Recent advances on the lithium impurity control system of IFMIF-DONES

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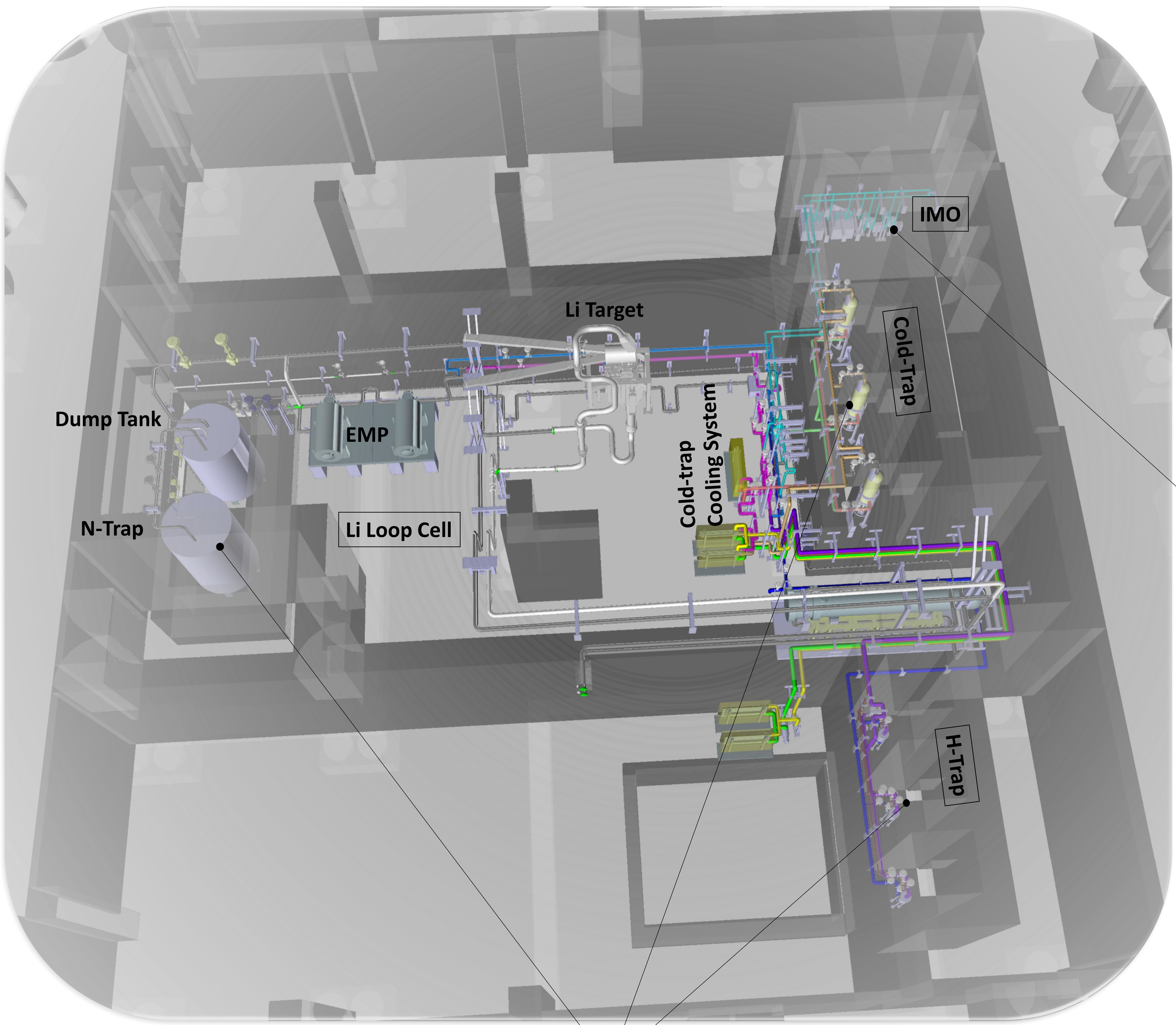
ABSTRACT

