Collimator Materials for LHC Luminosity Upgrade: Status of Irradiation Studies at BNL

Collimation Upgrade Specification Meeting
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Summary

1. Radiation Hardness Studies at KI and BNL
2. Goals of Irradiation at BNL
3. Equipment
4. Specimen Types & Identification
5. Summary of Tests
6. Vacuum Capsules Accident
7. Summary of Actions
8. Conclusions

Radiation Hardness Studies

- Radiation Hardness is a key requirement.
- Benefit from complementary studies in two research centers with different irradiation parameters, different materials and approaches
- Results Benchmarking

Ongoing Characterization Program in RRC-Kurchatov Institute (Moscow) to assess the radiation damage on:

- **CuCD**
- **MoCuCD**
- **SiC**

Features:

- Irradiation with protons and carbon ions at **35 MeV and 80 MeV** respectively
- Direct water cooling and T~100°C
- Thermo-physical and mechanical characterization at different fluencies (10^{16}, 10^{17}, 10^{18} p/cm^2)
- Theoretical studies of damage formation

Proposal for Characterization Program in Brookhaven National Laboratory (New York) to assess the radiation damage on:

- **Molybdenum**
- **Glidcop**
- **CuCD**
- **MoGRCF**

Features:

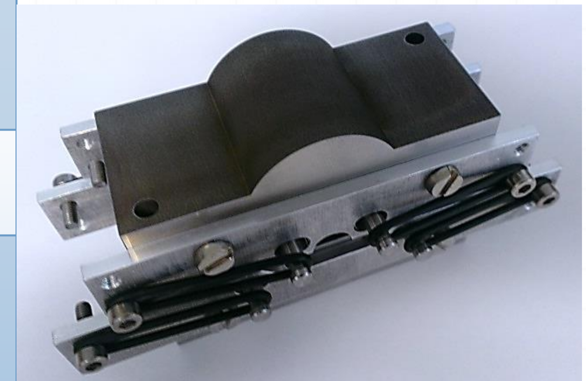
- Irradiation with proton beam at **200 MeV**
- Indirect water cooling and T~100°C (samples encapsulated with **inert gas**)
- Thermo-physical and mechanical characterization for fluence **up to 10^{20} p/cm^2**
- Possibility to irradiate with **neutrons** (simulate shower on secondary coll.)

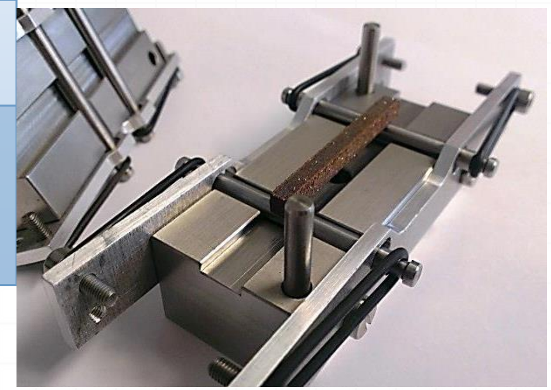
Goals of Irradiation in BNL

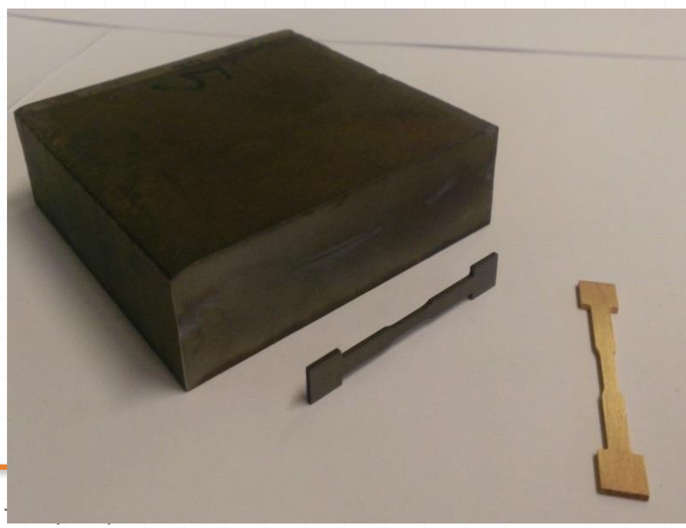
- Assess degradation of physical and mechanical properties of selected materials (Molybdenum, Glidcop, CuCD, MoGRCF) as a function of *dpa* (up to 1.0).
- Key physical and mechanical properties to be monitored :
  - Stress Strain behavior up to failure (Tensile Tests on metals, Flexural Tests on composites)
  - Thermal Conductivity
  - Thermal Expansion Coefficient (CTE) and swelling
  - Electrical Conductivity
  - Possible damage recovery after thermal annealing
- Compare *dpa* level to expected *dpa* level in LHC at nominal/ultimate operating conditions
- Is *dpa* a sufficient indicator to compare different irradiation environments?

