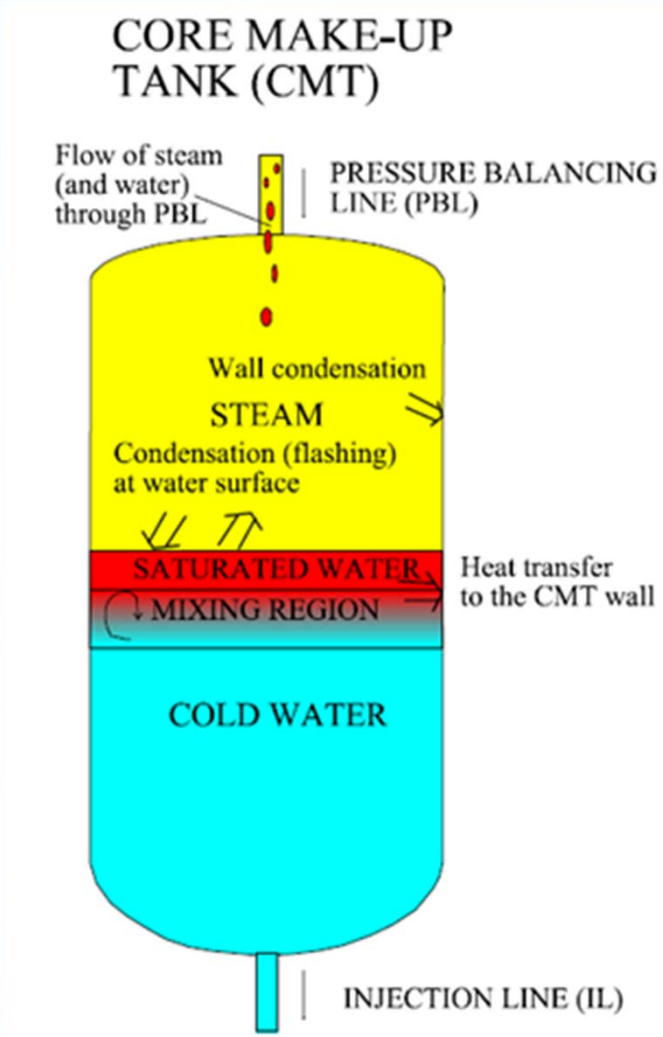
# SMART Passive Safety System (3/4)

## ❑ Previous Researches

- ❍ 핀란드 VTT Energy의 PACTEL 시험
- ❍ 중국 NPIC의 CMT Test Rig 시험
- ❍ 일본 JAEA의 ROSA/AP600 성능시험
- ❍ KAIST CP1300의 PSIS CMT 거동에 대한 실험 및 MARS 코드 이용 해석 연구

## ❑ Major T-H Phenomena

- ❍ 유동 압력강하: 유동 저항, 수두차, 밀도, 유동 면적, 유동 방향
- ❍ 자연대류: 노심-CMT 수두 차이,
- ❍ 직접접촉응축: CMT 입구, 다차원 현상
- ❍ 열성층화: 수직 성층 유동, 벽면 응축
- ❍ 노심냉각: 피동 안전주입 유량




Phenomena in the CMT during ECC injection

# SMART Passive Safety System (4/4)

## PSIS Operation Modes

### Recirculation Phase: 1-phase water

- The density difference between the PBL and the CMT created the driving force.

### Oscillating Phase: 2-phase flow

- It took place when the cold leg water-level was close to the PBL connection.
- The density difference was larger.

