

OXYGEN SENSORS FOR HLM POOL FACILITIES: FIRST RESULTS

A.Gessi, M. Tarantino, C. Venturi

G. Coccoluto ⁽¹⁾

⁽¹⁾ENEA Cr Brasimone, 40032 Camugnano (BO), Italy

Outline

- Impurities and oxides: remarks and open points
- Oxygen sensors
 1. CHEOPE III and LECOR sensors examples
 2. Design of sensors for pool type systems
 3. CIRCE activities and first outcomes
 4. Summary

Introduction

- The issue of solid impurities, “black dust” and macroscopic slags, has been one of the most important topics in the frame of HLM activities and experiments.
- Formed impurities have been sampled and analyzed: the presence of a relatively high amount of Γ and B phases together with the 40wt% ca. Of Massicot and Litharge (PbO) suggests a complex formation mechanism. Also, a sampling method problem exist: analytical methods can determine the composition of the samples, but not quantitatively determine a possible “formation rate”.
- during the experiments in pure Pb, solid powders were observed only after a large pollution event due to a flange damage.
- Thus, the use of Oxygen control systems and Oxygen meters/sensing devices is of primary importance for solid impurities formation prevention.
- A long and consistent experience has been gathered at ENEA Brasimone on Oxygen sensing in loop type facilities, where Russian made and ENEA made sensors were tested
- An experimental campaign in the CIRCE pool facility has been started, in the frame of the DEMETRA EUROTRANS activities, VI F.P., where deeply immersed sensors are being tested and implemented to a HLM pool type facility.

Impurities composition summary

Compound	Concentration
PbO	40 wt% ca.
LBE (γ β phases)	50 wt% ca.
Fe, Al, Cr	10 wt % Ca.

Table 1 Composition of a slag in the CHEOPE loop, LBE, 400 C.

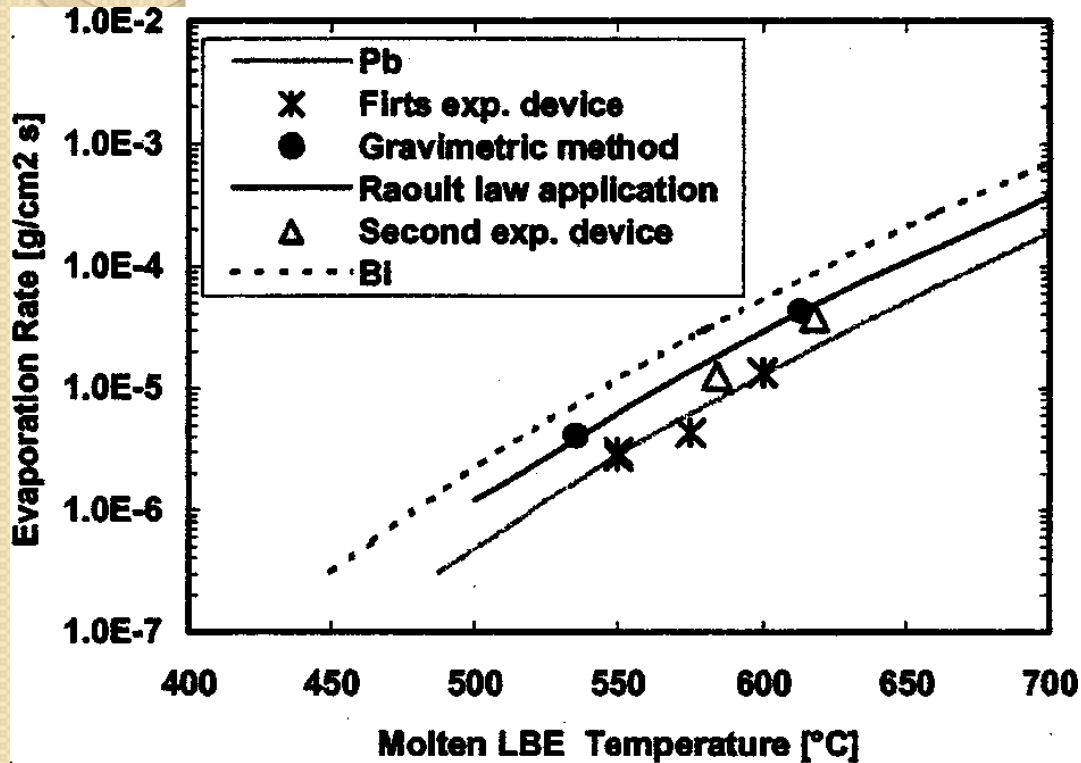
Compound	Concentration
PbO	40 wt% ca.
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Table 2. Composition of the filtered particles, fiberglass adsorption filter, LBE, CHEOPE III

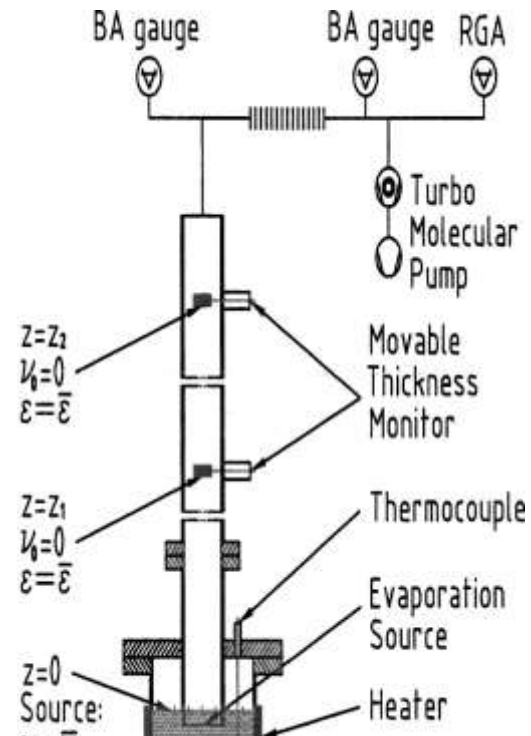
Compound	Concentration
PbO	15 wt% ca.
Pb	80 wt% ca.
Fe, Al, Cr	5 wt % Ca.

Table 3. Composition of the filtered particles, fiberglass adsorption filter, CHEOPEIII, Pb, 500 C.