In the European Fusion roadmap, **IFMIF-DONES** will be a pioneering **facility for the irradiation of fusion materials**, delivering a high-energy neutron flux with a spectrum similar to that expected in fusion reactors. A distinctive feature of this facility is the use of a liquid lithium jet as the target for a continuous wave deuteron beam produced by a powerful accelerator (125 mA / 40 MeV). A closed lithium loop continuously feeds the target with renewed lithium after proper conditioning. Various impurities produced and contained in lithium have been identified. They are non-metallic impurities, such as nitrogen, oxygen, hydrogen and carbon, and metallic impurities coming mostly from the lithium corrosion and erosion phenomena against stainless steel structural materials. In addition, other elements are produced as a result of the lithium-beam interaction, such as beryllium-7, tritium, and activated corrosion products. To safely operate the loop and control the corrosion phenomena, **the lithium circuit incorporates a purification branch where impurity levels are monitored and reduced up to acceptable thresholds** through different trapping mechanisms. In recent years, a significant advance of the engineering design of the purification branch has been made together with further developments of the monitoring and purification equipment. **This work provides an overview of the current design status of the impurity control system of IFMIF-DONES.**

Functions of the Impurity Control System (ICS)

- **To control and confine the sources of radioactivity** such as tritium (T), beryllium-7 (Be-7) and activated corrosion products (ACP), i.e. corroded/eroded metallic elements .
- **To control and capture the sources of the corrosion and erosion** on structural components such as oxygen (O), carbon (C), hydrogen (H) and nitrogen (N).
- **To monitor the impurities in the liquid lithium** and to assure the optimal physical conditions.

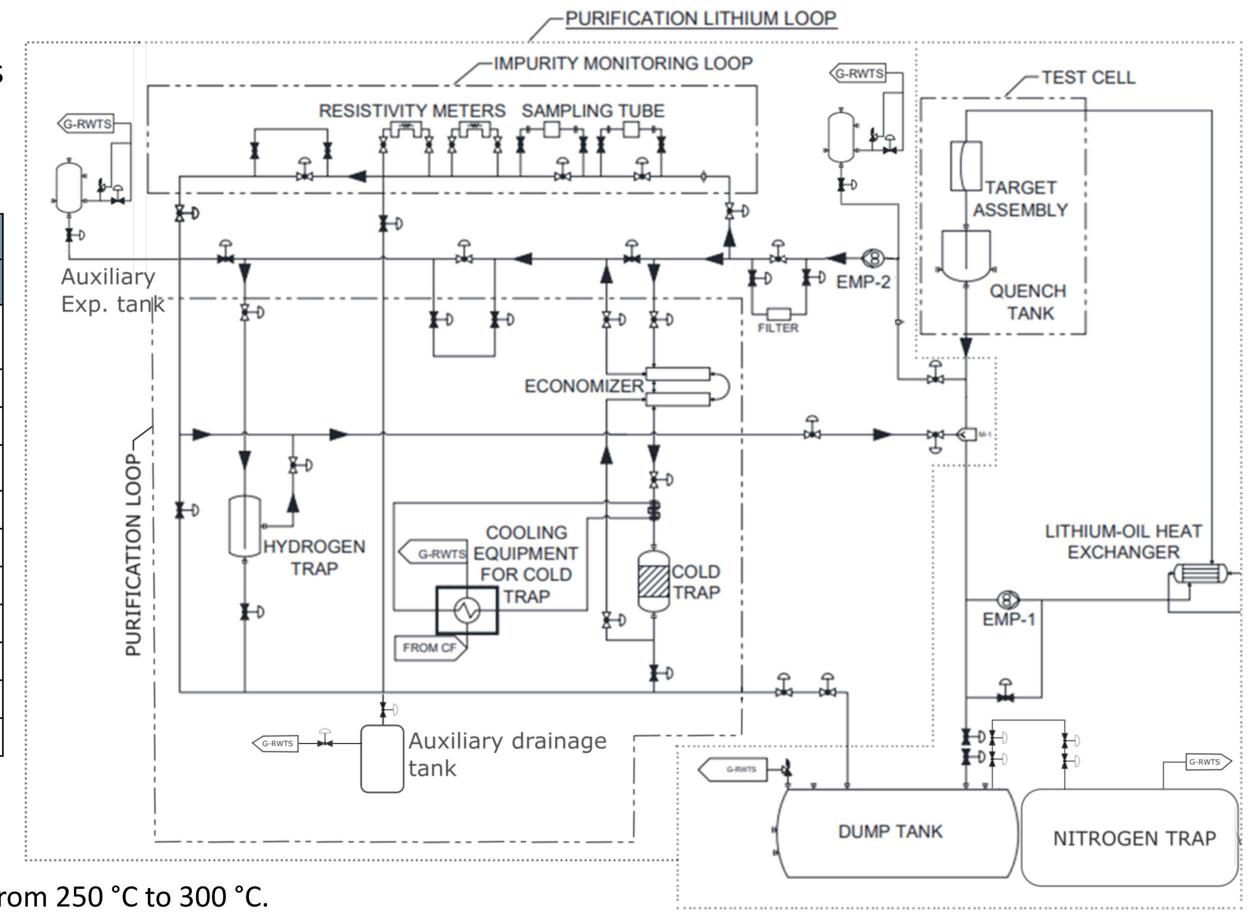


Layout and description

ICS consists of:

- Li Purification Loop (**LPL**): Traps
- Impurity Monitoring (**IMO**): on-line and off-line devices.