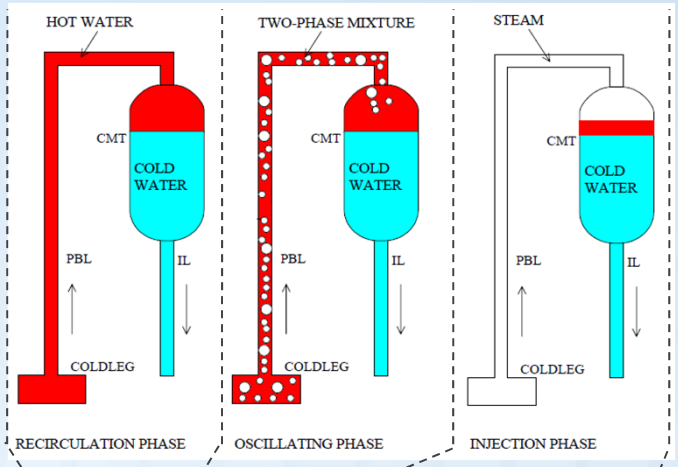
### Injection Phase: 1-phase steam & water

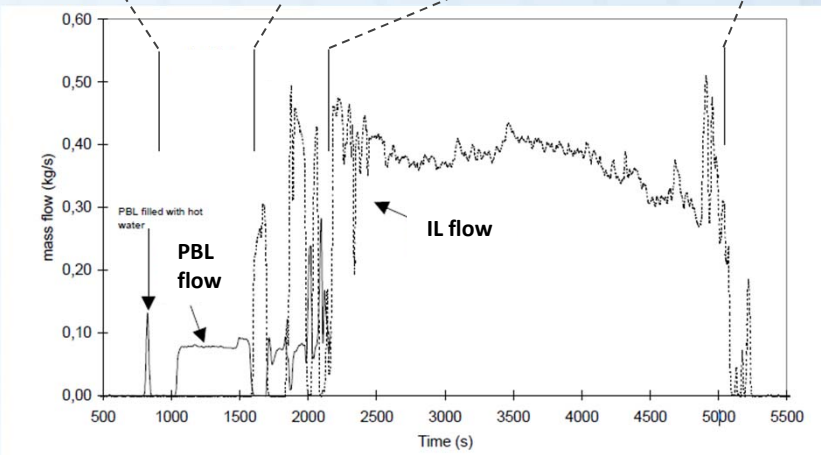
- Steam flows into CMT when the level near the PBL dropped so much.
- The stratified water is injected through IL.

