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The 4th J-PARC Symposium

Current Status of Handling Technologies for Lead-Bismuth Spallation Target in J-PARC

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Contents

Accelerator-driven system (ADS) proposed by JAEA –LBE target/cooled concept

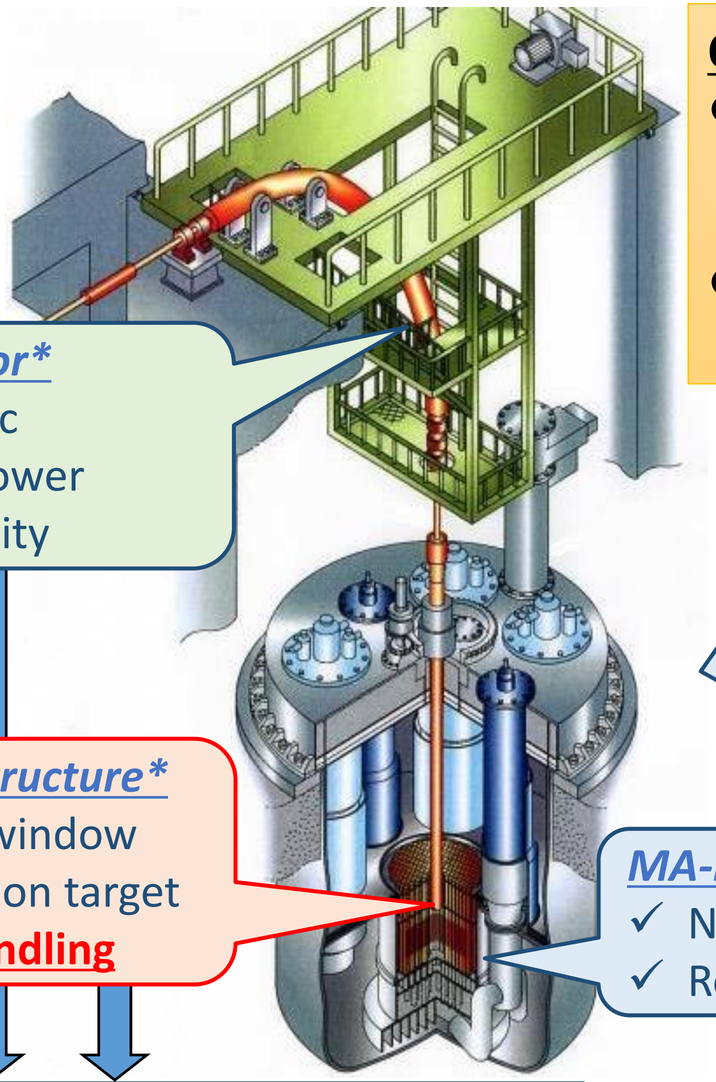
Specifications of a commercial ADS proposed by JAEA

- Proton beam: Energy 1.5GeV / Power 20MW
- Spallation target:

  Pb-Bi eutectic alloy (LBE)
- Coolant: LBE
- Subcriticality: $k_{eff} = 0.97$
- Thermal output: 800MWt
- Core height: 1000mm
- MA initial inventory: 2.5t
- Fuel composition:

  (60%MA + 40%Pu) Mono-nitride
- Transmutation rate:

  10%MA / Year (10 units of LWR)
- Burn-up reactivity swing: 1.8%Δk/k



Accelerator*
- ✓ SC Linac
- ✓ High power
- ✓ Reliability

Reactor structure*
- ✓ Beam window
- ✓ Spallation target
- ✓ **LBE handling**

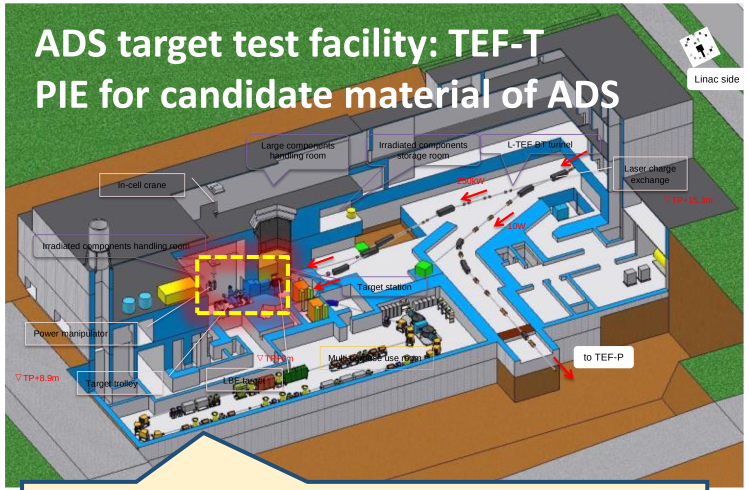
*Issues being studied at J-PARC

Objectives of ADS
- Reduction of long-term toxicity of radioactive waste
- Effective utilization of geological disposal space