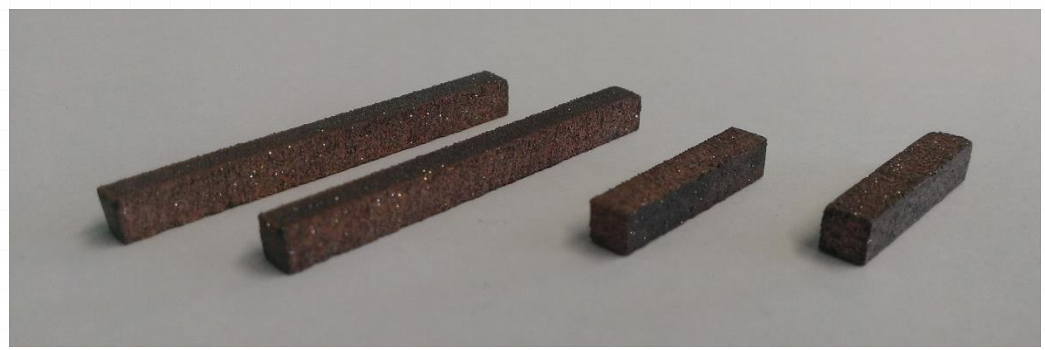
Equipment

Test	Instrument
Stress Strain behaviour up to failure (Tensile Tests on metals, Flexural Tests on composites)	Tinius-Olsen mechanical tester + CERN Fixture for Flexural tests
Thermal Conductivity	? (BNL to give indications on available equipment)
Thermal Expansion Coefficient (CTE) and swelling	LINSEIS dilatometer
Electrical Conductivity	4-point electrical resistance apparatus
Damage recovery after thermal annealing	LINSEIS dilatometer (for annealing and CTE verification after irradiation), 4-point electrical resistivity apparatus and Thermal Conductivity apparatus





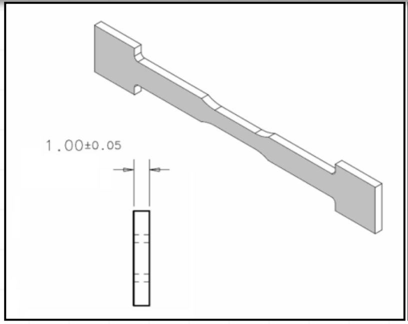




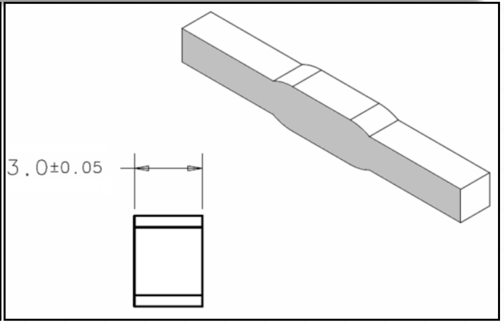
Specimen Types

Several Materials shapes exist for Metals and Composites
Different Sample manufacturing methods and tests techniques

