Special Session for APR1000 European Utility Requirement Assessment and Certification focusing on Lessons Learned

APR1000 PAFS Performance Evaluation and EUR Assessment

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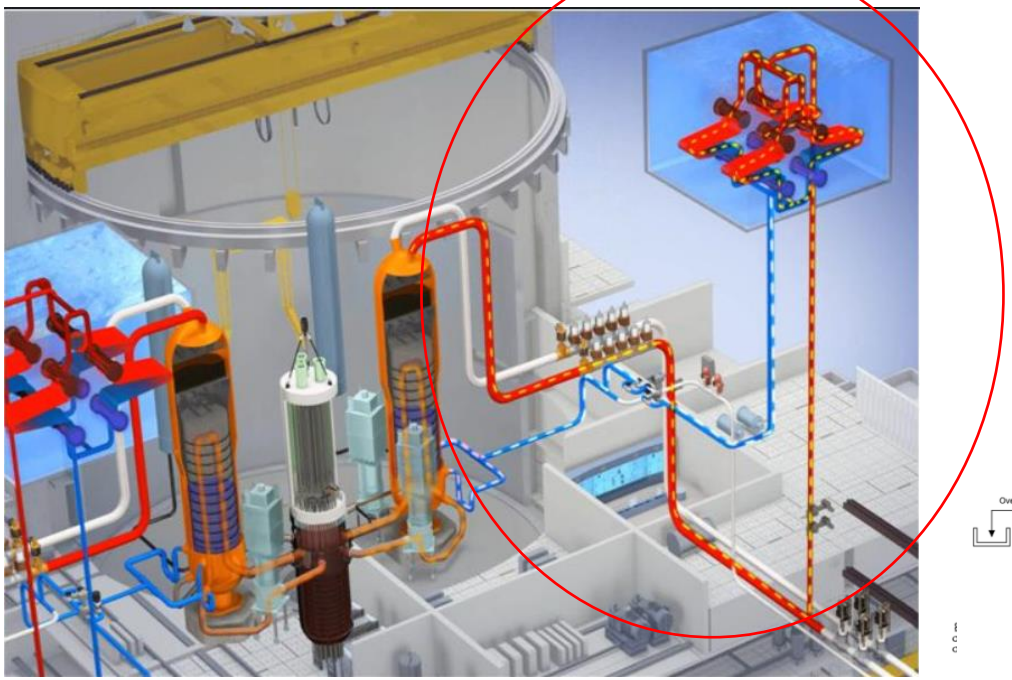
CONTENTS

1 Introduction

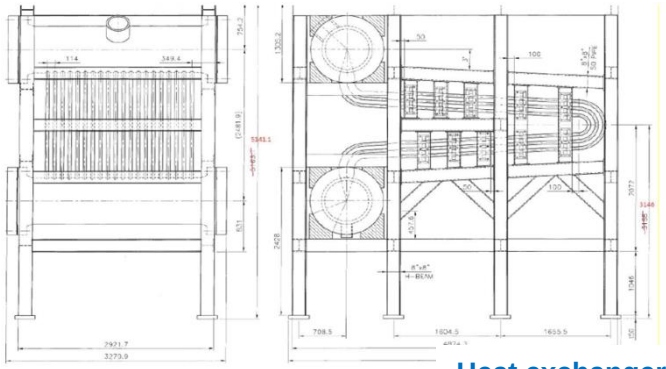
1 Introduction

PAFS (Passive Auxiliary Feedwater System) in APR1000

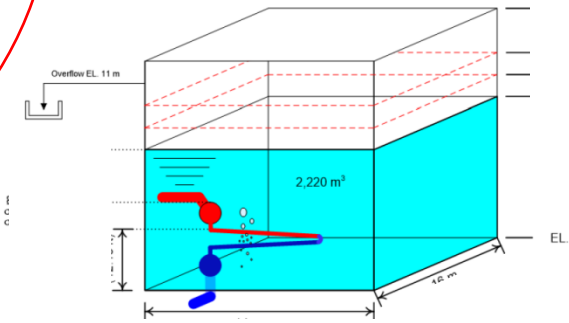
- Complete replacement of active AFW
- Decay heat removal until the entry of SCS (shutdown cooling system) within 14 hr
- Actuation: PAFAS (low SG level) -> Opening of startup valve



PAFS



Heat exchanger



PCCT

1 Introduction

Objectives

- To show the compliance of PAFS to EUR. Rev. E
- To show appropriate performance of PAFS using best-estimate thermal-hydraulic code, SPACE 2.22
- To show the assessment results of SPACE code against experiment

Acceptable design of PAFS in APR1000!

2 Compliance to EUR

2 Compliance to EUR

Functional requirements of EUR.E and compliance

- **Corresponding section: "2.8 3.4.5 PWR emergency feedwater system (EFWS)"**
- **Important requirements and compliance (selected)**

Section No. 2.8.3.4.5.2	
Requirement 'A'	• Heat removal from the RCS until the conditions for operation of the RHRS are reached • Decay heat removal in the event of an SBLOCA
Compliance	• The PAFS provides an independent heat removal means from RCS when FW system is inoperable. And, each PCCT has sufficient water inventory to cooldown the RCS to shutdown cooling initiation condition within 14hrs. • In case of SBLOCA, the water level of SG reduced to actuate the PAFS because the MSSVs are opened while MFWS and MSIV are isolated. After actuation of PAFS the MSSVs are no longer open.

2 Compliance to EUR

Functional requirements of EUR.E and compliance (cont'ed)

Section No. 2.8.3.4.5.3.1	
Requirement 'B'	• There shall be no bulk boiling or core uncovery in the RCS, in FLB
Compliance	• In the event of FLB, the PAFS in intact SG is automatically actuated, and removes heat rapidly to decrease the SG pressure and resultantly the RCS pressure and temperature. Thus, the bulk boiling or core uncovery does not occur.

Section No. 2.8.3.4.5.3.1	
Requirement 'D'	• Sufficient EFW capacity should be provided, assuming one EFW Train is in maintenance, to avoid feed-and-bleed actuation under all DBC and DEC.
Compliance	• The PAFS performs its safety functions with only one train without feed-and-bleed operation assuming that the other train is unavailable. The PAFS has two (2) 100% capacity of cooling water tanks.

2 Compliance to EUR

Functional requirements of EUR.E and compliance (cont'ed)

Section No. 2.8.3.4.5.3.2	
Requirement 'A'	• Capability to operate in Hot Shutdown Mode for at least 24 hours, bringing the plant to the operating conditions of the RHRS, with the RCS in natural circulation mode • Capability to operate in Hot Shutdown Mode in Station Black Out conditions, followed by subsequent cooling to the operating conditions of the RHRS
Compliance	• The PCCT has sufficient water to cooldown RCS by using the SGs to SCS initiation condition and maintain hot shutdown mode for at least 24 hours with RCS in natural circulation mode without makeup water being supplied to the PCCT. • The components to actuate PAFS and their associated instruments are all powered from DC power. Therefore, the PAFS is capable of operating in Station Black Out (SBO) conditions.

2 Compliance to EUR

Functional requirements of EUR.E and compliance (cont'ed)

Section No. 2.8.3.4.5.3.2	
Requirement 'C'	• It shall be possible for the water supply to be restored using Non-permanent equipment which is onsite and safety classified.
Compliance	• The non-safety classified Condensate Storage Tank (CST) can be provided in the long term to supply makeup water to the PCCT by using Alternate Auxiliary Pump (AAP).