Dust formation: mechanism*



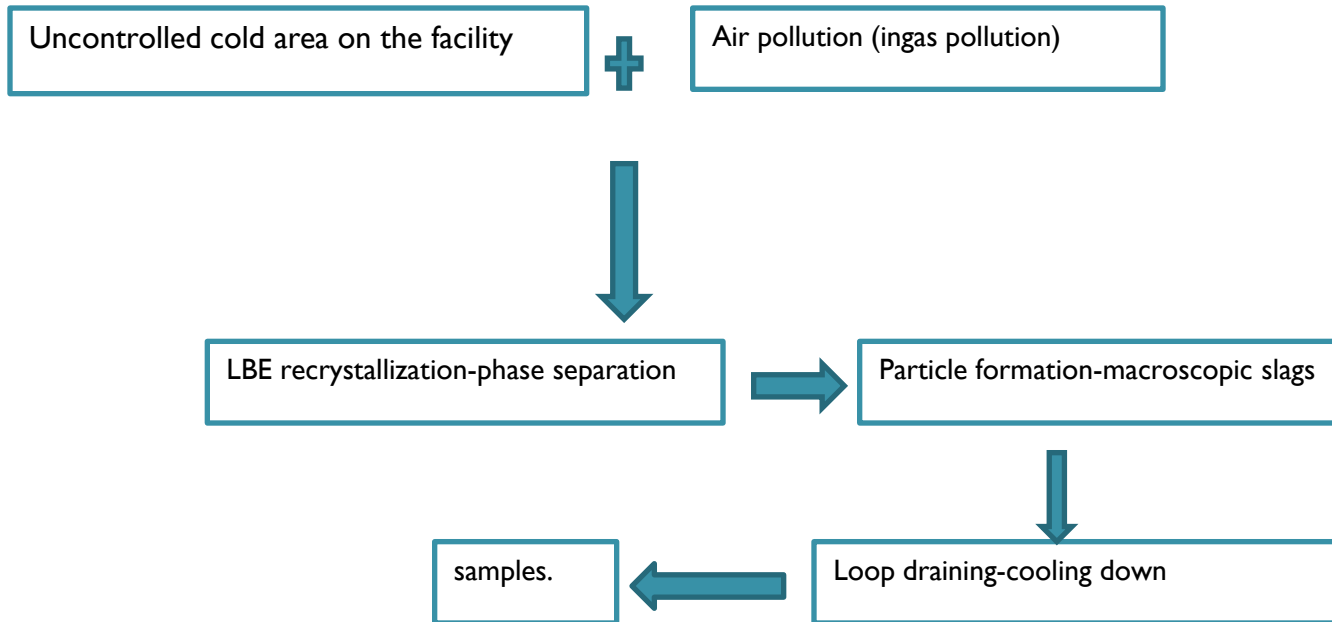
(* P. Turrioni et Al., J.Vac. Sc. Tech. A 22(4)).



Experiments performed in the frame of the TRASCO program: evaporation rates vs temperature.

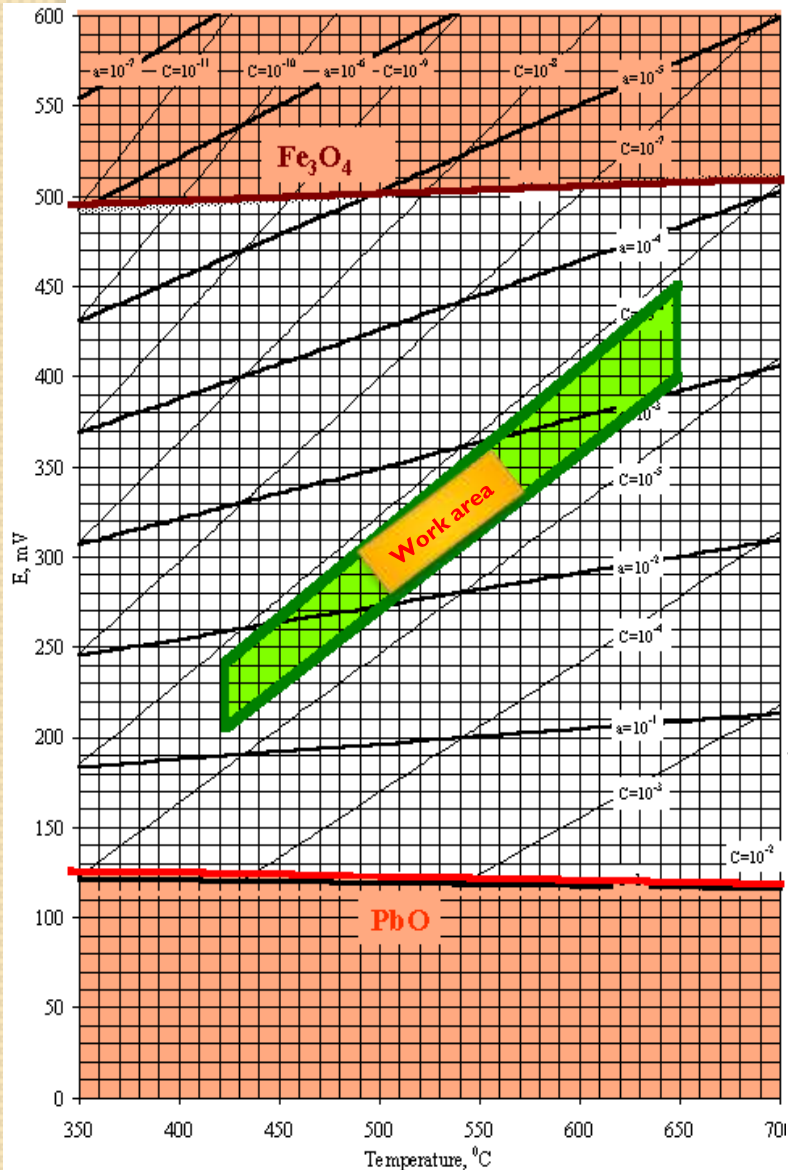
Mechanism of solid impurities formation

The observed mechanism of solid impurities (gas and liquid phase) can be summarized as follows, for LBE:



In pure Pb, only Oxygen pollution events can cause powders formation.