Metallic materials samples: Molybdenum + Glidcop

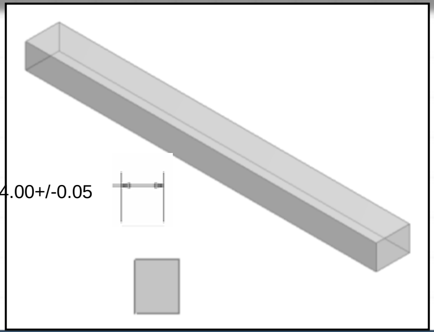


Tensile tests



Other

Composite materials samples: CuCD + MoGRCF



Parallelepiped shape for all tests

Material	Sample	Dimensions	Number X capsule
Metals	Tensile	42x6x1 mm	21
	Physical	29x4x3 mm	6
Composites	Flexural	40.9x4x4 mm	10
	Physical	20.5x4x4 mm	10

Samples Identification

For each material capsule the samples will be identified as following once the capsules are opened (top and bottom are arbitrary since the radiation profile is axial symmetric)

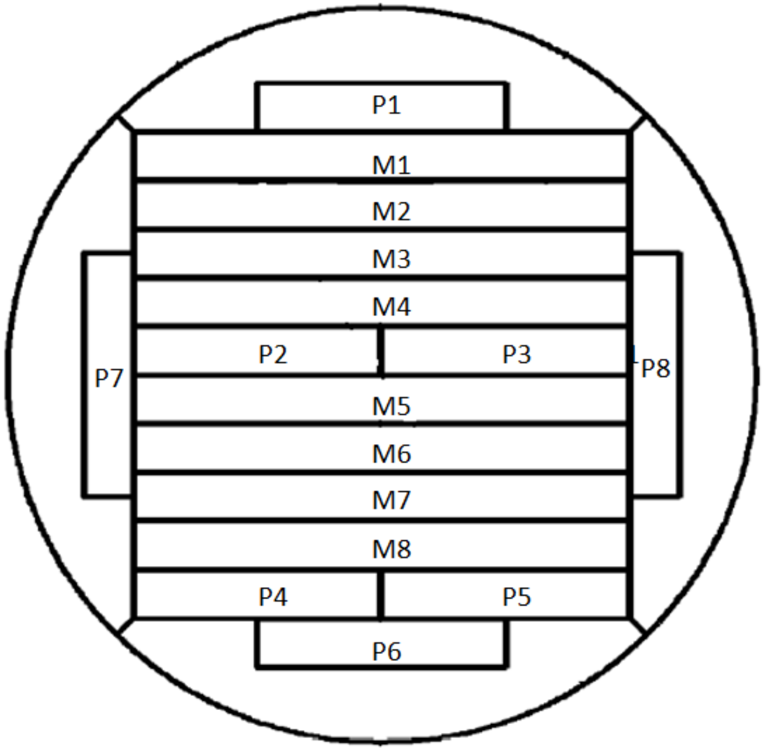
Mo: 2 capsules

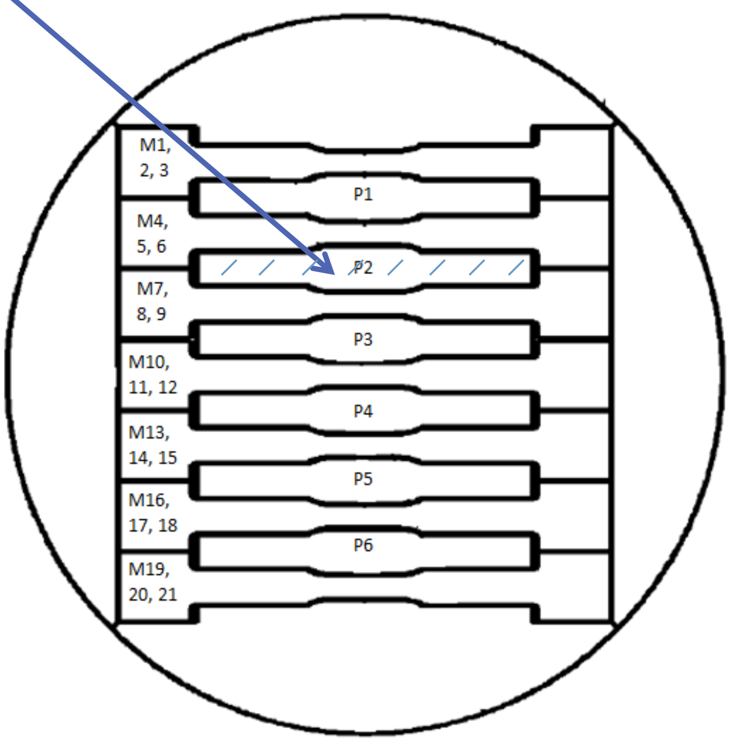
Glidcop: 1 capsule

MoGR: 1 capsules

CuCD: 1 capsules

example: Mo1-P2 = Mo capsule 1 (higher Energy), 2nd physical sample





Summary of Tests

Summary of Reference tests				
Material	Mechanical	CTE (+ Annealing)	Th. Cond.	El. Cond.
Glidcop	8	2	2	
Molybdenum	8	2	2	
CuCD	4	2	2	
MoGRCF	4	2	2	

Summary of After Irradiation tests				
Material	Mechanical	CTE (+ Annealing)	Th. Cond.	El. Cond.
Glidcop	21	3	3	
Molybdenum	42	6	6	
CuCD	8	4	4	
MoGRCF	8	4	4	

Notes:

