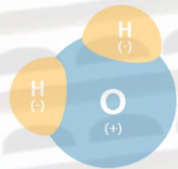
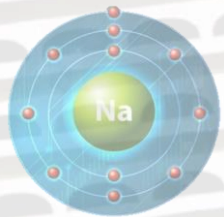


Experimental study of impingement wastage caused by Sodium Water Reaction in the Printed Circuit Steam Generator



14 May 2021

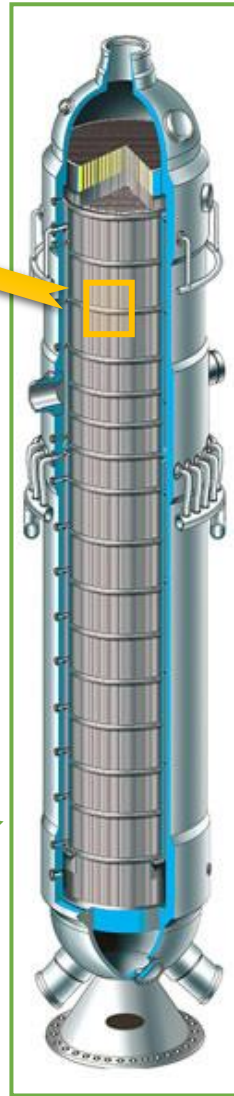
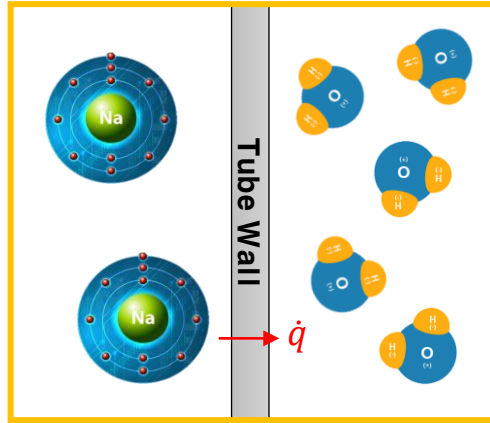
Transactions of the KNS spring meeting
Siwon Seo, Jaeyoung Lee

I. INTRODUCTION

Inherent Risk



Sodium-Water Reaction



25.5 m

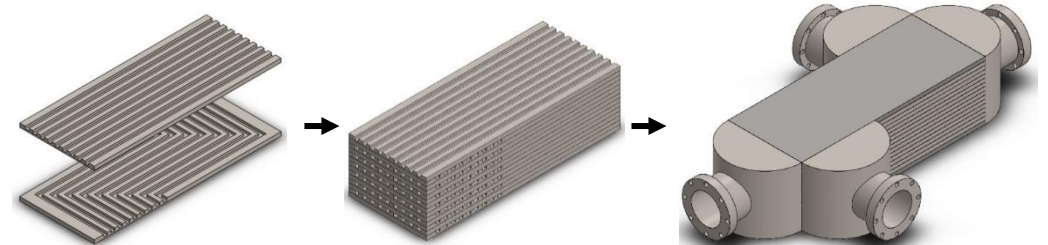
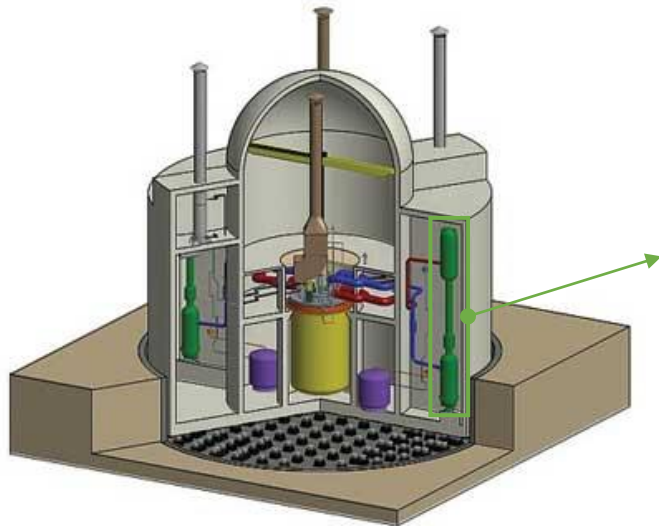
~2 m

PREVENTION

MITIGATION

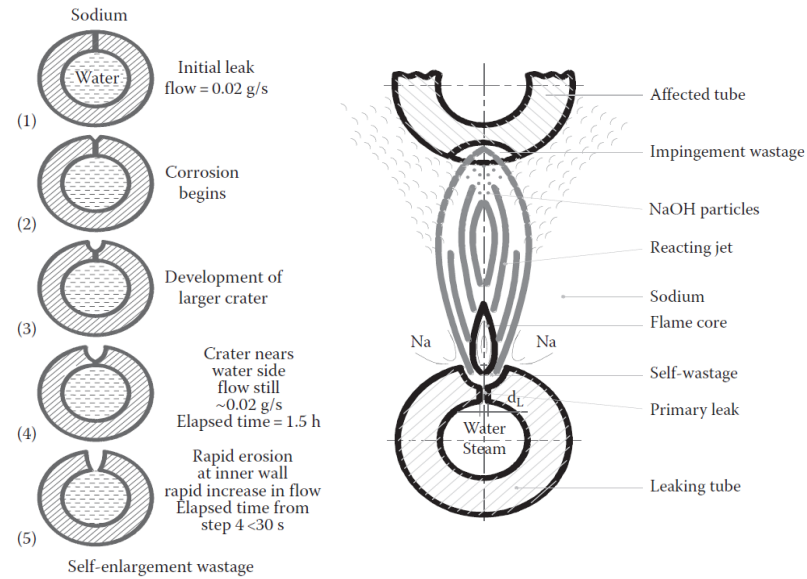
- There is no damage propagation by impingement wastage
- It is facilitate acoustic detection due to low background noise caused by laminarization of flow in the PCSG
- Effective accident management by modularization of the PCSG

Sodium-cooled Fast Reactor

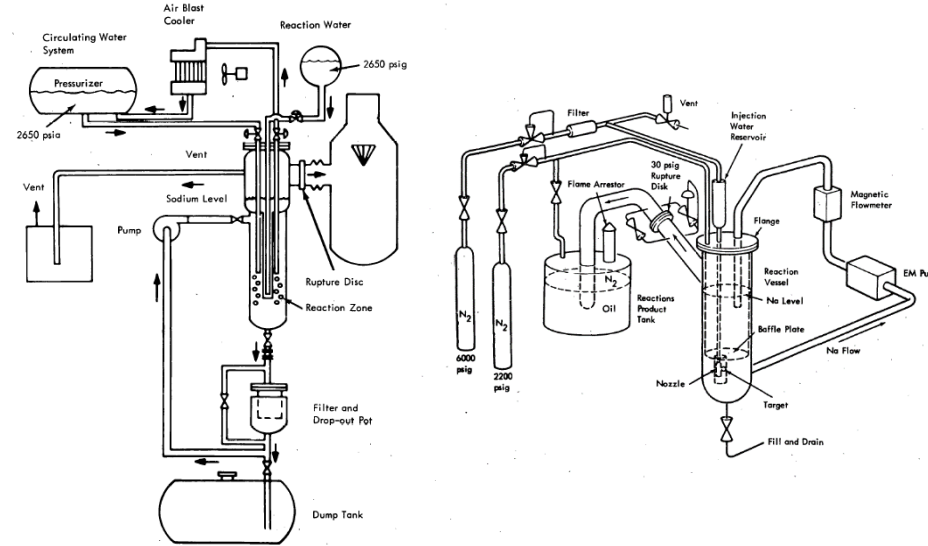


I. INTRODUCTION

Wastage in Shell and Tube SG



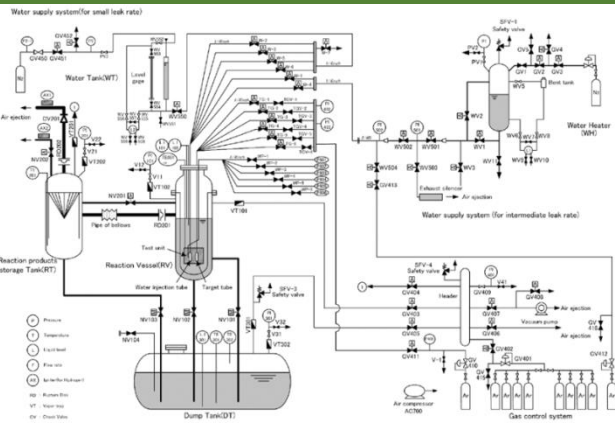
US(1970), APDA



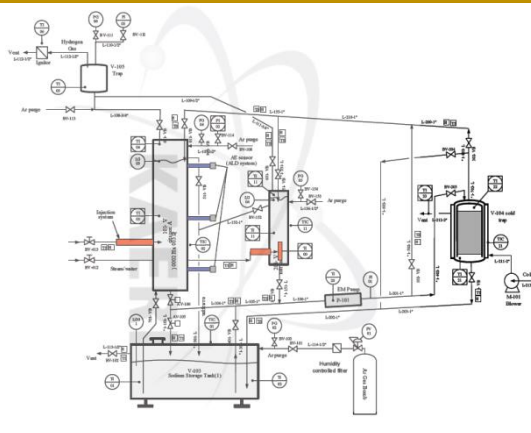
Sodium-water reaction in Shell and tube SG