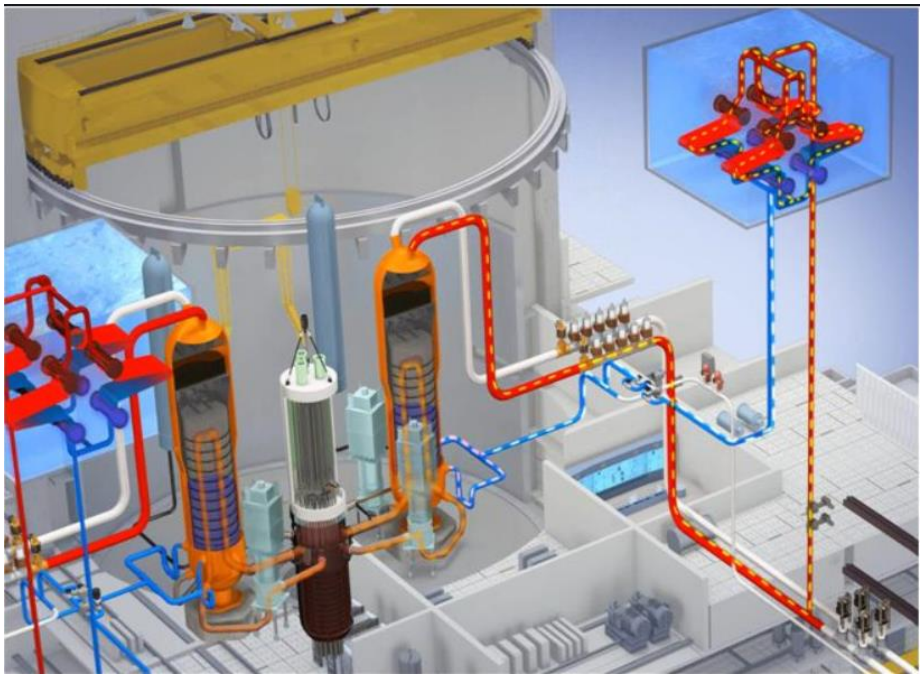
Section No. 2.8.3.4.5.3.4	
Requirement 'C'	• There shall be the facility to feed each tank from other system.
Compliance	• During normal power plant operation, normal makeup is provided from the Makeup Demineralized System (MDS) to the PCCTs. When normal makeup is unavailable, the backup makeup is provided from the (CST).

3 Performance of PAFS

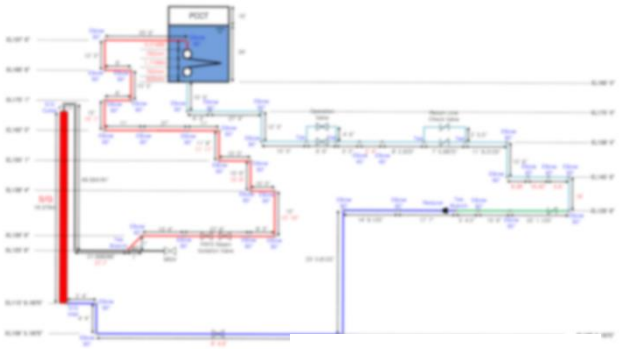
3 Performance of PAFS

Development of input deck of PAFS for SPACE code

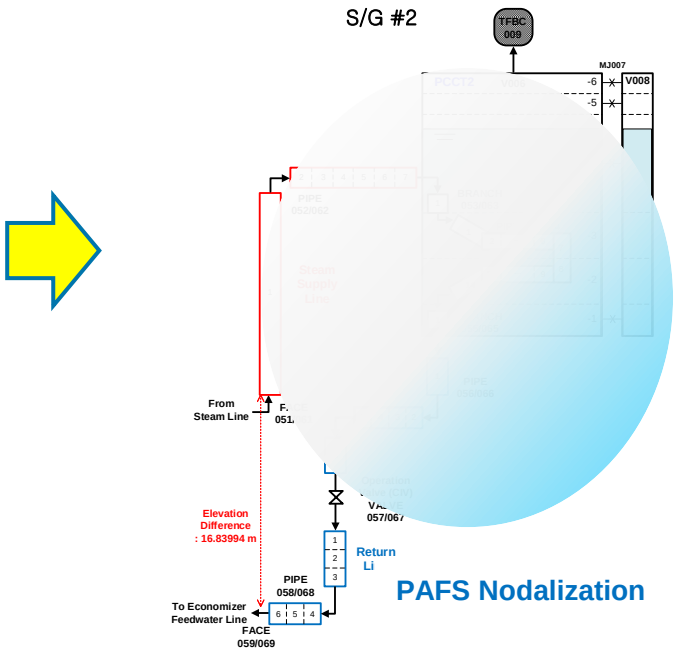
- Code version: SPACE V3.22
- Major components: PCCT, valves, piping
- Assumptions: conservative loss coefficients



PAFS



PAFS Piping (APR+)

