Status and Plans for ARIES PowerMat Material Studies

103rd ColUSM Meeting, 13.04.2018

Alessandro Bertarelli (CERN) on behalf of the ARIES WP17 collaboration

With contributions by C. Accettura, F. Carra, G. Gobbi
Outline

• Introduction to ARIES WP17 (PowerMat)
• 1st WP17 Workshop in Turin
• Workpackage Status
• Plans and Perspectives
  • Irradiation Tests in GSI
  • Characterization Tests in Polito
  • Characterization Tests in Polimi
What is Extreme Thermal Management?

- Applications dealing with **very high temperatures, pressures, strain rates, particle irradiation, in harsh environments** …
PowerMat in a Nutshell

• Push forward R&D of novel Ceramic Matrix and Metal Matrix Composites based on graphite and diamond reinforcements with various dopants

• **Simulate** and **test** materials under extreme thermal shocks (particle- or laser-beam induced) and particle irradiation

• Investigate radiation damage from theoretical, numerical and experimental standpoint

• Identify materials for a broad range of accelerator applications (high power collimators, beam targets, beam windows and luminescence screens …)

• Explore societal applications in advanced engineering, medical imaging, quantum computing, energy efficiency, aerospace …
PowerMat Partners

- Strong interaction with **WP14** (Promoting Innovation) – **Task 14.4**
- **WP17**: 6 main beneficiaries, 1 associate (**NIMP**)
- **WP14**: 1 beneficiary industry (**RHP-Technology**), 1 associate industry (**Brevetti Bizz**) in Task 14.4
Work Package Organization

• **PowerMat JRA** is organized in 5 Tasks:
  
  • 17.1: **Communication & Coordination**  
  A. Bertarelli, CERN; M. Tomut, GSI
  
  • 17.2: **Materials development and characterization**  
  A. Bertarelli, CERN
  
  • 17.3: **Dynamic testing and online monitoring**  
  L. Peroni, POLITO
  
  • 17.4: **Simulation of irradiation effects and mitigation methods**  
  A. Lechner, CERN
  
  • 17.5: **Broader accelerator and societal applications**  
  M. Tomut, GSI
  
• Within **WP14 (Promoting Innovation):**
  
  • 14.4: **Industrial production of materials for extreme thermal management**  
  F. Carra, CERN
First WP17 Workshop was held in Turin (IT), organized by Polito, on 27-28 November 2017
1\textsuperscript{st} ARIES WP17 Workshop

- 30 participants from all partners, plus Kurchatov Institute
- Very rich program (~20 talks, plus invited speakers and visits), lively and useful discussions
Monday 27 November 2017

Welcome Session (08:45-09:00)

A. Bertarelli (CERN)

Task 17.2 (09:00-11:45)

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Presenter</th>
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<tbody>
<tr>
<td>09:00</td>
<td>Task 17.2 - Objectives of Task 17.2</td>
<td>Bertarelli, Alessandro (CERN)</td>
</tr>
<tr>
<td>09:15</td>
<td>Task 17.2 - Status of C-based materials development and perspectives</td>
<td>Guardia Valenzuela, Jorge (Universidad de Zaragoza (ES))</td>
</tr>
<tr>
<td>09:40</td>
<td>Task 17.2 - Thermophysical and mechanical characterization of advanced graphitic materials</td>
<td>Bianchi, Laura (Universita &amp; INFN Pisa (IT))</td>
</tr>
<tr>
<td>10:00</td>
<td>Task 17.2 - UHV characterization of advanced materials and their coatings</td>
<td>Accettura, Carlotta (Politecnico di Milano (IT))</td>
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<tr>
<td>10:20</td>
<td>Coffee Break (20 minutes)</td>
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<tr>
<td>10:40</td>
<td>Task 17.2 - Results from recent investigations and characterization at GSI</td>
<td>Bolz, Philipp (GSI)</td>
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<tr>
<td>11:10</td>
<td>Task 17.2 - Discussion on task objectives, actions and deliverables</td>
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Additive Manufacturing (11:45-12:30)

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<tr>
<th>Time</th>
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<tbody>
<tr>
<td>11:45</td>
<td>Politecnico di Torino &amp; Additive Manufacturing</td>
<td>Fini, Paolo (Politecnico di Torino)</td>
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<tr>
<td>12:00</td>
<td>Visit to Additive Manufacturing Facilities</td>
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Lunch (12:30-14:00)

Task 17.3 (14:00-17:20)

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<tr>
<th>Time</th>
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<tbody>
<tr>
<td>14:00</td>
<td>Task 17.3 - Objectives of Task 17.3</td>
<td>Peroni, Lorenzo (Politecnico di Torino)</td>
</tr>
<tr>
<td>14:10</td>
<td>Task 17.3 - Multimat experiment</td>
<td>Pasquali, Michele (Cern)</td>
</tr>
<tr>
<td>14:40</td>
<td>Task 17.3 - Dynamic characterization: first findings from Multimat experiment</td>
<td>Ficheria, Claudio (Cern)</td>
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<tr>
<td>15:00</td>
<td>Task 17.3 - Measurement technique in HiRadMat experiments: requirements and solutions</td>
<td>Guinchard, Michael (Cern)</td>
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<tr>
<td>15:20</td>
<td>Task 17.3 - Collaborative efforts at GSI on irradiation and thermo-mechanical dynamic testing experiments</td>
<td>Tomut, Marilena (GSI)</td>
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<td>15:40</td>
<td>Coffee Break (10 minutes)</td>
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15:50 STI HRMT27 + HRMT42 + future PROTAD and nTOF experiments | Torregrosa Martin, Claudio Leopoldo (CERN)

