Acknowledgments

- Direct or indirect contributions from

Outline

- HiRadMat
  - motivations
  - the facility
- Failure from Beam Impact
- Experiments without failure...
- Do we have a problem???
- Conclusions
HiRadMat: Motivations

- **Collimation**
  - 360 MJ stored in LHC, 500 kW on collimators for a 10 seconds for 1% beam loss at 7 TeV.
  - On average, $10^{16}$ protons lost/year on collimators.
  - Will materials in collimators survive?

- **Machine protection**
  - Damage with 0.0005% of loss.
  - Lots of near beam devices (roman pots, wire scanner...)
HiRadMat: Motivations

- Large amount of information available for resistance to radiation (nuclear, aerospace, accelerators...)
- Typically, exposure to Co source or neutrons in a reactor up to a given dose
  - Displacement at the base of damage.
- That covers some of our problems but not all !!!
HiRadMat: Motivations

- How do materials react to “pulsed” solicitation
  - Shock waves
  - Fatigue superposed to material weakening due to radiation?

- What happens when a high (stored) energy beam hits a material?

- What parameter can we use for characterisation of material damage for practical use (i.e. to define limits for machine protection)?
Material characterisation by DPA?
- See N. Mokhov, WEO1B02, WEO1B05, and whole WEDO1B.
- No way to measure
- Large discrepancies among different simulation programs:

- N. Mokhov, in Proc. 10th Workshop on Shielding Aspects of Accelerators, Targets and Irradiation Facilities (SATIF-10), June 2-4, 2010, CERN, Geneva, Switzerland; also Fermilab-Conf-10-329-APC.
DPA & ED Comparison: 130 MeV/u $^{76}$Ge on W

MARS for FRIB

Pencil beam, uniform in $R=0.03568$ cm disc.
Target $W_{nat}$, cylinder with $R=0.03568$ cm, $L=0.12$ cm

TRIM and PHITS results: Courtesy Yosuke Iwamoto

SATIF-10, CERN, June 2-4, 2010
MegaWatt Beams - N.V. Mokhov 30/9/2010
Material characterisation by DPA?

- DPA effects disappear with annealing??
  - See MOPD065
- Does DPA mean anything for the following cases??
HiRadMat: Motivations

Examples of Beam Damage

Entry and exit holes of an electron beam impacting on a spoiler
(courtesy P. Tenenbaum)

Tungsten collimator in the SPS

Lead block accidentally put into a p beam

Damage of coating of a SLC collimator
(courtesy G. Stevenson)

Courtesy R. Assmann
CERN
HiRadMat: Motivations

Beam damage with SPS proton beam

- Controlled experiment, 450 GeV
- $8 \times 10^{12}$ protons clear damage
- beam size about 1 mm
- above damage limit for copper
- stainless steel no damage
- $2 \times 10^{12}$ protons
- below damage limit for copper

0.1% of the energy of the LHC beams with final parameters

Courtesy
R. Schmidt, V. Kain
CERN

R. Losito, CERN/EN-STI, HB2010 30/9/2010
HiRadMat: Motivations

- Therefore, primary goal is to understand which is the intensity limit to have visible (measurable?) damage!
  - melting, grain growth, modification of yield...

- Second (long term) is to develop a better understanding of the influence of beam impact on materials.
  - Need to have measurable parameters to set limits
  - Any idea? (for discussion!!)
HiRadMat: The facility

- Proposed by R. Assmann and finally approved in 2009.
- Presently under construction. Due to start sometimes in 2011 (depending on access conditions)
- Designed for test of materials hit by high energy proton or ion pulses
- Proposed in EUCARD as transnational access facility: experiment may apply for funding (see EUCARD website).
Specification for a Test Facility with High Power LHC Type Beam


Abstract

The characteristics of the LHC beam mean that the energy deposited in the event of interaction with accelerator components can be much above the damage thresholds of materials. This report specifies a test facility with high intensity LHC-type beam, as included in the framework of the “phase 2 LHC collimation project” and the “EUCARD proposal to FP7”. The specified facility is required to test accelerator components and materials for sufficient robustness with beam shock impact, prior to installation into the LHC or its injectors. A 7 μs long pulse can be extracted about every 30 seconds and delivered into a small transverse area (controllable around 1 mm²), carrying an energy of up to 2 MJ. The corresponding pulsed peak power is 340 GW for protons and 2.3 GW for lead ions. The facility will also provide opportunity for reproducing and analyzing any possible primary and secondary effects from beam-induced damage encountered during LHC operation.

