



Development of Sensors for High-Temperature High-Pressure Liquid Pb/Pb-16Li Applications

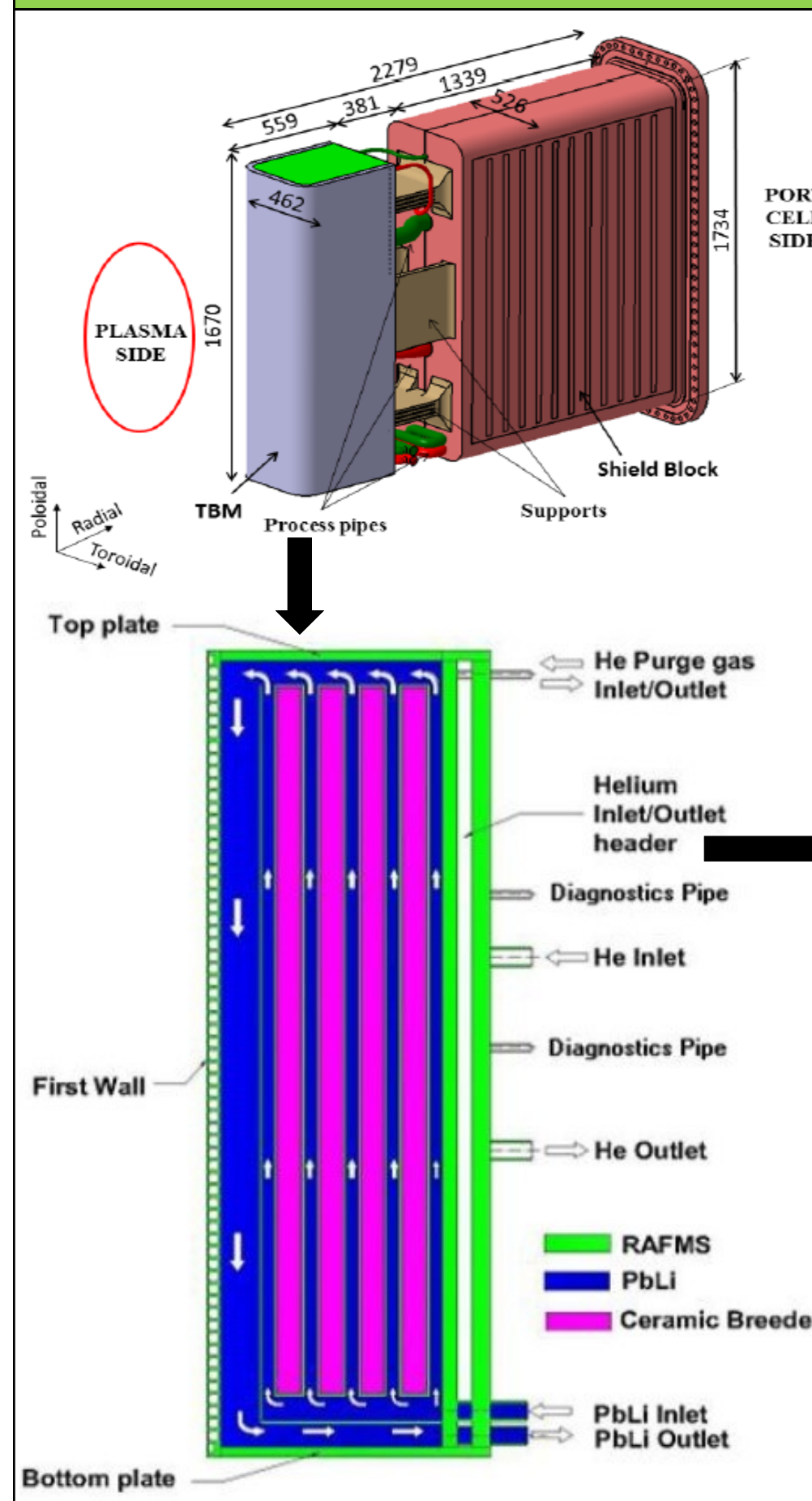