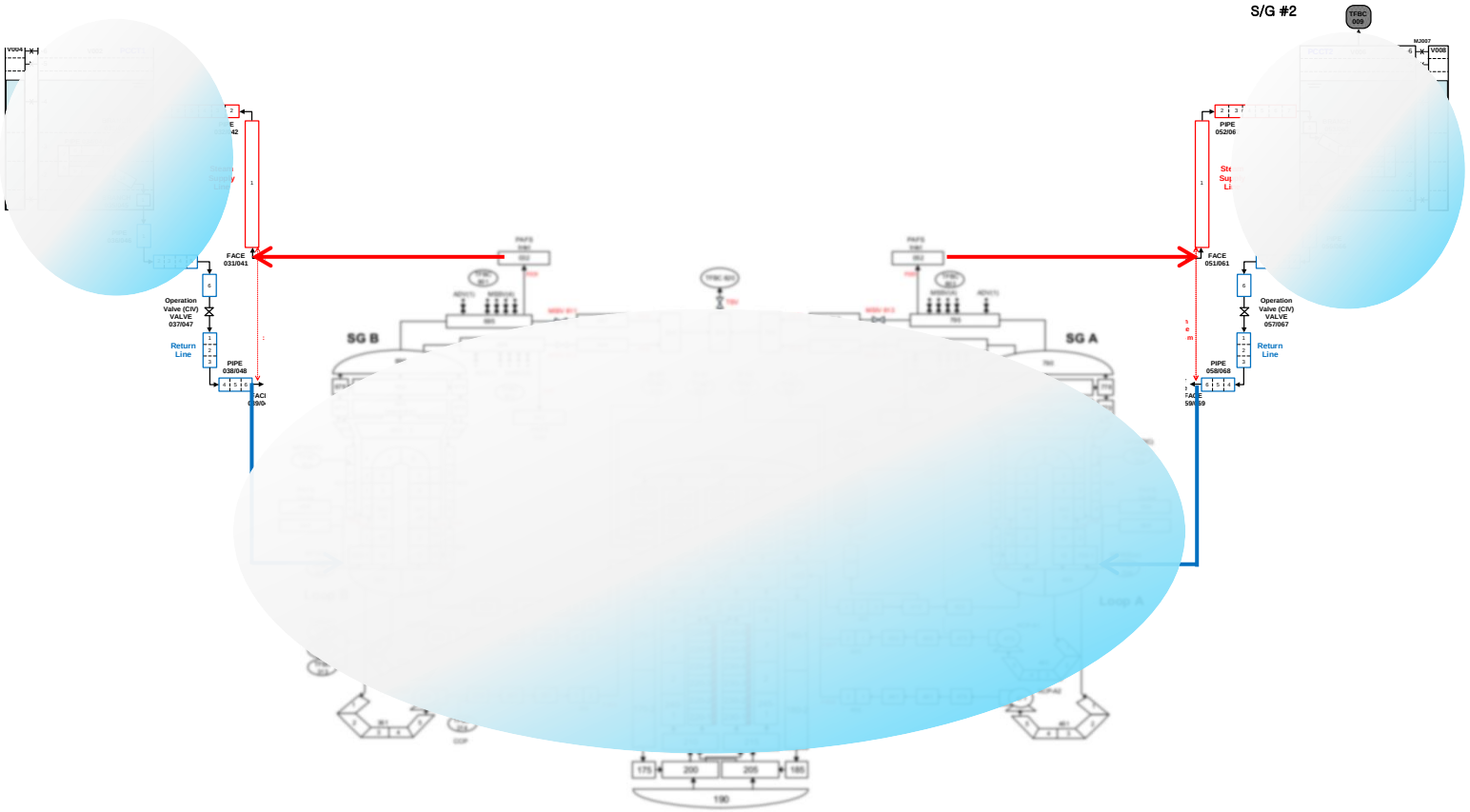


PAFS Nodalization

3 Performance of PAFS

Transient analysis for representative accidents

Nodalization of APR1000 with PAFS

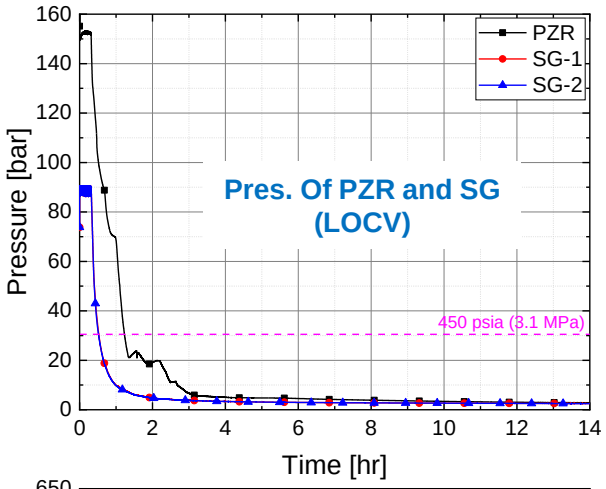


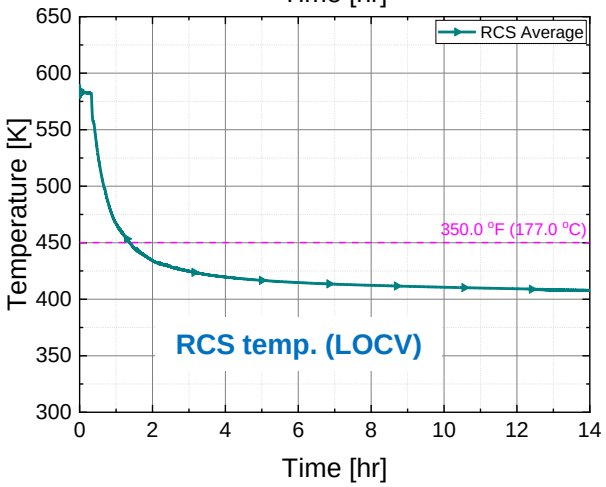
APR1000 Input model
(by KEPCO E&C)

3 Performance of PAFS

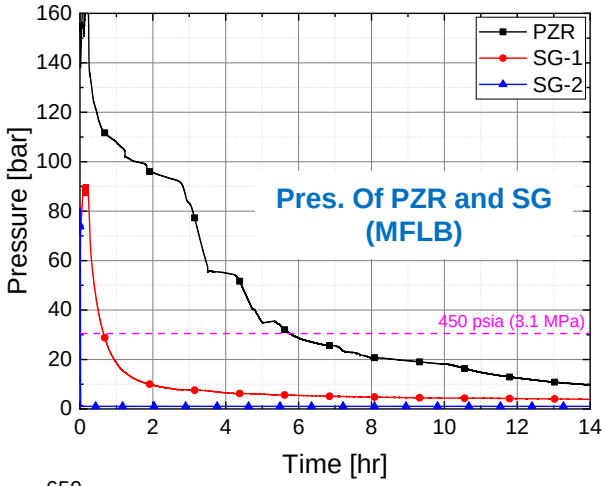
Transient analysis for representative accidents

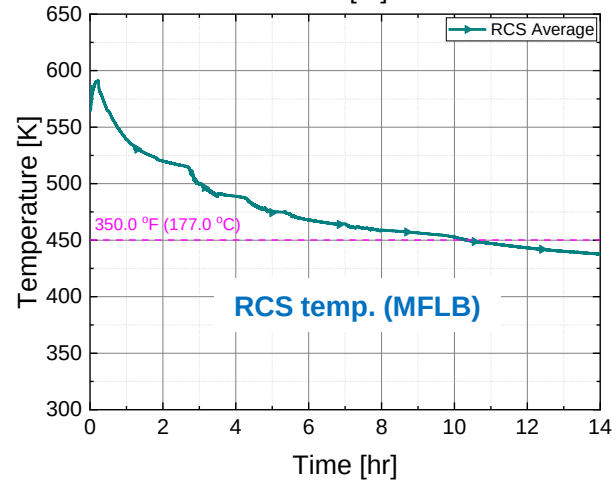
LOCV: both PAFSs available





FLB: only one PAFS available



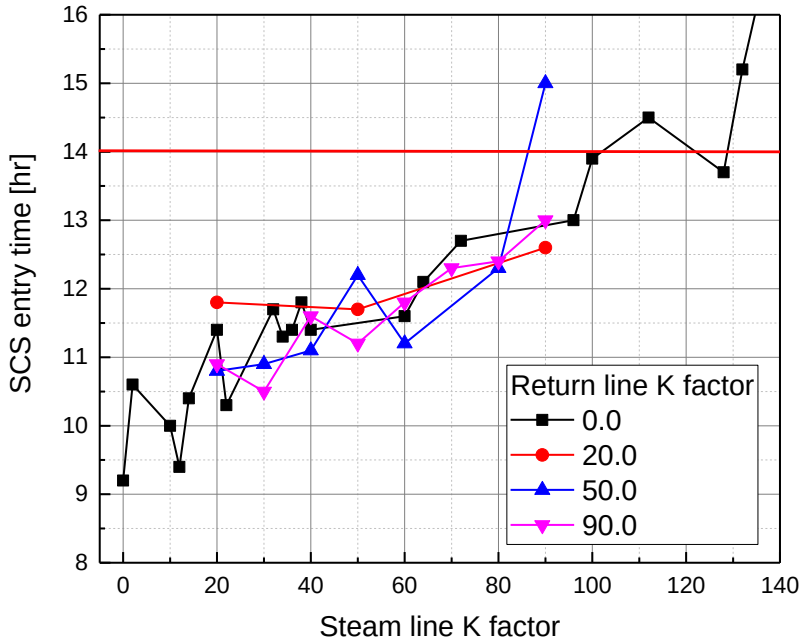


3 Performance of PAFS

Cooling performance of PAFS according to loss coefficient

Assessment the SC entry time in case of FLB

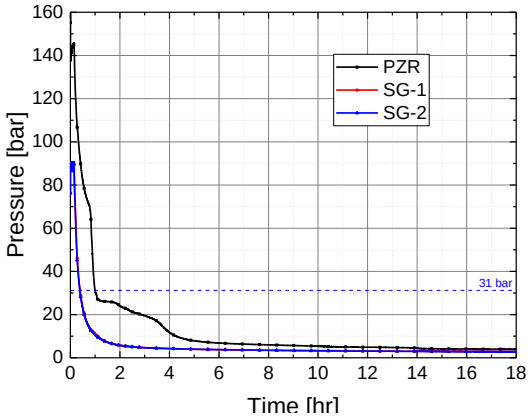
- More dependent on the steam line pressure drop



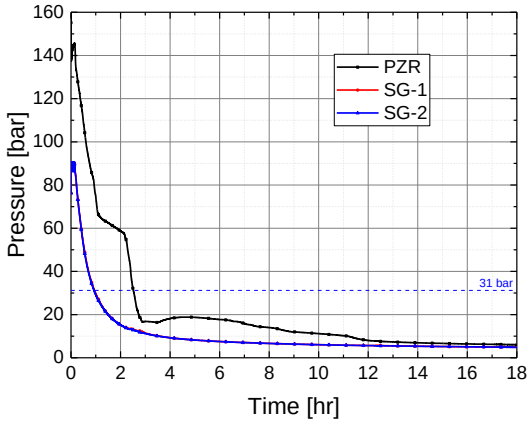
3 Performance of PAFS

Performance according to the available PAFS train

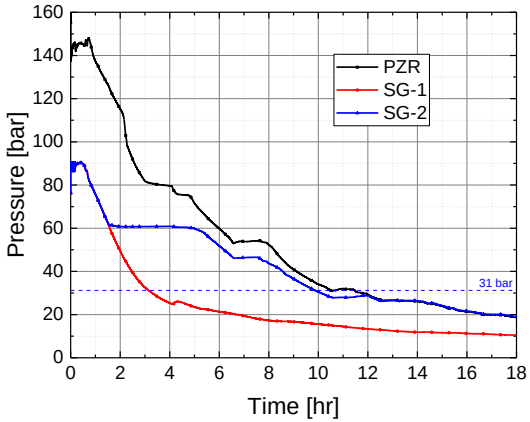
- In case of LOCV, the effect of the number of available train was analyzed.
- For 1 train (50%) case, the SC entry within 14hr failed.