30/9/2010
HiRadMat: The facility
HiRadMat: The facility

- Built in the old gallery of the WANF experiment, in a derivation from the TI2 line from SPS to LHC.
- Access possible when LHC runs.
HiRadMat: The facility

- **Protons:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beam Energy</strong></td>
<td>440 GeV</td>
</tr>
<tr>
<td><strong>Pulse Energy</strong></td>
<td>up to 3.4 MJ</td>
</tr>
<tr>
<td><strong>Bunch intensity</strong></td>
<td>$3.0 \cdot 10^9$ to $1.7 \cdot 10^{11}$ protons</td>
</tr>
<tr>
<td><strong>Number of bunches</strong></td>
<td>1 to 288</td>
</tr>
<tr>
<td><strong>Bunch length</strong></td>
<td>11.24 cm</td>
</tr>
<tr>
<td><strong>Bunch spacing</strong></td>
<td>25, 50, 75 or 150 ns</td>
</tr>
<tr>
<td><strong>Pulse length</strong></td>
<td>7.2 µs</td>
</tr>
<tr>
<td><strong>Beam size at target</strong></td>
<td>variable around 1 mm$^2$</td>
</tr>
</tbody>
</table>
HiRadMat: The facility

- **Heavy Ions**: 

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy</td>
<td>173.5 GeV/nucleon (36.1 TeV per ion)</td>
</tr>
<tr>
<td>Pulse Energy</td>
<td>up to 21 kJ</td>
</tr>
<tr>
<td>Bunch intensity</td>
<td>$3 \cdot 10^7$ to $7 \cdot 10^7$ ions</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>52</td>
</tr>
<tr>
<td>Bunch length</td>
<td>11.24 cm</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>100 ns</td>
</tr>
<tr>
<td>Pulse length</td>
<td>5.2 µs</td>
</tr>
<tr>
<td>Beam size at target</td>
<td>variable around 1 mm²</td>
</tr>
</tbody>
</table>
HiRadMat: The facility

- $10^{16}$ protons/year available
  - Divided in 10 slots to allow availability of beam for several experiments
    - Not sufficient for fatigue studies...
    - Pre-irradiation...
Safety aspects have been considered for the design of the facility:

- Access to experimental zone under strict controlled procedures: access in the area modified to allow access control dedicated to the facility
- Necessity to implement ALARA principle in the design of experiment
- Overhead crane and some remote handling available
- Experiments shall have to provide a risk analysis together with the scientific proposal.
HiRadMat: The facility

- The facility has been proposed within Eucard as a Transnational access facility. Experiments may apply for funding (see EUCARD website).
- CERN will provide some instrumentation (especially for measuring the quality of the beam), but every experiment shall have to provide the instrumentation necessary to its execution.
- We hope to build up a stock of useful instrumentation with time.
Impact with energy deposition keeping the material below elastic (rupture) limit

- Not really the goal of the facility
- However useful information can be extracted
  - Calibration of radiation detectors in different radiation fields.
  - Possibility of long term irradiation on small samples not excluded and can be proposed
  - Single Event Upset test station?
- Sometimes we believe we are below the elastic limit, but….
Failure from beam impact

Collimator jaw with copper support

Collimator assembly
Failure from beam impact
Failure from beam impact

Courtesy
A. Bertarelli
A. Dallocchio
CERN
Failure from beam impact

- Impact with energy deposition driving materials beyond the elastic (or rupture) limit:
  - Not easy to simulate for complex systems (like an LHC collimator)
  - Modeling of dynamic stresses is necessary to understand the behavior of the material
TCDQ is a 6 m long collimator that protects the elements downstream the extraction kickers from asynchronous beam dumps.