Fuel cycle
- ✓ Partitioning
- ✓ MA-bearing fuel fabrication
- ✓ Dry reprocessing

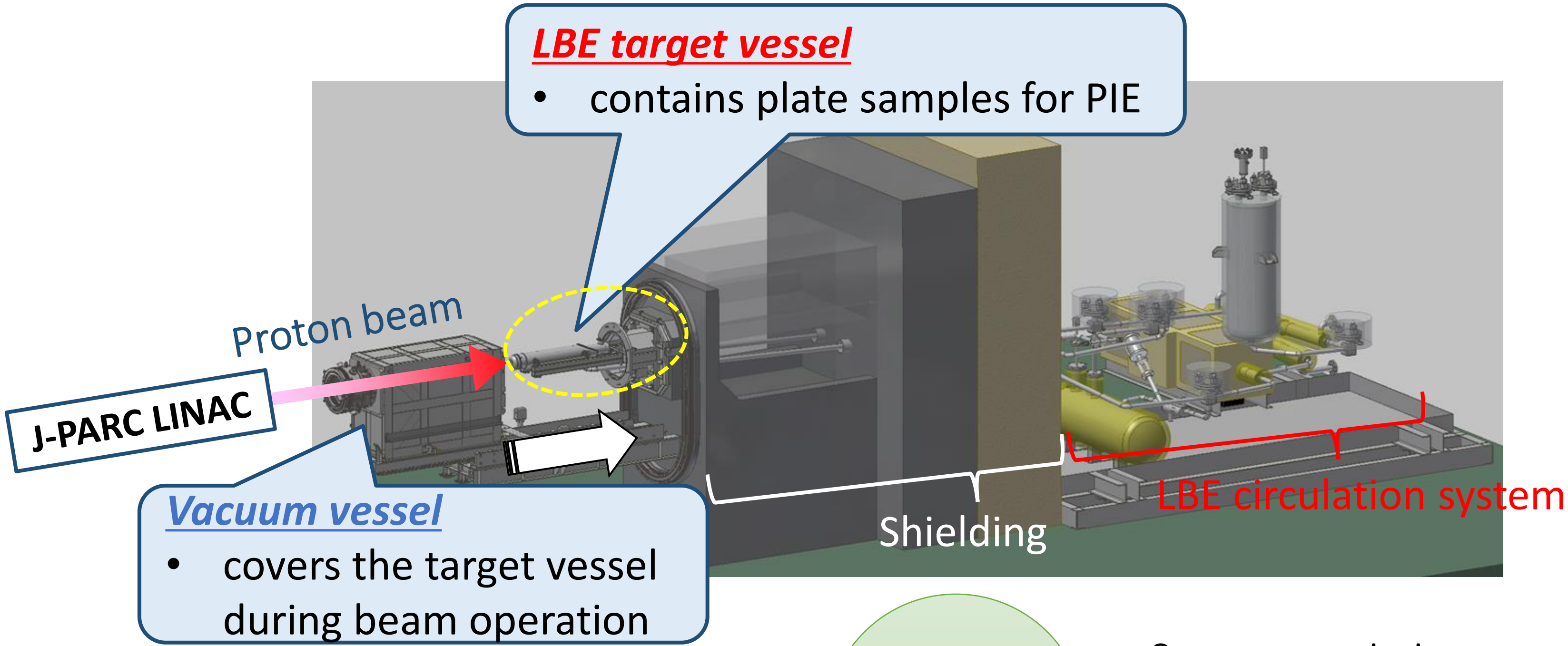
MA-loaded subcritical core
- ✓ Nuclear design
- ✓ Reactor physics

Plan of ADS target test facility (TEF-T) & LBE spallation target in J-PARC



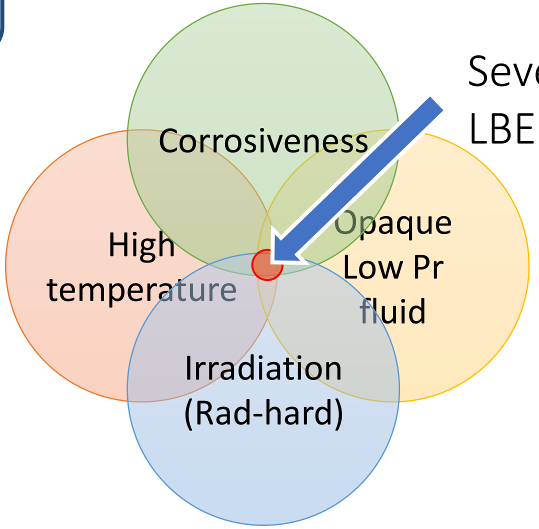
started reframing the facility plan
-> Meigo-san's plenary talk

Trolley-mounted LBE target based on Hg target (@MLF)



Specifications of the LBE target

- Proton beam: Energy 400 MeV / Power 250kW
- Target vessel structure: Double tube type (O.D.=150 mm, L=800 mm)
- Operation temperature: 450 deg C / 350 deg C
- Max. temperature: 500 deg C (Window), < 500 deg C (samples)
- Estimated life: 5,000 hours/year, 10 dpa
- Material: T91(mod. 9Cr-1Mo steel), 316SS



Establishment of LBE handling technologies especially for instrumentations

Contents

- Introduction
- Status of Lead-Bismuth handling technologies
  - Flow monitoring device
  - Dissolved oxygen control
  - Control of impurities
- Summary

Flow monitoring device: Ultrasonic flowmeter (1/4)

Typical flowmeter for high temperature LM

Electromagnetic flowmeter: Degradation (Corrosion or Accumulation of CPs), Calibration needed

Objective

Development of LBE flowmeter withstanding practical conditions

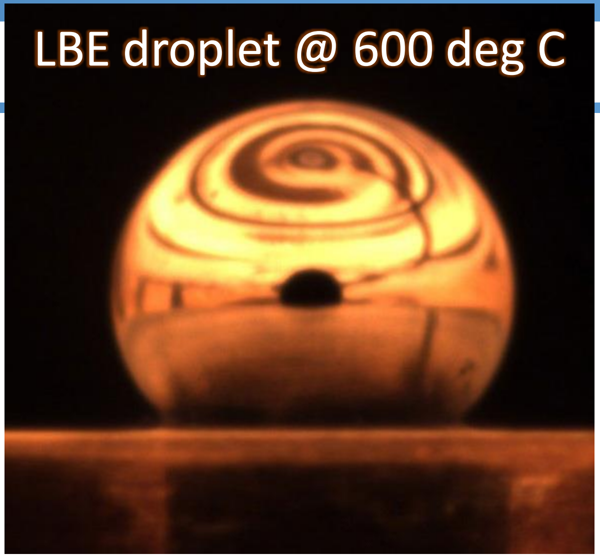
Coriolis(SCK CEN), Thermal mass flow(ENEA), **Ultrasonic** (Based on SFR's technology in JAEA)

- provides mean velocity along the signal path by using propagation time difference of ultrasonic signal.
- No need for calibration, Non-contact type is available

Features of ultrasonic sensor	
Element (Oscillator)	Lithium niobate ($LiNbO_3$)
Temperature range	< 500˚C
Radiation resistance	Worked well after γ-irradiation (Dose: 10 MGy)

Sufficient performance for LBE application

Flow monitoring device: Ultrasonic flowmeter (2/4)



How to ensure wet condition?

LBE shows poor wettability due to its surface tension.

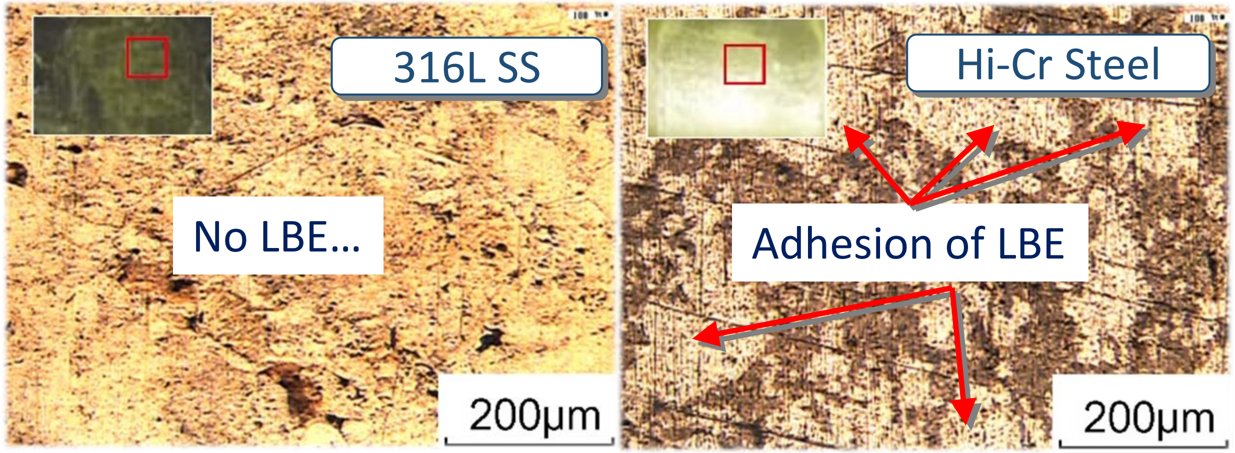
Non-wet condition (Solid/LBE boundary)