16:10 STI HRMT-28, HRMT-35 and future Deep Impact experiment | Nuiy, Francois-Xavier (Cern)

16:30 Towards proton acceleration with 1 PW beams at ELI-NP | Asavei, Theodor (IFIN-HH)

16:45 Task 17.3 - Discussion on task objectives, actions and deliverables |  

Visit to DYNLab (17:20-18:30)

Social dinner (19:30-22:30)
Tuesday 28 November 2017

**Task 17.4 (08:40-11:45)**

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<tr>
<td>08:40</td>
<td>Task 17.4 - Objectives of Task 17.4</td>
<td>LECHNER, Anton (CERN)</td>
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<tr>
<td>09:00</td>
<td>Task 17.4 - Requirements for radiation damage simulations regarding FAIR targets, beam dumps/catchers and previous experiments at GSI</td>
<td>TOMUT, Marilena Tatiana</td>
</tr>
<tr>
<td>09:20</td>
<td>Task 17.4 - Modelization of radiation-induced damage in FLUKA and material damage estimates for CERN injectors and future facilities</td>
<td>BRIZ MONAGO, Jose Antonio (CERN)</td>
</tr>
<tr>
<td>09:40</td>
<td>Task 17.4 - Update on radiation damage calculations for the HL-LHC betatron cleaning insertion</td>
<td>SKORDIS, Eleftherios (CERN)</td>
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<tr>
<td>10:00</td>
<td>Coffee Break (20 minutes)</td>
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<tr>
<td>10:20</td>
<td>Task 17.4 - CERN’s activities within the RaDIATE Collaboration</td>
<td>TORREGROSA MARTIN, Claudio Leopoldo (CERN)</td>
</tr>
<tr>
<td>10:40</td>
<td>Task 17.4 - Plans and contributions for radiation damage studies by POLIMI</td>
<td>BEGHI, Marco</td>
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<tr>
<td>11:00</td>
<td>Task 17.4 - Discussion on objectives, actions and deliverables of Task 17.4</td>
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**Task 17.5 (11:45-12:45)**

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<tbody>
<tr>
<td>11:45</td>
<td>Task 17.5 - Introduction and objectives of Task 17.5</td>
<td>TOMUT, Marilena Tatiana</td>
</tr>
<tr>
<td>11:55</td>
<td>Task 17.5 - Development of new diamond based composites for luminescence screens</td>
<td>GRECH, David (RHP)</td>
</tr>
<tr>
<td>12:20</td>
<td>Task 17.5 - First characterization tests and planned experiments on diamonds and diamond based composites for luminescence applications</td>
<td>SIMON, Pascal (GSI)</td>
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**Lunch (12:45-14:00)**

**1-tech: J-TECH@POLITO: Advanced Joining Technology at Politecnico di Torino (14:00-14:20)**

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<tr>
<td>14:00</td>
<td>J-TECH@POLITO: Advanced Joining Technology at Politecnico di Torino</td>
<td>FERRARIS, Monica (Politecnico di Torino)</td>
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**Task 14.d (14:20-15:10)**

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<tr>
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<tbody>
<tr>
<td>14:20</td>
<td>WP14.4</td>
<td>CARRA, Federico (CERN)</td>
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**Kurchatov Institute: Kurchatov Institute (15:10-15:30)**

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<tr>
<th>Time</th>
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<tbody>
<tr>
<td>15:10</td>
<td>Investigations of the effects of irradiation with fast particle fluxes on the material properties of Molybdenum Diamond composites for LHC Collimators using NRC-Ki cyclotron</td>
<td>RYAZANOV, Alexander</td>
</tr>
</tbody>
</table>

**Coffee break (15:30-15:45)**

**Wrap-up (15:40-16:30)**
Conclusions

A. New scaling method based on proton circulation time (ps) much better predictability based on 2015-2017 data
• A factor of ~10 less total proton lost in the collimation system compared to the old scaling with luminosity
• Revaluation for predicted DPA values for the HL-LHC lifetime ($8.4 \times 10^{16}$ protons lost)

<table>
<thead>
<tr>
<th></th>
<th>Collimator -&gt; Material</th>
<th>Primary Horizontal</th>
<th>Primary Skew</th>
<th>Secondary in MoGR (with Mo coating)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoGR</td>
<td>0.3</td>
<td>2.5x10^{-3}</td>
<td>4x10^{-4}</td>
<td></td>
</tr>
<tr>
<td>AC150 (Mo coating)</td>
<td>0.12</td>
<td>9x10^{-4}</td>
<td>(2x10^{-3})</td>
<td></td>
</tr>
</tbody>
</table>