- It has to withstand about 30 nominal LHC bunches
- Made of 12 graphite blocks, maximum of energy deposition (at 7 TeV) is between 6<sup>th</sup> and 9<sup>th</sup> block
Failure from beam impact

Steady state

Shock wave

Temperature
Type: Temperature
Unit: °C
Time: 1.486
4/09/2010 08:40

430.1 Max
350.0
295.31
232.30
189.26
154.15
125.55
102.25
85.282
67.83
55.245
44.995
36.647
29.848
24.31 Min
Failure from beam impact

Courtesy C. Maglioni, CERN
Failure from beam impact

- An important goal is to validate our capacity to simulate dynamic behaviour of the systems.
- It is an ideal facility to study shock waves
- Can fatigue studies be carried out with $10^{15}$ protons?
- Vacuum windows?
One could be interested into the dynamic effects of beam impacts.

- Hydraulic behavior of molten metal loops under beam impact
- “Explosion” of powders (or microspheres)
- Gas jets....
- Localized melting of thick targets: how does it influence the production yield...
Experiment without failures...

nTOF target: a problem of water chemistry, radiolysis, cooling flow....
Experiment without failures...

3. Water chemistry

There are very clear signs of a strong pitting corrosion at the entrance of the proton beam. Such effects are very well known in nuclear power plants (cracks in the fuel cladding): the very hot (boiling) water carries more oxygen, thus allowing the Pb to change its oxidation state to higher values:

\[ \text{Pb} \rightarrow \text{Pb}^{2+} + 2e^- \]
\[ \text{Pb} \rightarrow \text{Pb}^{4+} + 2e^- \]

Hydroxides are formed and a very acid local medium which attacks the metal is produced:

\[ \text{Pb}^{2+} + 2\text{H}_2\text{O} \rightarrow \text{Pb(OH)}_2 + 2\text{H}^+ \]
\[ \text{Pb}^{4+} + 4\text{H}_2\text{O} \rightarrow \text{Pb(OH)}_4 + 4\text{H}^+ \]
Experiment without failures...

Wouldn’t it be better with beam???

Courtesy
S. Sgobba
CERN
Experiment without failures...

- MERIT:
  - A proof-of-principle test of a target station suitable for a Neutrino Factory or Muon Collider source using a 24-GeV proton beam incident on a target consisting of a free mercury jet that is inside a 15-T capture solenoid magnet.

- BNL, MIT, ORNL, Princeton University

- CERN, RAL
Experiments without failures...

The MERIT experiment

A proof-of-principle test of a target station suitable for a Neutrino Factory or Muon Collider source using a 24-GeV proton beam incident on a target consisting of a free mercury jet that is inside a 15-T capture solenoid magnet.

Proposal submitted to CERN – May 2004
Experiment approved as nTOF11

Participating Institutes
- BNL, MIT, ORNL, Princeton University
- CERN, RAL

Spokespersons
- H. Kirk (BNL), K. McDonald (Princeton Univ.)
Do we have a problem???

- CERN has very limited capacity to do post irradiation analysis.
- An hot cell will be available in 2013/2014 for dismantling of ISOLDE targets, no analysis tool for material testing (for the moment)
- What equipment do we really need in house and what facilities can we use outside CERN?
- Where can we find what we miss?
Conclusions

- HiRadMat is aimed at testing the behaviour of mechanical systems with high energy proton or ion beams (pulsed).
- CERN will provide some on line test infrastructure, but every “experiment” shall have to provide its own instrumentation for testing.
- CERN today has no dedicated facilities for post irradiation test and analysis.
- HiRadMat will be open to external users, and supported by the European commission as a transnational facility (users may apply for funds to EUCARD).
- Main question to be answered: how to quantify damage in a measurable way?