Advancement and Innovation for Detectors at Accelerators

AIDAInnova 3rd Annual meeting

Work Package 10

Task10.2: Ultra-light and 3D-printed structures with integrated cooling

Activities at CERN

Massimo Angeletti

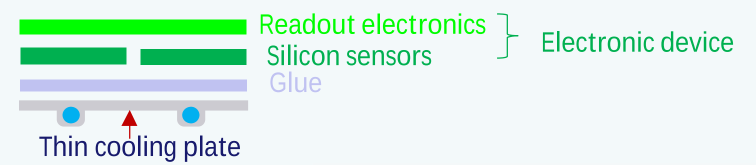
On behalf of CERN team

https://indico.cern.ch/event/1307202/sessions/502041/#20240320

Collaboration with CERN EP R&D Work Package 4

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004761.

Outline:

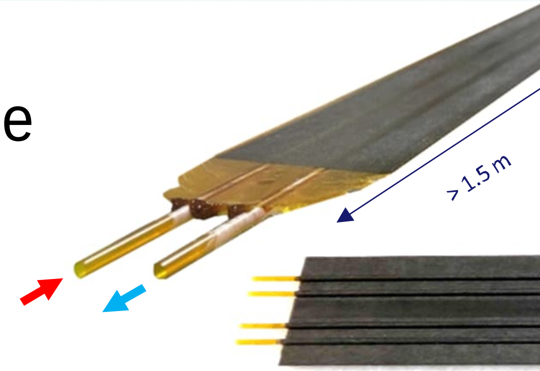


- Task C: Ultra-light structures with integrated cooling

Carbon cold plate with embedded Kapton pipe

Purpose:

- Technology compatibility with high-pressure boiling coolants.
- Produce large surfaces cold plate (CP) for high-pressure boiling coolants.
  - i.e. evaporative CO_2 and new coolants (Krypton, …)

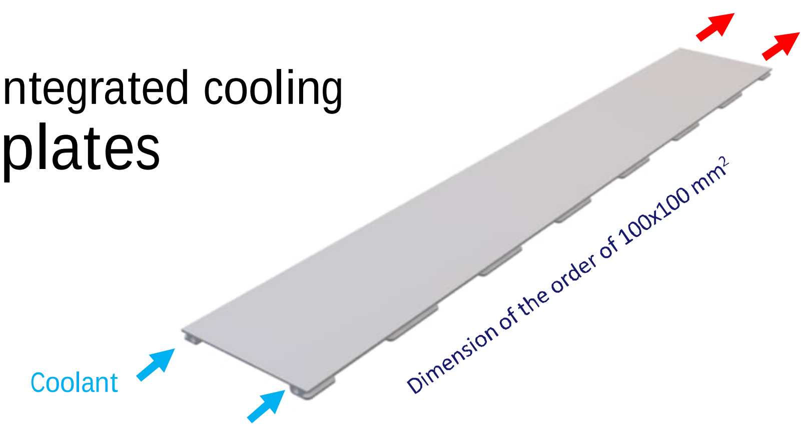


- Task B: 3D-printed structures with integrated cooling

AM Ceramic & Metal cold plates

Purpose:

- Generation of new standards to produce micro-structured cold plates produced by additive manufacturing, (ultra-thin wall).



Carbon cold plate with embedded polyimide pipes

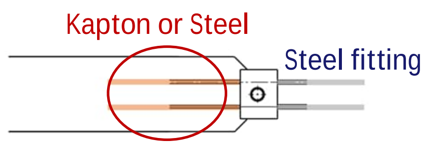
CERN EP R&D WP4

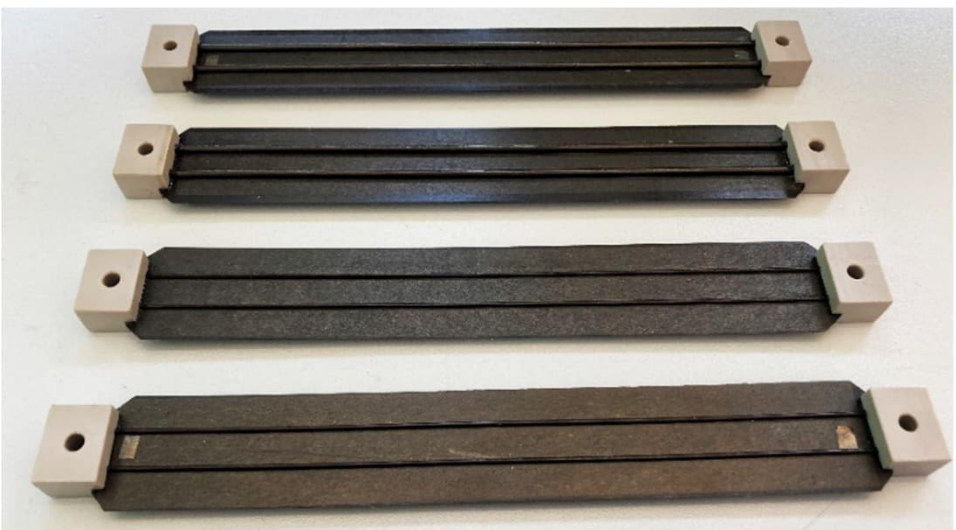
D. Hellenschmidt, M. Angeletti

- **Achievement:** Established low-mass cold plate design with embedded Kapton pipes adapted and tested successfully with evaporative CO_2