⇒ Ultrasonic signal cannot propagate to LBE

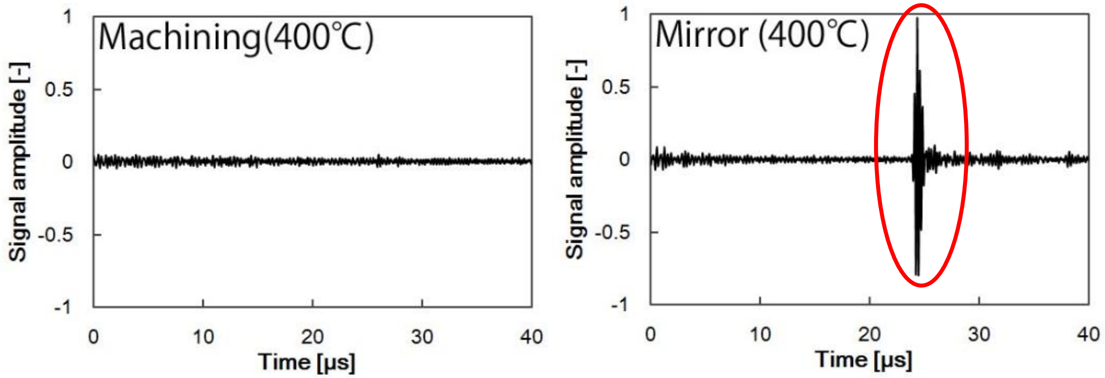
- Application of Hi-Cr steel
- Fine mirror-finishing on solid surface

} Improve LBE wettability

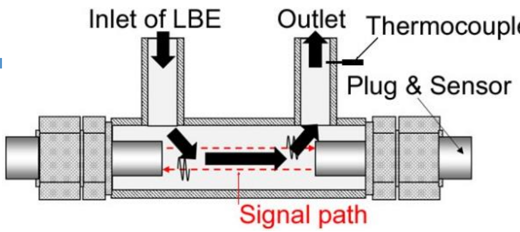
SEM/EDX observation image



Comparison of received signals in each surface condition



Flow monitoring device: Ultrasonic flowmeter (3/4)

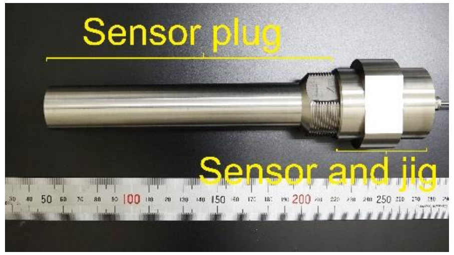


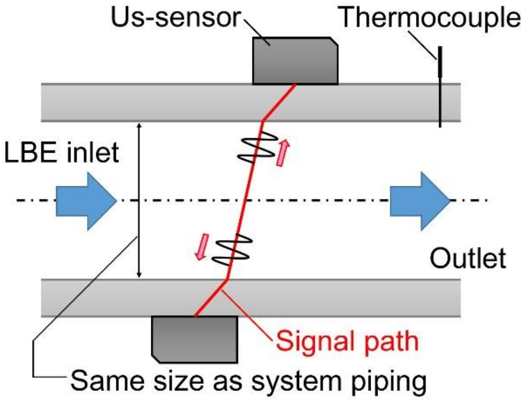
Plug immersion type

- Us-signal propagates opposite side via the sensor plug.
- Sufficiently work with accuracy less than 3% under TEF-T condition

⇒Already applicable to LBE target system.

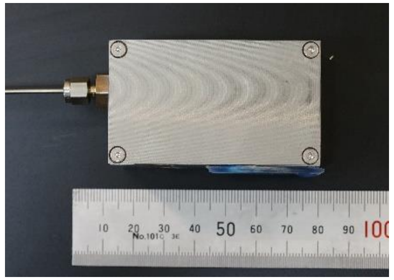
Disturbed flow due to the π-shaped piping promote erosion on the downstream side.





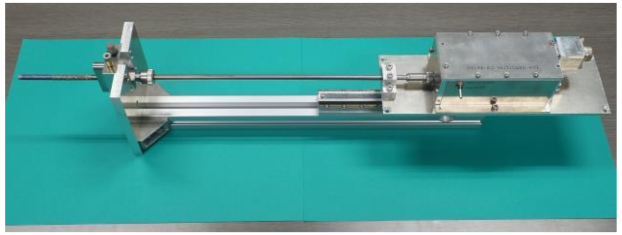
Non-contact type

- Us-signal propagates opposite side via the wall of round tube. Two sensors are placed outside the flow channel.
- Measurement section is composed of a straight pipe with the same diameter as the system piping ⇒ Flow disturbance can be minimized



Other method for local flow: EM probe

- Miniature electromagnetic flowmeter
- Diameter: 6 mm, Up to 450 deg C



J. Pacio, et al., NED, vol. 399, 1 December 2022, 112010

Flow monitoring device: Ultrasonic flowmeter (4/4)

Signal strength (Peak value)	
Before loop shutdown	1
Required for Meas.	0.02
Loop restart	0.1
1,500 hours later	0.99