## CMT of AP600 (Tests using PACTEL)

### Injection is delayed due to condensation.

### With flow distributor, it functions properly.



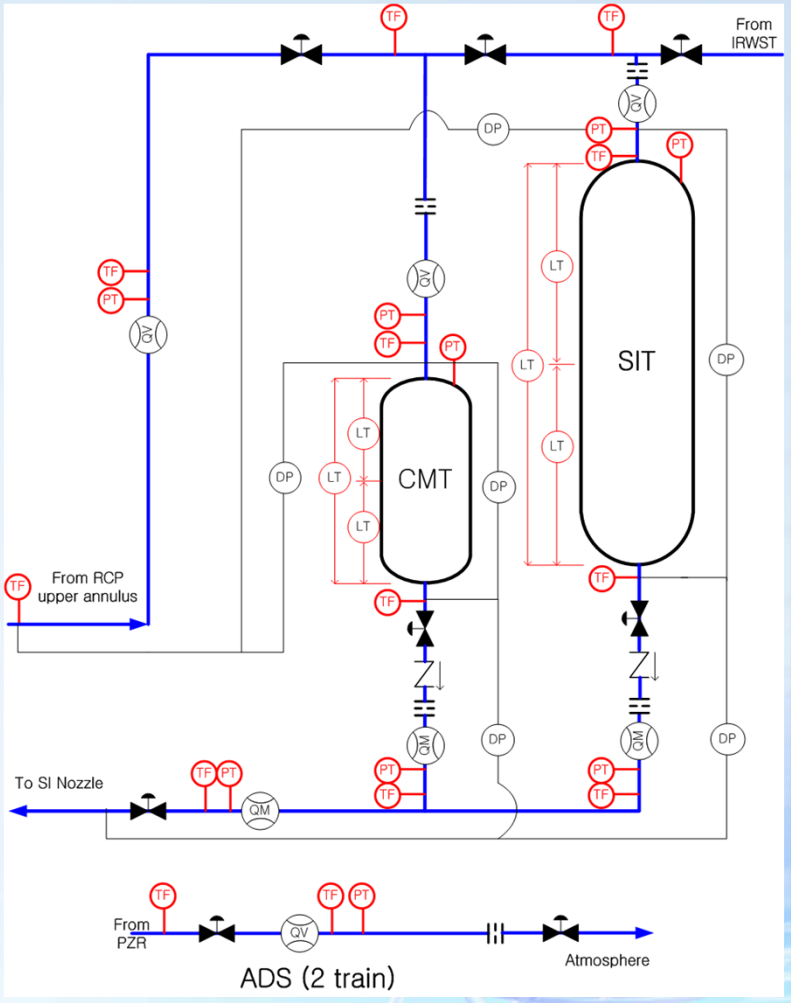



# Validation Tests for SMART PSS (1/8)

- Scaled-Down Facility for SMART PSS: SMART-ITL-PSS
- Test Objectives
  - To assess the performance of PSIS (CMT, SIT, ADS) together with PRHRS for SMART
  - To analyze the physical phenomena occurring inside of the tank, for example, direct contact condensation and flashing.
  - To provide data to assess the related models of safety analysis codes
- Expected Test Results & Application
  - The thermal-hydraulic performance of the PSIS can be understood.
  - The performance of the sparger nozzle geometry, break size and tank geometry could be assessed using the quantitative data.