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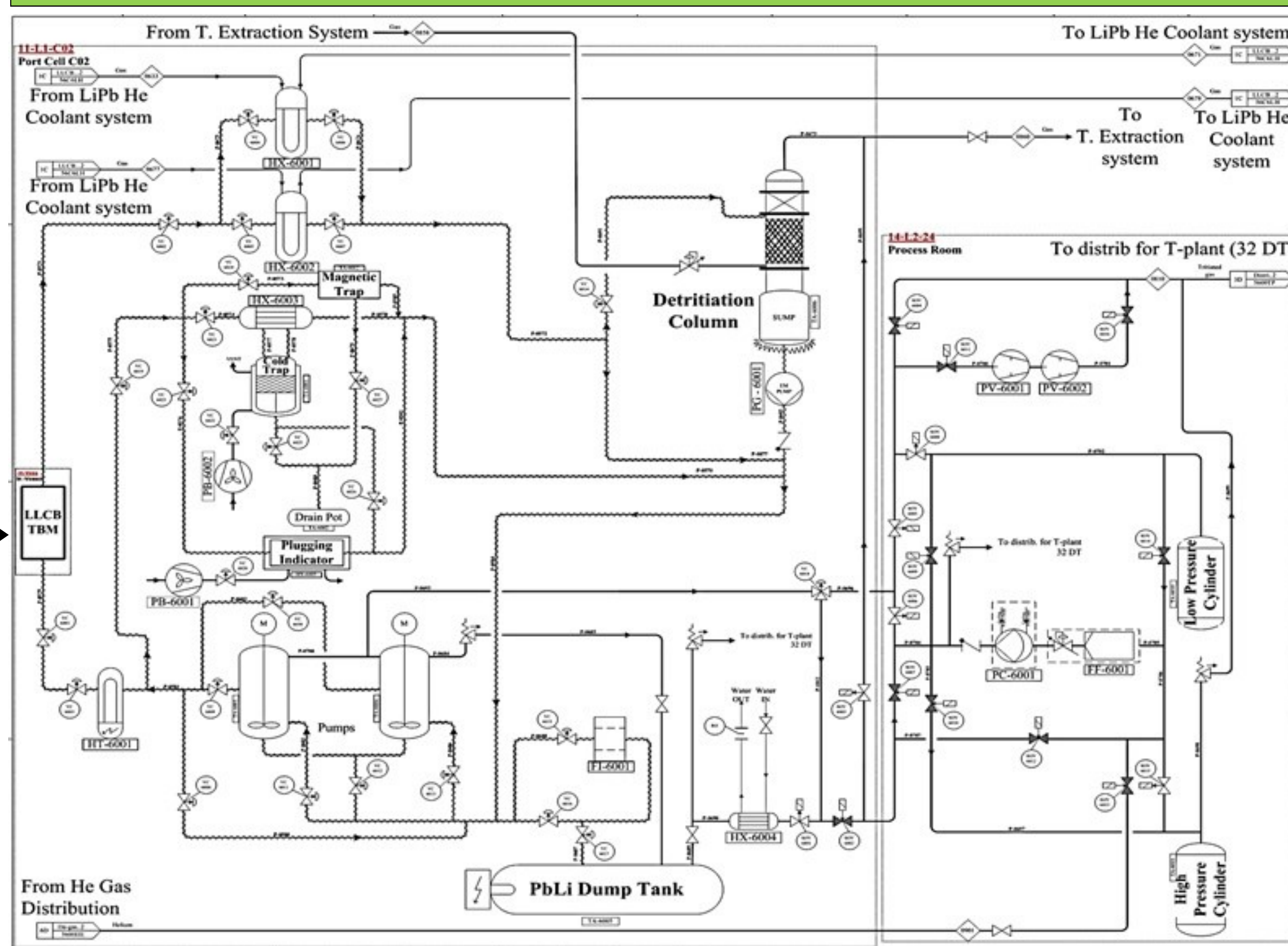
Introduction