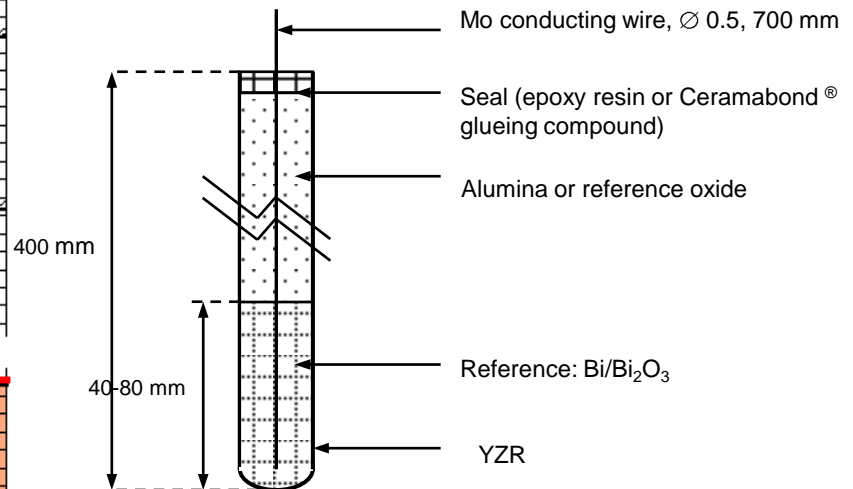
Oxygen sensors used in LBE and Pb coolants technology



E-t diagram of state of Pb melt in term of oxygen impurity relative to the reference electrode {Bi} - Bi_2O_3

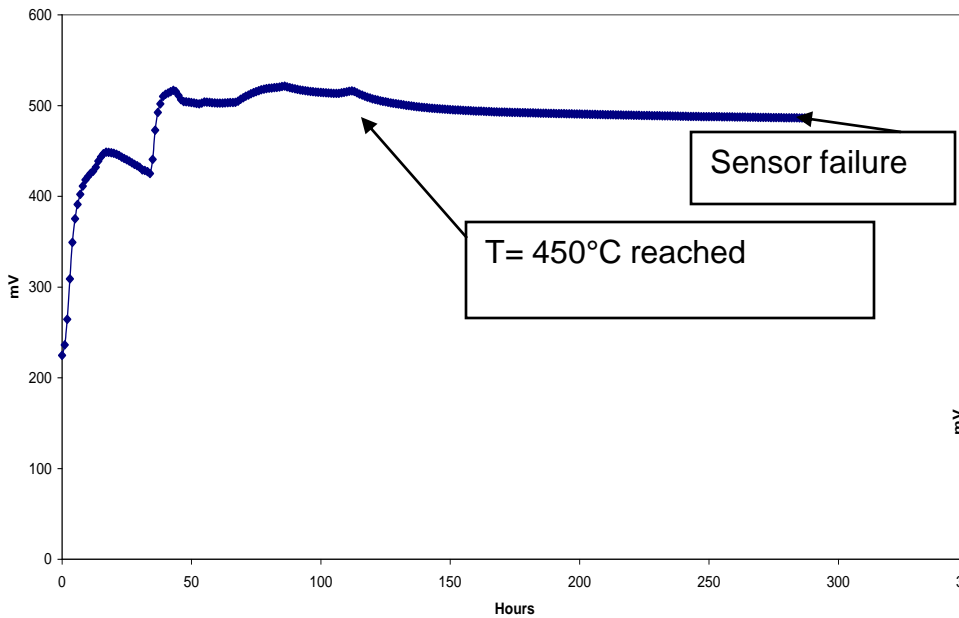
Assumed range of oxygen concentrations in Pb coolant:
 $C_{[\text{O}]} = (1 \div 5) \times 10^{-6} \%$ mass. The Nernst equation gives:

$$\ln C_{o(\text{wgt}\%)} = -23.21 \cdot \frac{E_{(mV)}}{T} - \frac{18853}{T} + 2.968$$