  - By analyzing the test data, the existing model could be assessed for direct contact condensation occurring in PSIS (CMT, SIT & ADS).

# Validation Tests for SMART PSS (2/8)

- CMT and SIT for SMART-ITL
  - Based on volume scale methodology
  - Conservation of heights: 1/1
  - Scale ratio of diameters: 1/7
  - Scale ratio of the tank cross-section & volume : 1/49
- Major Phenomena & Instrument
  - Flashing, direct contact condensation, wall condensation and injection flows are expected in the CMT, SIT, and pipes.
  - Appropriate thermocouples and flow meters have to be installed in the pipes and tanks.




**Schematics of SMART-ITL PSS (1 Train)**

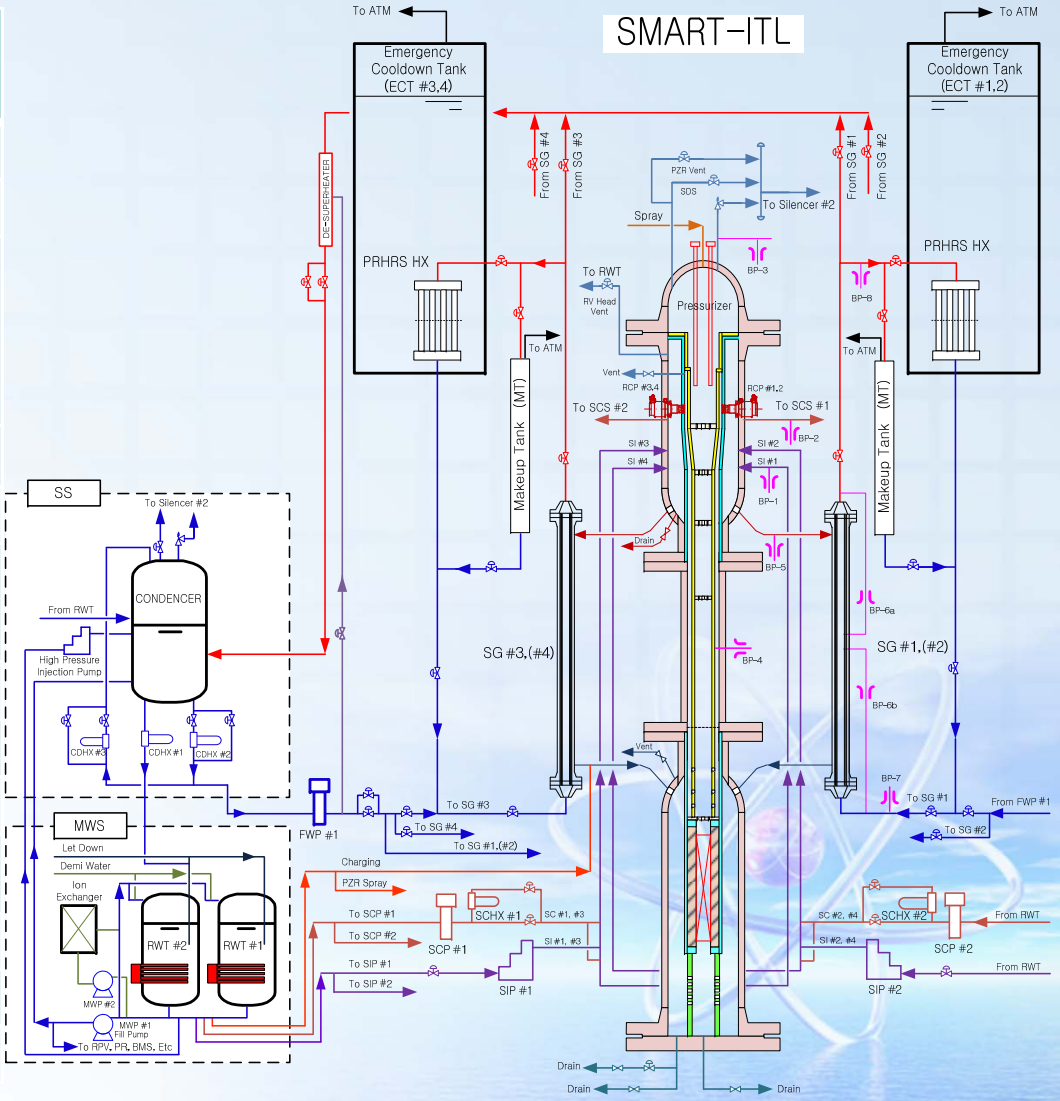
# Validation Tests for SMART PSS (3/8)