- Experiments for SWR in the conventional shell & tube steam generator had been implemented in US, Japan, India, and Korea.
- Used methodologies are similar in all experiments.
- In this case, sodium pool can supply considerable amount of sodium to reaction region.
- However, it is expected that an aspect of the SWR in the PCSG is different from previous experiments because the PCSG has no sodium pool.
- In these researches, dominant parameters of target wastage were leak rate, target distance, and sodium temperature.

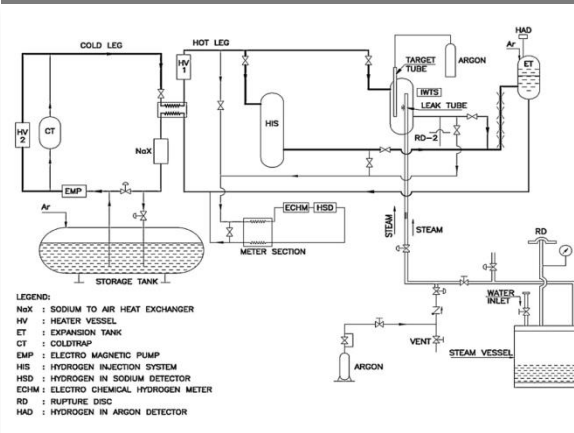
Japan(2003), SWAT



Korea(2009), KAERI

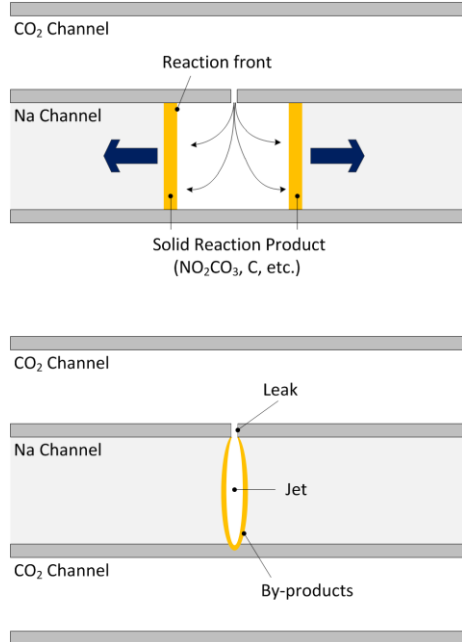


India(2012), SOWART



I. INTRODUCTION

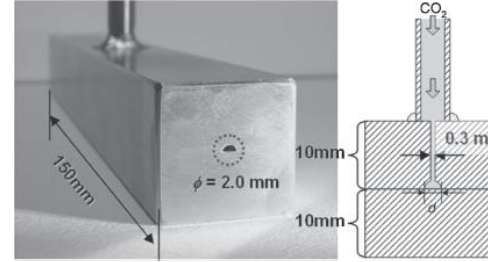
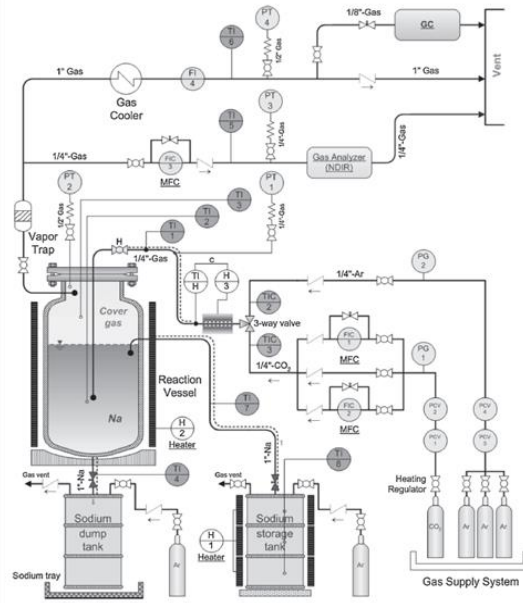
Na – CO₂ Reaction in PCSG