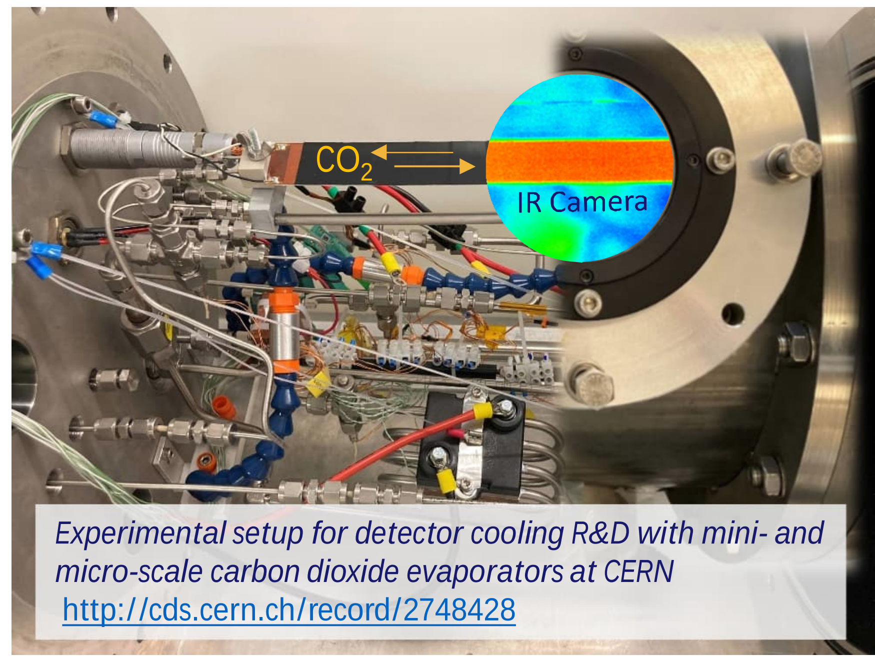
Sample production

	Steel	Steel	Kapton	Kapton
ID [mm]	2.15	1	1.97	1.024
WT [mm]	0.51	0.29	0.17	0.076





Experimental setup



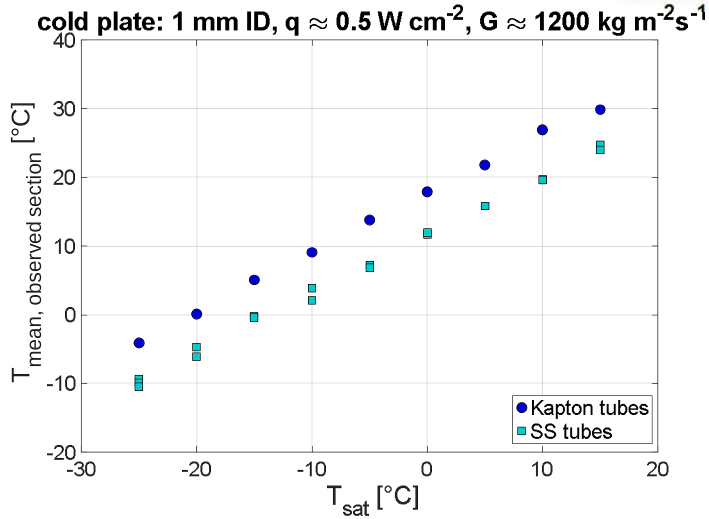
Experimental setup for detector cooling R&D with mini- and micro-scale carbon dioxide evaporators at CERN
http://cds.cern.ch/record/2748428

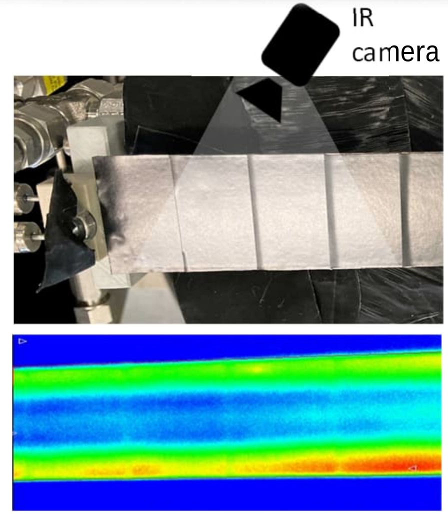
Carbon cold plate with embedded polyimide pipes

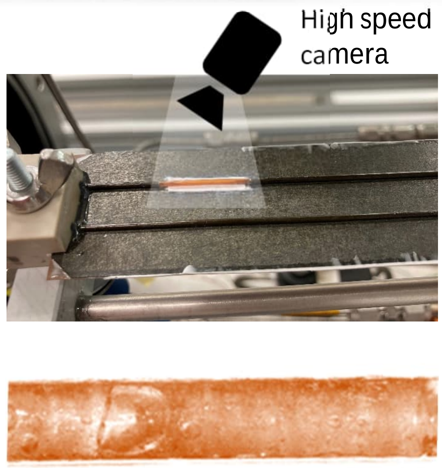
CERN EP R&D WP4

- Validation tests:
  - can be operated at high CO_2 pressures .
  - Thermal performances in agreement with published results with boiling CO_2 at a small scale.
  - thermal performance ↓($\Delta T_{KAPTON-SS}$ from 2 to 8°C); low material budget ↓ (X_0 15 time less); with respect to steel pipe.

D. Hellenschmidt







Article under internal review: *On-detector cooling systems based on low-mass carbon dioxide evaporators: cold plates with embedded Kapton tubes* (D. Hellenschmidt, ...)

Carbon cold plate with embedded polyimide pipes

- Know-how transferred to Workshape

ONGOING: 1.5m cold plate production (ITS2 like)

CERN EP R&D WP4

CERN Knowledge Transfer

- The Workshape team encountered challenges in producing the cold plates due to differences in the resin being used compared to the specified material.
- Their resin system proved to be significantly more fluid, resulting in suboptimal fiber impregnation.
- However, they selected a new resin system (Sicomin SR1710 + SD2824 hardener + aerosil) which is thicker and should address the issue.
- Cold plates manufacturing will be completed before the end of April.

NEXT: 1.5m cold plate (High-pressure resistance)

Moulds for CP up to 1.5 m

Task10.2b Ceramic additive manufacturing

Type of ceramics under investigation

- Aluminum oxide (Al2O3, LithaLox350 well consolidated AM techn.).
- Aluminum nitride (AlN, CTE matching, K ↑, new AM techn.).
- Polymer-Ceramics composite (polymeric matrix, no firing): Define and optimise polymeric matrix such to achieve good mechanical properties and high ionizing radiation tolerance.

