Date: June 15, 2012

To: Dr. Ilias Efthymiopoulos  
Lead, HiRadMat Test Facility, CERN

From: External Review Committee

Re: HiRadMat Experimental Review – April 23, 2012 Review Meeting

Dear Dr. Efthymiopoulos:

On behalf of the Scientific Advisory Board attached please find the collective assessment of the proposed experiments presented and discussed during the April 23, 2012 review meeting at CERN.

Sincerely,

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Cc: B. Riemer
S. Sgobba
OVERVIEW AND CHARGE

On April 23, 2012 and during an experimental review held at CERN seven (7) experiments aiming to utilize the HiRadMat facility and its capabilities were proposed and were presented to the Scientific Advisory Board and the HiRadMat leadership. This experimental cycle at the HiRadMat represents the first series of experiments following the completion of the facility infrastructure and its commissioning. The facility aims to provide high-intensity pulsed beams enabling the irradiation of accelerator-related materials as well as accelerator component assemblies under extreme conditions of energy deposition and shock. Specifically, experiments will utilize a 440 GeV proton beam extracted from the CERN SPS with a pulse length of 7.2 µsec, to a maximum pulse energy of 3.4 MJ. In addition to protons, ion beams with energies of 173.5 GeV/nucleon and total pulse energy of 21 kJ can be used. The beam parameters can be tuned to match the needs of each experiment.

For this first experimental cycle at HiRadMat seven experiments covering a wide range of accelerator applications from material studies to large component response to an LHC-like stray beam have been proposed and are undergoing review. The review meeting aimed at evaluating the scientific merit of each proposed experiment and its feasibility and make recommendations both to the HiRadMat facility leadership as well as provide advice to the proposers stemming from accelerator-related experience.

Mandate to the Board:

The Scientific Advisory Board’s role in this review was to assess the following key elements of the proposed experiments:

- The scientific case of each experiment and the importance/contribution towards the advancement of the state-of-the-art knowledge on materials, components and systems associated with particle accelerators
- The feasibility of the proposed experiment based on HiRadMat beam parameters and availability
- The completeness of the proposed experimental process from concept to in-situ experimental configuration
- The thoroughness of the pre-experiment assessment, parameter envelope and the clarity of the experimental goals
- The clarity and the detailed description of the post-irradiation analysis and the identification of the key scientific and technical questions/answers that are to be deduced following from the experiment
- Publication of experimental results and their utilization by the accelerator community
Safety procedures have been prepared and archived in EDMS. Safety, as well as technical/scheduling considerations is to be assessed by a different facility-relevant committee.
EXPERIMENTAL REVIEW AND ASSESSMENT

The proposed experiments spanned a wide spectrum of research interests. Specifically, they ranged from aiding the development of equations of state of materials under the extreme conditions in the matter generated by the intense beam leading to solid material melting and plasma formation to proof-of-principle testing for next generation target concepts of high power accelerator targets. Part of the matrix comprising the scientific breath of the experiment array are validation and benchmarking of predictive simulations and beam testing of large-scale accelerator components of sizes that utilize the entirety of the experimental space at the HiRadMat shown in Figure 1.

![HiRadMat Experimental Station](image1.png)

*Figure 1: HiRadMat Experimental Station*

Prior to the presentations and discussions of each of the seven experiments a status report for the readiness of the HiRadMat was presented to the board according to which the test facility is commissioned and in ready-mode position for experimental activities following all the technical and safety reviews.
EXPERIMENT EVALUATION

Experiment I: HRMT-10 “NTHIMBLE”
Tungsten Powder Test at HiRadMat - Scientific Motivation/Experiment Details
P. Loveridge, T. Davenne, O. Caretta, C. Densham, J. O’Dell, N. Charitonidis

This experiment aims to explore the feasibility of a high power accelerator target concept that is between a solid and a fluid based medium in an effort to avoid serious issues associated with the two phases (dynamic stresses and shock-induced failure in solids, splashing and cavitation consequences in liquids). It is asserted that the utilization of high-Z powder will provide sufficient beam-target interaction and avoid splashing or violent events because of its discrete nature. Individual powder particles do not easily transmit pressure waves to neighboring particles as such pressure waves tend to be contained within the particles. While, in principle the survivability of such target interacting with intense pulses of energetic protons is a major benefit, a mechanism for powder eruption has been identified as a result of a beam induced pressure rise in the carrier gas, such as He (providing an inert gas environment) being considered for the concept. The expansion of the carrier He gas as a result of the beam interaction and energy deposition in both phases (solid and gas) may be violent enough to aerodynamically lift some powder. In the proposed experiment that sample is a mixture of tungsten and helium, 50% solid fraction by volume.

Establishing or identifying critical thresholds for the onset of such violent process, which may have target design implications and potential concept limitations, is an important parameter sought by the proposed experiment. Preliminary estimates, however, made by the proposing team indicate that eruption velocities of the “fluidized” W powder will be significantly lower than the splashing velocities of liquid targets (i.e. Hg jets) thus minimizing the effects on the target enveloping structure. The experiment seeks definite answers to the questions of (a) powder target splashing or eruption potential and threshold and (b) the propagation of pressure waves through the “fluidized” W to the container.