MAIN PARAMETERS	
ITEM	**VALUE**
Flow rate	LPL = 1.95 l/s IMO = 0.065 l/s
Li speed	< 6 m/s
Fluid	Liquid Lithium
Temperature range	190 ÷ 600 °C
H concentration in Li (target)	≤ 10 wppm
T requirement (Li or traps)	≤ 0.3 g
N concentration in Li (target)	≤ 30 wppm
O, C concentration in Li (target)	≤ 10 wppm
Corrosion	≤ 50 µm / 30 years
Component Material	SS316L
Replaceability of component	Possible



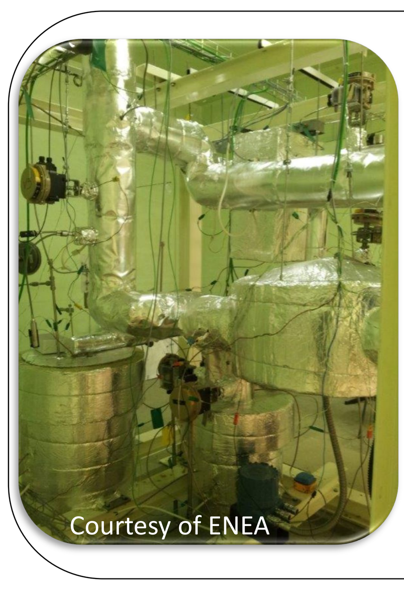
Total lithium Inventory ~14 m^3

➢ Major update:

- Increase of nominal Li temperature from 250 °C to 300 °C.
- Increase of three times the flow rate through the traps.
- Independent replacement of each trap without stopping the operation.
- Sectorization of different traps.

Impurity generation and distribution

- Corrosion Products (CP) are generated continuously due to the contact between the liquid lithium and components of the lithium loop. As the CPs go through the neutron stream, they can be activated, ACPs (typically ^{55}Fe, ^{51}Cr, ^{54}Mn, ^{56}Co, ^{57}Co, ^{60}Co, ^{64}Cu.).
- Other impurities, such as Hydrogen isotopes (mainly T) and ^{7}Be, are produced as results of the nuclear interaction Li-Deuteron beam.
- Whilst N, O and C may be incorporated due to maintenance or replacement of Li equipment.



LIFUS 6 (ENEA Brasimone). Facility devoted to corrosion and erosion tests of structural material under flowing lithium.

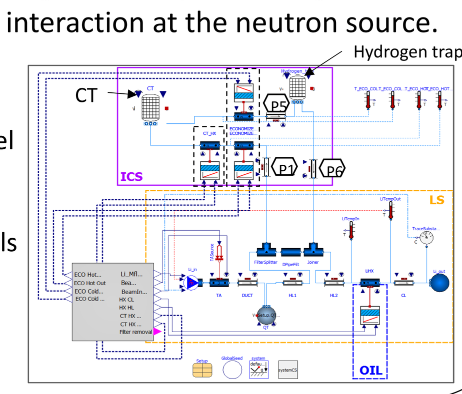
- Upgrade of facility

→ Corrosion/erosion rate of ~0.2 micron/year for Eurofer-97 (N<30wppm, T=330°C, V = 15 m/s).

CATE code

Development of a specific numerical model for the analysis of transport and distribution of relevant radionuclides along the Li loop, including their generation and interaction at the neutron source.