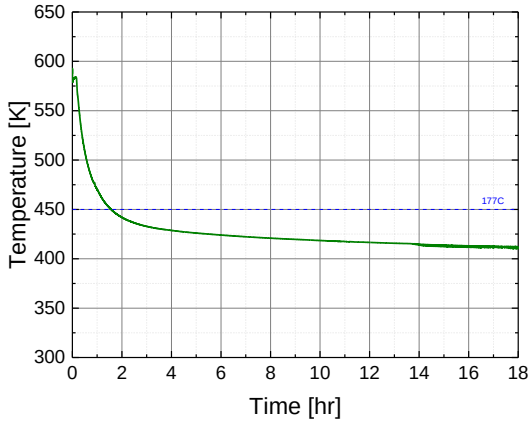
4 Train (200%)

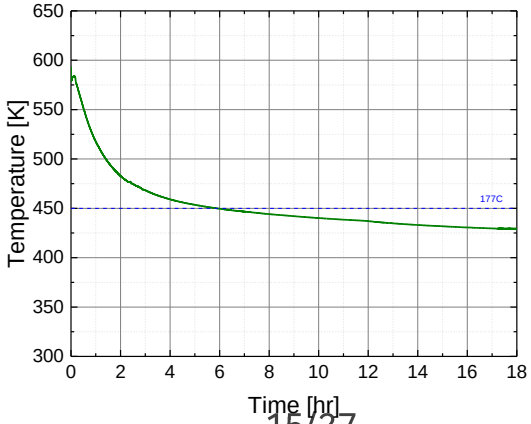


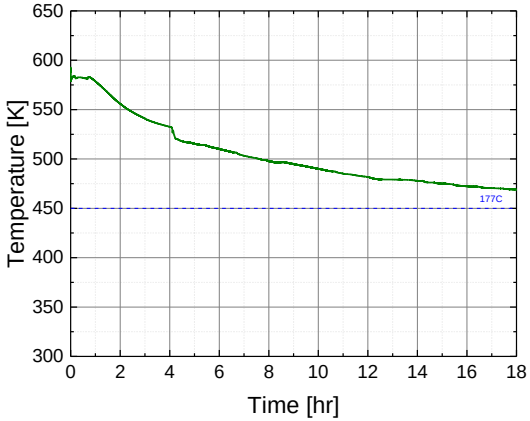
2 Train (100%)



1 Train (50%)





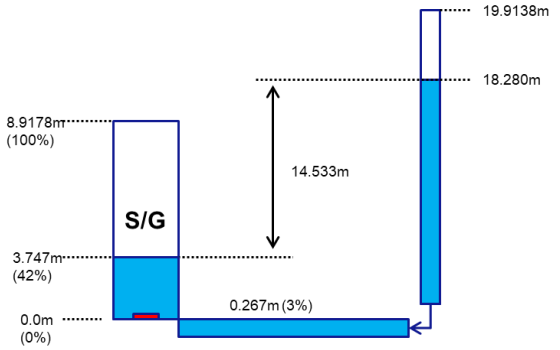


3 Performance of PAFS

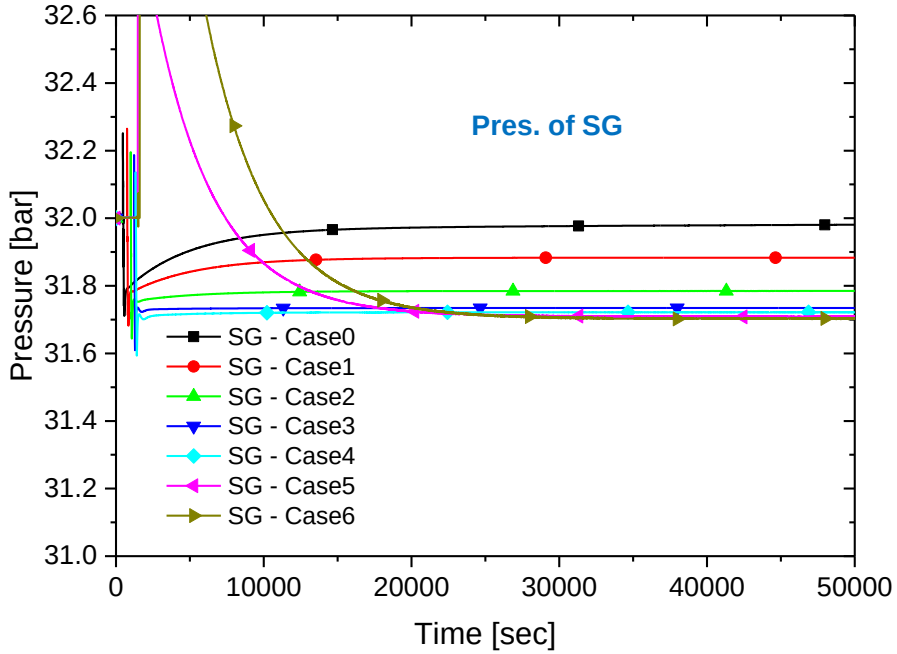
PAFS performance according to the inventory

In case of heater submerged

- The cooling performance is not fatally affected
- Very high water level can slightly decrease the performance



Case #	SG_WL [m(%)]	Inventory
0	3.747(42%)	100
1	2.703(30.3%)	72.1
2	1.836(20.6%)	49.0
3	0.950(10.7%)	25.4
4	0.508(5.7%)	13.6
5	0.331(3.7%)	8.83
6	0.271(3.0%)	7.23

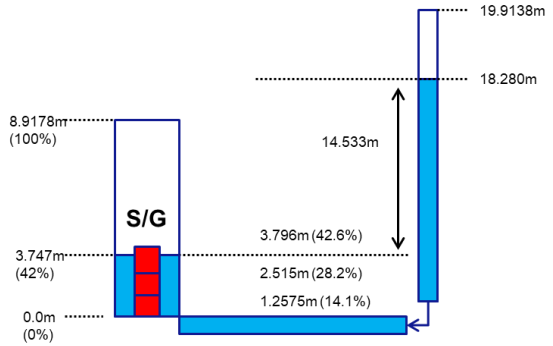


3 Performance of PAFS

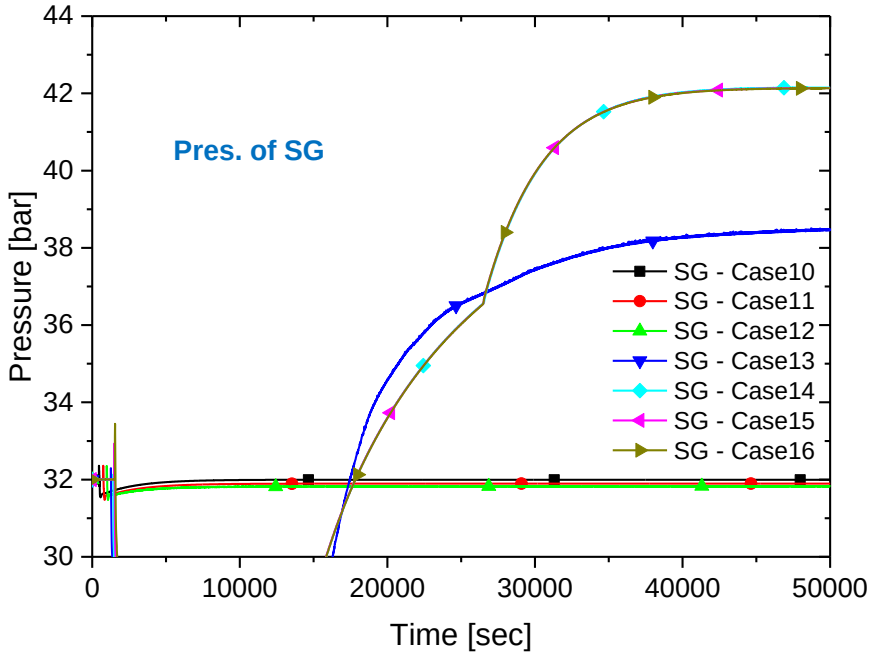
PAFS performance according to the inventory (cont'd)

In case of heater dryout

- The cooling performance degraded.