- SIP를 이용한 SIS SBLOCA 모의시험: 완료 (~2014. 5.)
  - 피동안전계통 전 계열 구축 전에 펌프를 이용한 시험 수행 (총 2회)
  - Break: SI #1; CMT/SIT simulation: SI injection through SI #3/#4
- 압력 평형 배관(PBL)/주입배관(IL) 차압시험 (~2014. 6.)
  - Cold Loop Tests (총 6회)
  - CMT#1-1/CMT#1-2/SIT 각각에 대해 Orifice 예비 선정
- SMART-ITL을 이용한 SMART PSS 1계열 모의시험
  - 1계열 PSS 이용 Flow Distributor 선정 시험 (~2014. 9)
    - Flow Distributor 선정 시험 (총 8회) → Type C로 선정
    - Flow Distributor 유무 / CMT Type & SIT / Break Size (2 & 0.4 inch)
  - 1계열 PSS 이용 CMT+SIT 연계 시험 (~2014. 10)
    - CMT+SIT Coupling 시험 (총 4회)
    - CMT Type (#1-1, #1-2) / Break Size / SIT Type (가압식 또는 배압식)

# Validation Tests for SMART PSS (4/8)

## ❑ Major Sequence of SBLOCA Scenario

| Event | Trip signal and Set-point |
|---|---|
| Break | - |
| LPP set-point | PZR Press = $P_{LPP}$ |
| LPP reactor trip signal | LPP+1.1 s |
| - FW stop, Pump Coast-down<br>- CMTAS triggering | |
| Control rod insert | LPP+1.6 s |
| MSHP set-point | LPP+4.1 s |
| PRHR actuation signal (PRHRAS) | MSHP+1.1 s (=LPP+5.2 s) |
| PRHRS IV open, FIV close | PRHRAS+5.0 s |
| MSIV close | PRHRAS+20.0 s |
| CMT injection start | CMTAS+300 s |
| SIT actuation signal (SITAS) | PZR Press = $P_{SITAS}$ |
| SIT injection start | SITAS+300 s |
| ADS #1 open | CMT level < 35% |
| Test end | - |