Material properties *(irradiated and non-):*

Flexural modulus/strength (DIN EN 843-1/5)

Samples: Bars
- Size type B
- 3x4x45 mm³

Thermal conductivity (ASTM D5470 - 12)

Samples: Disks
- D = 16 mm,
- Height = 3 and 6 mm

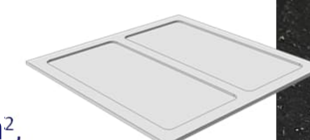
Geometrical limits:

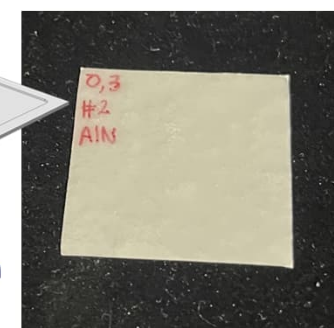
Leak tightness & pressure tests
Vs wall thickness (WT)

Samples: Pipes
- L = 50 mm
- OD= 3.2-1.6 mm
- WT = 0.2-0.6mm

Flatness
Vs plate thickness

Samples: Plates
- Area ~30x30 mm²,
- WT = 0.2-.6mm
- Framed plate: WT-plate 0.2mm,
  WT- frame 0.4-0.5mm





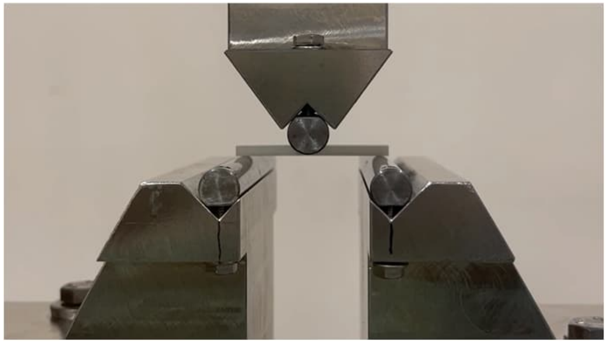
C. Manoli

Material properties: Summary of the pre- and post-irradiation tests

- Flexural modulus/strength (DIN EN 843-1/5)

Al203-Lithalox 350

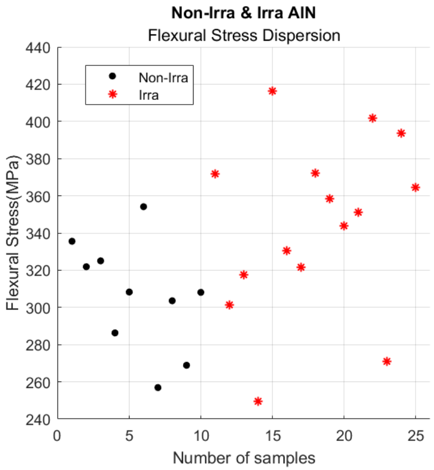
- 3.9 MGy @Enea Casaccia irradiation fac.
- Flexural modulus (300 GPa), non- and irradiated compatible with datasheet (+5%)
- Flexural strength (400 MPa), non- and irradiated compatible , but slightly below datasheet (-15 %) (due to manuf. tolerance, sensor accuracy, printing orient.)

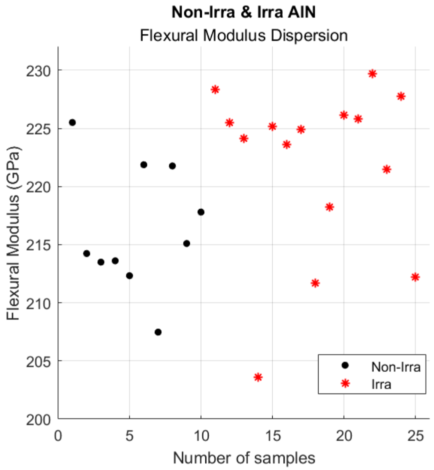


@EP-DT Composite lab setup

AlN

- 1 MGy @panoramic 60Co gamma irradiation facility.
- Flexural modulus does not change pre- and post-irradiated (~220 GPa)
- Flexural strength does not change pre- and post-irradiated (~340 MPa @CERN test , 292.2 (+/-)40 MPa @Lithoz test)





NEXT: Irradiaton campaign up to 5 MGy (up to 10 to be evaluated)

Task10.2b Ceramic additive manufacturing

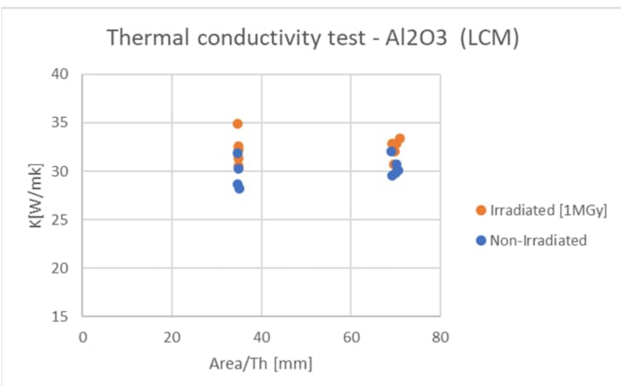
M. Angeletti

Material properties: Summary of the pre- and post-irradiation tests

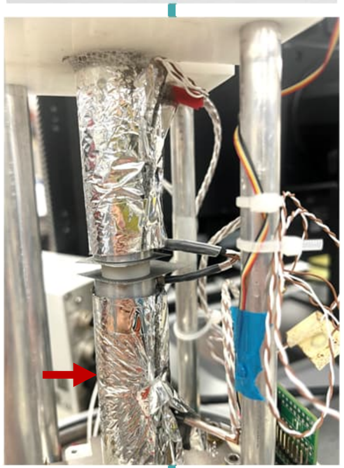
- Thermal conductivity (ASTM D5470 - 12)

Al203- Lithalox 350

- @1 MGy, @panoramic 60Co gamma irradiation facility.
- The thermal conductivity of Al2O3 material does not change pre- and post-irradiated (~33 W/mK).
- K Datasheet = 37 W/mK



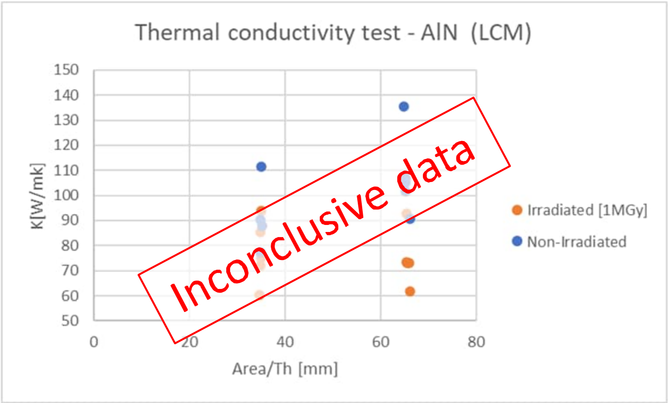
(2x) contact resistance ~ 0.15-0.25 K/W



@EP-DT setup

AlN

- @1 MGy, @panoramic 60Co gamma irradiation facility.
- E-DT setup (ASTM D5470 – 12) is not suitable for measuring the thermal conductivity of AlN material.