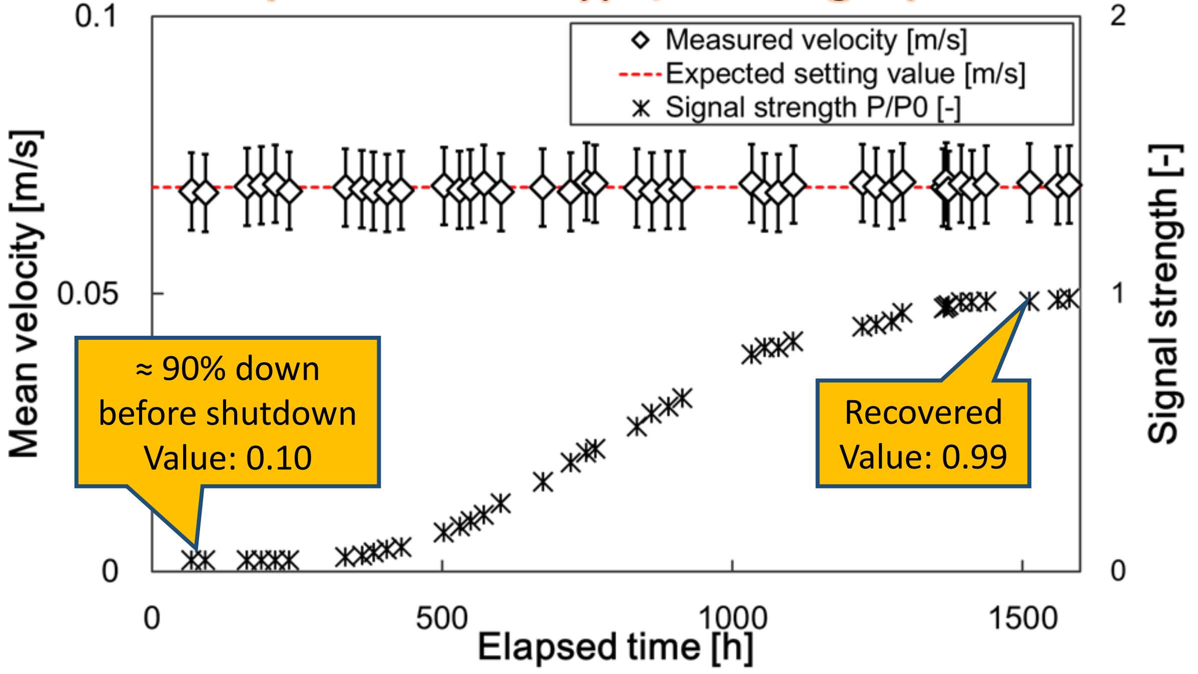
Common problem for Us-tech.

Wetting is lost under re-wetted conditions.

⇒Overcome by improving wettability

(Previous slide: Material, Surface treatment)

Measurement result after loop restart
(Non-contact type, 350 deg. C)



- ✓ The signal strength was reduced by 90%. However, the signal strength required for measurement was ensured.
- ✓ After 1500 hours of operation, the intensity recovered to the value before shutdown.
- ✓ The system has provided stable measurement results for more than 20,000 hours.

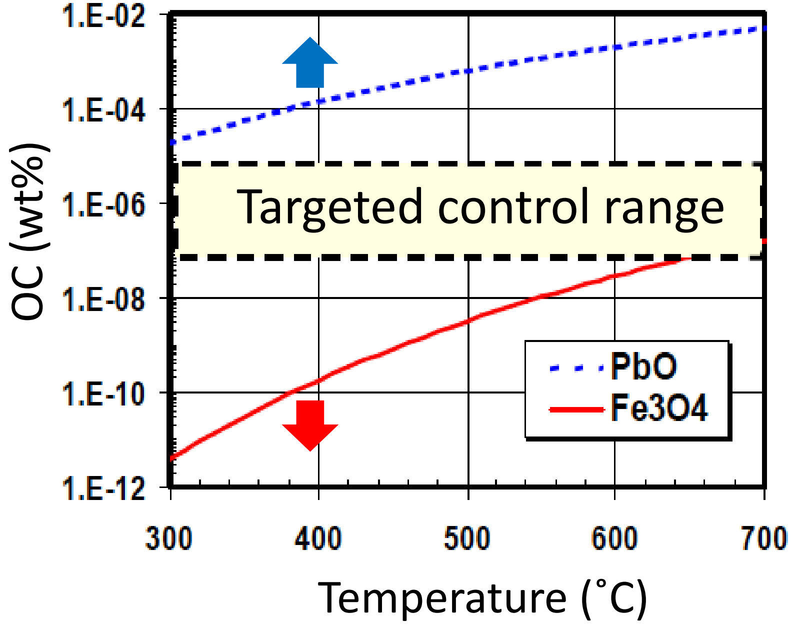
Remaining issue for long-term application

Evaluation regarding the influence of changes of boundary condition

Contents

Oxygen sensor / dissolved oxygen control

Relationship between PbO formation/material leaching by dissolved oxygen concentration (OC)



Erosion/corrosion observed in JLBL-1 (Low OC condition)

Protection method

Formation of oxide film (Fe_3O_4) on base material by controlling oxygen concentration