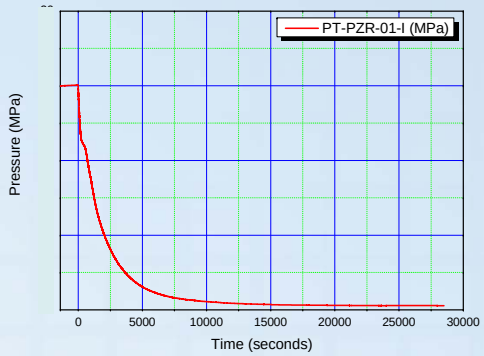


# Validation Tests for SMART PSS (5/8)

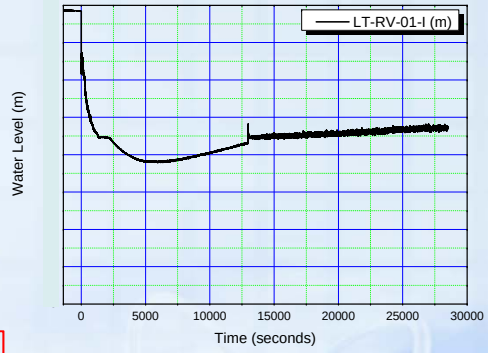
## ❑ SIP를 이용한 SIS SBLOCA 모의시험: 주요 결과 요약

- The SBLOCA scenario for SMART PSS was simulated well using the FESTA facility with calibrated active pumps instead of CMTs and SITs.
- The reactor pressure vessel was cooled down efficiently with the operation of PSS including CMT, SIT, ADS and PRHRS.
- The RPV level was sufficiently recovered with a proper operation of safety injection systems.
- The PRHRS is actuated. Except for Train #3, only 3 of 4 trains were actuated. They show asymmetric characteristics between the four trains. Train #1 has lower flow rate, both Trains #2 and #4 show similar trends.
- The PSS of SMART can function properly during a SBLOCA scenario.

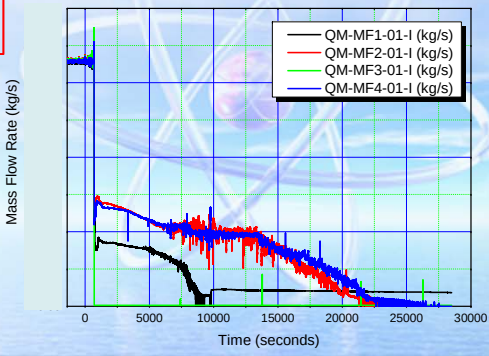
Primary pressure




RPV water levels




Secondary System flow rates

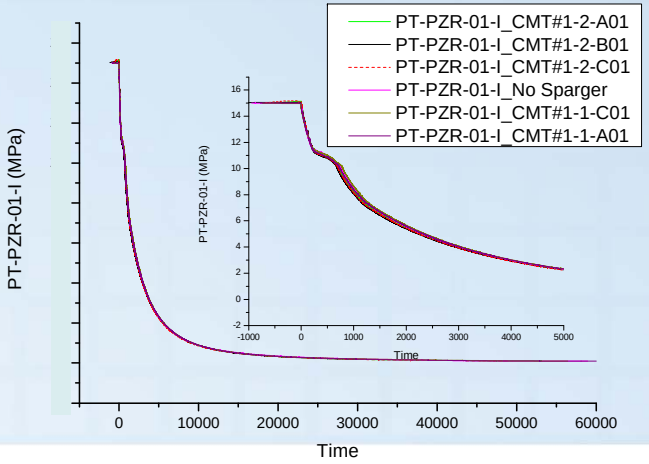


# Validation Tests for SMART PSS (6/8)

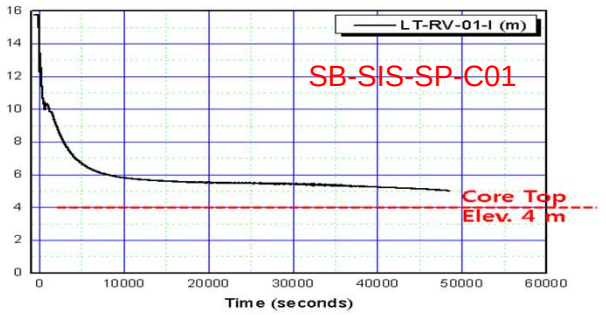
## ❑ SMART-ITL을 이용한 SMART PSS 1계열 모의시험: (1) Flow Distributor 선정