Total resistance ~ 0.25-0.45 K/W

- NEXT: testing based on flash method measurements.

NEXT: Irradiaton campaign up to 5 MGy (up to 10 to be evaluated)

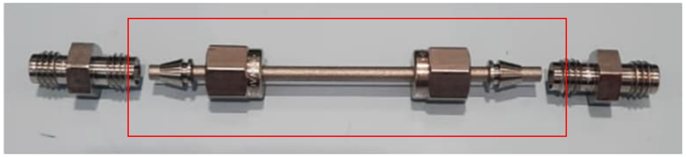
Task10.2b Metal additive manufacturing

- Type of metals under investigation:
- Aluminum alloy (AlSi12),
  EN AC-44300 @CSEM, worse CTE , K
- KOVAR
  (new AM, CTE matching, worse k)

- Geometrical limits:

  Leak tightness & pressure tests
  Vs wall thickness (WT)

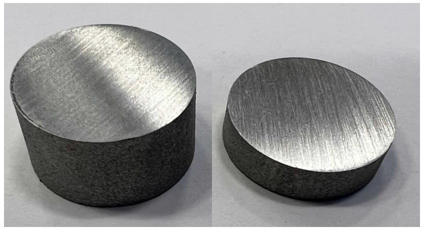
  Samples: Pipes
  - L = 50 mm
  - OD= 3.2-1.6 mm
  - WT = 0.2-0.6 mm



- Material properties:

  Thermal conductivity (ASTM D5470 - 12)

  Samples: Disks
  - Polished and non-
  - D = 19 mm,
  - Height = 5&10 mm



Task10.2b Metal additive manufacturing

Leak tightness & pressure tests

Vs minimum wall thickness (WT)

- Multiple pipe samples have been printed (>100) with varying:
  - Laser power settings (150-70W),
  - Laser head speed (1850-1400 mm/s),
  - Number of laser passes (1 line, 2 lines),
  - Powder sizes (D100 - 45, 63 um),
  - Diameter (7 mm, 1/8inch, 1/16inch)

85mm

- For each diameter, printing parameters ensuring leak-tight pipes have been identified, resulting in a minimum wall thickness of the pipe ranging from 160-190 µm.

ONGOING: Additional samples have been sent to an external company for post-heat treatment (550C, hydrogen atm.) to further compact the powders and potentially achieve thinner pipe walls. They will be tested in the coming weeks. MetShape

X-ray scan (EN-MME)

OD=1/8inch, WT= 0.149 mm, laser power =100W, 1500mm/s 2 lines, powder size D= 63 um

THIS IS THE END...

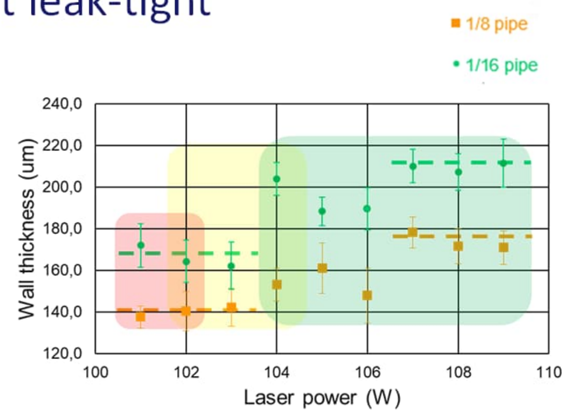
Thank you
for your attention

Task10.2b AM (micro)-channel cooling technology

3D envelopment of integrated cooling circuits in the structure

csem

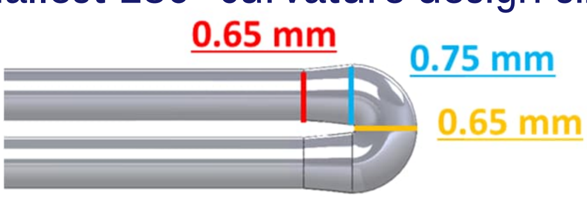
- Investigation on the smallest leak-tight wall thickness for Al alloy
  - 160 um 1/8'' pipe
  - 190 um 1/16'' pipe



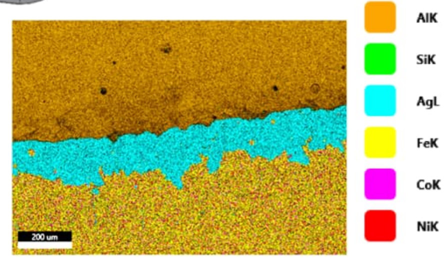
Updates: CSEM

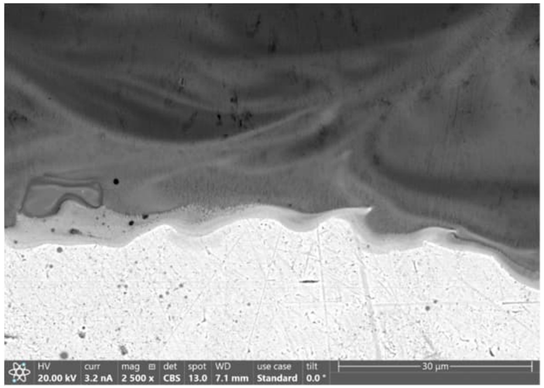
- The printing limits of AlSi12 material have been thoroughly understood.
- KOVAR powder has been purchased; and printing capabilities with KOVAR material is currently under study.