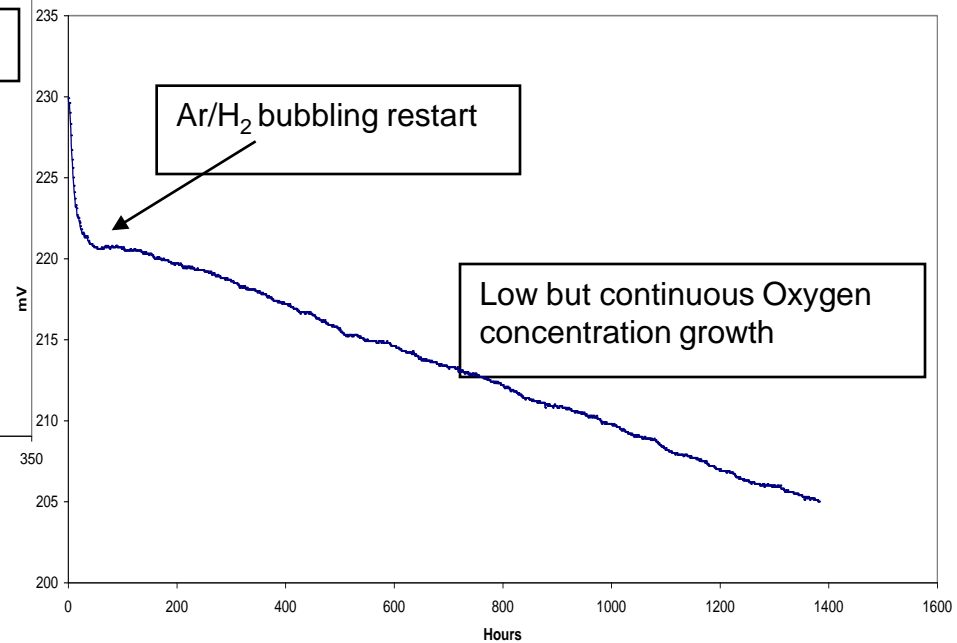


LECOR loop example

Lecor Startup: IPPE sensor

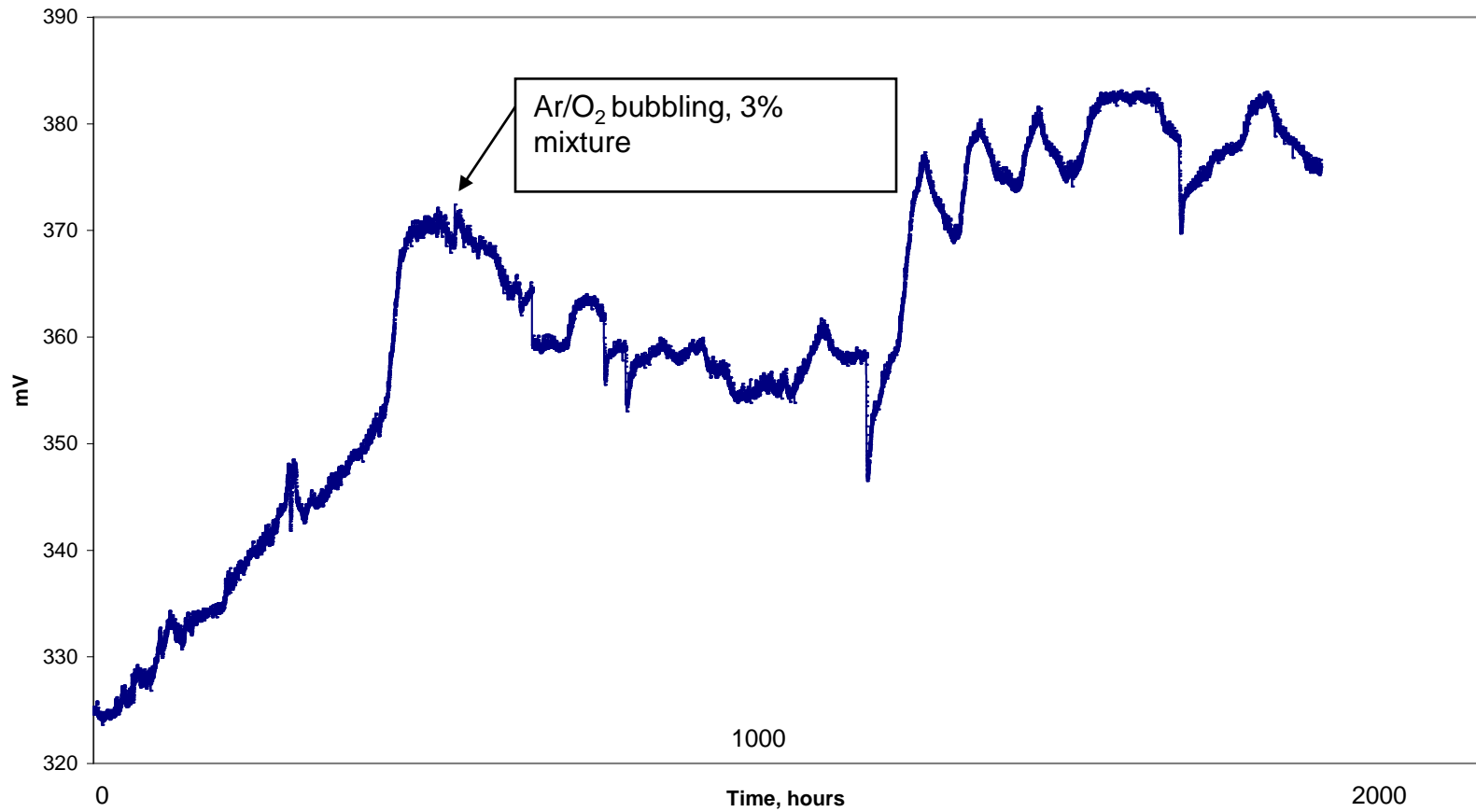


Indium Sensor- continuous Hydrogen bubbling, 0,5 l/m; 3% mixture

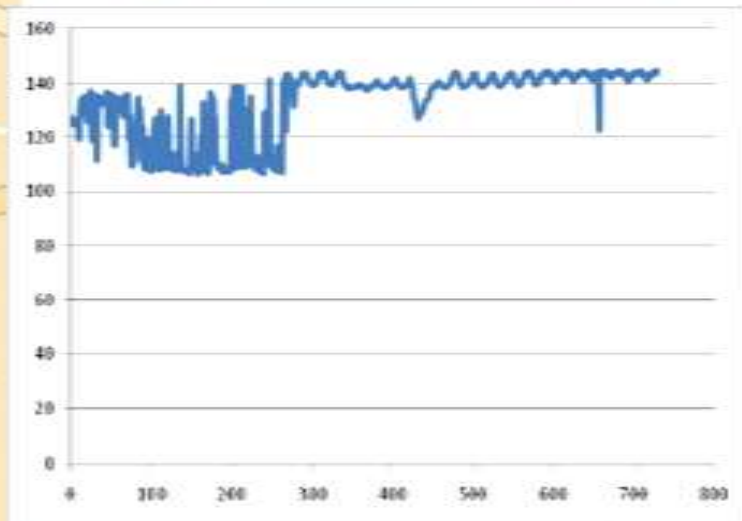


CHEOPE III loop example

Oxygen Sensor, 2000 hours, total



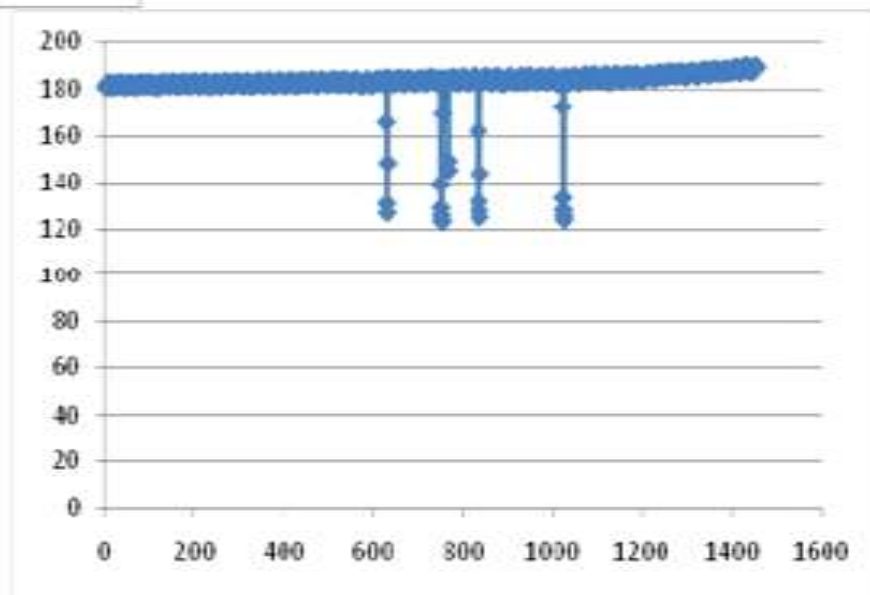
In₂O₃ reference sensor (ENEA)



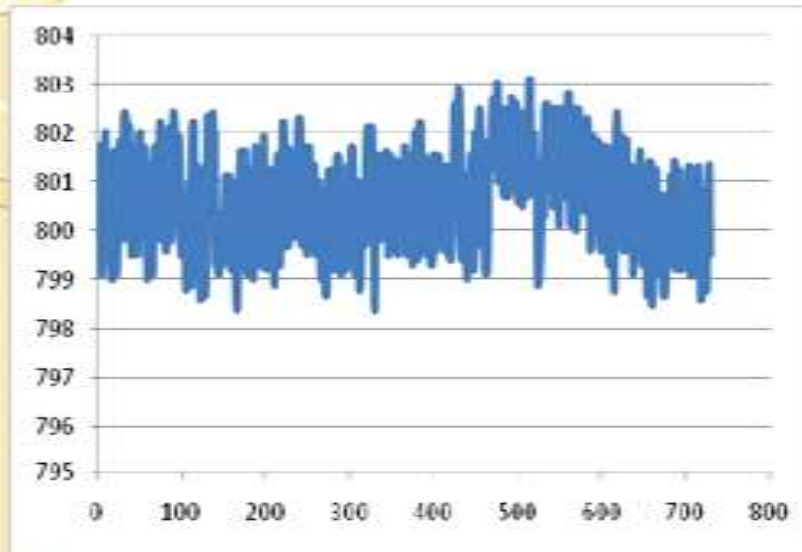
An Indium-Indium oxide reference sensor made in ENEA was tested both in OFM and in CHEOPE III. The signal appears to be higher than the one obtained in LBE. YZR tubes were manufactured in Faenza ENEA labs.