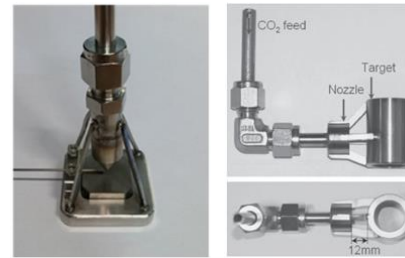
Self-plugging

wastage

Korea(2010), KAERI

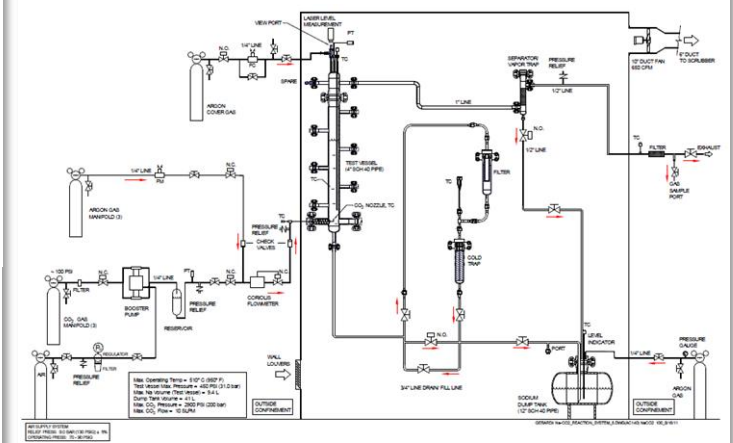


Self-plugging test



Wastage test

US(2012), SNAKE

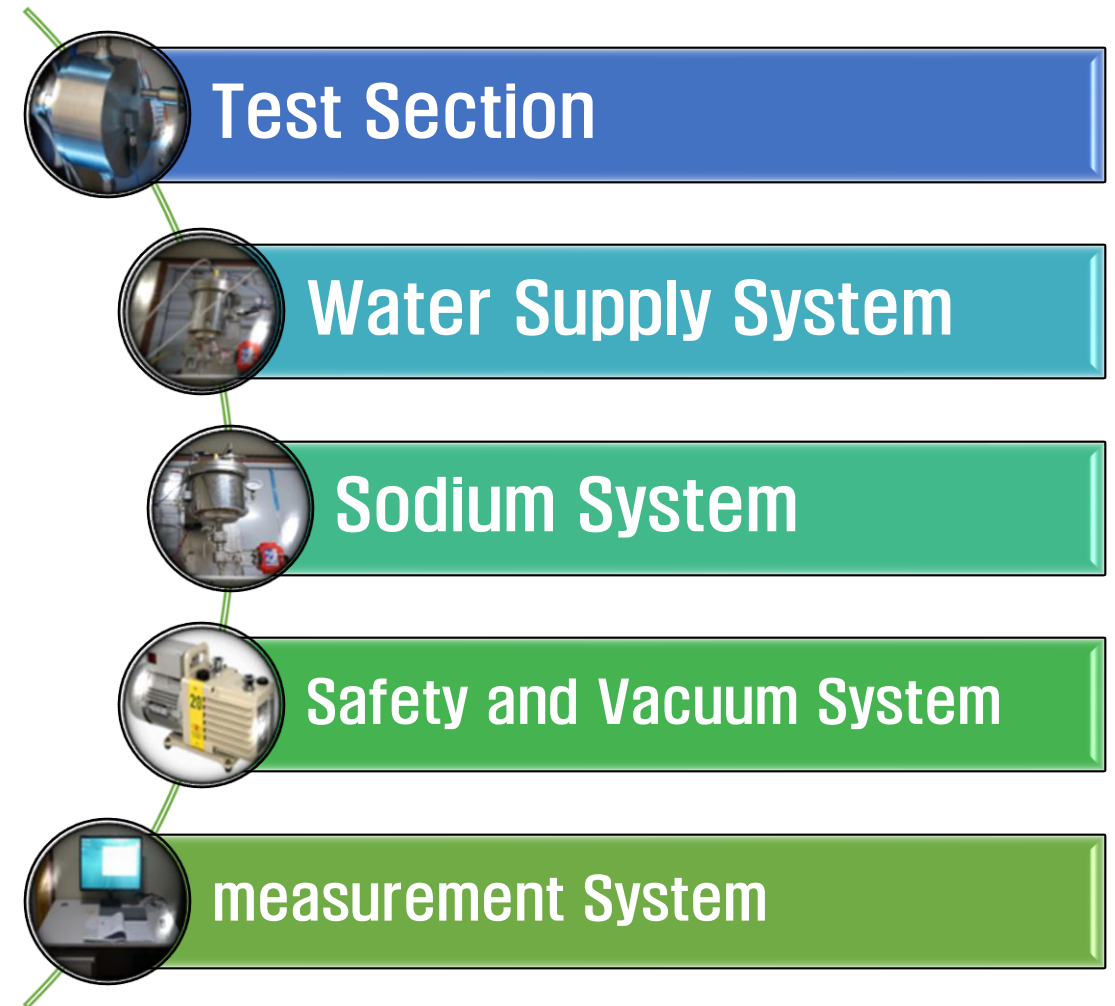
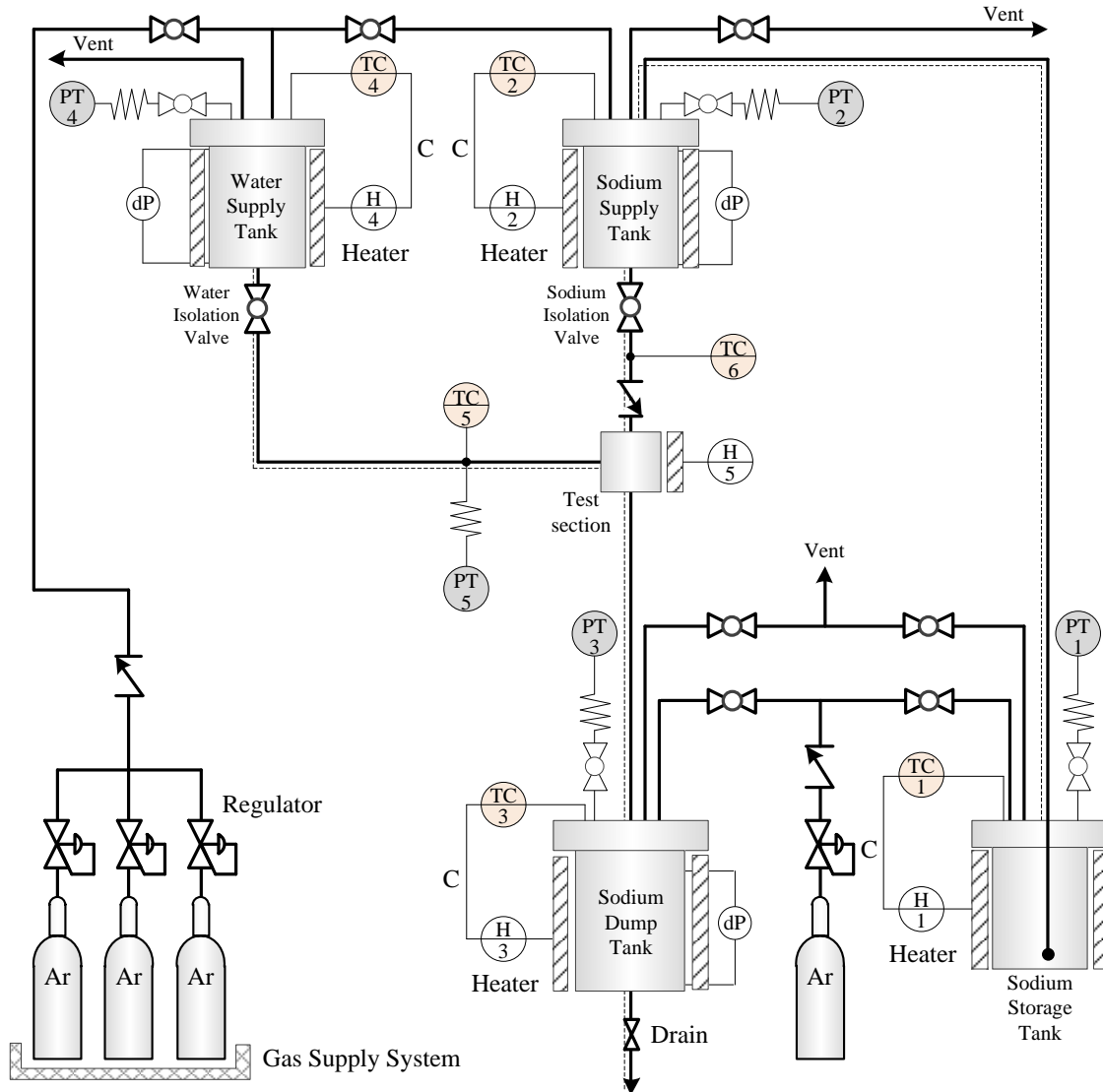


S-CO₂-Na reaction in the PCSG

- Study about the SWR in the PCSG is never performed up to now.
- However, studies about the **S-CO₂-Na reaction in the PCSG** had been performed in US and Korea.
- Designing test section about the PCSG is difficult because channel size is small (~4 mm). Therefore, almost test section can NOT reflect practical geometry of the PCSG. **Only target distance** is realized in previous studies.
- Test section realized practical target distance, Sodium flow, and pressure difference between two sides of the PCSG is needed.