- ❍ During the initial stage of CMT injection, the fluid temperature measured in CMT shows good stratification phenomena.
- ❍ During the initial stage of CMT injection, the water is injected efficiently from the start.
  - ⏩ The results show a different tendency compared with previous CMT test results from KAIST CMT rigs and PACTEL tests. A more detailed analysis is required in the near future.
- ❍ A flow distributor of Type C is chosen.
- ❍ Primary pressures, RPV water level, CMT injection flow rates are shown.

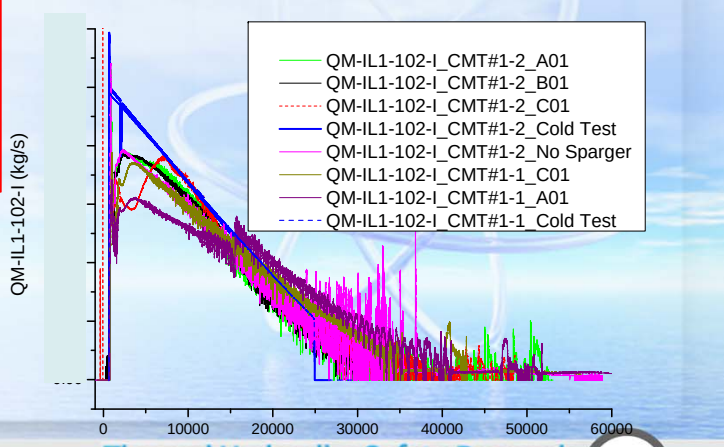
Primary pressures




RPV water level




CMT injection flow rates

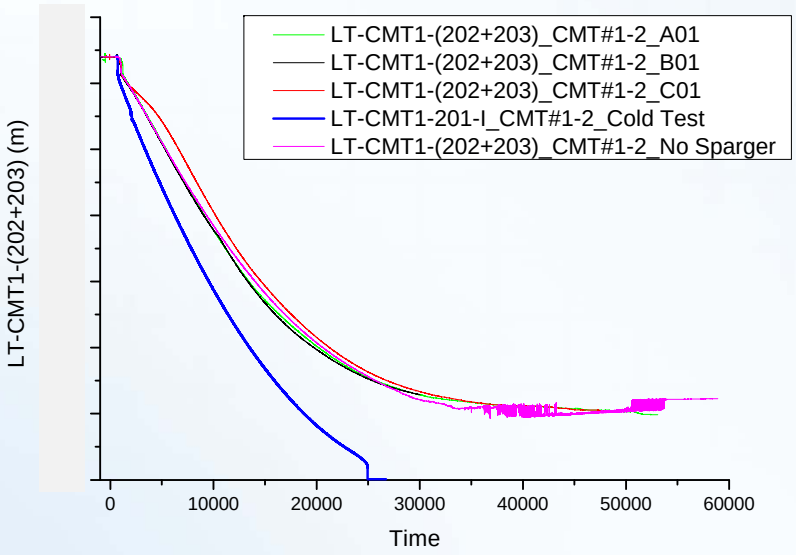


# Validation Tests for SMART PSS (7/8)

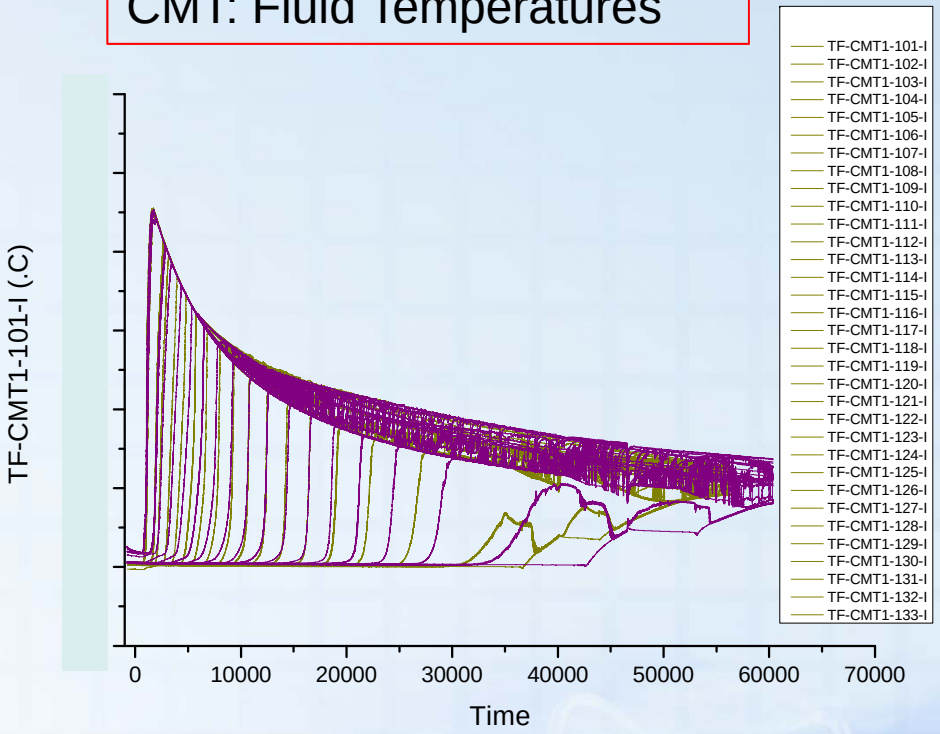
## ❑ SMART-ITL을 이용한 SMART PSS 1계열 모의시험: (1) Flow Distributor 선정