While numerical simulations of the exact system configuration (especially the representation of the flowing W particles along with the carrier gas) are extremely challenging and unattainable at the current computational capability state, the simplified equivalent versions attempted by the team in order to qualify/quantify interactions may provide significant insights following benchmarking of the processes against experimental results. The board feels that this is a worthwhile effort that may provide the basis for exploring the feasibility potential of this target concept in high power accelerators.

The board, following the presentation and the discussions, recommends that the experiment moves forward since it has both significant scientific merit and overall maturity. The board feels that there has been a comprehensive assessment and evaluation of the experimental plan with attention to technical details. The board also recommends the following:

Special attention should be paid to the “free-surface” of the fluidized W jet that may require a unique technique that ensures the capturing of the surface condition prior to the beam interaction, a key feature required to establish the baseline for numerical benchmarking, and during/between successive proton pulses which will help in the identification of beam power and flux thresholds. As noted, it is quite possible that the high-speed video misses the surface motion or malfunctions on a given test pulse. If this happens, the initial condition for successive pulses could be misunderstood thus invalidating the benchmark.
**Experiment II: HRMT-12 “LPROT”**

R. Schmidt, N. A. Tahir, D. Grenier, C. Maglioni, T. Besset, W. Jozef Zak and J. Blanco Sancho

This experiment aims to assess and quantify the performance of LHC protection systems based on sophisticated computer simulations that incorporated material phase space under the extreme conditions of the new regime of LHC energy and intensity (Fig. 2). Damage limits are sought to help the design of protection systems and protection procedures. Due to the extreme power carried by the LHC beam that forces intercepting materials far beyond their linear elastic limits, the verification of the simulation tools is of paramount importance. Thus benchmarking of the numerical simulation of the beam interaction against a controlled experiment will render higher degree of confidence in assessing the consequences of a full LHC beam impact. The experiment, prompted by observations of previous studies on beam/copper interaction and simulation confirmations, is proposing to attempt and reproduce the “tunneling effect” that has been observed which may have significant beam protection implications.

![Figure 2: Density space of matter](image)

To address the issue of tunneling and also benchmark the simulations of density changes during interaction of matter with LHC-level beams the investigators are developing a softly coupled simulation approach to capture the damage that LHC beam excursions might cause.

Three copper targets composed of fifteen 8cm diameter and 10 cm length cylinders are being proposed. According to simulations performed by the proposing team using the LHC beam parameters a beam penetration up to ~35 cm in copper could be experienced. The team built the case for the experiment following beam/matter simulations using the SPS and LHC beam parameters with beam sizes as low as 0.1mm on copper and carbon composite. An iterative process utilizing energy deposition data generated by the FLUKA transport code and the BIG-2 two-dimensional hydrodynamic code for target material physio-mechanical response has been formulated and used for predictions.
The so-called tunneling effect presents the simulation challenge that calculated energy deposition fields should include the rapidly changing density changes that occur from material damage (melting, vaporization, ejection, etc.). LProt aims to capture the extent of the tunneling effect in three long, segmented copper targets to which different intensity beams are to be directed.

The board’s consensus is that the LPlot experiment has strong scientific merit and has the potential for deducing valuable information that can assist in designing beam protection systems and also provide an excellent reference to validate numerical codes dealing with extreme state of matter. Both of these elements are crucial towards the conceptualization and the design of high power accelerators.

The board also wants to make several recommendations that may help streamline the experiment and lead to a more enhanced output of the proposed effort. Specifically,

- The experimenters rely heavily on indirect indication of the tunneling in near real-time by particle detectors. These were complimented by vaguely defined post irradiation inspections of the copper target segments. While the detection method may work it was not clear to what level of precision; their innovative nature may not be robust. Extraction of the full value of the experiment will depend on thorough post irradiation examination of the segments. Visual examination of the segment ends seems significantly impaired by the highly angled view to the cylinder ends through the 1 cm segment gaps.

- It is recommended to the experimenters that improved and more developed post irradiation methods are included in their plans. Direct photography of the end faces of the cylinders should be possible after some months cool-down by removal from the enclosure. Longer term, some subset of the segments could be sectioned and microscopy done that would accurately reveal the extent of the beam tunneling; this would be excellent data for benchmarking the coupled simulation approach.

- The issue of potential galvanic corrosion should be taken seriously. Months (or years) of storage of the copper target segments in the aluminum alloy enclosure should be avoided. If direct photography of segment end faces can be arranged in a few months, this would seem an opportune time to store the segments in a protective and dry environment.

- Create and study Warm Dense Matter – While the extreme conditions that will be generated by beam interaction with copper may push the material to the warm dense matter zone (not clear though given the SPS/HiRadMat beam parameters) there is no clear path referenced/proposed that will lead to such assessment at this time.