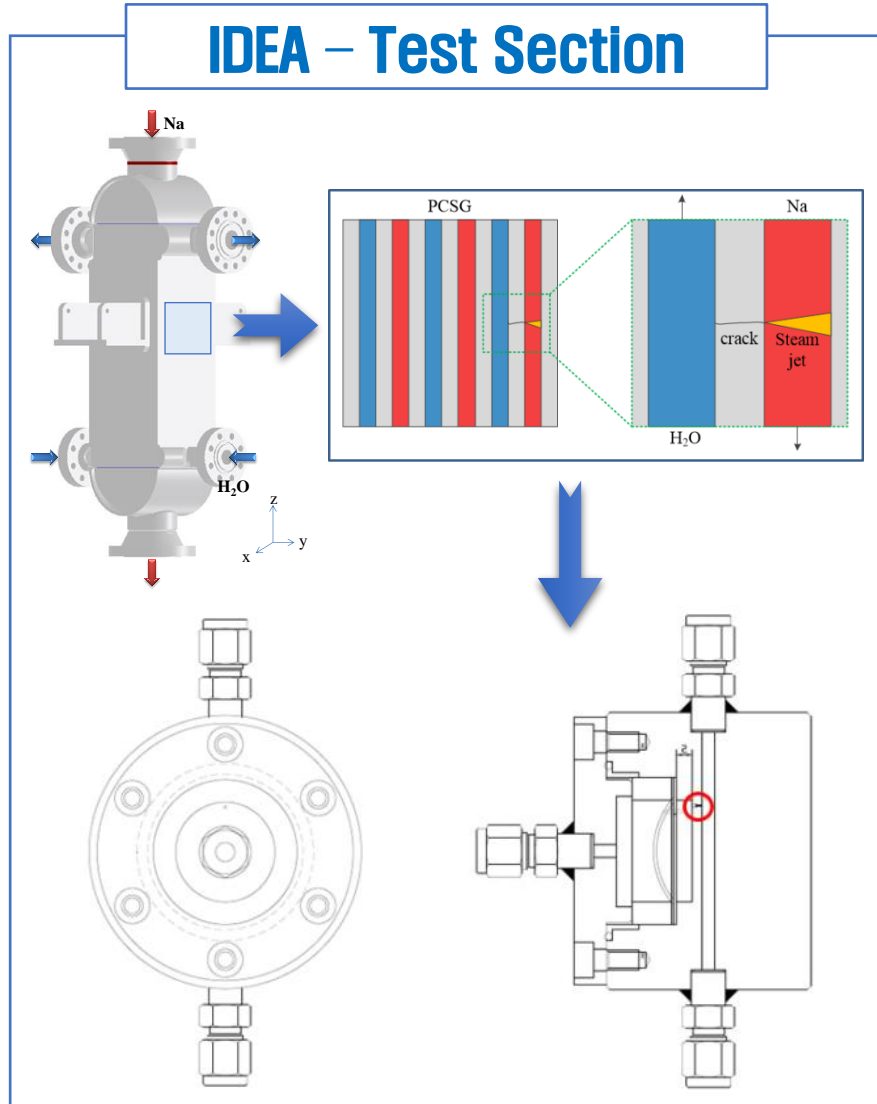
II. METHODOLOGY – DESIGN & CONSTRUCTION

❖ Classification of CATS-S

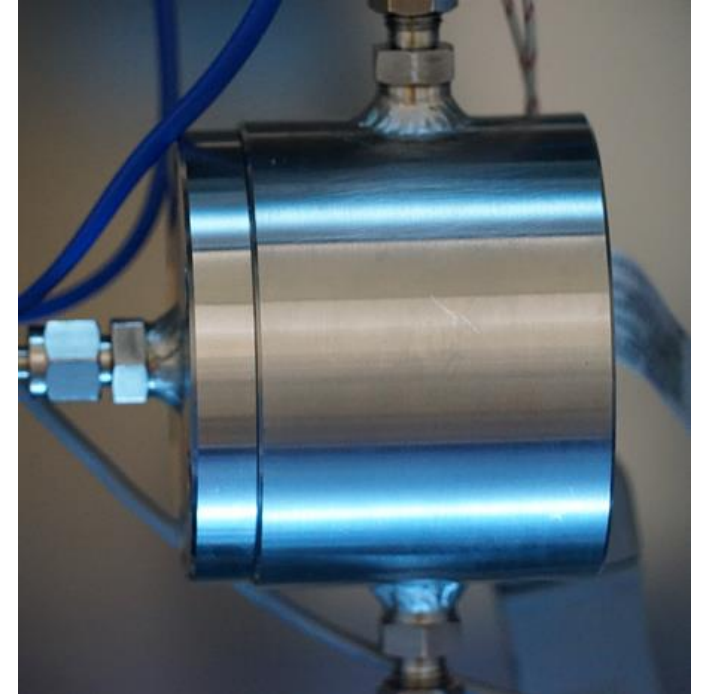
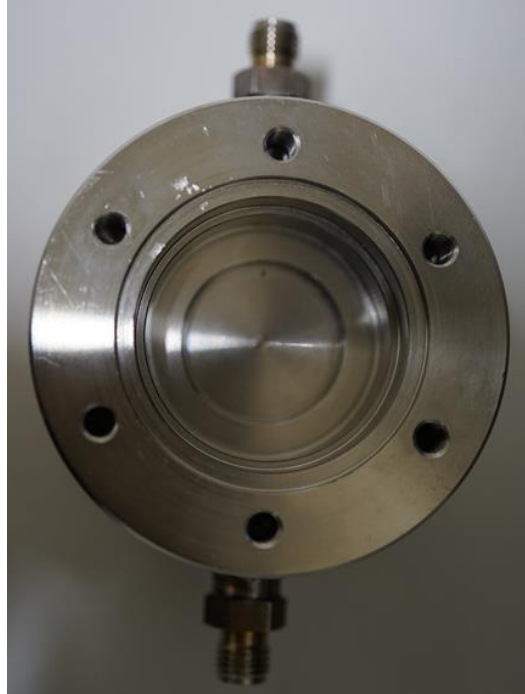


II. METHODOLOGY – DESIGN & CONSTRUCTION

❖ Test Section

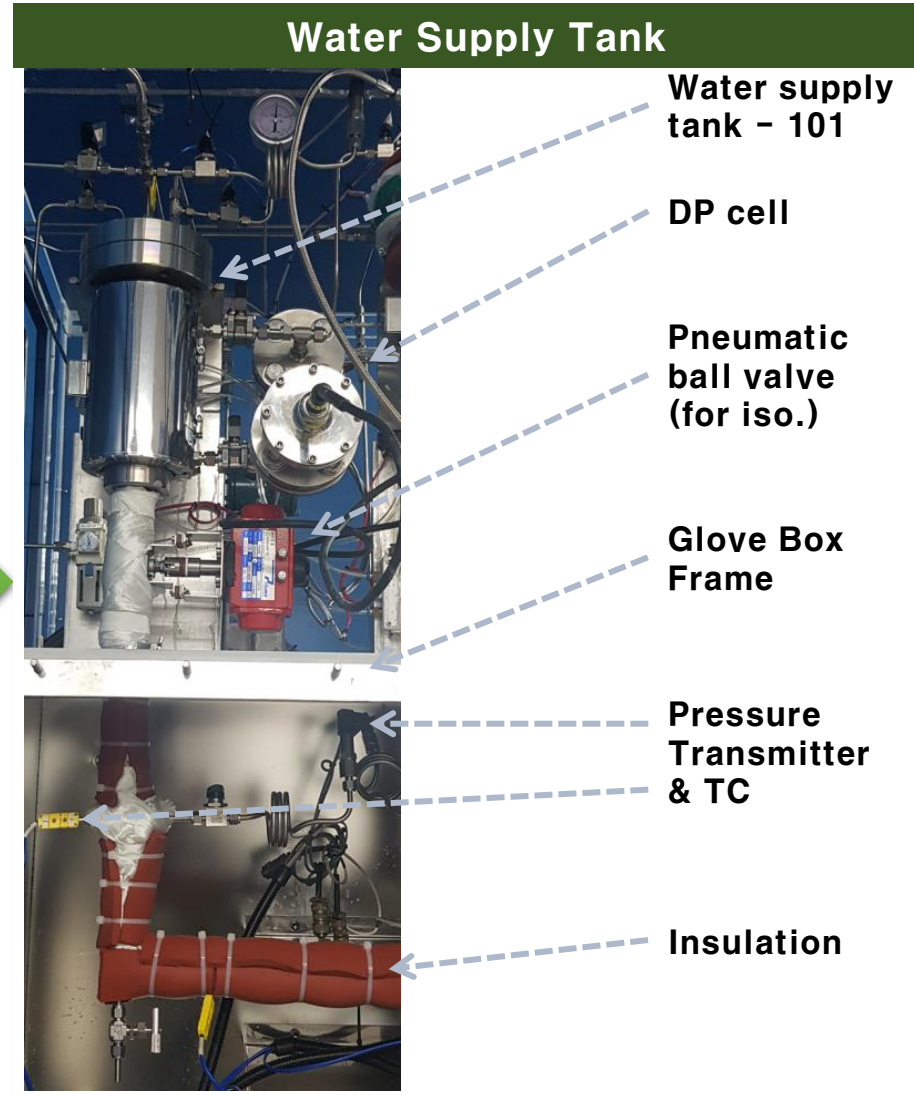
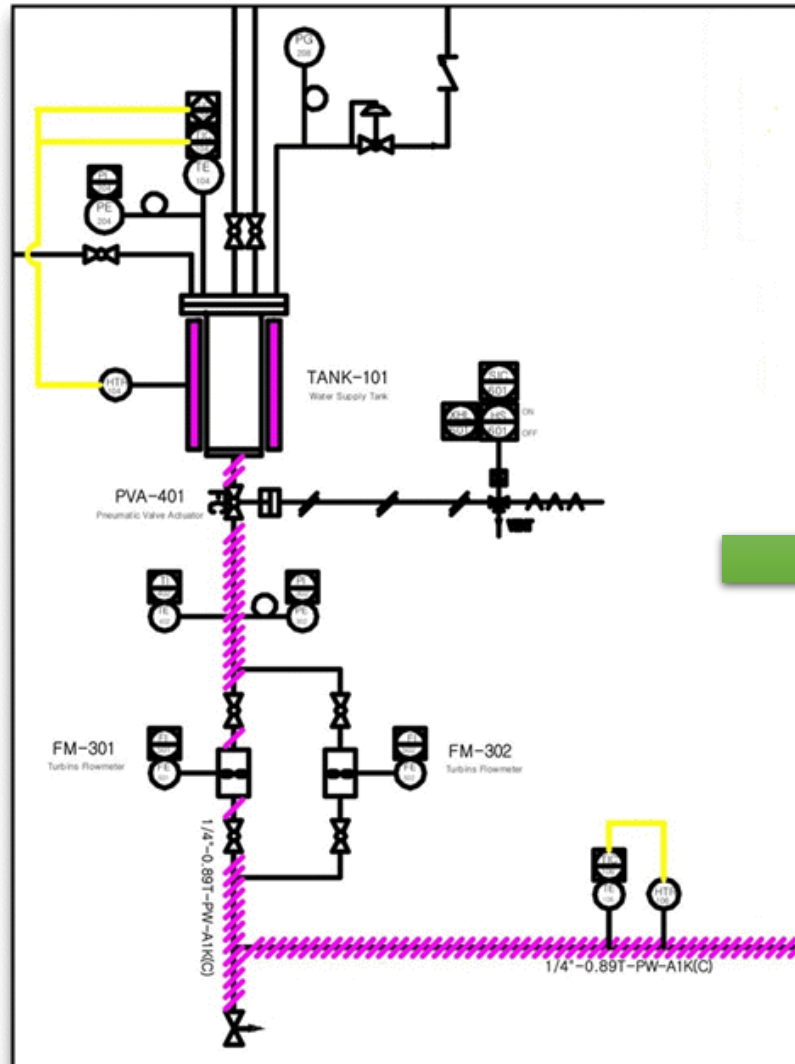