- Update of neutronics model
- Update of solubilities
- Simplified models of the traps

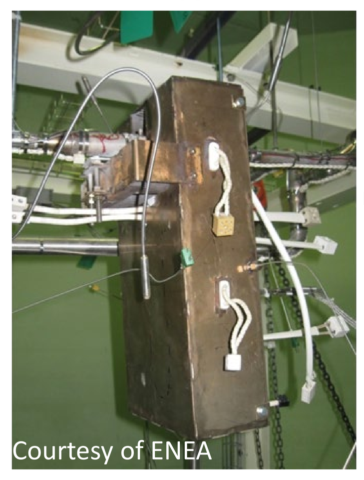


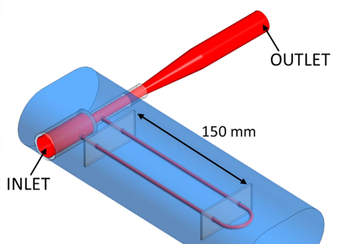
Impurity Monitoring System

IMO is devoted to monitor the impurities. Main technologies:

- **Resistivity-meters**: The measuring principle relies on the change in metal resistivity caused by the presence of dissolved anions. It can be affected by various impurities, but it is particularly sensitive to **nitrogen** and hydrogen impurities.
- **Electro-chemical Hydrogen Sensor**: to measure the **dissolved hydrogen in liquid metal** based on differential of potential (voltage) with respect to a reference sample using the Nernst's equation.
- **Plugging-meter**: it is based on the temperature-sensitive solubility of dissolved impurities. Essentially, it involves a controlled flow of lithium through a capillary, with the temperature being monitored to determine the saturation point. **Used extensively for Oxygen impurities in Na loops**.
- **Off-line samplers**: chemical analysis of Li samples extracted regularly from the Li loop. Different procedure under research:
  - Metal impurities. Determined by ICP-MS, ICP-OES or Flame-AES after acid digestion (high accuracy ppm).
  - Non-metallic impurities: H, N, and C could be quantified by QMS after chemical dissolution and thermal treatment, whilst O by Karl Fisher coulometric titration.

Prototype of Resistivity-meter.





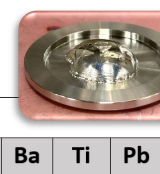
Upgrade:

- Reduction of the electromagnetic noise
- Optimization of the heating element's location and power rate

Prototype of electro-chemical Hydrogen sensor

Upgrade:

- Reduction of size
- Multichannel measurement and long-term stability
- Investigation on different isotopes



Sample	ELEMENTS (wppm)							
	Be, Cr, Mn, Co	**Fe**	**Ni**	**Cu**	**Sr**	**Ba**	**Ti**	**Pb**
Li-s1	<0.5	2.5	< 1.8	1.9	14	13	2.9	92
Li-s2	<0.5	3.7	< 1.8	1.6	13	13	2.9	31

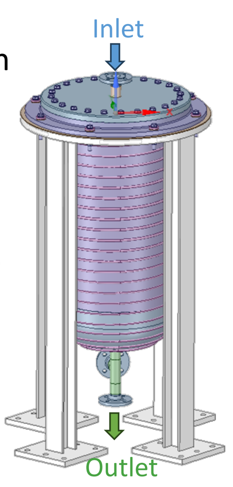
Chemical analysis of high purity Li samples at CIEMAT lab.

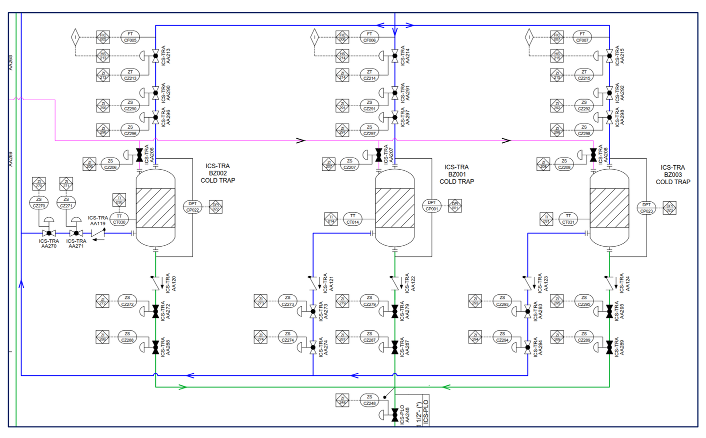
Li Purification Loop

The LPL is devoted to confining and capturing the impurity content in Lithium by different traps technologies:

- **Cold traps:** To remove soluble compounds with temperature dependent solubility by crystallization on a wire mesh substrate. The processes are film driven after initial crystallization. Mainly focused of Li with O, H and C; but also for CPs and ACPs, including ^{7}Be compounds.