- Investigation on the smallest 180° curvature design size to remove powder
  - Pipe length: 85 mm
  - Pipe hole: 0.44 mm



- Multi-material printing
  - Aluminium-kovar with silver inter-layer
  - Thermal cycling to be tested





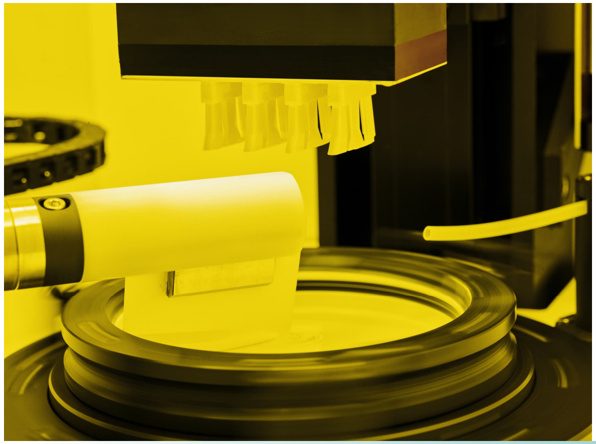
Task10.2b AM (micro)-channel cooling technology

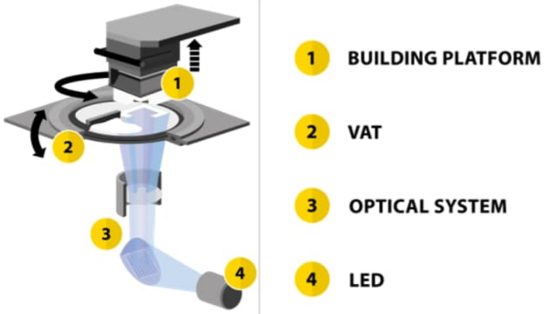
3D envelopment of integrated cooling circuits in the structure

- Materials and technologies:
  - AM: Lithography-based Ceramic Manufacturing (LCM) technology.
  - Ceramics: Aluminum oxide (Al_2O_3),
    ONGOING: Aluminum nitride (AlN),
    Polymer-Ceramic composites.
  - Aim: Define the optimal geometrical features attainable
    e.g. Minimum achievable wall thickness of pipes/plates,
    Flatness optimization (Firing step, 1500-2000 C, warping effect).

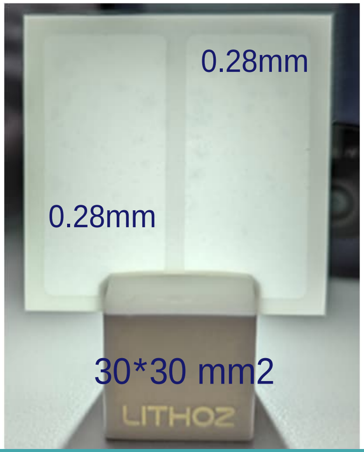
Updates: Lithoz

- The printing limits of Al_2O_3 material have been thoroughly understood.
- Additional samples in AlN are in production for future irradiation test campaign.
- Optimization of cold plate flatness investigation currently on going





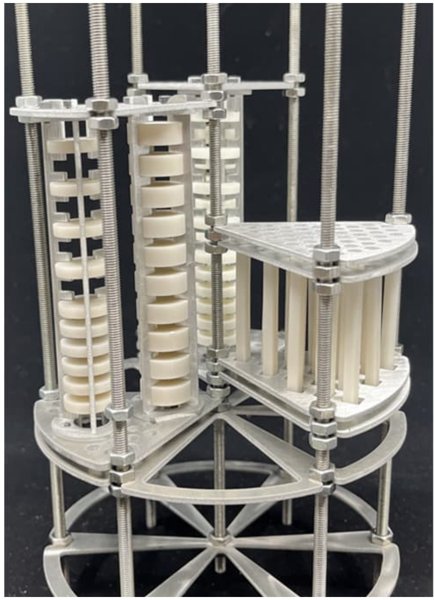
Blue light cures the photosensitive formulation



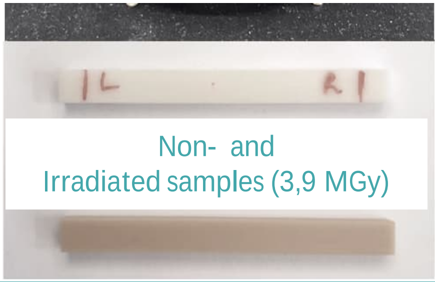
Task10.2b AM (micro)-channel cooling technology

- Analysis, experimental tests:
  - Metrology, mechanical characterization tests (CERN)

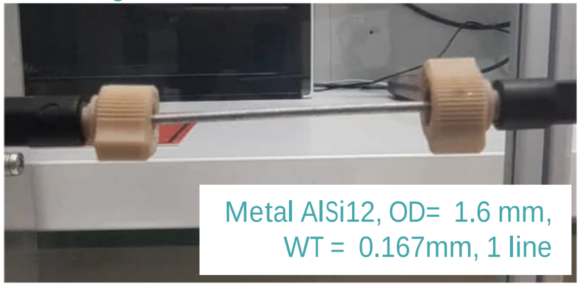
Material properties investigation



Aluminium cradle for Irradiation test campaign



Leak-tightness

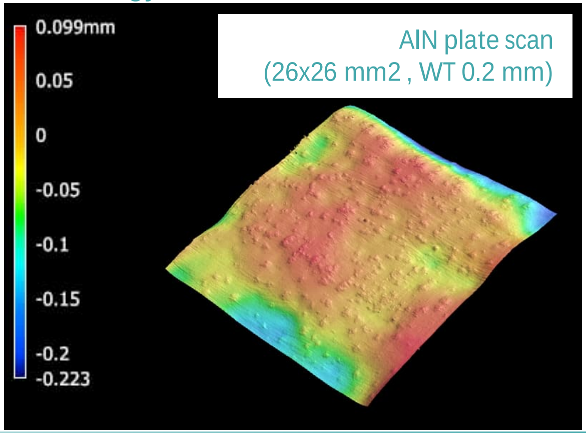


Updates: CERN

- Geometrical limits for AlSi12, Al2O3 and AlN have been identified.
- First irradiation campaign and characterization tests completed for Al2O3 and AlN. No relevant changing in material properties (thermal conductivity, Flexural modulus/strength) have been noticed.