Test Section & Rupture Disc



II. METHODOLOGY – DESIGN & CONSTRUCTION

❖ Water Supply System



Water Supply Tank

Water supply tank - 101

DP cell

Pneumatic ball valve (for iso.)

Glove Box Frame

Pressure Transmitter & TC

Insulation

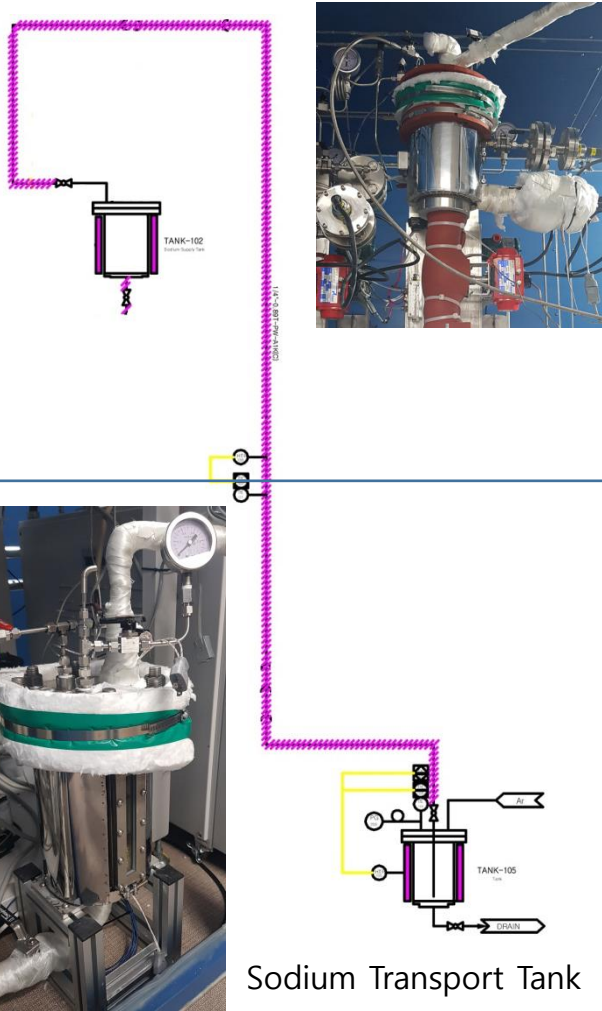
Determination of Experimental Pressure

- Operational Pressure of water side = 180 bar
- Expected minimum Pressure occurring choked flow = 9.2653 bar (assuming outlet pressure = 5 bar)
- Experimental Pressure of water side = 10 ~ 35 bar (for leak rate variation)

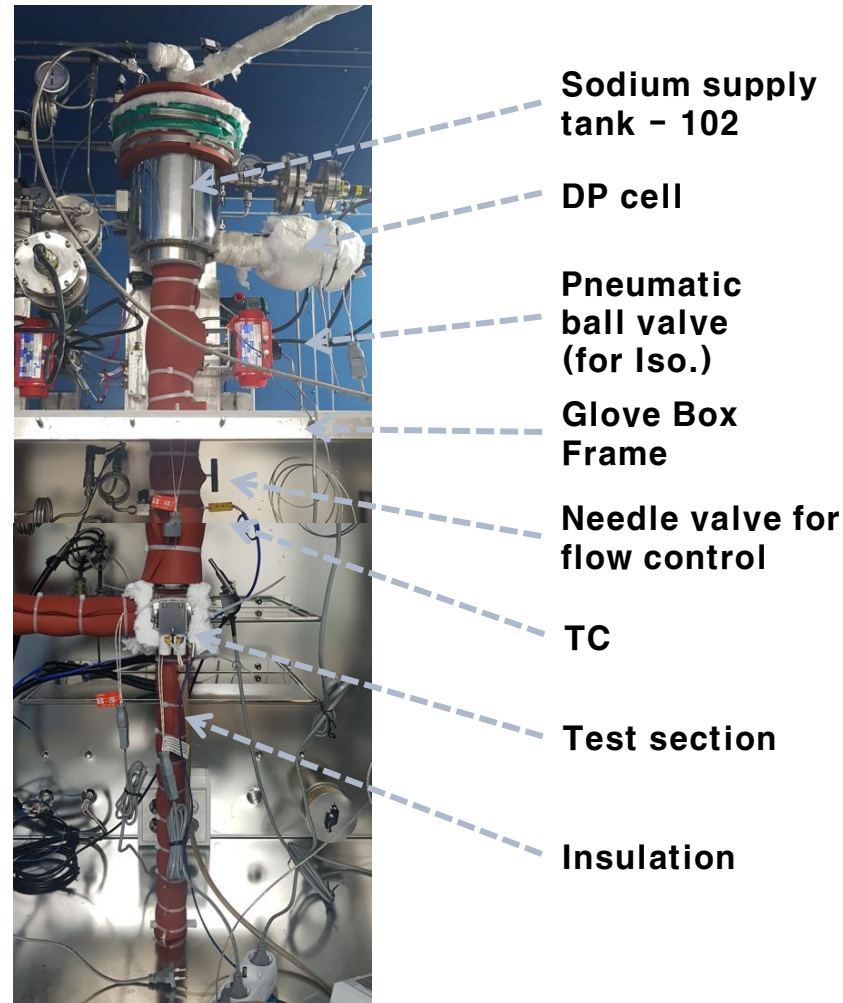
II. METHODOLOGY – DESIGN & CONSTRUCTION

❖ Sodium System

Sodium Transport Tank



Sodium Supply Tank



Sodium Dump Tank

$$\text{Na} + \text{H}_2\text{O}(\text{l}) \rightarrow \text{NaOH} + \frac{1}{2} \text{H}_2$$

$$\Delta H_{298}^\circ = -147.37 \text{ kJ/mol}$$

Expected max. leak late = 0.00194 kg/sec (Assumed that all leak water reacts with sodium immediately.)

$$147.37 \text{ kJ/mol} \times 0.1077 \text{ mol/sec} = 15.872 \text{ kJ/sec}$$

Vol. of Sodium Dump Tank = 3L

$$15.872 \text{ [kJ/sec]} \times 1000/3 \text{ [1/m}^3\text{]} = 5.29 \text{ MPa/sec}$$

Design Pressure of Sodium Dump Tank = 10 MPa (=5.29 MPa/sec + margin)

II. METHODOLOGY – DESIGN & CONSTRUCTION

❖ Safety and Vacuum System

Safety Case



Filtered Venting System



Vacuum System



- Min. pressure in the CATS-G was **179 Pa(a)**
- Saturation temperature at **179 Pa(a)** = **-15.8°C**
- It is estimated the Na side of CATS-S can be used for SWR test.