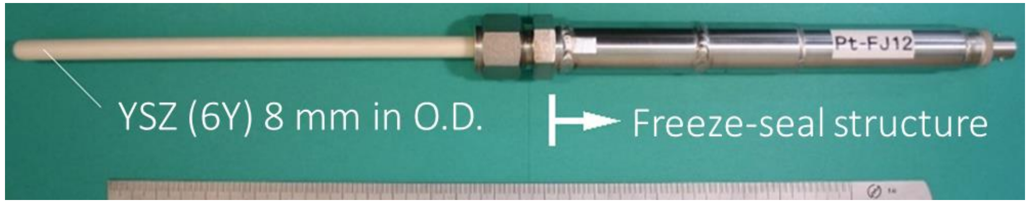
Oxide film: Barrier to LBE

Objective

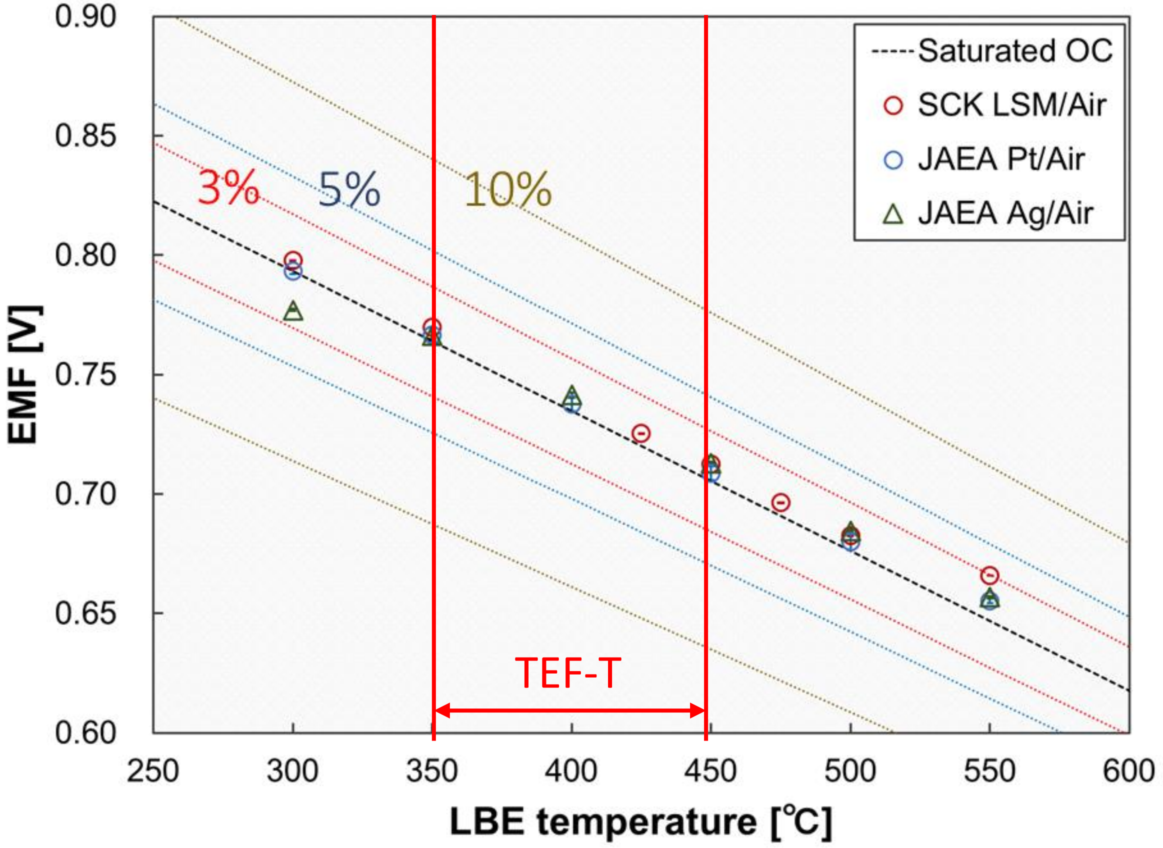
Developing reliable dissolved oxygen detection technology and technology to control OC in LBE

Oxygen sensor

JAEA's oxygen sensor (Air-referenced type)



Result of performance comparison test (Stagnant LBE)

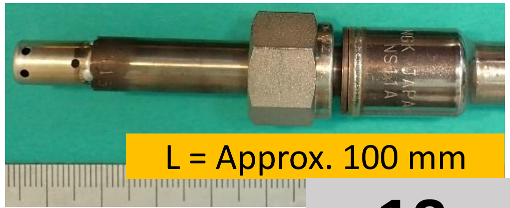


Freeze-seal structure (Original design)

⇒prevents outflow of LBE when the YSZ is broken

Performed performance comparison tests with a sensor developed by another research institute (SCK CEN)

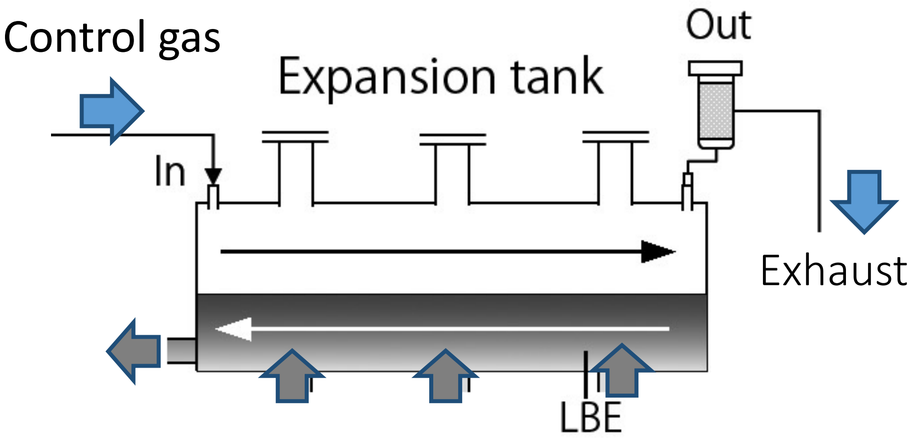
- ✓ Developed sensor achieves the same performance as sensors in other institutions.
- ✓ EMF error @ 450 deg C was 0.5%.
- ✓ There are individual differences in degradation due to long-term (several years) use. ⇒Under investigation
- ✓ A compact sensor with the same performance was also developed in cooperation with a company.



Control technology for dissolved oxygen: gas/LBE oxygen-transfer method

Dissolved oxygen in LBE flow:
constantly consumed for oxide film growth
⇒To maintain OC, oxygen must be supplied to the LBE.

Gas/LBE oxygen-transfer method



__Gas/LBE oxygen-transfer method__

Control gas is supplied to the cover gas and oxygen is supplied to the LBE via the interface.
Control gas: $Ar+2\%O_2$