First sensor test in OFM

1400 hours of test in CHEOPE III. Pb at 1m/s.



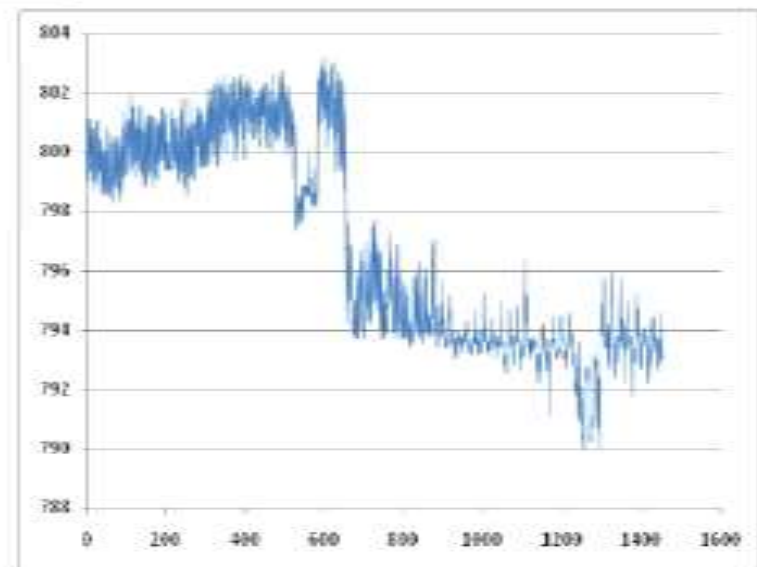
Pt/Air reference sensor (ENEA)



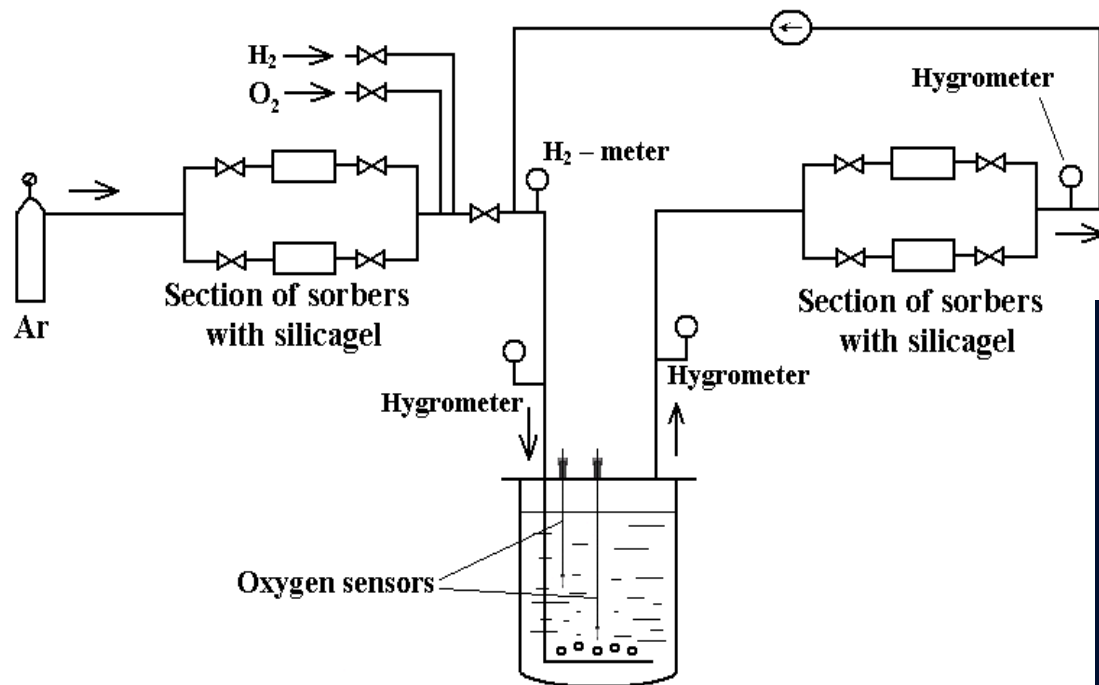
The Pt/Air sensor, ENEA made, is the last one to be tested in Pb. YZR is again ENEA made.
The sealing of the ceramic tube is performed by means of alumina powder mixed with AREMCO Ceramabond504 compound.