Monitoring System



Na fire Extinguisher



II. METHODOLOGY – Test Matrix

❖ PCSG Operating Conditions

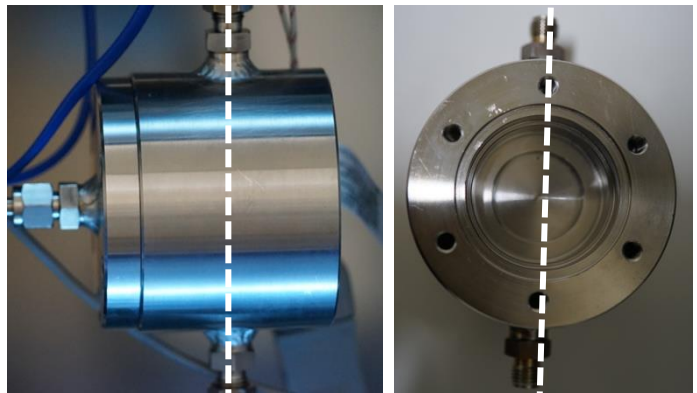
Input Parameters	Water side	Sodium side
Pressure (MPa)	18 ~ 16.7	0.5
Temperature (°C)	210 ~ 503	528~ 332

❖ Test Matrix

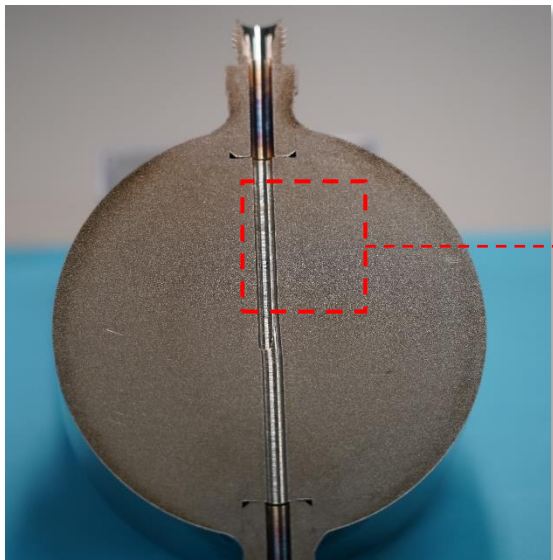
hole size = 0.3 mm	$T_{na} = 332^{\circ}\text{C}$	$T_{na} = 450^{\circ}\text{C}$
$P_{stm} = 25$ bar	Test 1	Test 4
$P_{stm} = 35$ bar	Test 3	Test 2

hole size = 0.2 mm	$T_{na} = 450^{\circ}\text{C}$
$P_{stm} = 25$ bar	Test 6
$P_{stm} = 35$ bar	Test 5

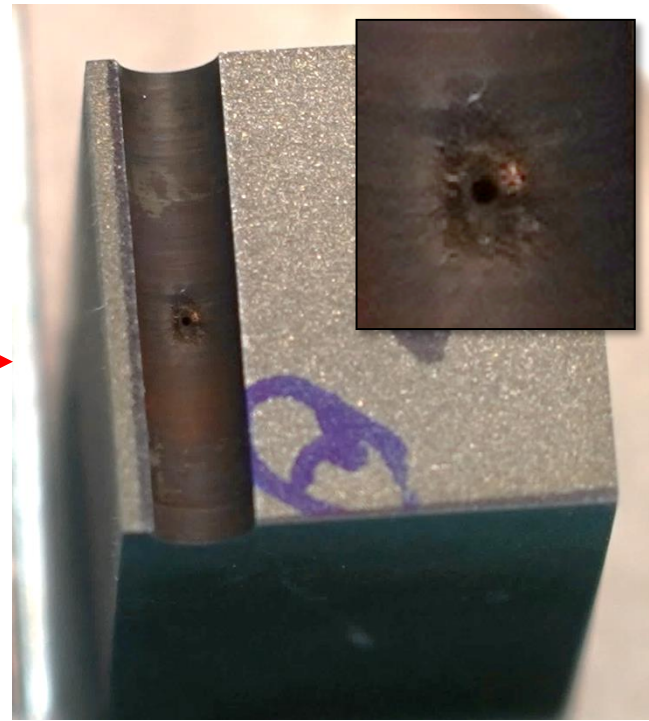
III. RESULTS AND DISCUSSIONS



Test section - Wire cutting

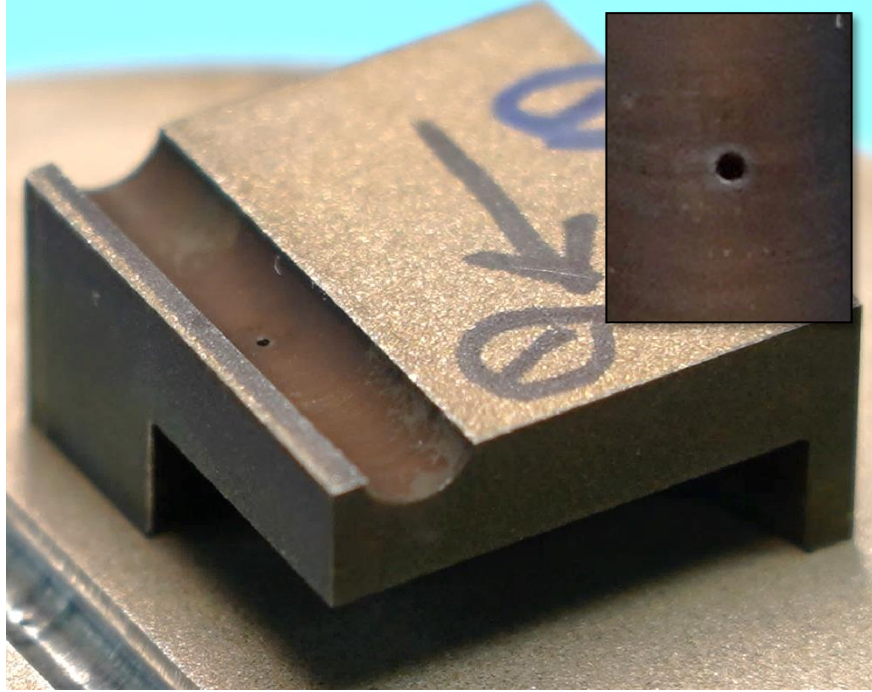


Test section - target wall

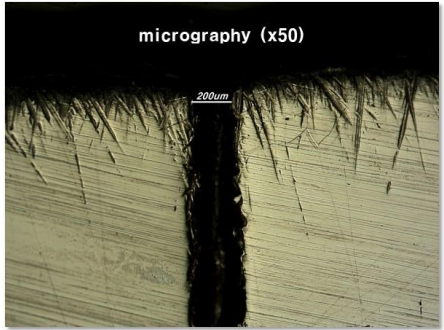


- Some mark of impingement wastage is identified.
- Now, post processing of specimen is being proceeded.