- **Not all MoGR and CuCD** reference samples ready yet;
- **Irradiation Levels** to be extensively defined for each sample **in terms of dpa** by Fluka Experts:
  L. Lari BE/ABP/LCU,
  M. Brugger EN/STI/EET.

Metallic Samples After Irradiation Tests Definition								
Tests	Irradiation Level 1		Irradiation Level 2		Irradiation Level 3		Irradiation Level 4	
	Position	N.	Position	N.	Position	N.	Position	N.
Mechanical	M10, 11, 12	3	M7, 8, 9, 13, 14, 15	6	M4, 5, 6, 16, 17, 18	6	M1, 2, 3, 19, 20, 21	6
CTE (+ Annealing)	P3	1	P2	1	P1	1	-	-
Thermal and Electrical Conductivity	P4	1	P5	1	P6	1	-	-

Composite Materials Samples After Irradiation Tests Definition								
Tests	Irradiation Level 1		Irradiation Level 2		Irradiation Level 3		Irradiation Level 4	
	Position	N.	Position	N.	Position	N.	Position	N.
Mechanical	M4, 5, 6	3	M3, 7	2	M2, 8	2	M1	1
CTE (+ Annealing)	P2	1	P4	1	P1, 6	2	-	-
Thermal and Electrical Conductivity	P3	1	P5	1	P7, 8	2	-	-

Materials Specimens Holding Box

The specimens are encapsulated into special vacuum tight capsules (vacuum or inert gas), the different capsules being mounted into a Holding Box.