First sensor test in OFM

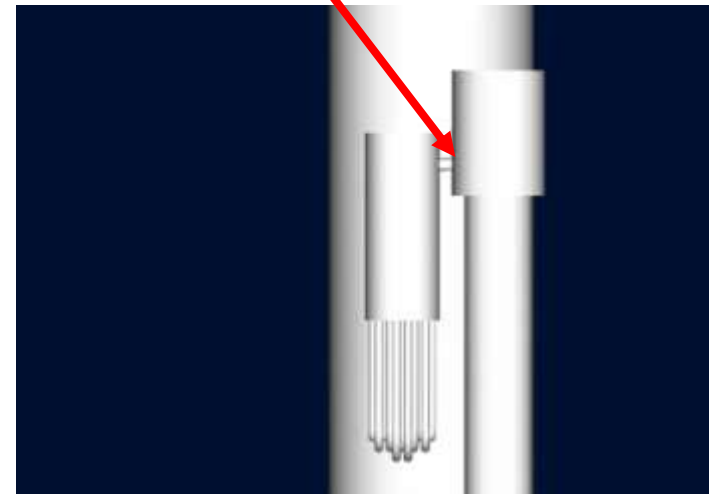
15000 hours of sensor test in CHEOPEIII



CIRCE program



ICE Sensor position



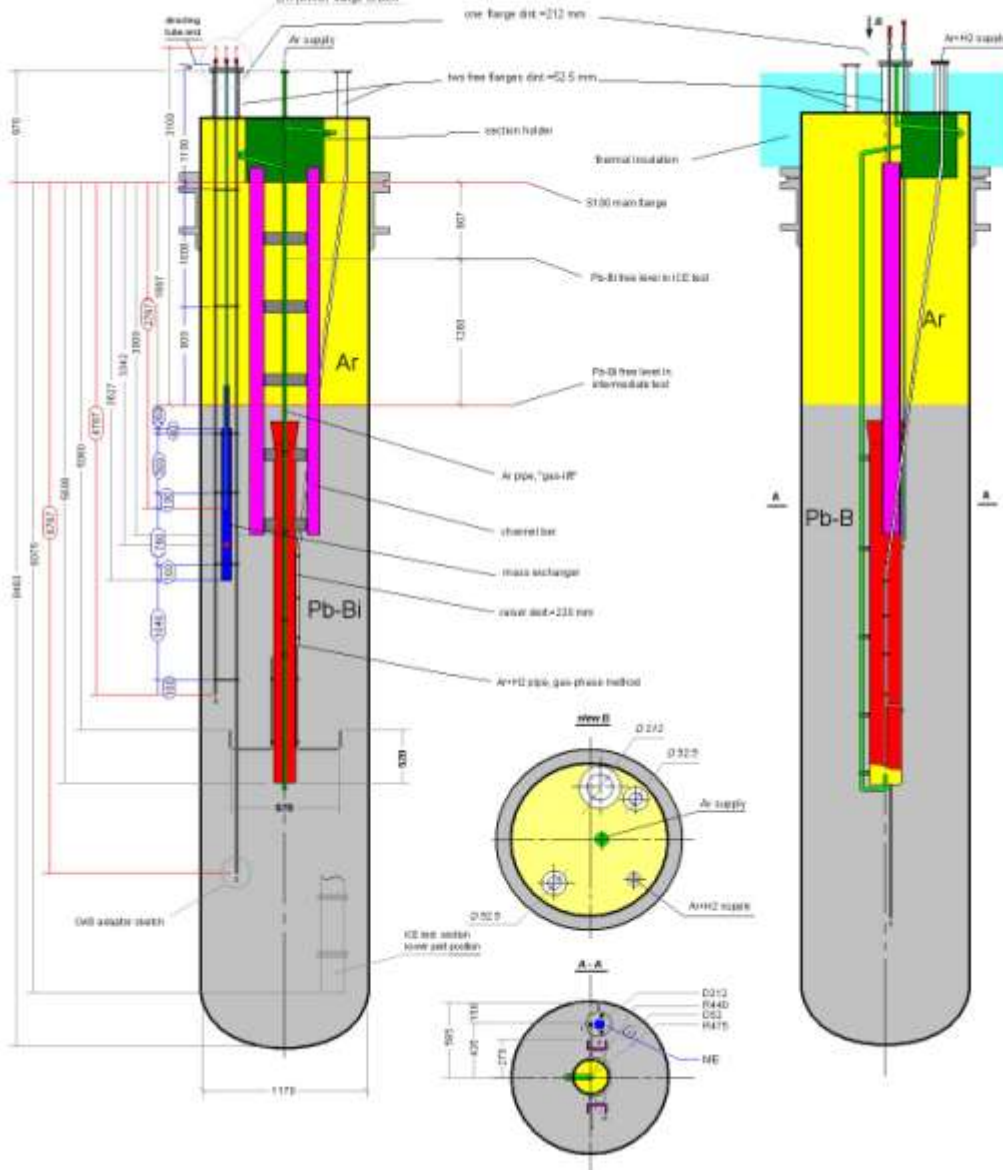
CIRCE loop: 2007 and 2008 activities

OXYGEN SENSORS IN CIRCE

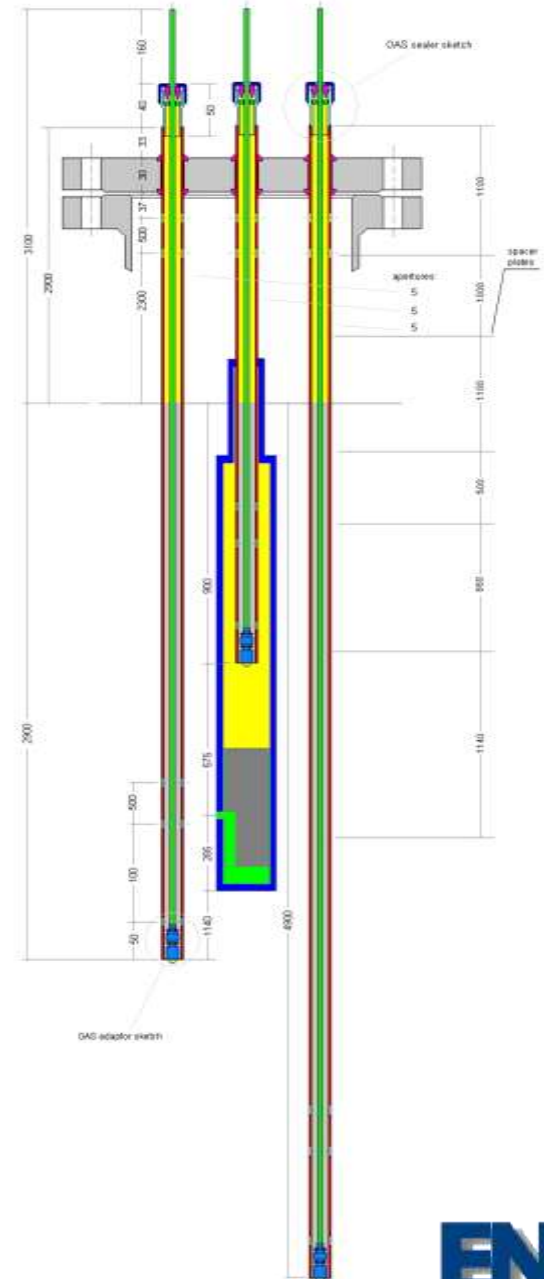
CIRCE configuration with the intermediate test section inside

sensors are at the points of immersion relative to main target level: 1- 2767 mm, 2- 4767 mm, 3- 6767 mm
 immersion relative to the free Pb-Bi level: 1- 303 mm, 2- 2900 mm, 3- 4900 mm
 directing tubes length: 1- 3000 mm, 2- 5000 mm, 3- 7000 mm
 sensors length: 1- 4000 mm, 2- 6000 mm, 3- 8000 mm