Test section - Inlet nozzle

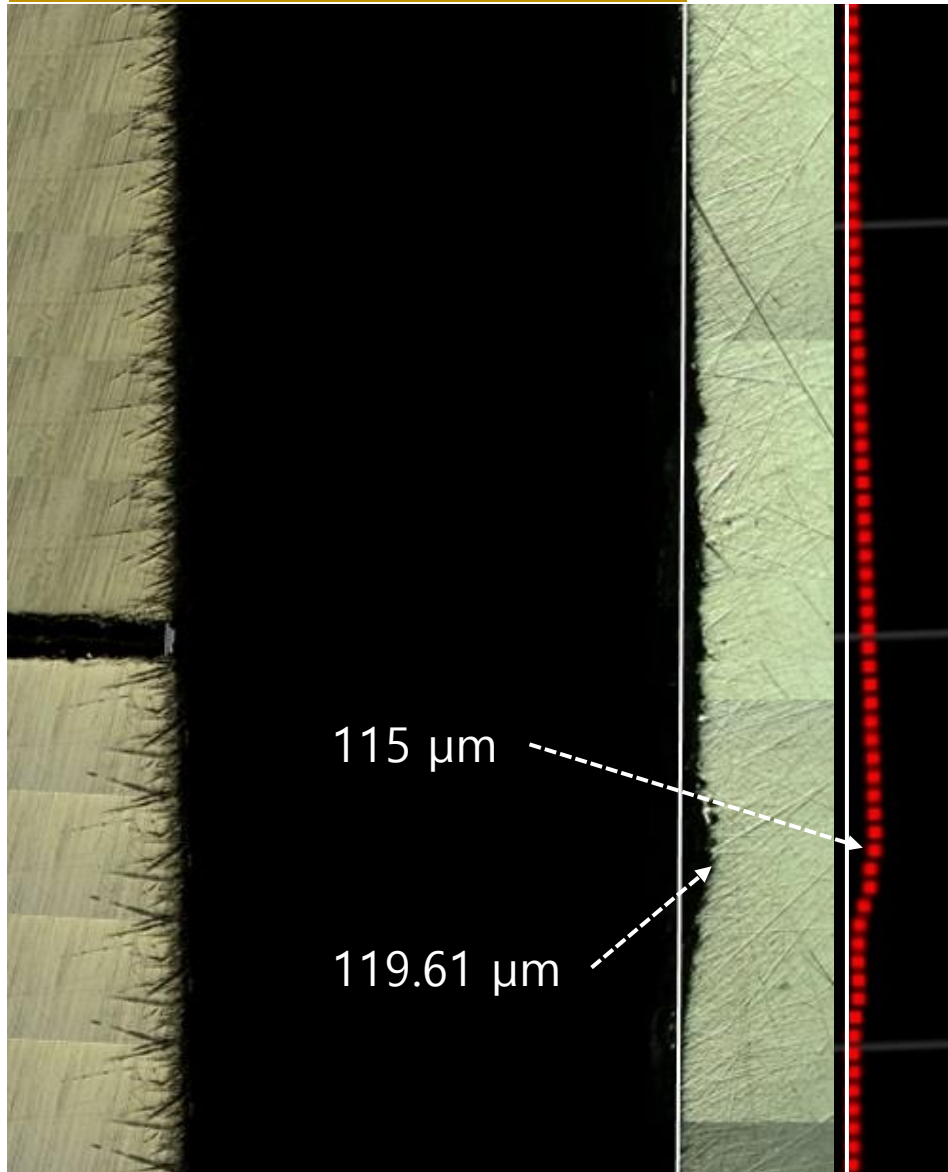


- There is **NO self-wastage**.

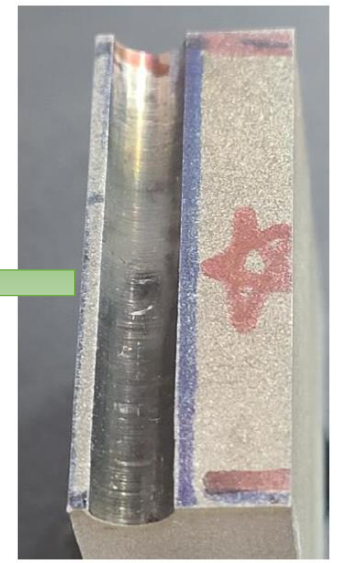
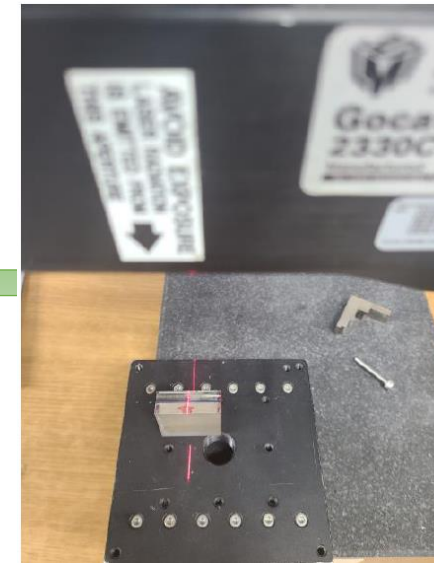
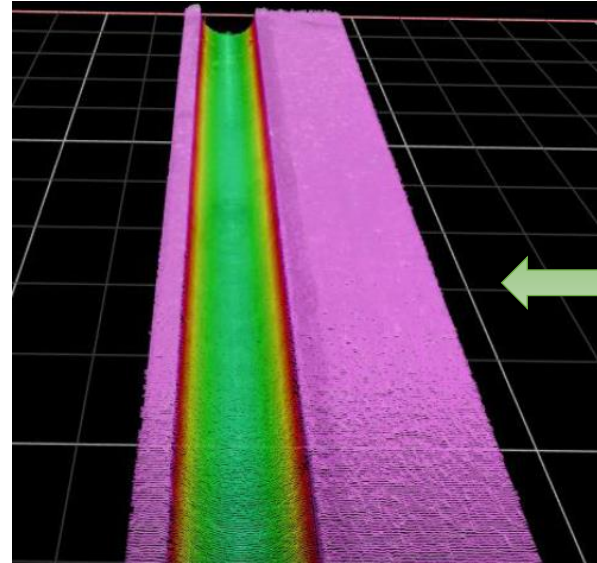


III. RESULTS AND DISCUSSIONS

Microscopic observation



LDS (Laser Displacement Sensor)

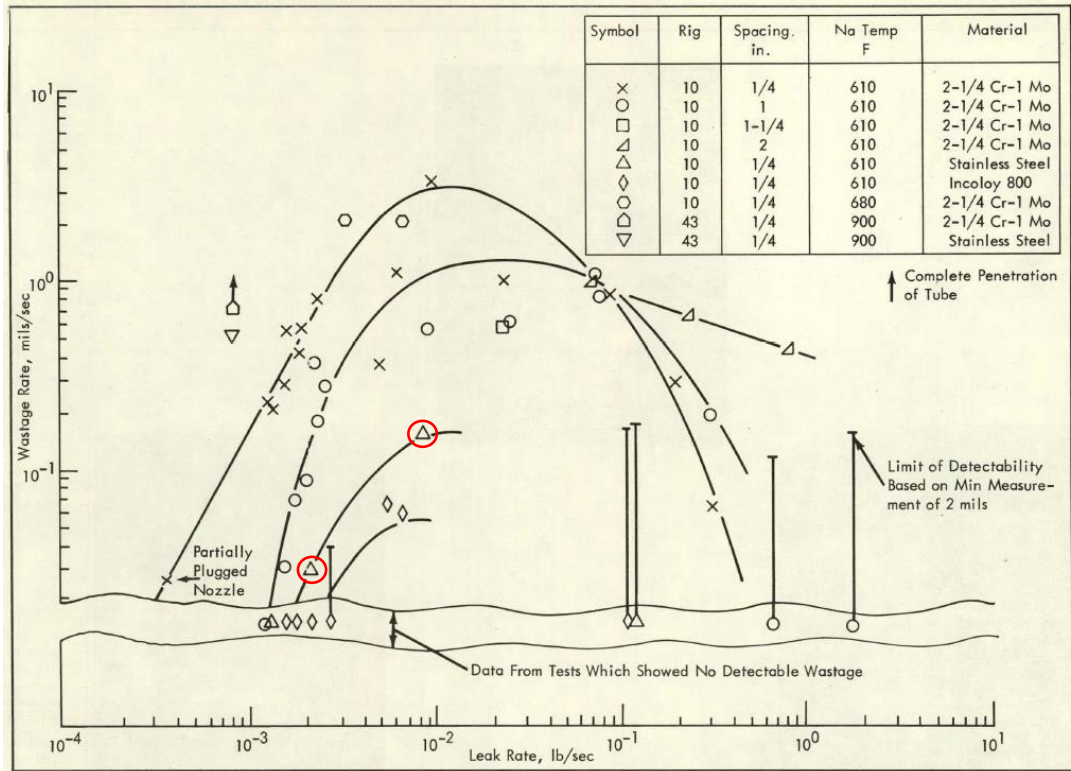


- Impingement Wastage by using microscope = 119.61 μm
- Impingement Wastage by using LDS = 115 μm
- Error between two methods = 3.85%