Burst pressure test

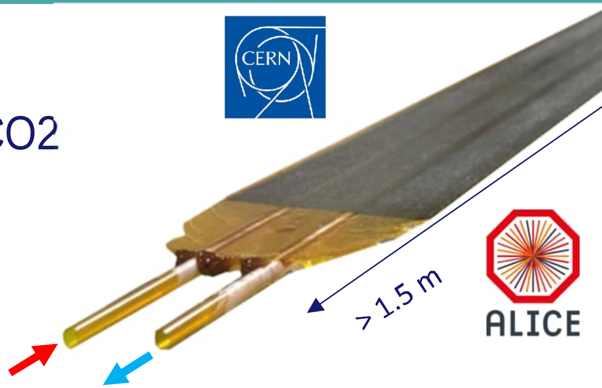
Metrology



NEXT:
5 MGy irradiation campaign

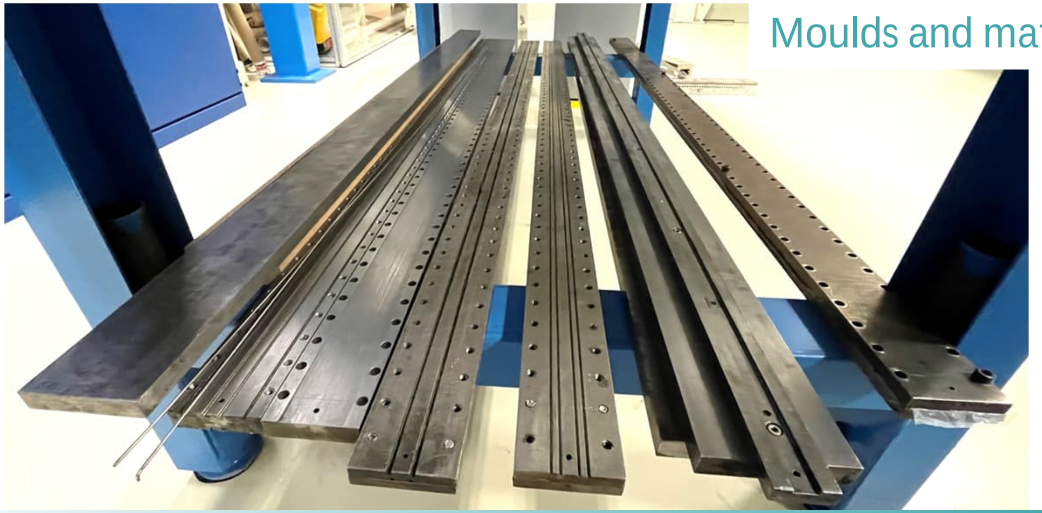
Task10.2c Ultralight carbon cooling technology

- Compatibility with boiling fluids
  - Main outcomes: Revised layout can operate with boiling CO_2

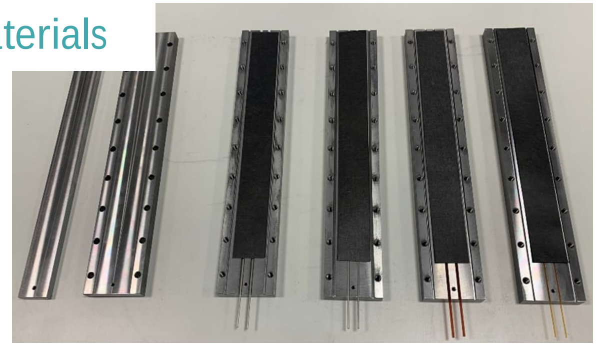


Updates: Workshape

- Ongoing cold plates series production at Workshape, 1.5 m length.



Moulds and materials



CERN EP R&D WP4

Back-up

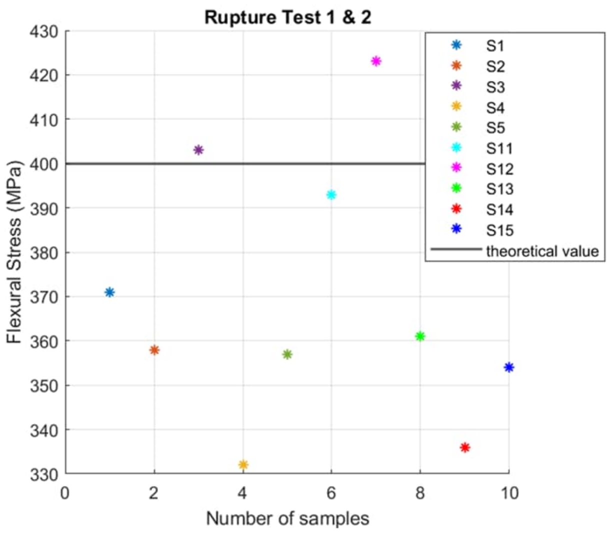
Task10.2b Ceramic additive manufacturing

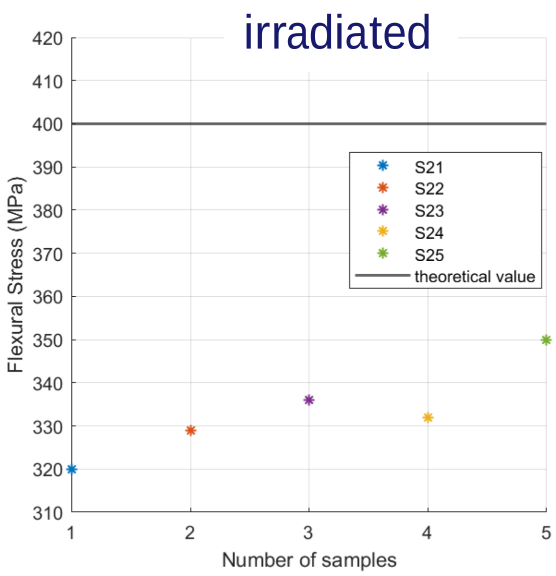
C. Manoli ; M. Angeletti

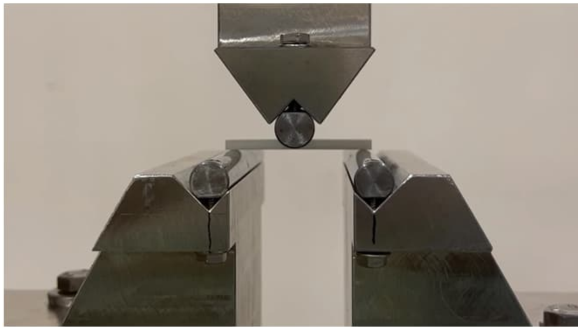
Flexural modulus/strength (DIN EN 843-1/5)