Liquid Lead Lithium (Pb-16Li) is of primary interest as one of the candidate materials for coolant fluid and tritium breeder in liquid metal blanket concepts relevant to fusion power plants. For effective and reliable operation of such high temperature liquid metal coolant systems, monitoring and control of critical process parameters like pressure, level, temperature and flow is essential. However, high temperature operating conditions coupled with the corrosive nature of Pb-16Li severely limits the application of commercially available diagnostic tools. This paper illustrates indigenous test facility designs and experimental methods used to develop non-contact configuration radar level sensor and wetted configuration diaphragm seal pressure sensors for high temperature, high pressure liquid Pb and Pb-16Li. Calibration of these sensors at high temperature between 380°C - 400°C and high pressure upto 10 bar was performed. Reliability and performance validation were achieved by continuous long duration testing of sensors in liquid Pb and liquid Pb-16Li environment for over 1000 hour. Estimated error for radar level sensor lies within ± 10 mm and estimated error for pressure sensors lies within 1.1% of calibrated span over the entire test duration. Results obtained and critical observations from these tests are presented in this paper.

LLCB Test Blanket Module

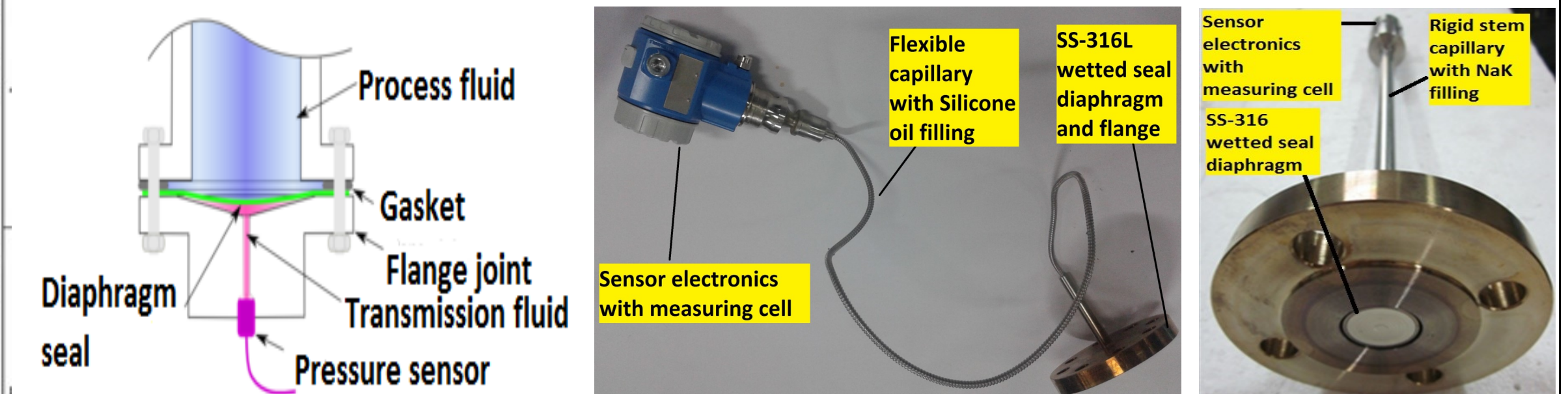


Lead Lithium Cooling System (LLCS): Process Flow

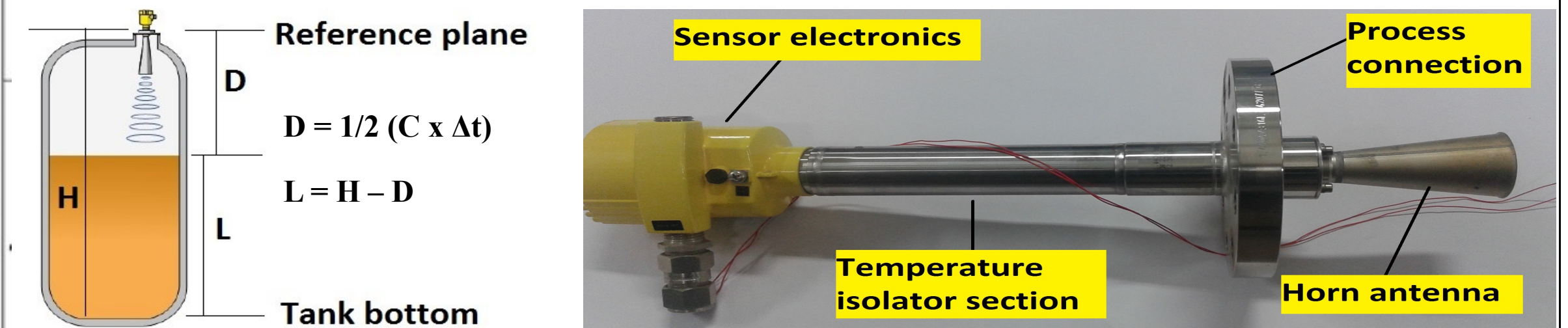


Sensor Selection

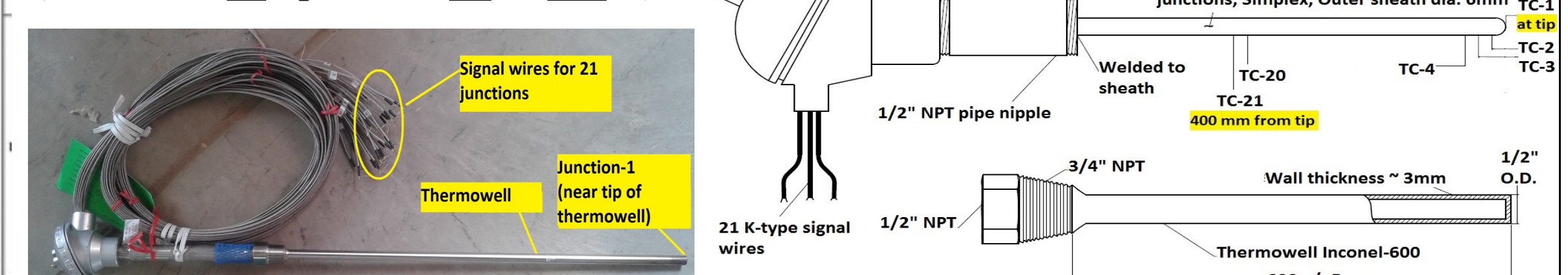
1) Piezoresistive effect based remote diaphragm seal type pressure sensor:



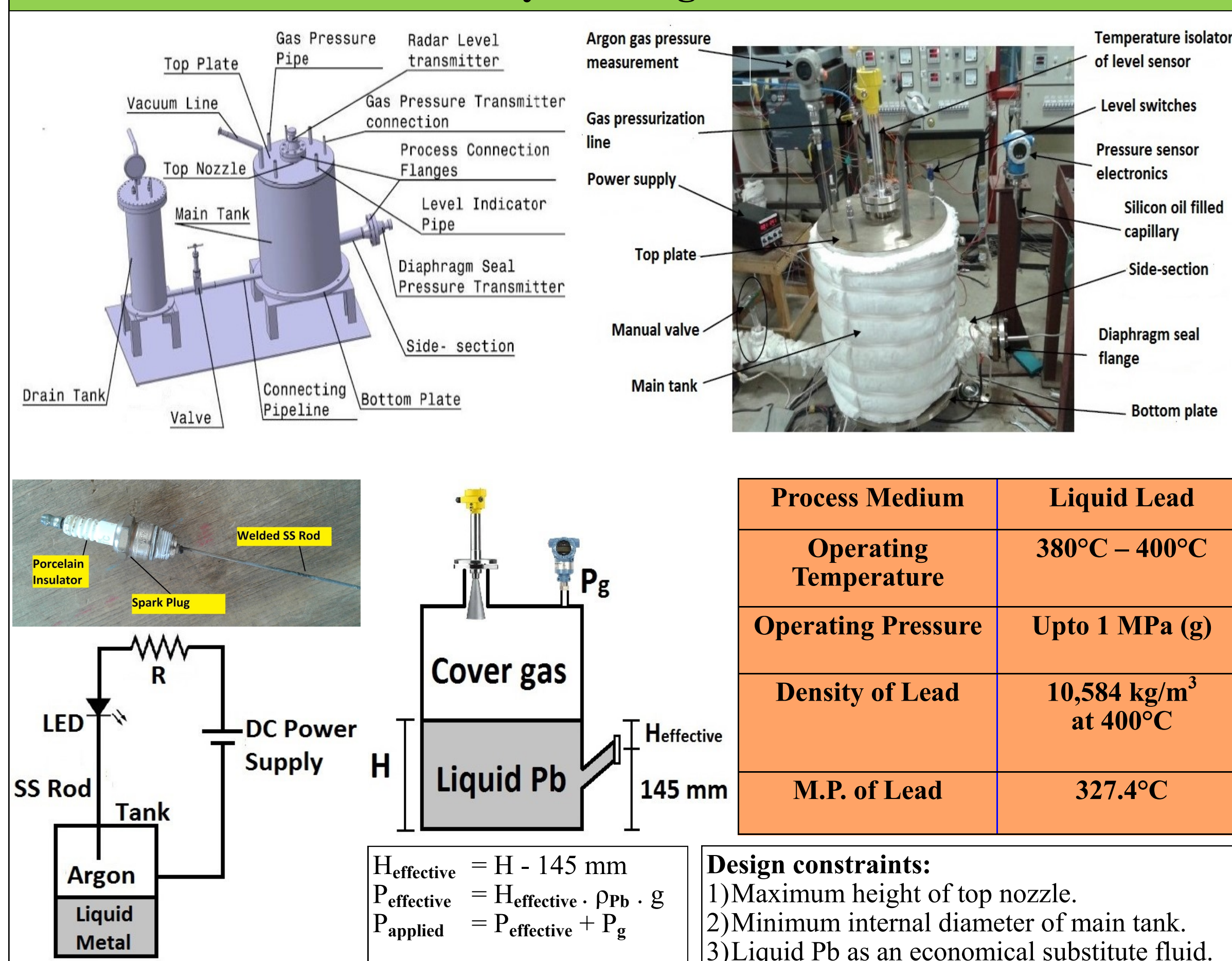
2) Non-contact configuration pulse radar level sensor:



3) TeLePro (Temperature Level Probe):



Test Facility-1: Design & Methods



Process Medium	Liquid Lead
Operating Temperature	380°C – 400°C
Operating Pressure	Upto 1 MPa (g)
Density of Lead	10,584 kg/m ³ at 400°C
M.P. of Lead	327.4°C

Design constraints:

- Maximum height of top nozzle.
- Minimum internal diameter of main tank.
- Liquid Pb as an economical substitute fluid.

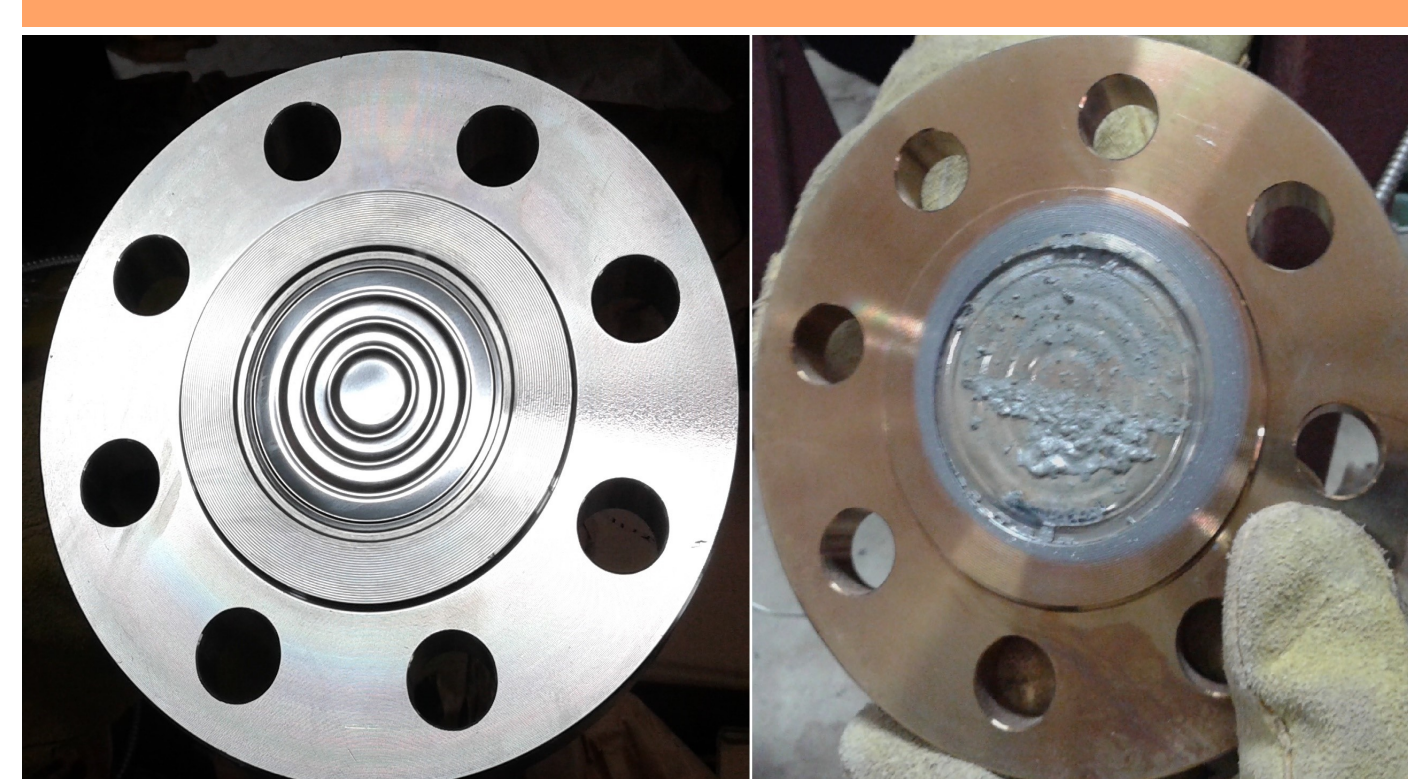
Test Facility-1: Calibration & Performance Results