  Main Feature:
  - Three cold traps working online in parallel for the full lifetime of the plant.
  - Isothermal configuration working at reduced temperature 190-200ºC. Temperature controlled by heat exchanger and Economizer.
  - Isolated from rest of systems by double valves.
  - Theoretical residual concentrations of non-metallic imp. (wppm): C~0.24, O ~ 5.5, H ~ 50 and N ~ 1200.

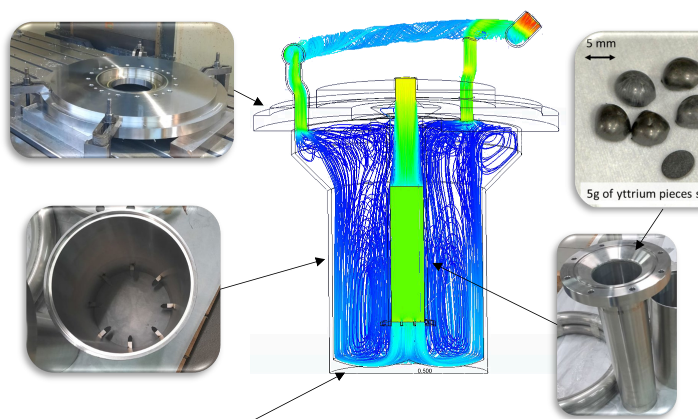




Schematic configuration of Cold-traps

- **Hydrogen traps:** To remove the H isotopes from the liquid lithium. The process is driven by mass transfer in the liquid lithium and subsequent H capture and diffusion inside the getter. Yttrium (Y) has been selected as a suitable getter material, since it has a high chemical affinity with H isotopes (formation of yttrium hydrides) and solubility (higher than in Lithium).

  Main Features:
  - Three H-traps, but only one working online, whilst others are in stand-by. Monthly replacement.
  - Isothermal working conditions (250-300ºC).
  - Yttrium pebbles 5-10 kg (each trap).

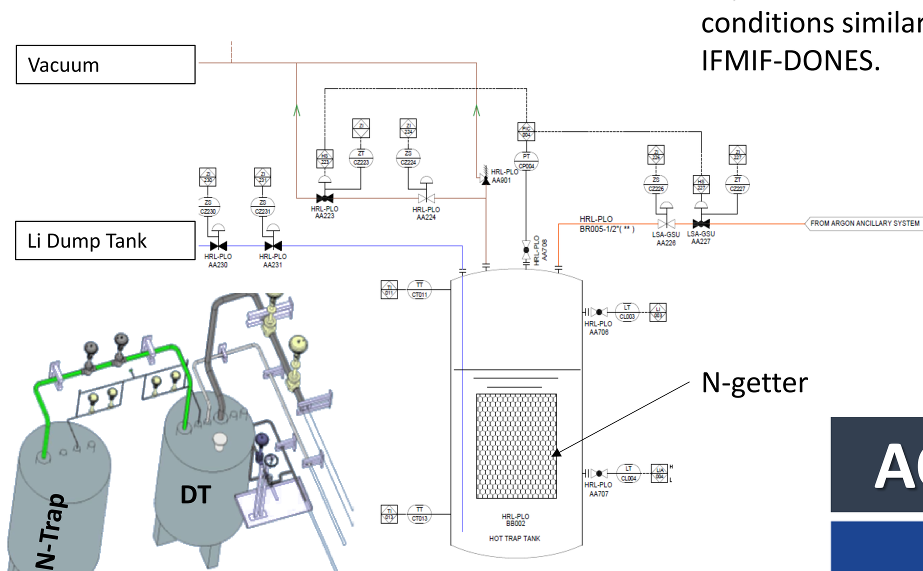


Design - manufacturing of a prototype of H-trap for LITEC facility (Li Impurity Technology Experimental Circuit). Courtesy of IDOM and CIEMAT)

- **Nitrogen trap:** To remove the N isotopes by a gettering process similar to the H-trap. In this case the trap operates statically on the whole Lithium inventory (off-line).

  Several theoretical and experimental investigations in ANGEL and Lifus6 show:
  - Titanium-based sponge works well, being able to reduce N<30 wppm and making stable compounds.
  - Optimal working temperature 550-600ºC.

ANGEL facility. (ENEA Brasimone). Facility aiming at investigating getters materials for **N trapping** in Liquid Lithium in conditions similar to IFMIF-DONES.



Conceptual illustration of the N-trap

- Designed for the full lifetime of the plant.
- Getter allocated inside a cartridge immersed in the liquid lithium

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