Non- and irradiated (TID 3,9 MGy) samples

- Flexural modulus (300 GPa), non- and irradiated compatible with datasheet (+5%)
- Flexural strength (400 MPa), non- and irradiated compatible , but slightly below datasheet (-15 %) (possibly due to manuf. tolerance, sensor accuracy, printing orient.)







@EP-DT Composite lab setup

Ceramic additive manufacturing

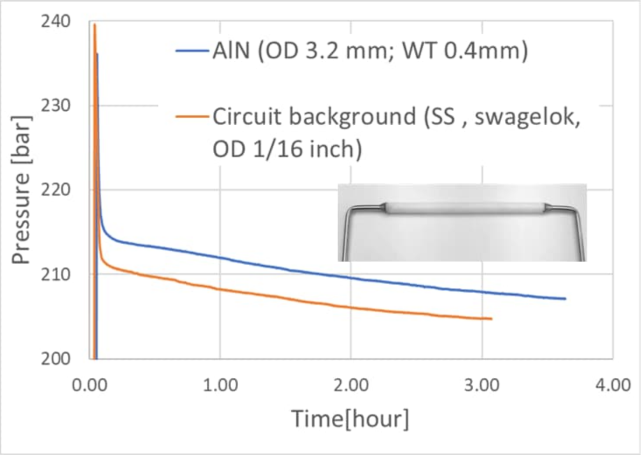
Leak tightness & pressure tests

Aluminum oxide (Al2O3, Lithaloz350) & Aluminum nitride (AlN)

- He leak rate ≤10^{-10} mbarl/s
  for wall thickness (WT) down to 0.2 mm (design)
- High pressure resistance
  >200bar (Al203 all, AlN OD 3.2mm, WT > 0.4mm)

C. Manoli; M. Angeletti

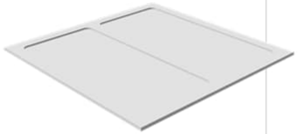
Pressure test (long term)

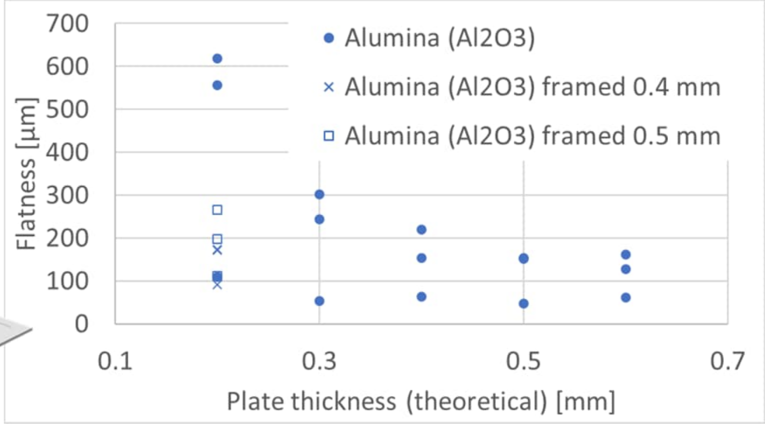


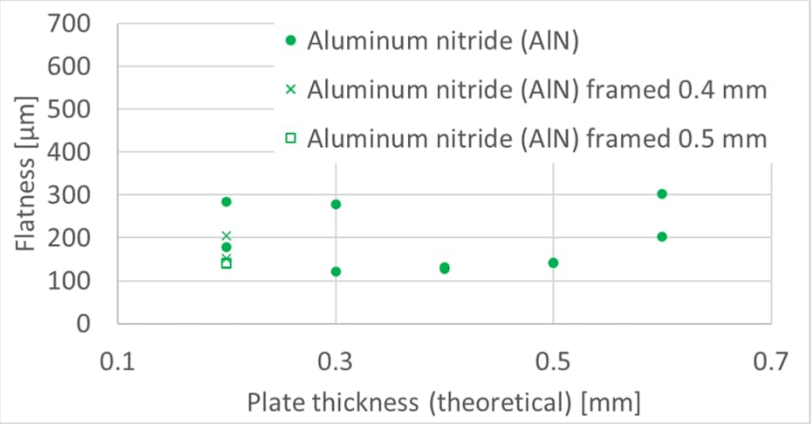
Flatness:

Aluminum oxide (Al2O3, Lithaloz350) & Aluminum nitride (AlN):

- Area ~30x30 mm², Flatness target ~ 100 (+- 50) µm







Ceramic additive manufacturing

Irradiation campaign for material properties **investigation**

- 1st campaign (TID= 3.9MGy). @Enea Casaccia irradiation fac.
  - Al203 bars

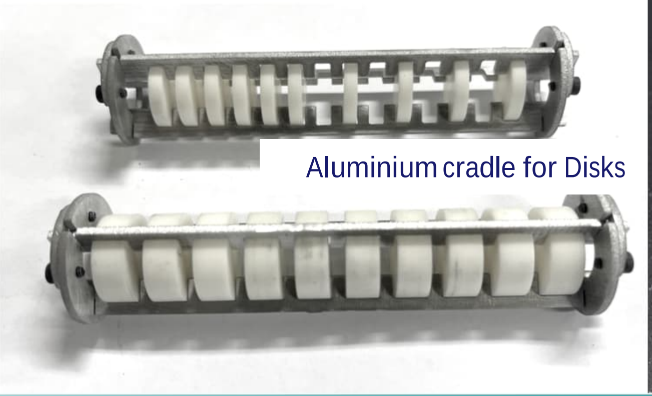
Bars before and after irradiation

- 2nd campaign
  ONGOING (TID = 1 MGy)

@panoramic 60Co gamma irradiation facility.