Case #	SG_WL [m(%)]	Inventory
10	3.683(41.3%)	100
11	2.703(30.3%)	73.4
12	1.836(20.6%)	49.9
13	1.050(11.8%)	28.5
14	0.597(6.7%)	16.2
15	0.413(4.6%)	11.2
16	0.351(3.9%)	9.5



4 Assessment of SPACE code

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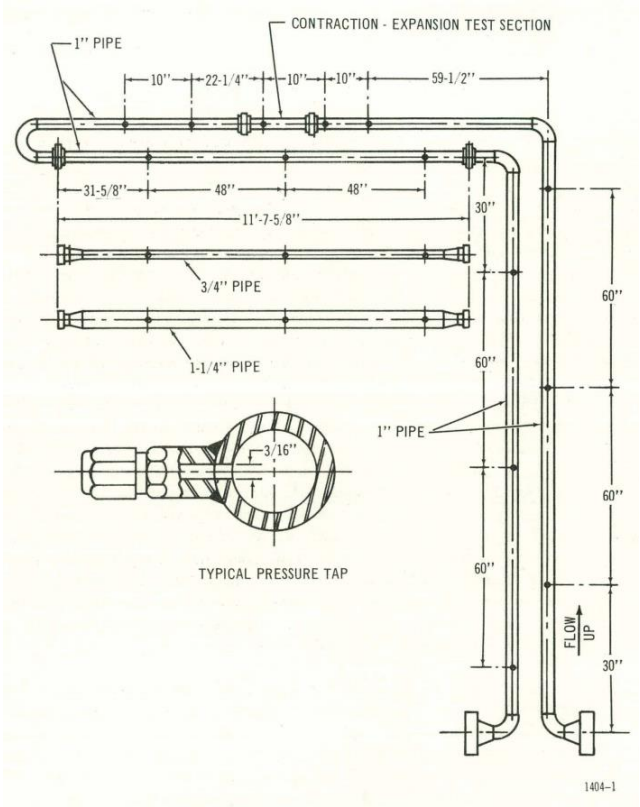
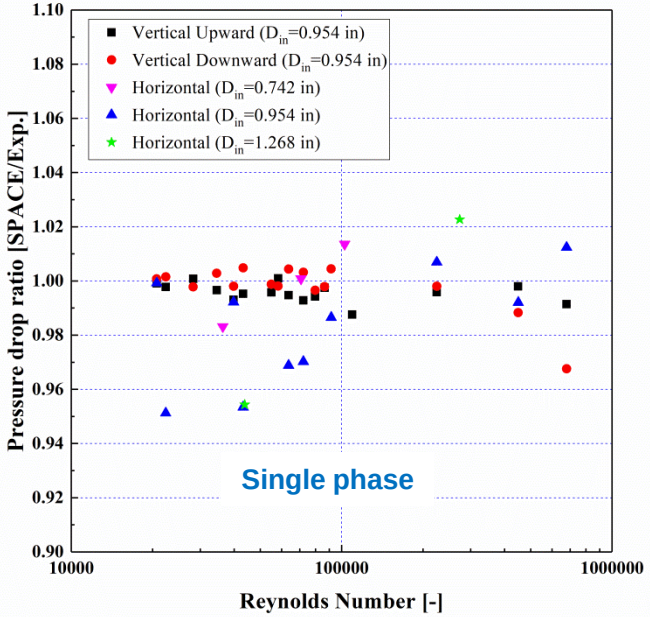
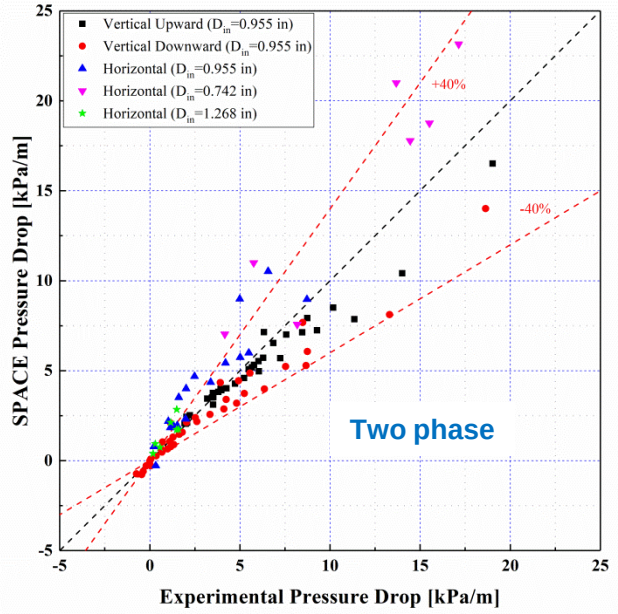
Pressure drop assessment