Analytically estimated level (mm)	Level indicated by radar sensor (mm)	Error (mm)
198.42	200.91	+2.49
104.97	112.60	+7.63

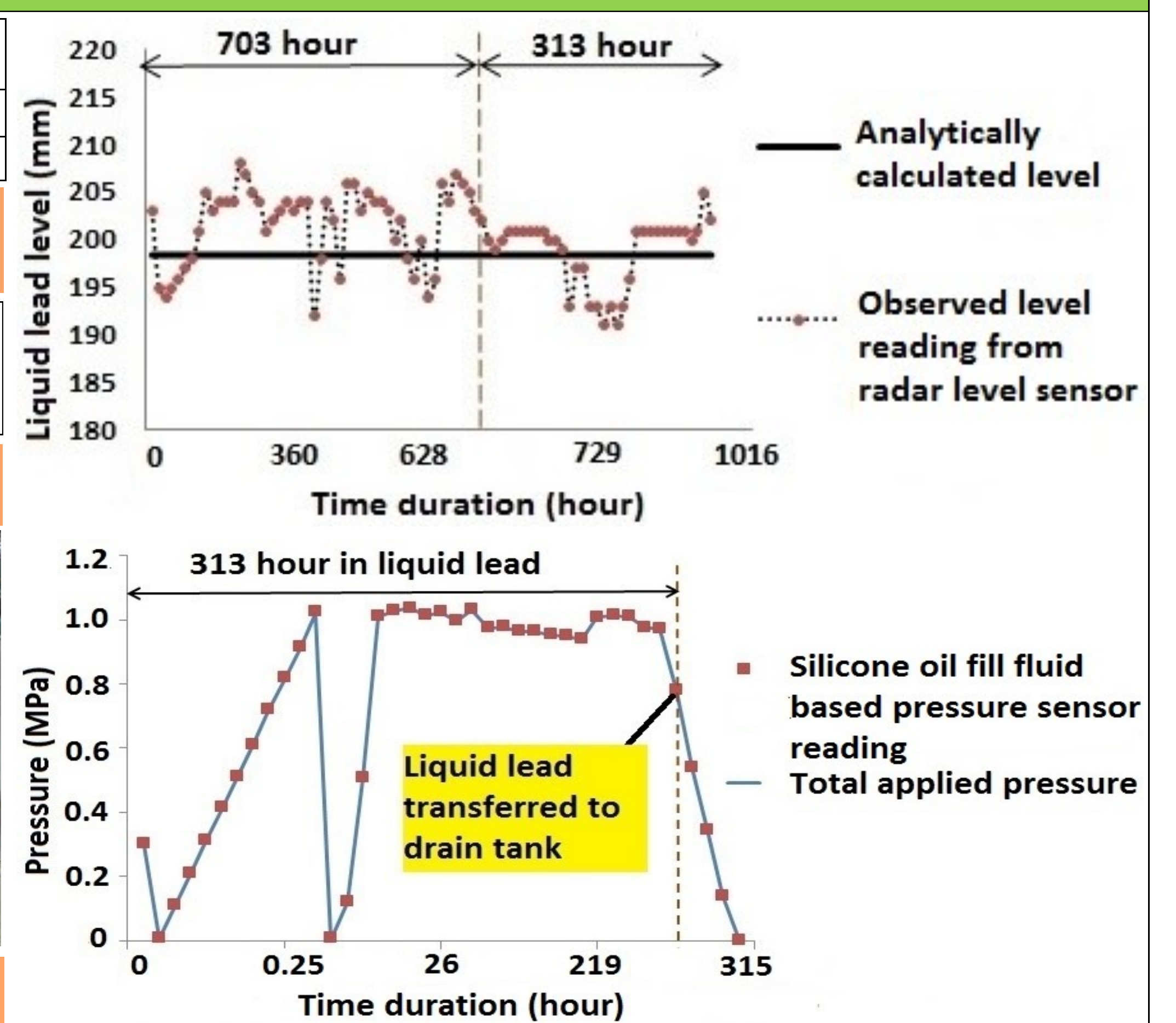
Estimated error for radar level sensor: Over 1000 hour duration on liquid Pb: [-7.42 mm, +9.58 mm]. Ambient calibration using metallic reflector: [+1 mm, +5 mm].

Sources of error: Manual dimensional measurements, assumption of constant bulk density for liquid lead, manual operation of isolation valve, error from conductivity level switch and accuracy of radar sensor.