III. RESULTS AND DISCUSSIONS

Stainless Steel에 대한 impingement wastage 기존 연구

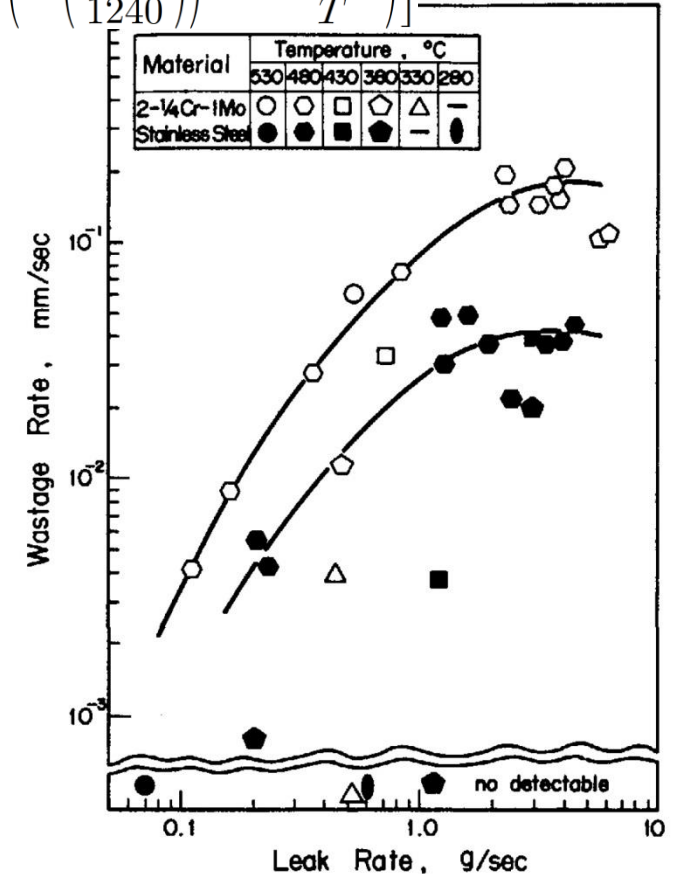
H. V. Chamberlain, "SWR related to LMFBR SG", USAEC, APDA-257, 1970



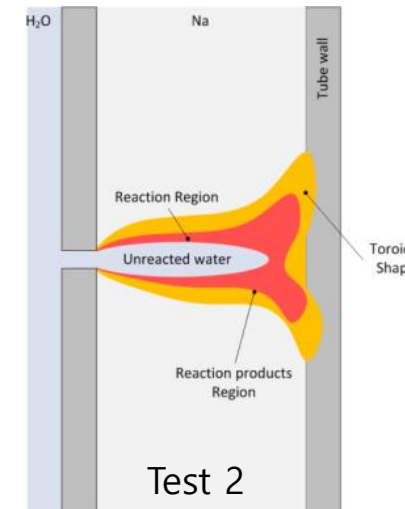
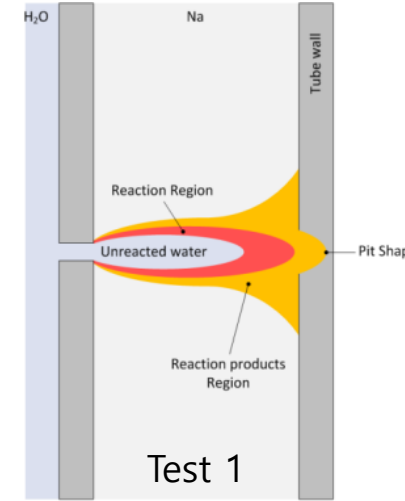
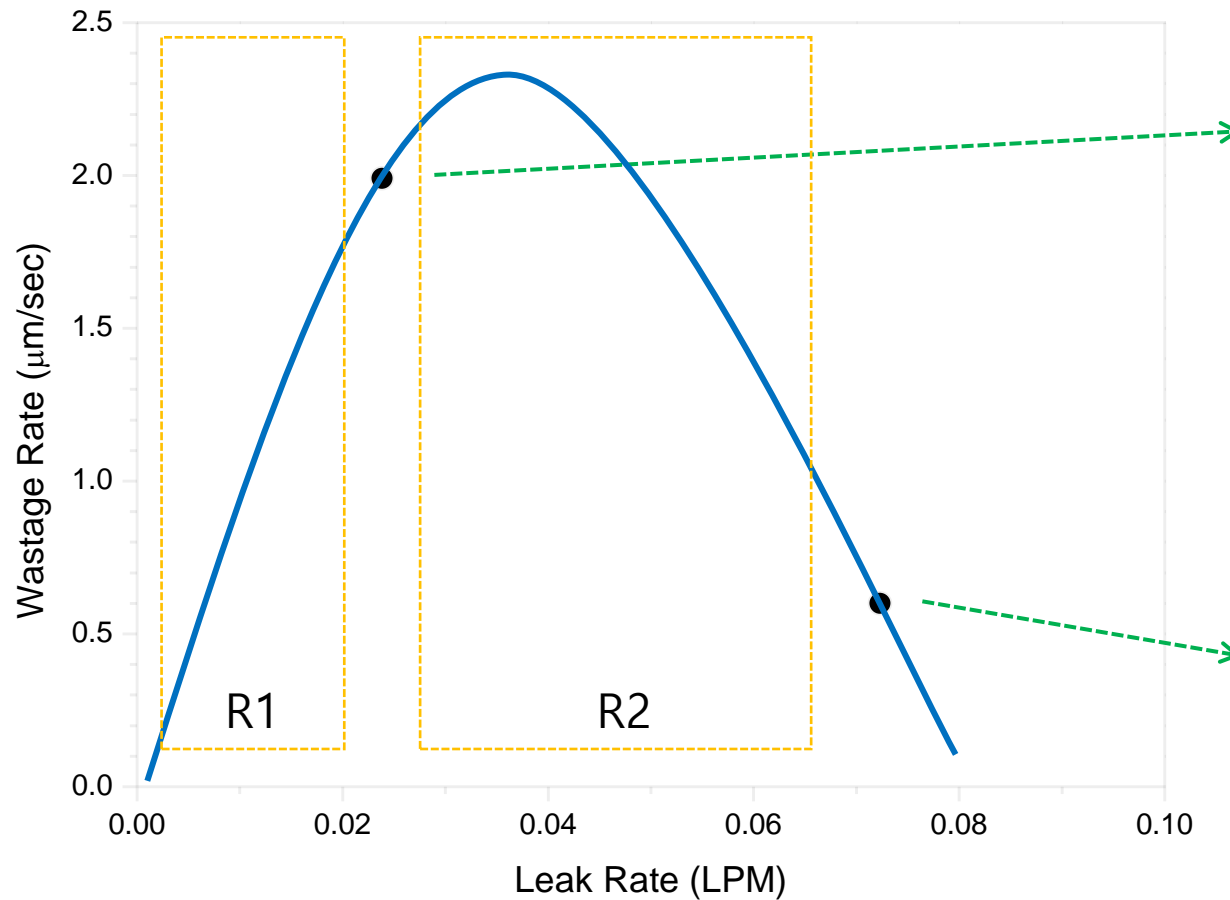
- Chamberlain의 연구에서는 단 2 case의 실험만 수행되었고, Sodium temp.나 Target distance에 대한 정보가 없음.
- Hori et al.의 연구는 고정된 target distance 조건에서 수행되어, wastage rate에 영향을 주는 변수가 leak rate(G)와 Sodium temp. (T)밖에 없음.
- 즉 기존 연구 결과는 PCSG에서의 wastage 실험 결과와는 1:1 비교 불가능함.

Ref. M. Hori, "Sodium-Water Reaction Studies for MONJU Steam Generator", IAEA, International Working Group on Fast Reactor, 1975.

$$W_R = 8470 \exp \left[- \left(0.0602 \left(\ln \left(\frac{G}{1240} \right) \right)^2 + \frac{7520}{T} \right) \right]$$



III. RESULTS AND DISCUSSIONS



- Jet shape is determined based on leak rate and target distance between discharging point and opposite wall.
- In case of Test 1, it is estimated pit shape jet was occurred.
- In case of Test 2, it is estimated toroidal shape jet was occurred.
- It is reported that pit shape jet can make maximum wastage rate.
- More data in R1 and R2 are required for modeling impingement wastage rate in the PCSG.

IV. Conclusion

Conclusion

- **CATS-S facility was designed and constructed to study about sodium-water reaction in the PCSG.**
- **Four cases of sodium-water reaction experiment were performed and two cases of experiments were analyzed.**
- **Measurement of impingement wastage in the PCSG by SWR was performed firstly.**
- **There is no self-wastage.**
- **More data are required for modeling impingement wastage rate in the PCSG.**

Further works

- **Further experiments will be performed.**

THANK YOU