- **GE-1 assessment**
  - Single phase: ~2%
  - Two phase: ~40%



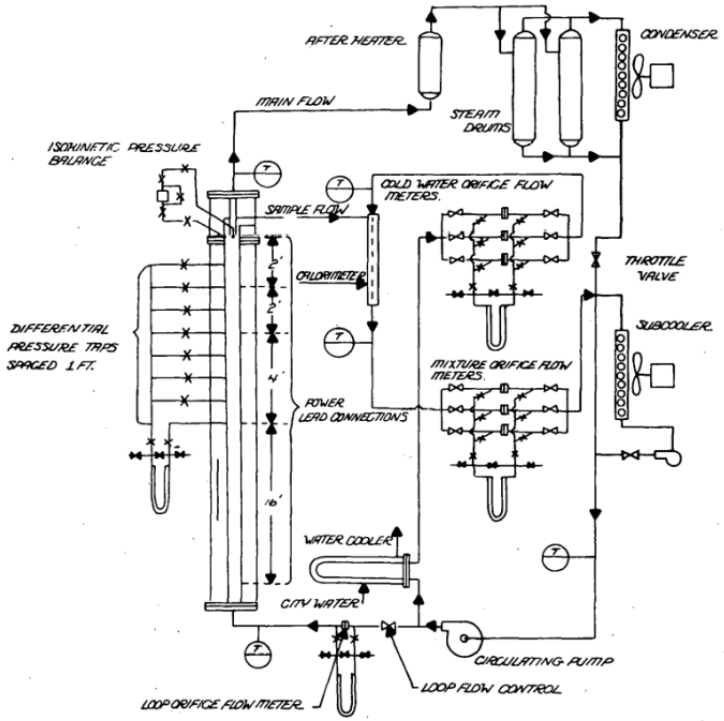


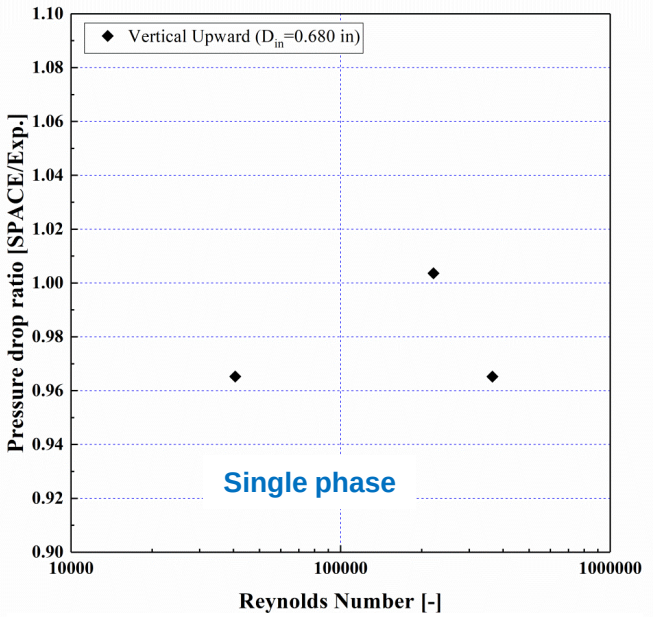


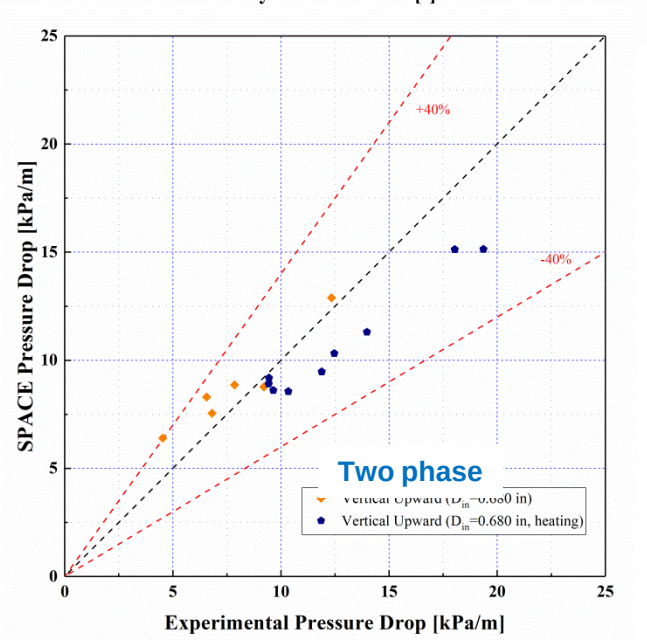
4 Assessment of SPACE code

Pressure drop assessment

- GE-2 assessment
  - Single phase: ~3%
  - Two phase: ~20%



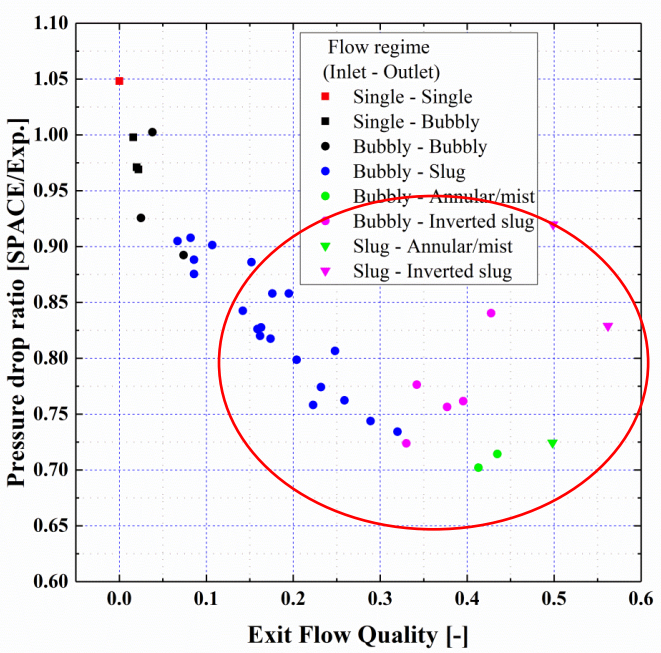


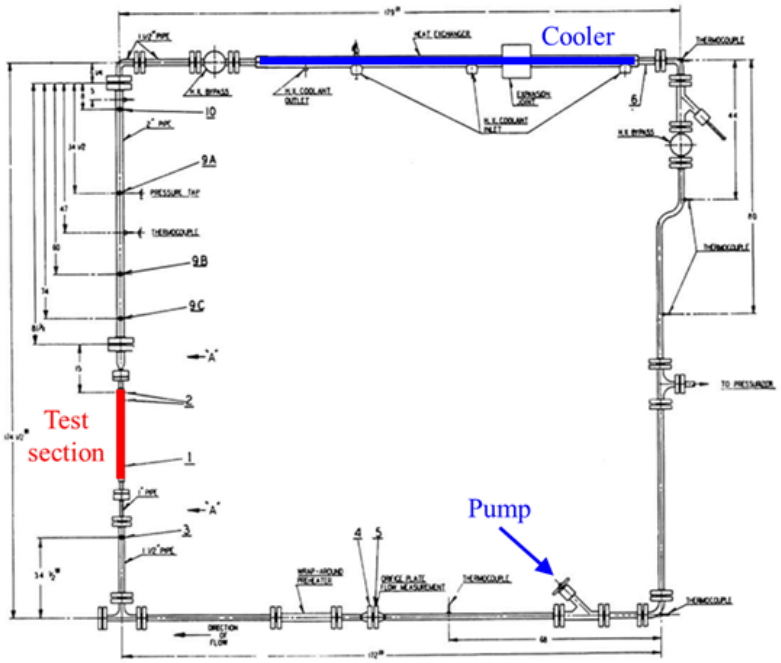


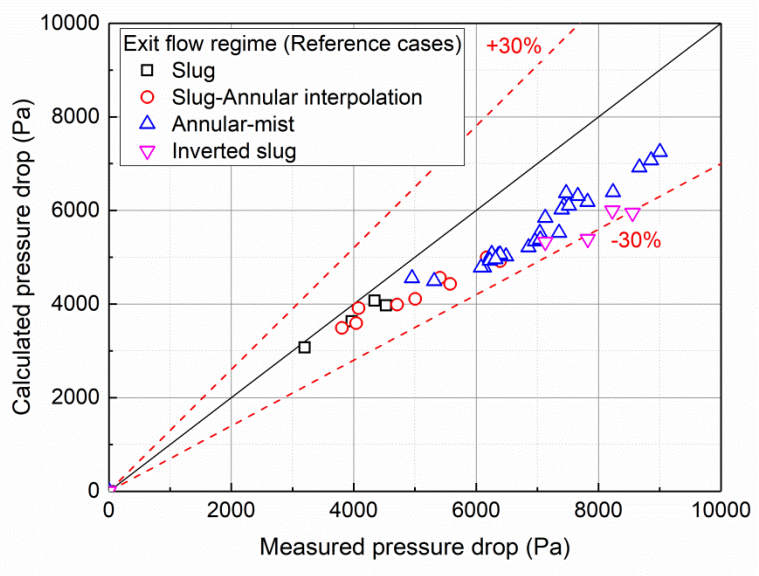
4 Assessment of SPACE code

Pressure drop assessment

- **Bettis assessment**
  - Two phase: ~20%
  - Large gap for high quality condition (Ann-mist)
    - Due to specialty of SPACE code for downcomer sweep-out model