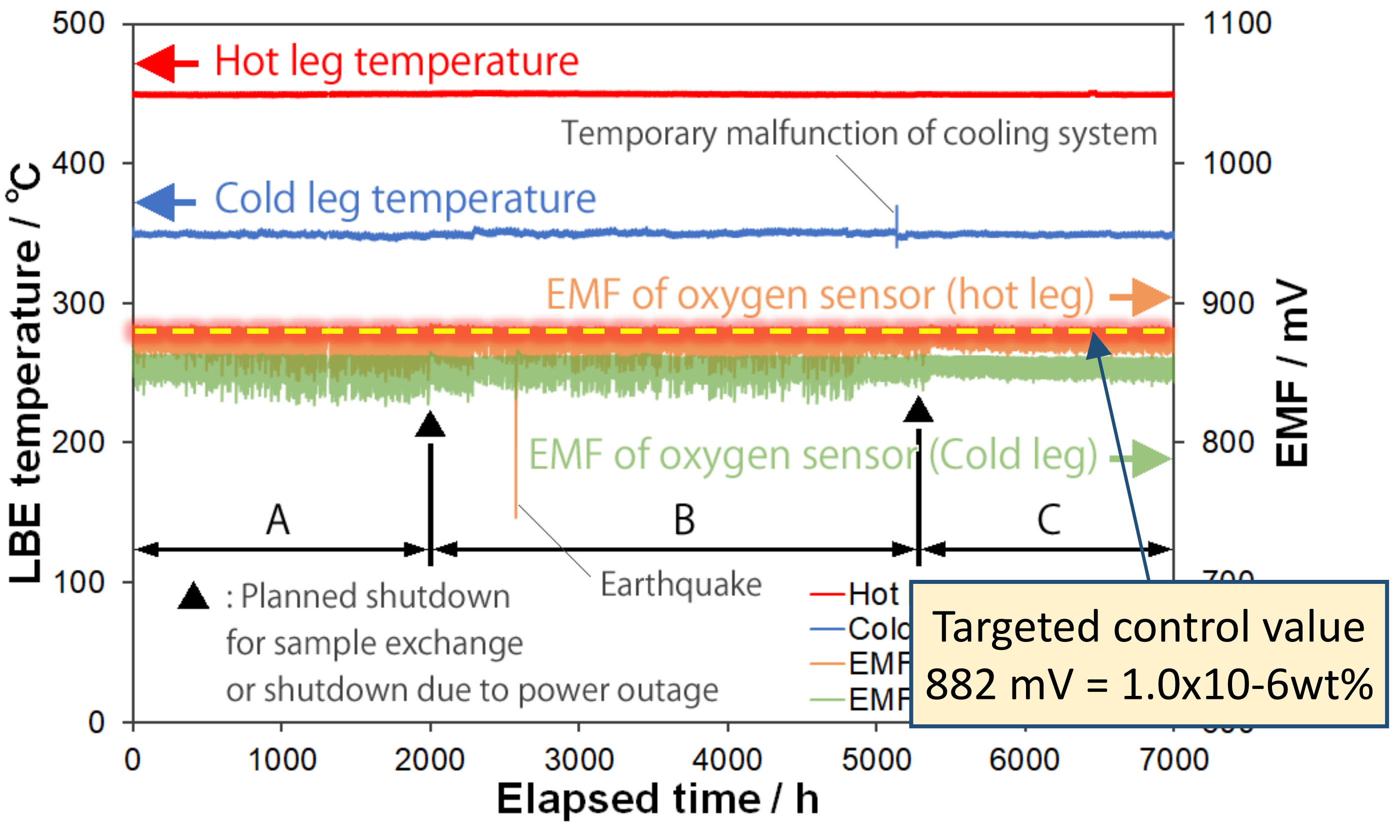
OLLOCHI: corrosion test loop

- Corrosion test under flowing LBE
- Demonstration test of OC control

Temperature: Max. 550 deg C
LBE inventory: 100 L
LBE flow rate: Max. 40 L/min
Material: T91(Hot leg), 316SS(Cold leg)
Corrosion sample: Rectangular plate x27/holder

Control technology for dissolved oxygen: gas/LBE oxygen-transfer method

Temperature & EMF during a corrosion test



Experimental condition

Operating conditions for TEF-T

- Temperature: 450/350 deg C
- OC: 1x10^{-6}wt%
- Beam operation time: 5,000 hours

(This corrosion test: 7,000 hours)

OC control result

Max: 3.1x10^{-6}wt%, Min: 1.0x10^{-6}wt%

Total of exhaust gas: 2.2 m^3

✓ The OC has been well controlled in the appropriate range for more than 5,000 hours.

✓ Long term & stable control of OC has been achieved.

☐ Upgrades are underway to provide more precise control.

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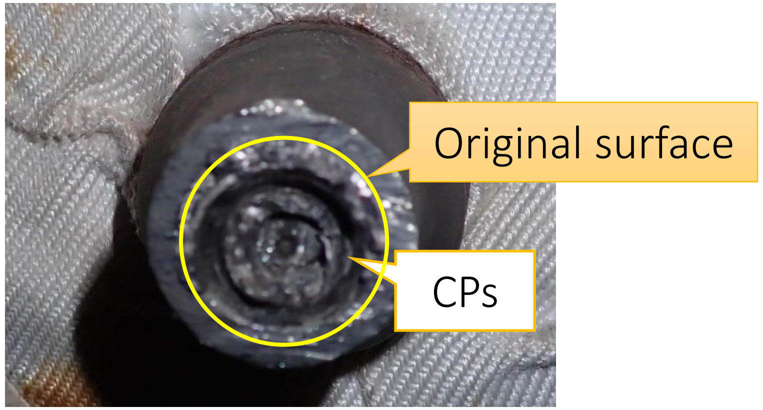
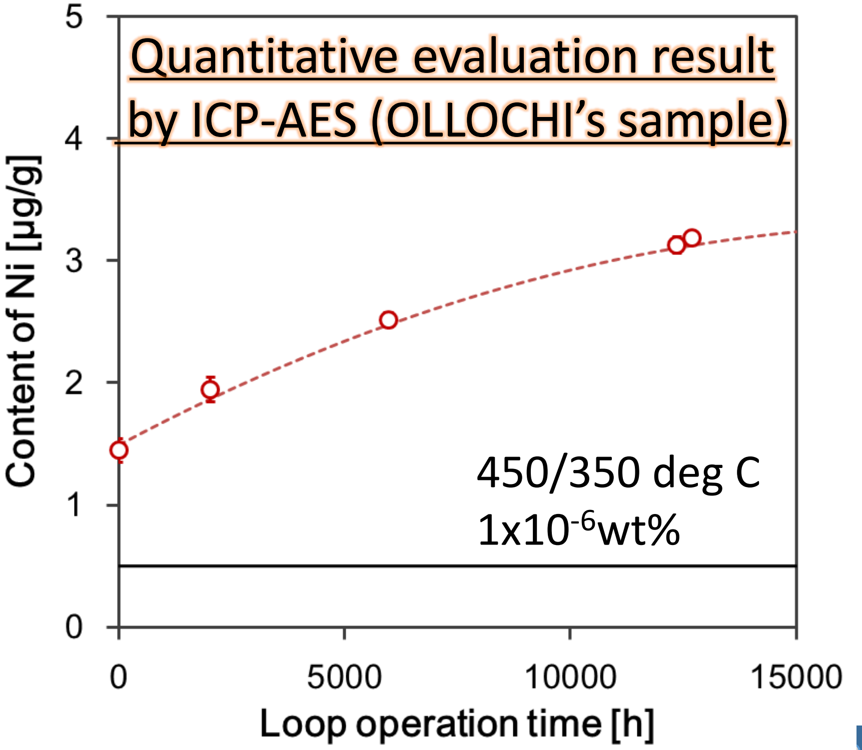
Evaluation of impurities content

LBE dissolves various material components due to its corrosiveness.
(e.g. Ni: 1-2 kg / 1000 kg LBE)
Dissolved impurities or their compounds precipitate in the cold leg and eventually cause plugging.
⇒Need technology to purify LBE

Plugging by Fe, Cr compounds (& Pb oxide)