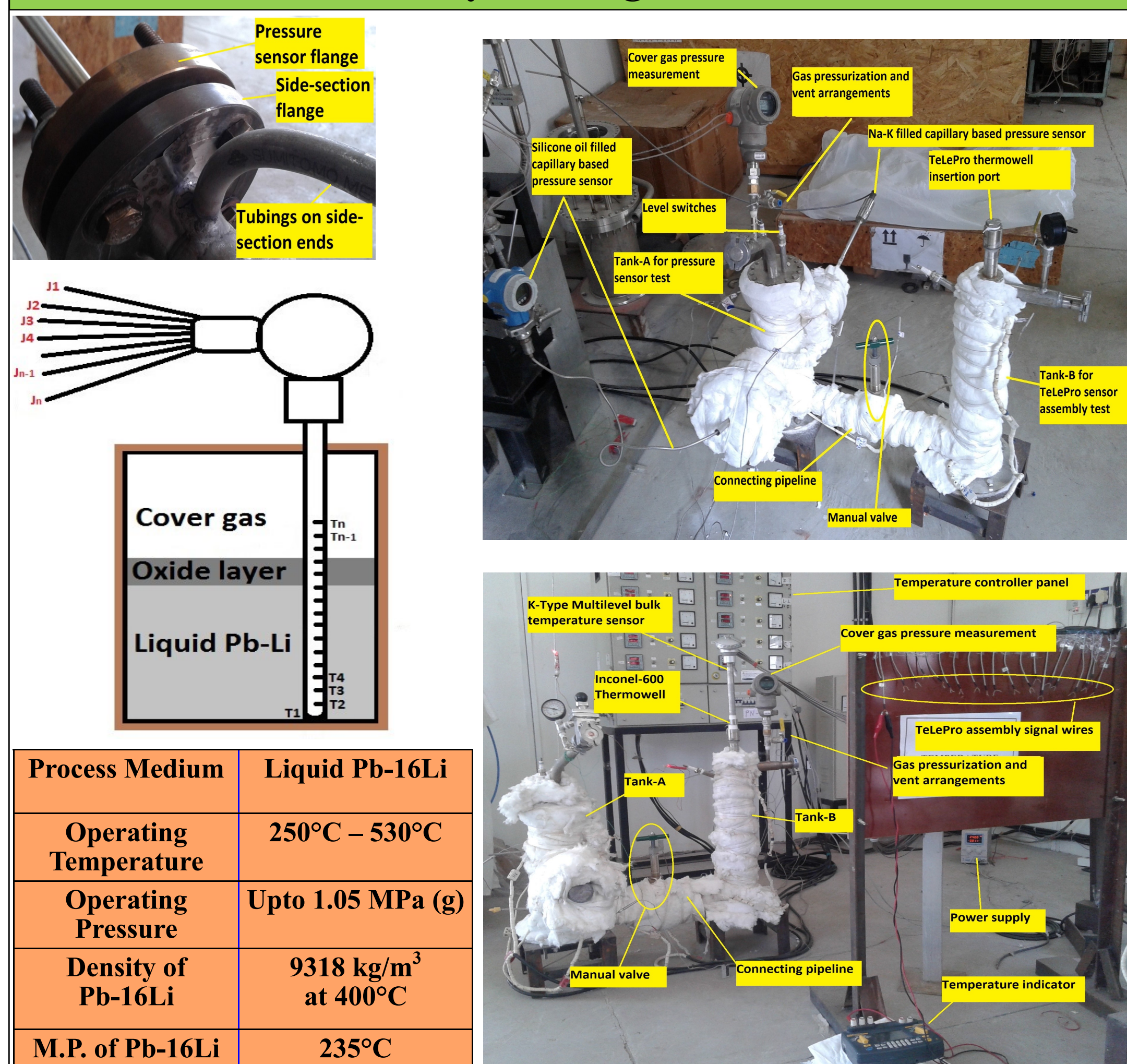
Validation for liquid lead → Validation for liquid Pb-Li and other liquid metals



Estimated error for pressure sensor with silicone oil fill fluid: Over 310 hour duration on liquid Pb: Within 0.3% of span.