B. New results (both DPA and Energy density):
• For Skew collimator in both MoGR and AC150GPH
• For newly considered Mo coating -> Energy density gradient between coating and MoGR could cause stresses?
• For primary horizontal in MoGR -> Energy density values in the order of 5kW peaked and 1.8 averaged on a 0.4*0.4 mm²

Thank you!
Research Focus of RaDIATE

- Challenges in Targetry technologies
  - Target system simulations (physics & reliability)
  - Rapid heat removal
  - Radiation protection
  - Remote handling
  - Radiation accelerated corrosion
  - Manufacturing technologies

- Challenges in predicting Target material behavior
  - Thermal “shock” response
  - Radiation damage
  - Highly non-linear thermo-mechanical simulation

Main focus within RaDIATE
WP Status: Contribution from Task 14.4

- Deliverable D14.4: 80% complete (due by M24, it will be anticipated to M12 or so)
- It includes production of **CuCD** (RHP) and **carbon-ceramic** (BrevettiBizz) samples for WP17 and for other purposes (luminescence, superconductive thin films...)

**RHP:**

  - **July 2017:** 10 rods 247x10x10 mm produced for tests in Multimat
  - **May 2018 (production ongoing):** 14 samples of the same grade as Multimat, for thermomechanical characterization at EN/MME lab
  - **Luminescence** and **MgB₂** out of the scope of WP17, not discussed here
WP Status: Contribution from Task 14.4

- **Brevetti Bizz:**
  - **December 2017:** 25 threaded samples of MG6403Fc (or equivalent), for dynamic characterization at PoliTo
  - **February 2018:** 36 samples of a new material Carbide-Graphite, sintered at a lower temperature than MoGr, not disclosed yet for IP reasons. Being characterized at the EN/MME lab with promising results
WP Status: Material Characterization (Task 17.2)

- Extensive microstructural and termo-physical characterization of recent material grades (MoGr and CuCD – also in the frame of Market Survey qualification – ) and advanced commercial carbon materials as TPG and Carbon Foams (at GSI)

![Graphs showing Conductivity and Diffusivity](image)

- **MG-6541Fc.**
  Highest thermal conductivity so far

- **Thermal pyrolytic graphite.**
  Note traces of electron channelling due to highly ordered structure
WP Status: Material Characterization (Task 17.2)

- Non-destructive tests to detect possible internal defects to be related with the results of dynamic tests on going at PoliTo

**X-rays**

**Tomography**

- No internal cracks
- 3 samples out of 25 show big inclusions (light grey spots) possibly related to carbide agglomerations → material feature
Tomography

- Tomography allows for a 360° scan of the samples and a quantitative analysis → classification of the inclusions based on the volume
What’s next: GSI irradiation test (Task 17.4)

- An Irradiation campaign is planned for Sep-Oct 2018 at GSI (through GSI Transnational Access)
  - 13 shifts granted (~ 100 h)
  - MoGr (≠ grades) and CFC coated and uncoated, comparable with BNL
  - Light ions ($^{48}$Ca, $^{12}$C)
  - DPA level in the coating similar HL-LHC after 60h of irradiation

<table>
<thead>
<tr>
<th>DPA/hour</th>
<th>DPA collimator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mo coating</td>
<td>$\sim 5 \cdot 10^{-5}$</td>
</tr>
<tr>
<td>MoGr</td>
<td>$\sim 1 \cdot 10^{-3}$</td>
</tr>
</tbody>
</table>

Courtesy of A. Lechner
What’s next: GSI irradiation test (Task 17.4)

- Thermo-mechanical and electrical measurements of irradiated thin-films

- Thermo-reflectance for thermal diffusivity
- 4-probes method on thin sample
- Impedance measurements

On-going activities on pristine materials
What’s next: Polimi Thin Film Analysis (Task 17.4)

- Brillouin Spectroscopy and Substrate curvature: optical methods to measure elastic properties and CTE of thin films
- \( \sim 100 \text{nm} \) irregularities (comparable with \( \lambda_{\text{laser}} \)) coming from the substrates diffuses light in all direction
- Countermeasures:
  - Deposition on silicon wafer (same properties?)
  - Different images correlation algorithm
Outlook

• PowerMat WP started in May 2017, with implication of 9 partners
• Extensive characterization campaigns on pristine materials performed at CERN and GSI
• Successful Workshop held in Turin in November 2017.
• What’s ahead:
  • Deliverable 17.1 to be submitted by end of April
  • Special Issue on specialized journal on compilation of HiRadMat tests, including theoretical and numerical predictions and instrumentation methods to be prepared
  • Thin film characterization in Polimi
  • Dynamic characterization in Polito
  • Irradiation test in GSI
PIE of high-activity materials

- Possible collaboration with UKAEA MRF (UK)
  - Cutting and polishing of small/big sample with max 1.15 Sv/h in hot cells
  - Thermo-mechanical and microscopic characterization of sample with max 1.15 mSv/h in shielded room or gloves boxes max 10μSv/h (ongoing upgrade)