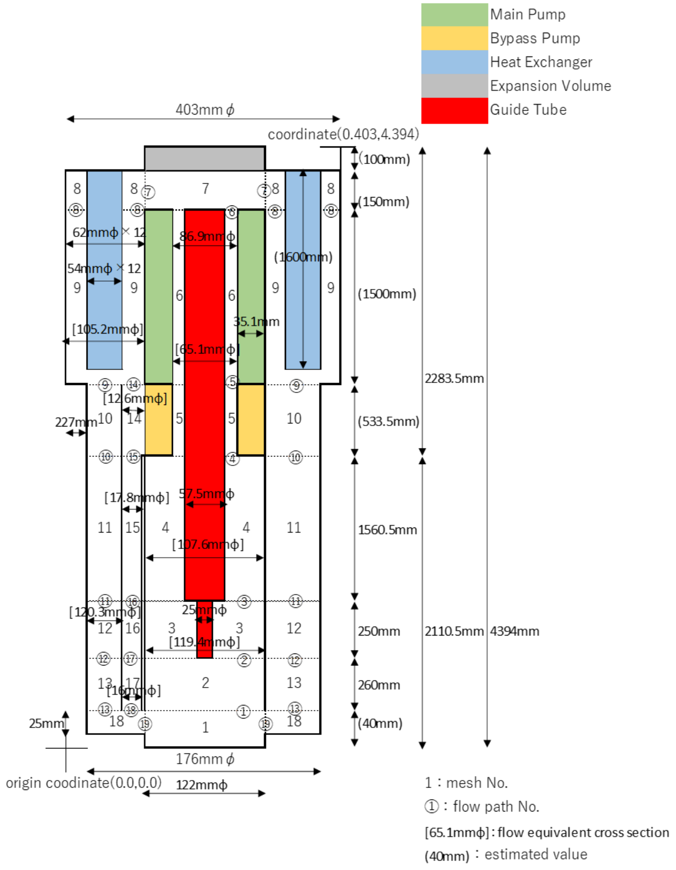
Observations of dissolved major material components (Fe, Cr, Ni) in LBE sample (from OLLOCHI) was started.

- ✓ Fe: below detection limit
- ✓ Cr: below detection limit
- ✓ Ni: Continuously rising over time

Ni solubility: 23**mg**/g@450 deg C

Analysis code for impurity transfer: collaboration with Fukui univ.

TRAIL analysis model for LBE circulation loop of MEGAPIE.



Analysis code: TRAIL

Predict the time dependent behavior of SPs within the LBE coolant system of ADS

S. Miyahara, et al., NED, vol. 403, March 2023, 112147

- ✓ This code was verified by comparing the results with the distribution data in MEGAPIE spallation target.
- ✓ This code could reproduce the released amount of volatile SP material from LBE into the cover gas reasonably.

Purification system design

- ☐ Modifications are ongoing to predict elution and transfer of material components.

⇒Sensitivity analysis on deposition of CPs (especially Ni compound)

Contents

Summary

✓ The development of LBE handling technologies has progressed and is being established.

Further enhancements are under development.

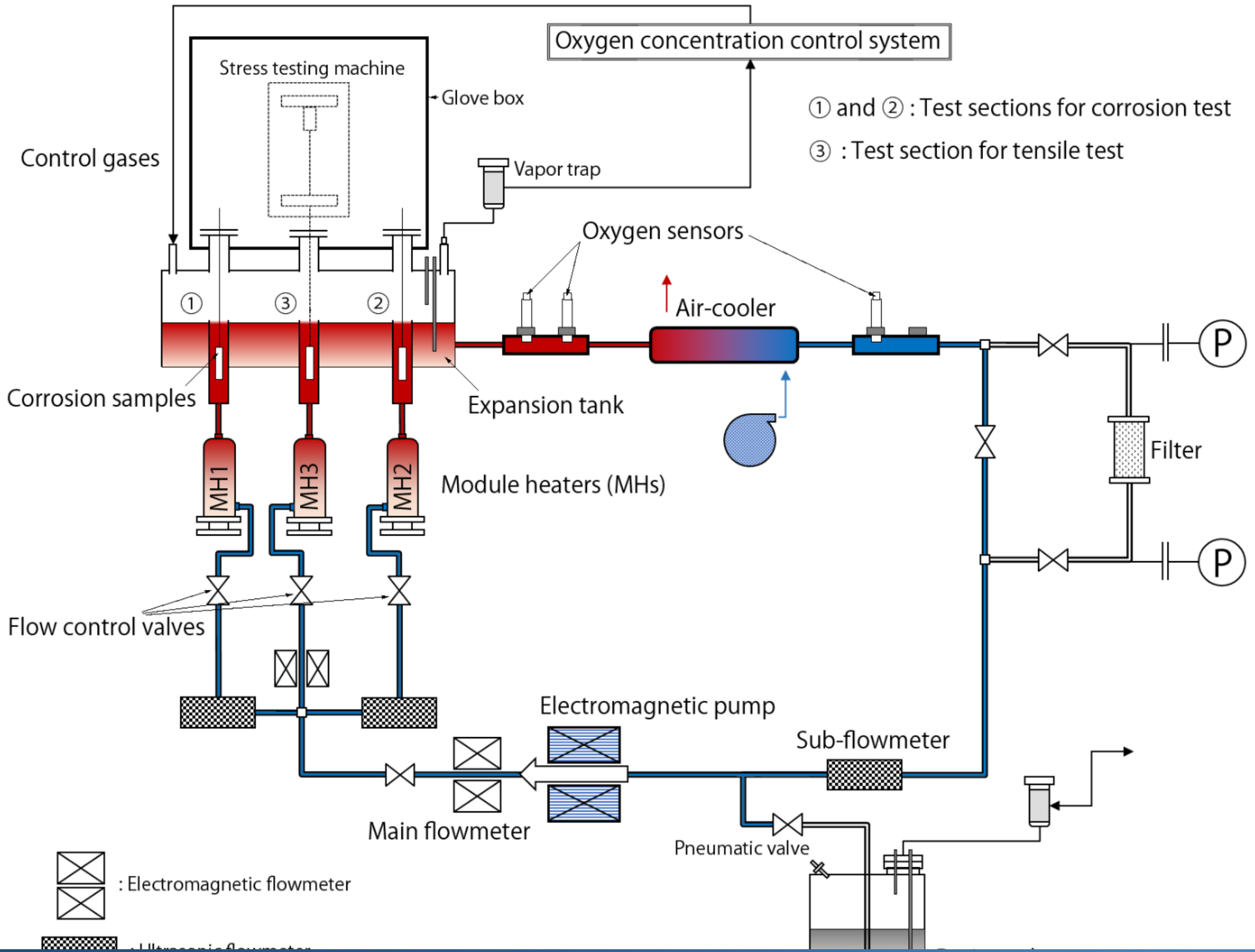
□ Handling of dissolved impurities is a key remaining issue that is essential to establishing LBE system.

Predictive analysis method and analysis of LBE samples are being performed in parallel to realize LBE purification system.