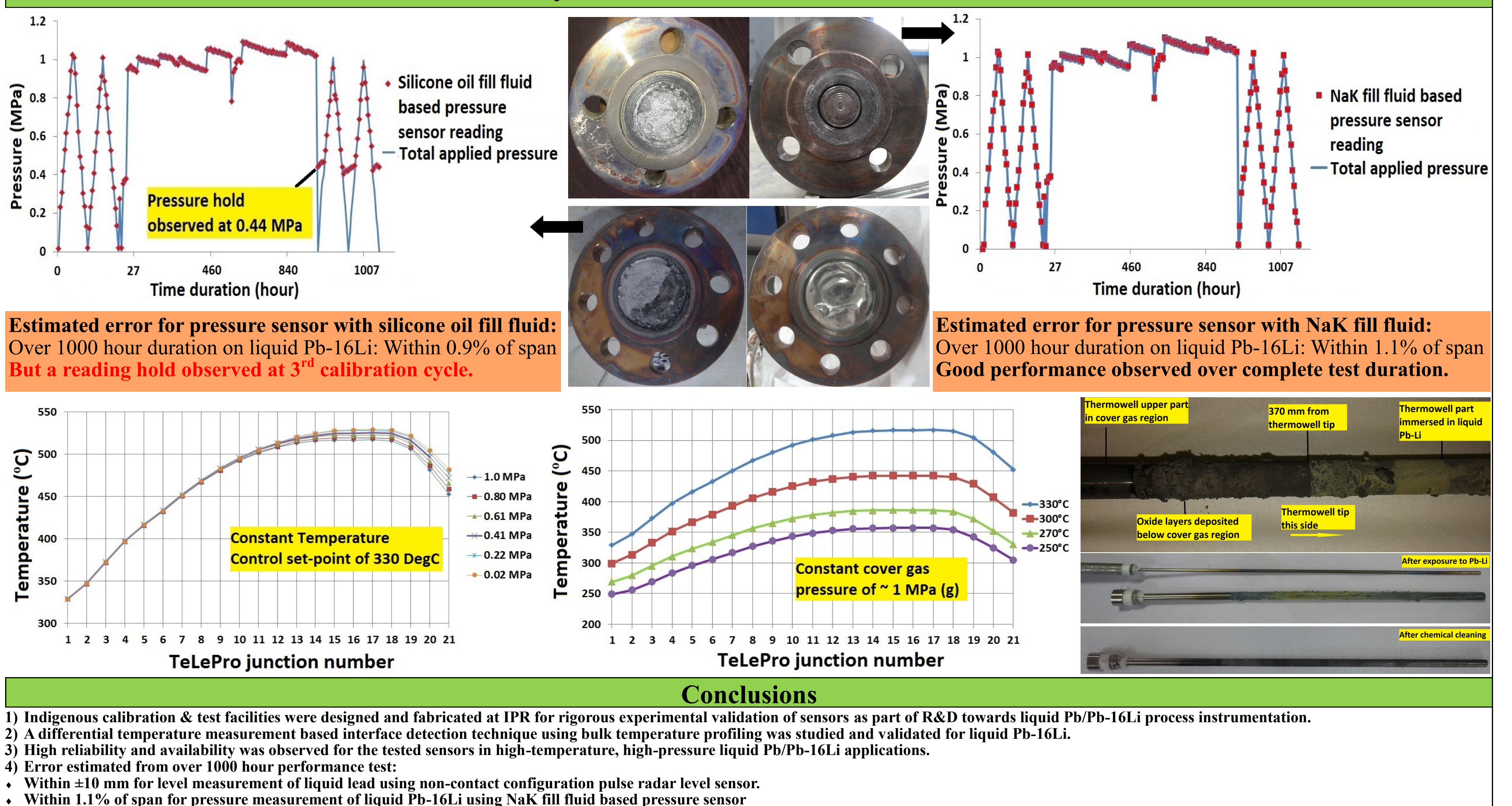


Test Facility-2: Design & Methods



Process Medium	Liquid Pb-16Li
Operating Temperature	250°C – 530°C
Operating Pressure	Upto 1.05 MPa (g)
Density of Pb-16Li	9318 kg/m ³ at 400°C
M.P. of Pb-16Li	235°C

Test Facility-2: Calibration & Performance Results



Conclusions

- Indigenous calibration & test facilities were designed and fabricated at IPR for rigorous experimental validation of sensors as part of R&D towards liquid Pb/Pb-16Li process instrumentation.
- A differential temperature measurement based interface detection technique using bulk temperature profiling was studied and validated for liquid Pb-16Li.
- High reliability and availability was observed for the tested sensors in high-temperature, high-pressure liquid Pb/Pb-16Li applications.
- Error estimated from over 1000 hour performance test:
 - Within ± 10 mm for level measurement of liquid lead using non-contact configuration pulse radar level sensor.
 - Within 1.1% of span for pressure measurement of liquid Pb-16Li using NaK fill fluid based pressure sensor