optical

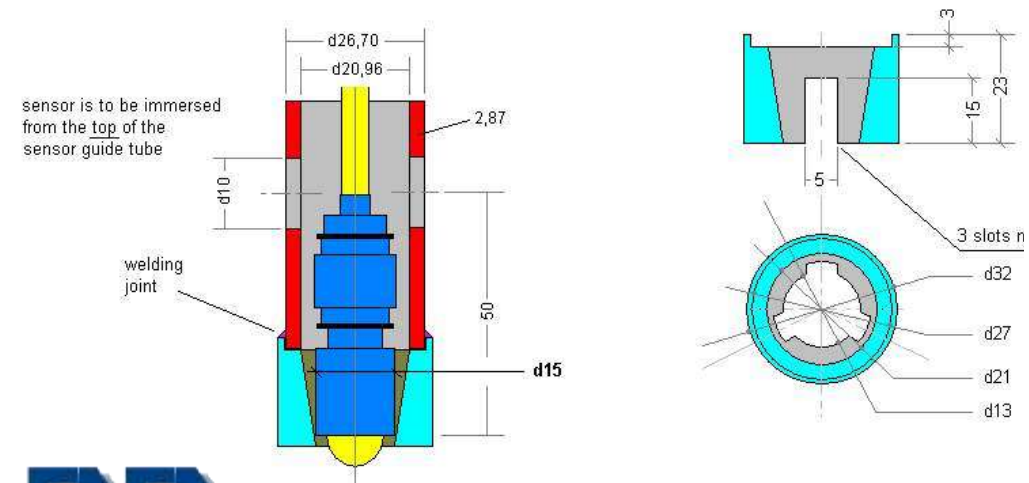


CIRCE oxygen activity sensors leading-out assembly
 option 1



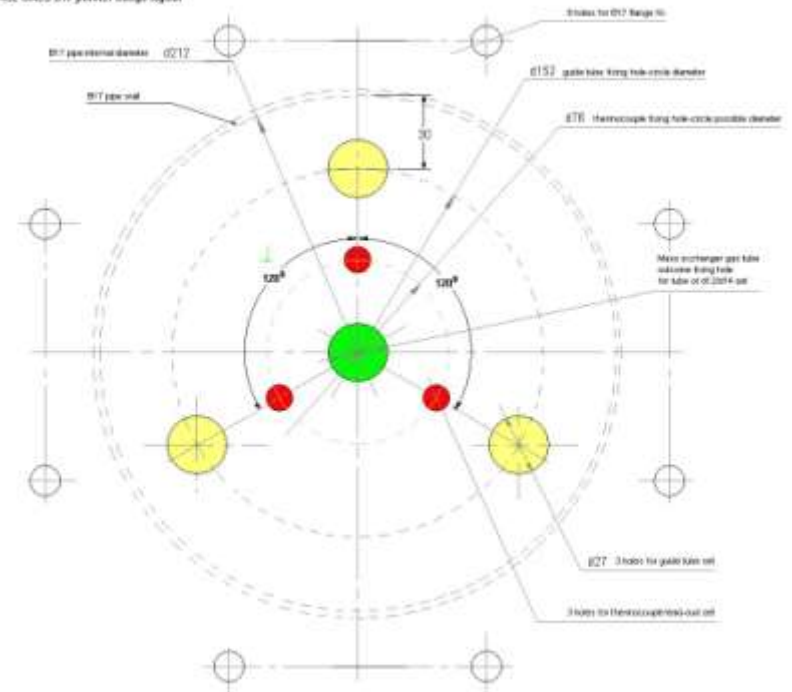
OXYGEN SENSORS IN CIRCE

CIRCE OACS sensor guide tube terminal slotted sleeve

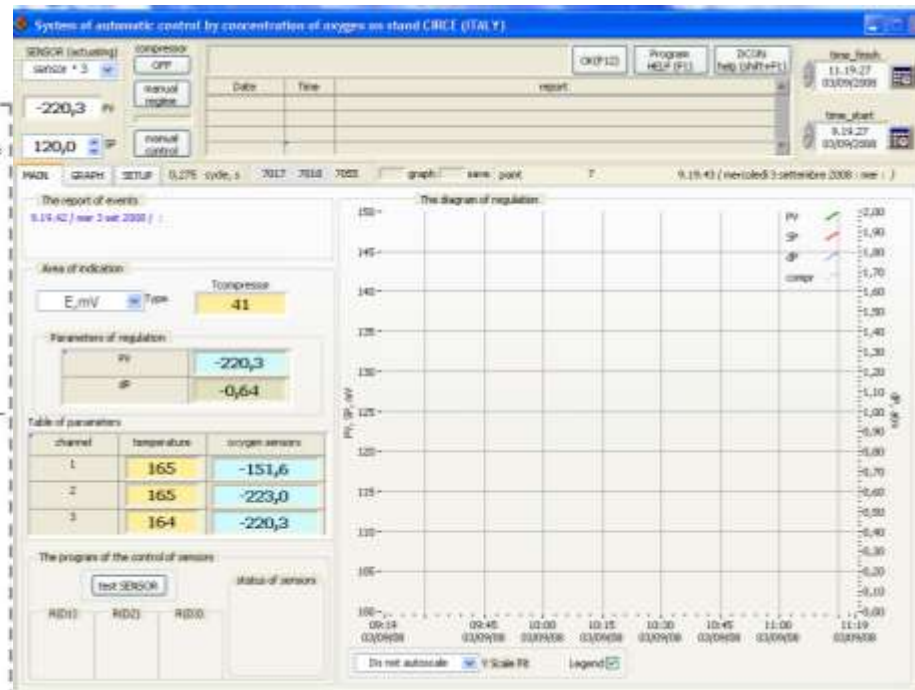
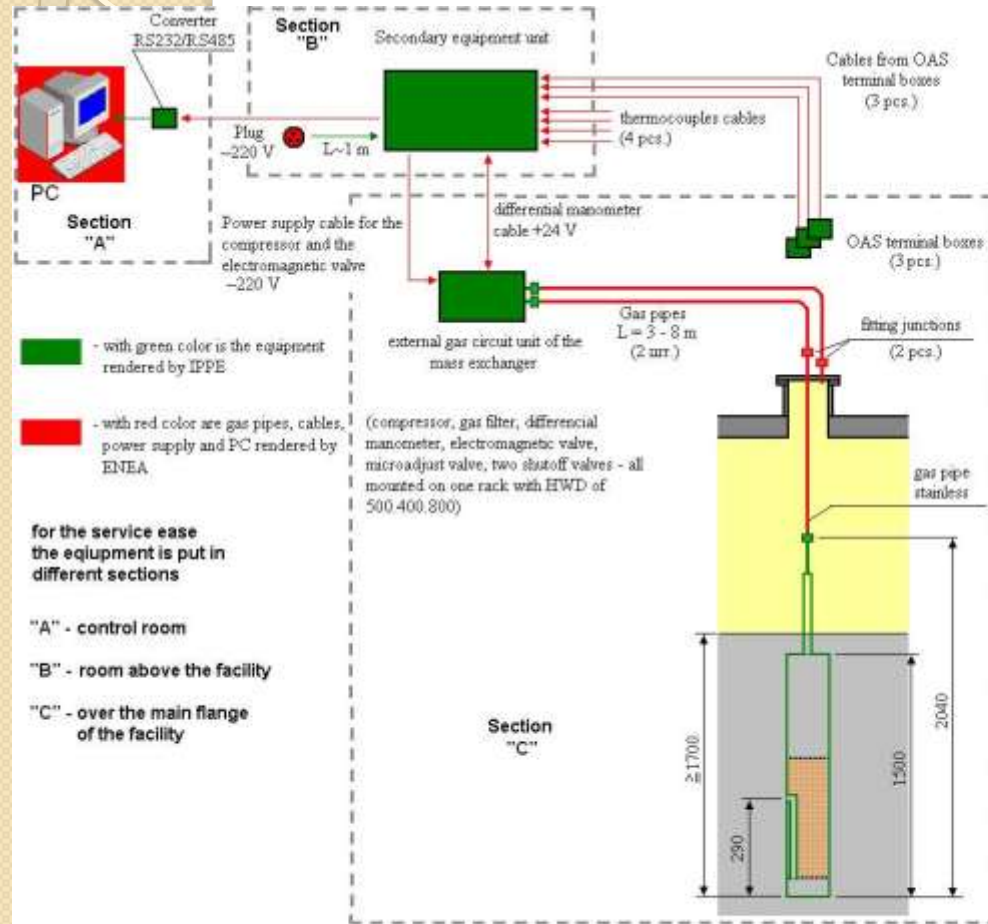