Fin

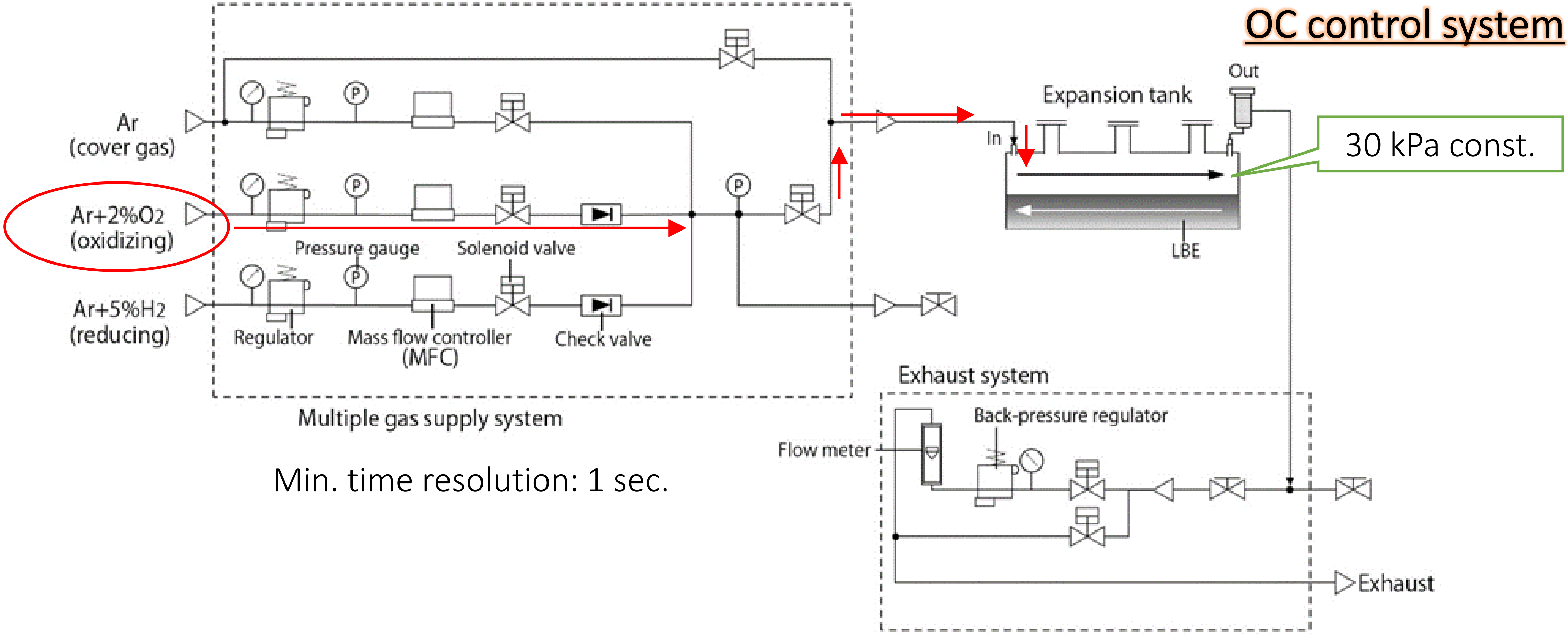
Thank you for your kind attention.

Diagram of OLLOCHI



Location	Material	Inner surf. area [m^2]
Hot-leg	T91	3.04
Cold-leg	316SS	4.64

System diagram of OC control system

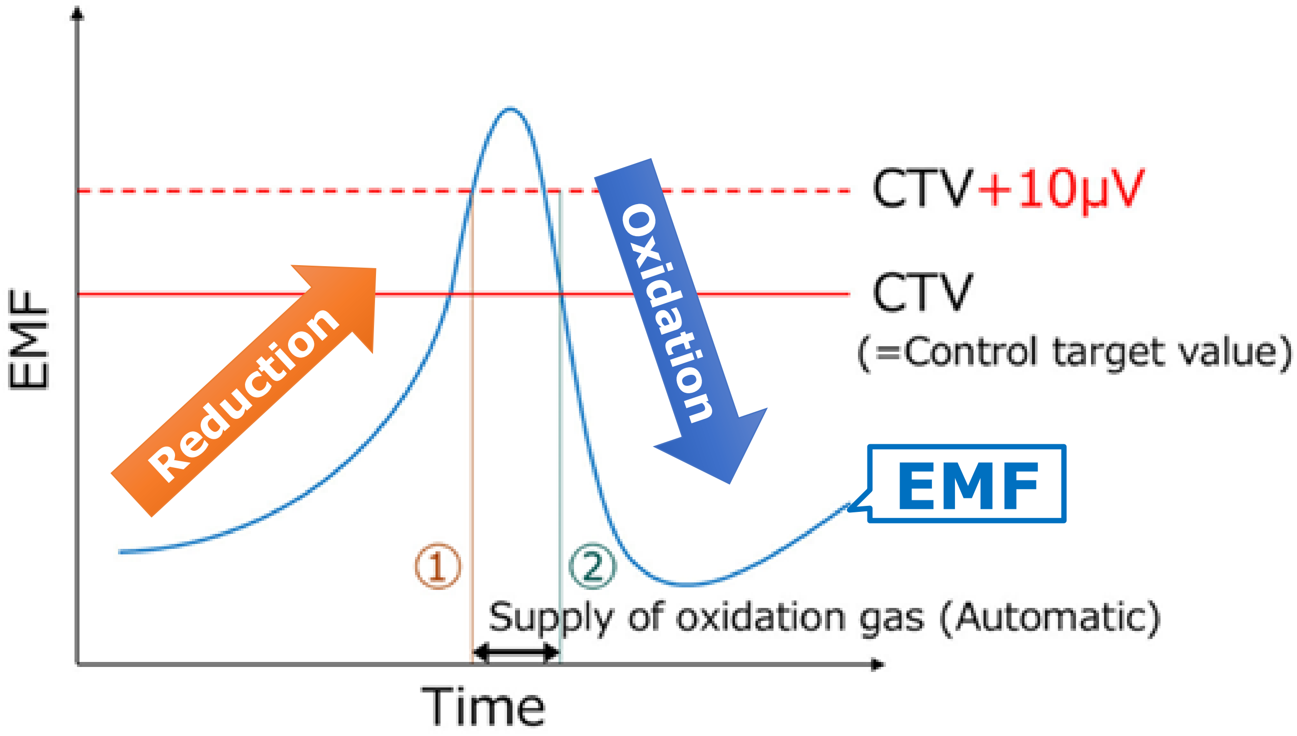


Min. time resolution: 1 sec.

- OC is controlled by adding control gases to the cover gas in exp. tank.
- Oxidation / reduction reaction proceed via the free surface.
- Only oxidizing gas is used for OC control during corrosion test.

OC control method (2/2)

OC control process during loop operation



Dissolved oxygen is continuously consumed for the growth of the oxide film.

① When EMF reached CTV+10μV, the system starts supply of the control gas.

② Gas supply is stopped immediately afterwards when EMF decreases again to CTV.

Control gas speed is constant.
(250 ml/min)