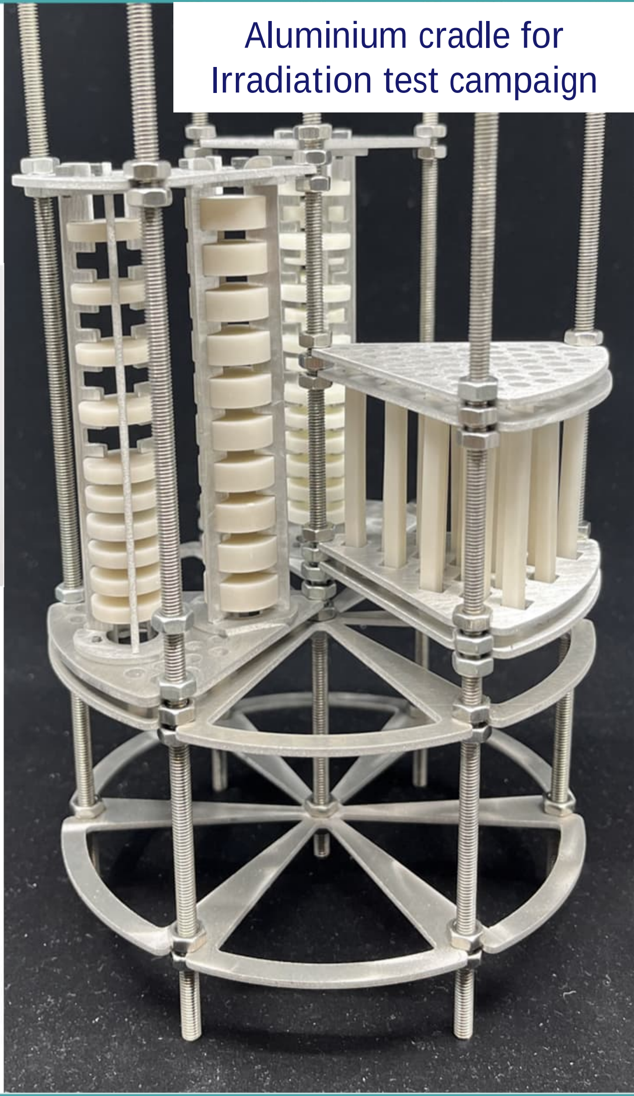
Ruđer Bošković Institute (irb.hr)

(Contact: Nicola Pacifico)
  - Al203 disks
  - AlN bars and disks



Aluminium cradle for Disks

- NEXT:
  (TID = 4 , 10 MGy)

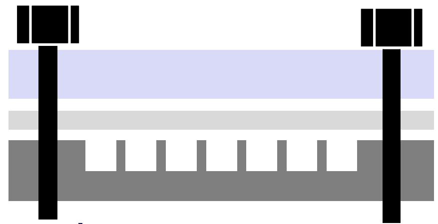


Aluminium cradle for Irradiation test campaign

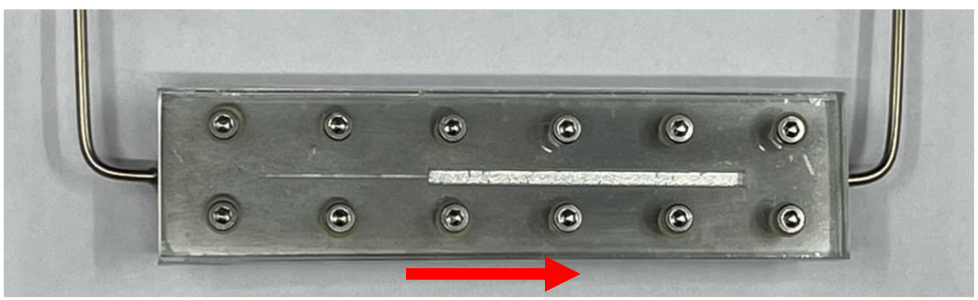
Metal additive manufacturing

Devices for boiling CO2 distribution visualization

- Define a reliable solution for sealing and optically inspects AM boiling cooling plates. Avoiding flow mixing between channels.

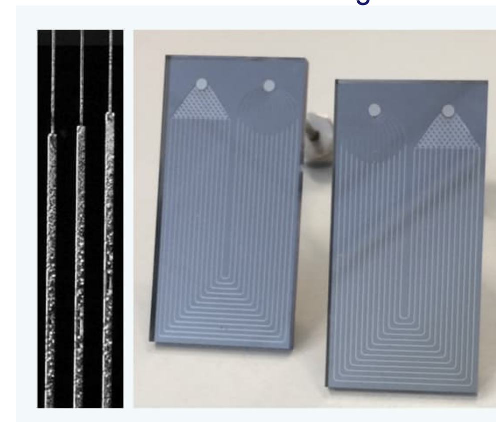


- Prototypes with single boiling channel

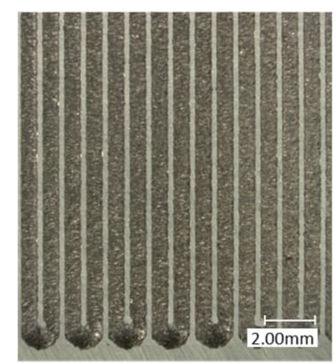


- Samples: Polished/un-polished metal surface, (mylar, polyimide, silicon foils; WT = 50- 100 µm)
- P ~ 40bar (some cases 110 bar), He leak rate < 10^{-10} mbar l/s

Visual inspection like
for silicon boiling devices



@ CSEM



Calculations

The flexural stress is calculated as:

$$\sigma_f = \frac{3Fl}{2bh^2} \quad (MPa)$$

The flexural modulus of elasticity is calculated as:

$$E_f = \frac{l^3 m}{4bh^3} \quad (GPa)$$

where

F , the force (N)

$l = 40mm$, the distance between centers of the outer support rollers

b, sample's width

h, sample's thickness

m, the slope of the initial straight-line portion of the load deflection curve (N/mm)