3 pcs.

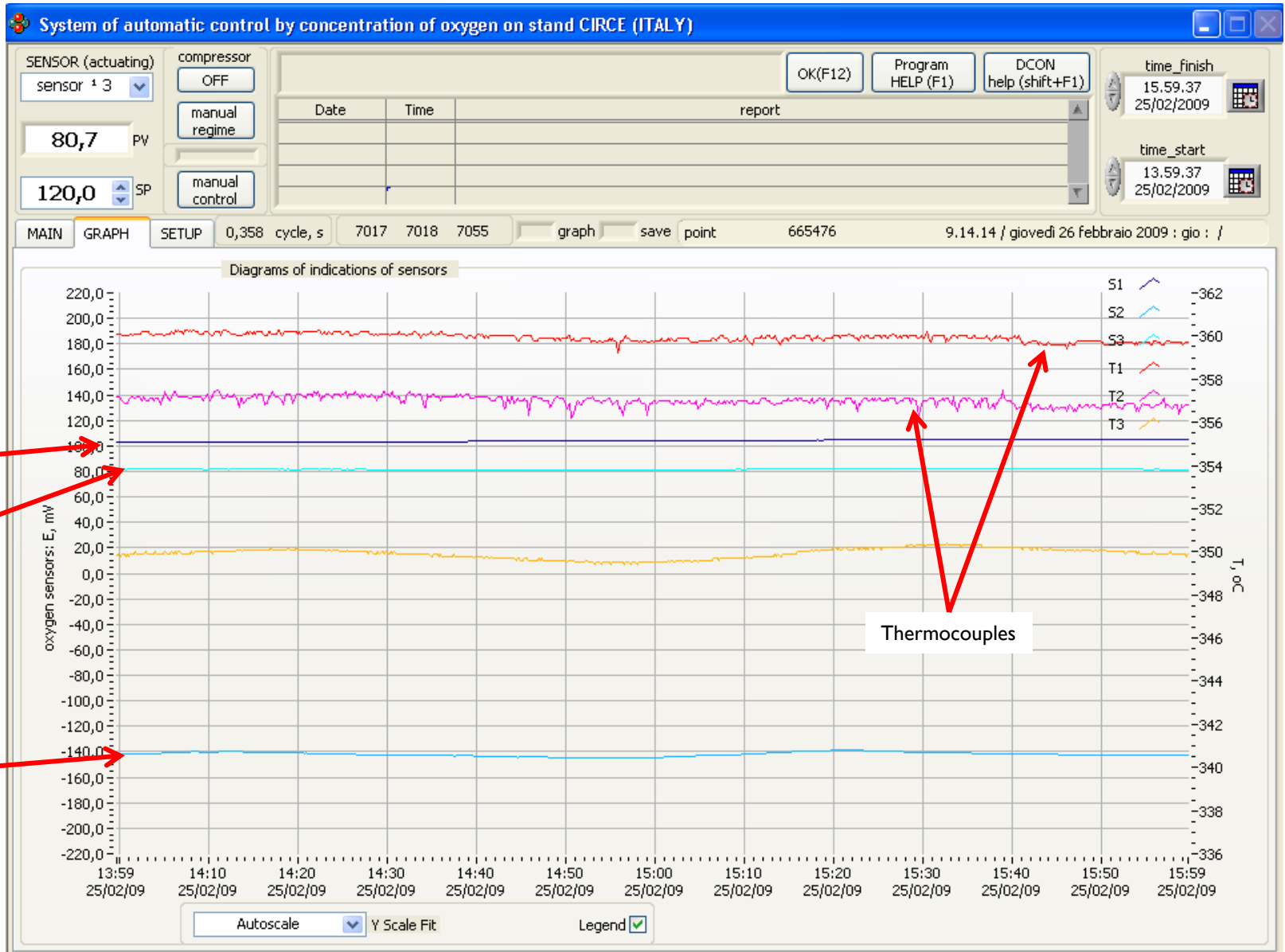
CIRCE OACS B17 Inserter Flange layout



OXYGEN SENSORS IN CIRCE



OXYGEN SENSORS IN CIRCE: DATA ACQUISITION SYSTEM



Summary

- The average compositions of solid slags into the liquid phase and of the “black dust” usually do not differ, consisting of PbO up to 40 wt% and recrystallized LBE. No powders have been observed in pure Pb during normal operation; only after a strong pollution event.
- The role of air (Oxygen) pollution is fundamental in the formation mechanism of solid impurities, which composition is mainly PbO and recrystallized melt. A sampling problem still exists.
- An effective Oxygen control system has been tested in several loop facilities, and demonstrated its effectiveness in preventing pollution.
- The know-how has now been implemented in the CIRCE pool, giving very promising first results.
- The goal of this activity is to model Oxygen diffusion in the melt at different temperatures.

Thanks to Giuseppe Polazzi and Giuseppe Fasano for their precious help and work.