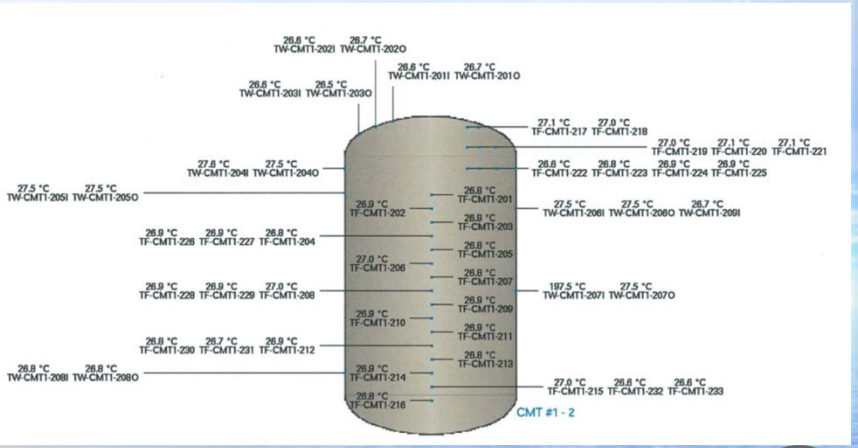
- ❍ CMT: Levels & Fluid temperatures

CMT : Levels




CMT: Fluid Temperatures



# Validation Tests for SMART PSS (8/8)

## ❑ SMART-ITL을 이용한 SMART PSS 1계열 모의시험: (2) CMT+SIT 연계 시험

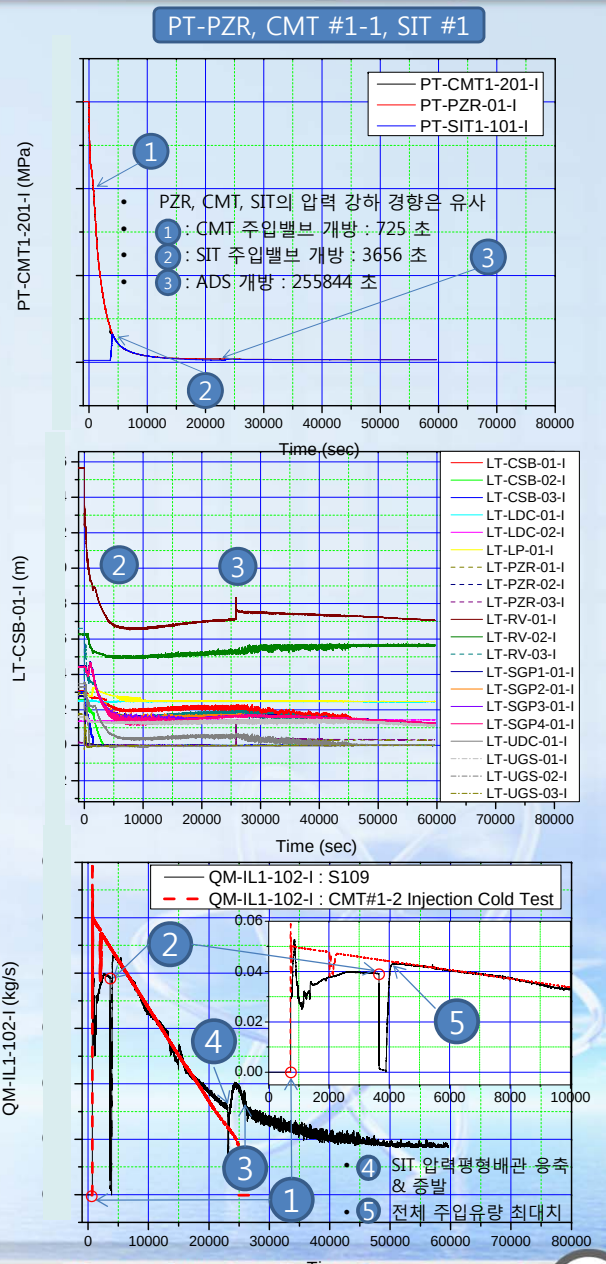
- Primary pressures, RPV water levels, CMT+ injection flow rates are shown.
- Major results
  - SI **배관 파단 이후** SOE**에 의해 시험 진행**
    - ✓ PZR pres.=$P_{LPP}$ → CMT **개방** (1)
    - ✓ PZR pres.=$P_{SITAS}$ → SIT **개방** (2)
    - ✓ CMT level=35% → ADS #1 Open (3)
  - CMT **작동**: **안정적 주입**
  - SIT **작동**: **안정적 주입**
  - ADS **작동**: CMT **주입 유량과 압력 변화를 유발**
  - CMT, SIT, ADS **작동에 의한 상호 연계 작용**
    - ✓ **상호간의 연계 작용에 의한 국지적 현상이 존재함을 확인함**
  - CMT + SIT coupling**에 의해 다차원적인 열유동 현상이 발생하는 유동 불안정 구간이 관측되었으나 대체적으로 설계값을 잘 모사하는 것으로 판단됨**

Primary pressure

SB-SIS-PSS-S109

RPV water levels

CMT+SIT injection flow rates



# Summary

- A set of SMART-ITL tests to validate the performance of SMARS PSS (Passive Safety System) are being performed from 2013.
  - SMART-ITL-PSS (1/1-height, 1/49-volume scale, full P & T conditions)
- Some findings from the validation tests of the SMART passive safety system during 2013-2014 were summarized.
  - A couple of SMART PSS tests using active pumps
  - Several 1-train SMART PSS tests: FD selection & CMT-SIT connection tests
- It was proven that the SMART PSS has sufficient cooling capability to deal with the SBLOCA scenario of SMART.
  - During the SBLOCA scenario, the water layer was well stratified thermally in the CMT and the safety injection water was injected efficiently into the RPV from the initial period and thus cooled down the RCS properly.
- 4-Train PSIS Validation Tests will be performed during 2015.

# Thank you for your attention!

SMART-ITL (FESTA)