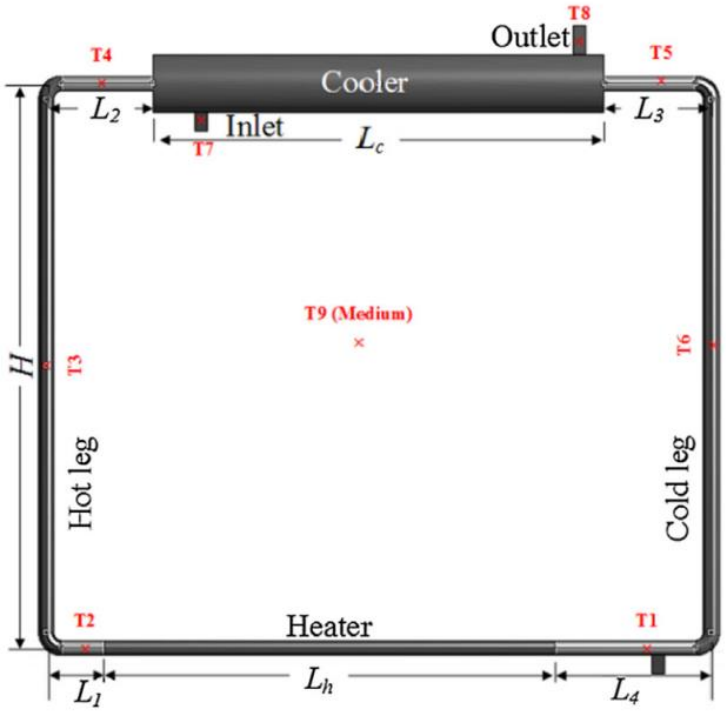


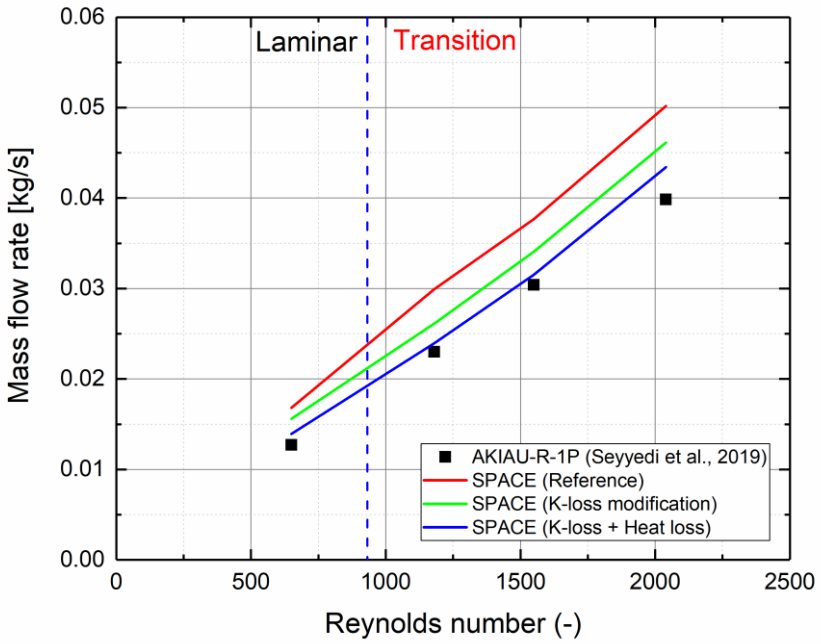
4 Assessment of SPACE code

Pressure drop assessment

AKIAU-R-1P assessment

- Loss coefficient depending on *Re* is necessary



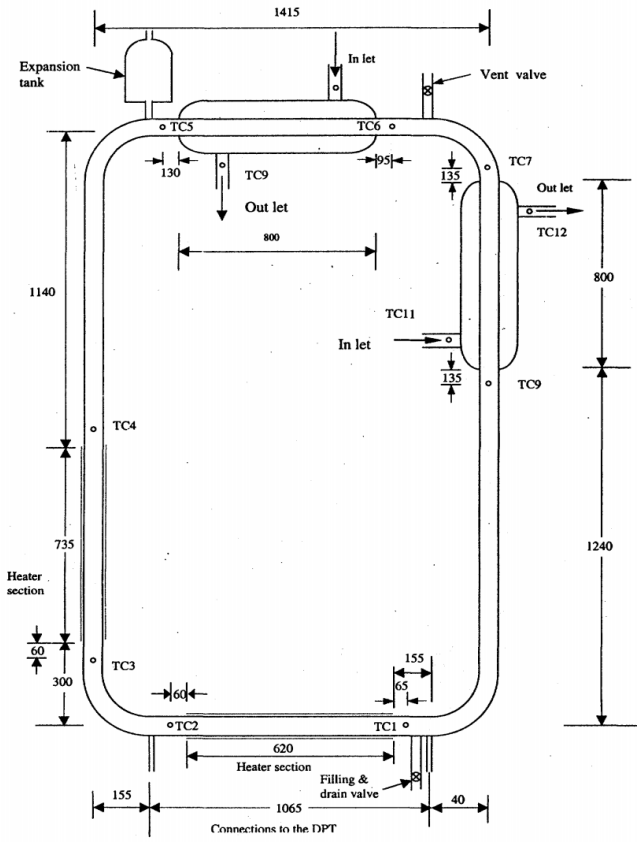


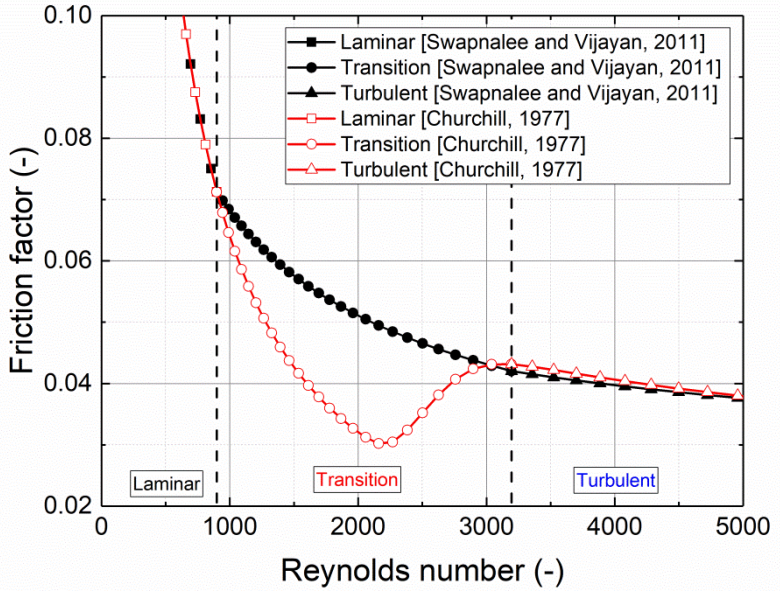
4 Assessment of SPACE code

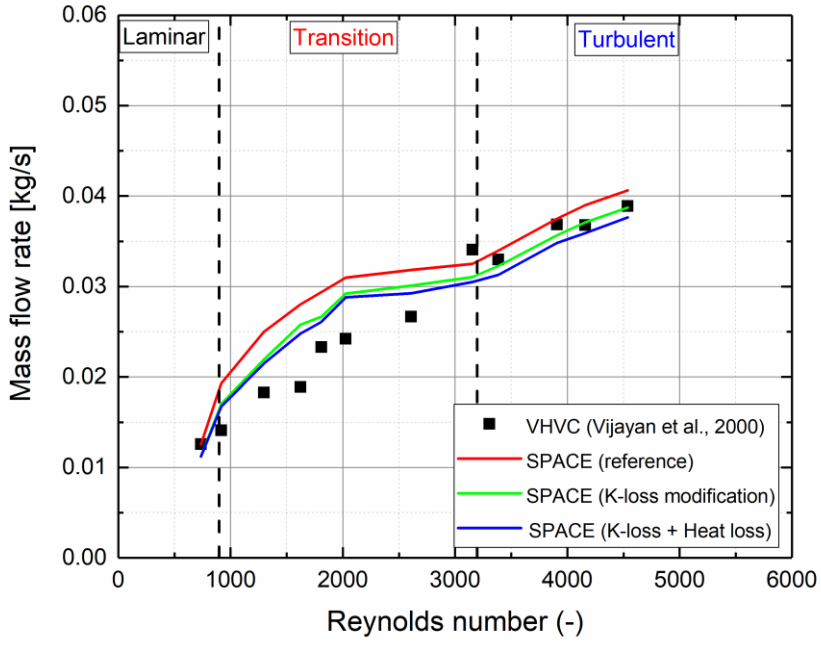
Pressure drop assessment

Vijayan assessment

- Discrepancy in transition regime





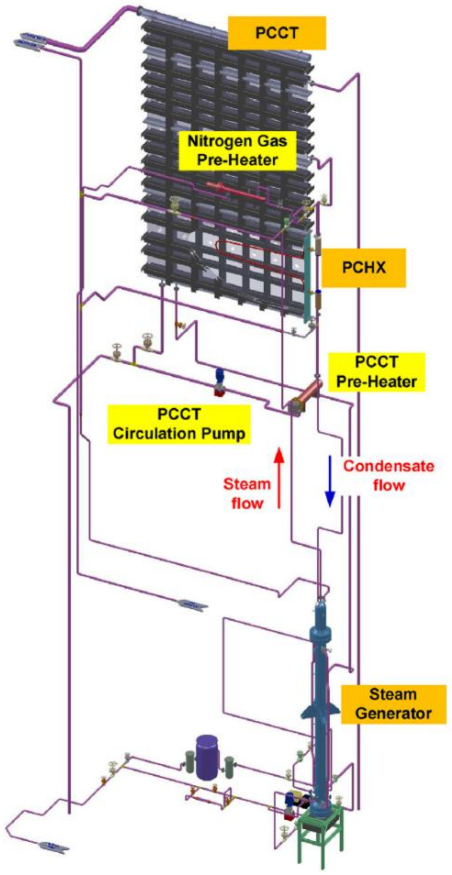


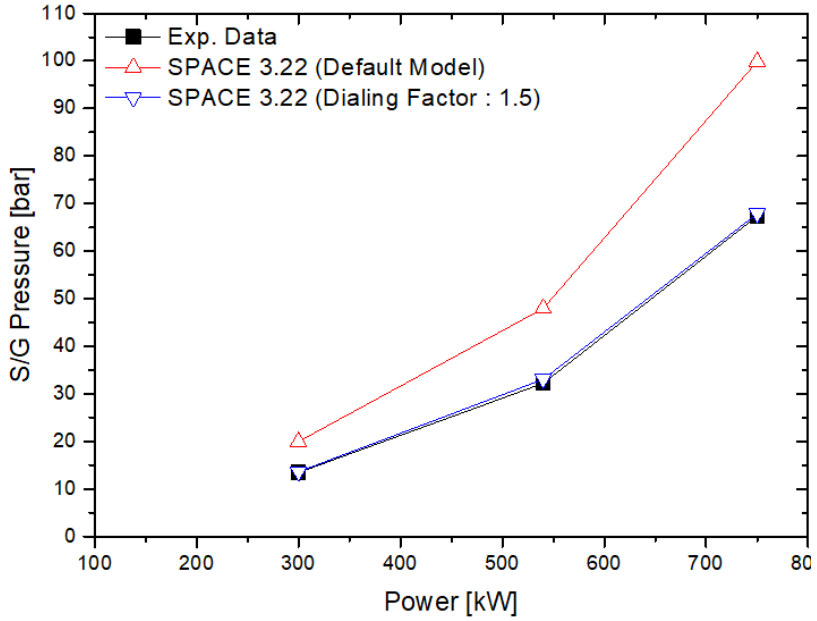
4 Assessment of SPACE code

SET assessment: natural circulation heat transfer

PASCAL

- Conservatism in default heat transfer model of SPACE code was identified.