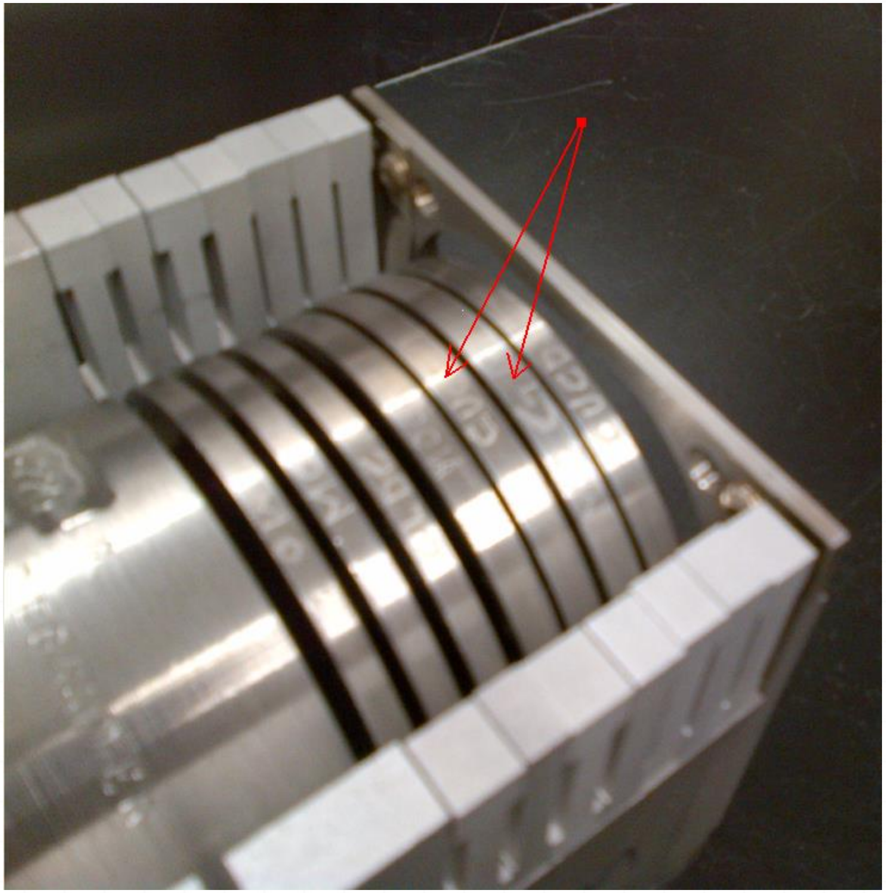
The cooling is made by water flow between adjacent capsules

➔ Insufficient cooling between CuCD and MoGR capsules provoked the expansion of CuCD1 capsule, that **damaged both CuCD1 and MoGR1** capsules (with isotopes contamination);

➔ **Emergency stop** and layout modifications to allow better cooling.

➔ Final layout:

- 1 Holding Box
- **5 capsules x Holding Box**



Picture and status report by N. Simos (BNL)

Summary of Actions I

BNL – Complete SRIM energy deposition calculations and MCNPX isotope production calculations - DONE

BNL – Complete Thermo-mechanical analysis of whole holding box - DONE

CERN – perform FLUKA energy deposition calculations - DONE

BNL – Present the calculations to the safety committee - DONE

BNL – CERN: validate the proposed samples geometry and number - DONE

CERN – Composite materials production in RHP Technology and in BrevettiBizz + samples preparation at CERN. - DONE

CERN – Machine metallic samples at CERN Atelier. – DONE

BNL – Weld the vacuum capsules and mount them in holding box – DONE

BNL – Insert the holding box in BLIP Facility – DONE

Summary of Actions II

CERN – Prepare specification document for tests. – DONE

CERN – Produce Flexural tests fixture for composite materials. – DONE

CERN – Produce reference samples for characterization before irradiation – Ongoing (not all CuCD and MoGR produced now)

CERN – provide the expected dpa level and absorbed dose for each sample – Ongoing

CERN - Provide Materials Certificates – Ongoing (only Molybdenum available!)

BNL – Start Irradiation at BLIP – Started

- **Insufficient cooling damaged CuCD1 and MoGR1 capsules**
- **Irradiation restarted after layout modifications and damaged capsules removal**

Conclusions

Beam-induced material damages (both due to instantaneous high intensity impacts and long-term irradiation) are one of the most serious threats to High-energy, High-intensity accelerators, as stated by **RRC-KI and BNL Irradiation Studies** on Phase I Materials.

A first irradiation campaign is already ongoing at KI on selected novel advanced materials of interest for **Phase II Collimators**.

A new irradiation campaign at BNL just started to complement the material characterization from the radiation hardness point of view for **future collimators design**.

The campaign suffered from technical issues, that have been promptly resolved by BNL in a very short time.

Samples irradiation restarted at nominal proton current (105-110 μA),

irradiation phase end foreseen in 9-10 weeks.

To be discussed with BNL if it will be possible to check the contaminated samples and to re-use them for further testing.

Thanks for Your Attention

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