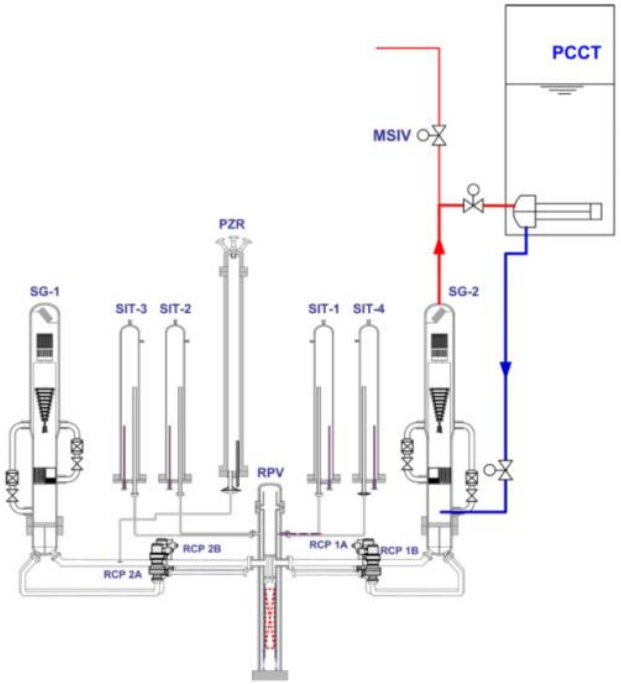




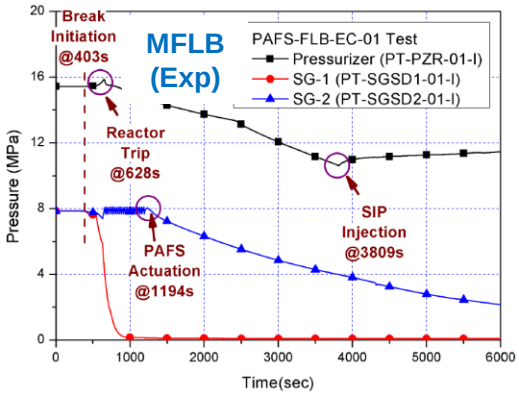
4 Assessment of SPACE code

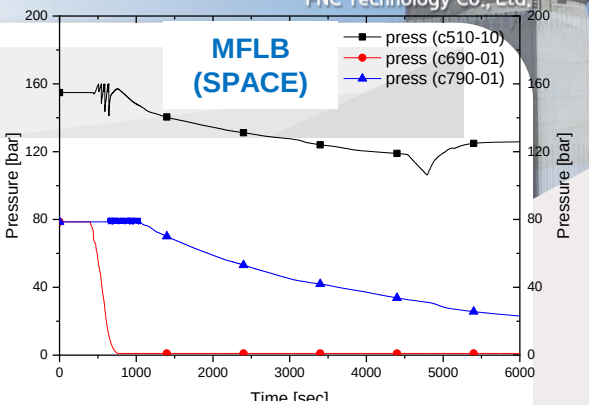
IET assessment

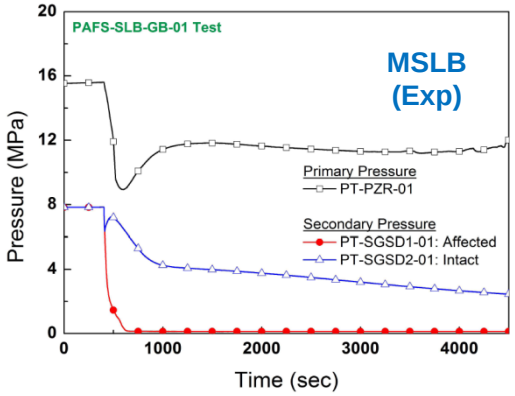
- ATLAS-PAFS: MFLB & MSLB & SGTR

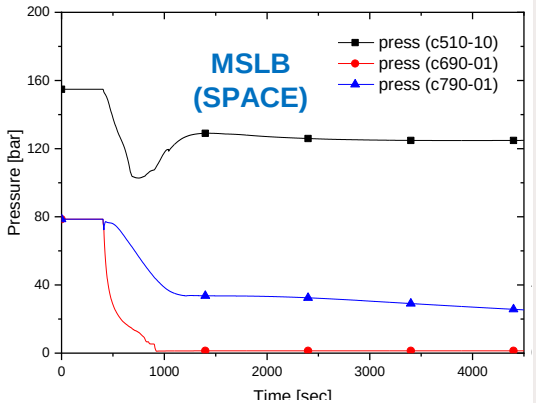


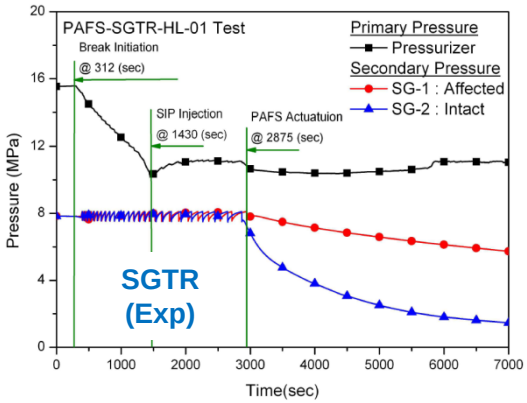
ATLAS-PAFS Facility

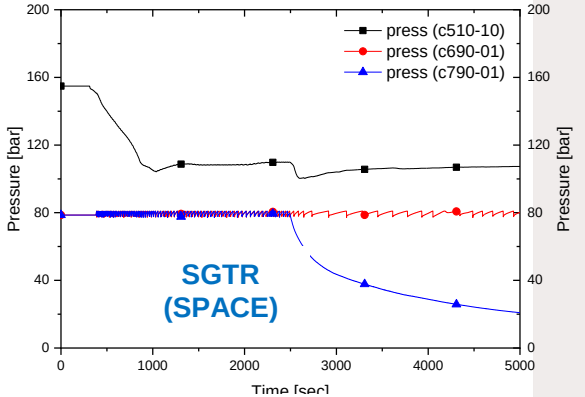












5 Conclusions

4 Conclusions

Summary and conclusion

- **Reasonable compliance to EUR Rev. E for emergency FWS**
- **Acceptable performance of PAFS of APR1000 for limiting transients**
  - More comprehensive behaviors of PAFS were identified
- **Extensive assessment of SPACE code for the analysis of PAFS behavior**
  - Good prediction for pressure drop in single phase and two-phase for the relevant flow regime
  - Conservative heat transfer model and natural circulation phenomena in SPACE
  - Good prediction for IET of representative transients

ABOUT

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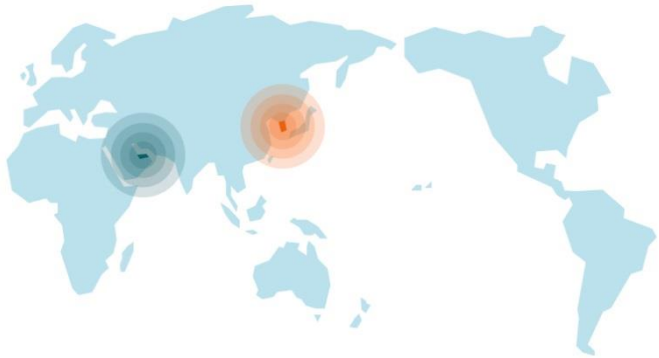

THANK YOU

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