- A clearer post-irradiation (rather than post-mortem which has the connotation of target failure) evaluation procedure needs to be thought out. Especially regarding the potential of microscopic evaluation and the potential challenges of testing irradiated materials (even at low integrated dose levels) in available synchrotron facilities. If that is an option that is being entertained then the experimenters should design some part of the target in a way that x-ray penetration into the altered matter state can be achieved (i.e. thinner stacked disks replacing a single 10 cm length disk)
**Experiment III: HRMT-14 “LCMAT”**  
**HiRadMat Tests on Collimator Materials, Alessandro Bertarelli**

Proposed in this comprehensive study is testing of LHC collimator materials which will be able to absorb the LHC beam energy that is at least two orders of magnitude above what has been experienced in accelerators to-date and three orders of magnitude in stored energy density. The proposers are seeking to explore the feasibility of novel composite materials that appear to have the intrinsic resilience required but yet to be tested under such extreme beam conditions. The experimental study will focus on Metal Matrix Composites (MMC) for advanced thermal management that combine properties of diamond or graphite (seeking a combination of high thermal conductivity $k$, low density and low thermal expansion) to desired properties typically exhibited by metals such as strength, endurance, etc.. Novel materials under consideration include copper-diamond (Cu-CD), molybdenum-diamond (Mo-CD), silver diamond (Ag-CD) and molybdenum graphite (Mo-Gr). More conventional materials such as INERMET® 180 tungsten alloy, Oxide Dispersion Strengthened (ODS) copper (GlidCop®), molybdenum will also be tested for comparison. Because of the nature of the event these materials, including the materials of LHC Phase-I collimators, must be able to survive, the understanding of the response of the entire collimator structure is important. Therefore the use of benchmarked numerical models that capture the beam interaction during accident events is crucial. The proposers aim to qualify the simulation models that have generated to study accident events and help benchmark these new Hydrocodes under these extreme conditions.

Based on the detailed and comprehensive experiment preparatory effort and the clarity of the goals as well as the approach the board strongly supports the proposal to be one of the 2012 HiRadmat experiments. It is the board’s opinion that the scientific/technical merit of the proposed experiment is strong and stems from the following facts:

- The experiment will test conventional and innovative materials used/considered for beam interrupting devices under extreme beam pulse conditions that simulate LHC beam accident scenarios.

- Both real-time data and comprehensive post-irradiation analysis/assessment is included in the scope of the experiment

- An extensive array of simulations of beam accident scenarios has been carried out prior to the actual beam experiments which can be compared with test results and enable benchmarking

- The real-time data acquisition plan proposed for the experiment is impressively broad in technique and well thought out, which is to be commended.

Much pre-irradiation testing has been done (LDV, HSV, etc), and having multiple physics-based sensing provides a level of robustness suitable for difficult and expensive experiments. However, dynamic strain measurements in high radiation, large pulsed electro-magnetic fields can present difficulties. The experimenters had not considered EM field vulnerability in their sensor selection; they are encouraged to find an opportunity with a preceding HiRadMat experiment to verify sensor functionality near the beam.
Post irradiation examination (PIE) can provide invaluable data not possible by other means. Such work requires careful and determined planning and resources to complete. Experimenters are strongly encouraged to more fully develop PIE plans at the earliest time.

**Experiment IV: HRMT-09 “LCOL”**

TCTA/SLAC Collimator Beam Tests - Stefano Radaelli

In this proposed experiment two collimator design assemblies are proposed for testing under extreme conditions approximating LHC beam accident scenarios.

The LCOL-TCTA (Fig. 3a) experiment complements the LCMAT experiments as it tests full scale collimator assemblies instead of assessing the performance of conventional and novel jaw materials. The primary goal is to verify the robustness and performance integrity of the assembly and in particular of the tungsten jaw and collimator tank following direct beam impact. Testing under extreme beam conditions will allow for benchmarking of numerical simulations that can eventually be used to study different accident scenarios. Two distinct tests are envisioned namely (a) design error case where effects of asynchronous beam dump during operation or during collimator setup will be addressed and (b) disruptive scenario where direct impact of 4 LHC bunches (equivalent power) will be evaluated.

![Figure 3: (a) TCTA Collimator; (b) SLAC Collimator](image)

For the SLAC collimator (Fig. 3b) which is in its final assembly stages the objectives are to:

- measure the full extent of the GlidCop® collimator jaw that melts and vaporizes as a function of deposited energy
- determine the extent of the molten and vaporized spray released from the surface, how far it travels and how it congeals to the hit surfaces.
- verify that the water cooling circuit survives a beam impact with no water to vacuum leak
- verify the rotation mechanism will continue to operate after beam impact
- determine if nearby facets will get deposited with molten material from a hit facet.
- measure permanent deformation from beam impact

Key feature of this collimator to be tested is the rotational functionality following a severe beam event or interception by the collimator structure.

The board supports the proposed experiment as one of the 2012 HiRadMat tests. The board feels that several of the objectives of the experiment had both technical merits, were clearly defined and had high chance of being met (i.e. verification of water coolant integrity and collimator jaw rotation function). However methods for measurement of damage/melting/deformation were less clear. In particular, direct measurement of damage implied accessing the activated / contaminated collimator interior, but plans for this were not well defined. These may
present special difficulties for which advance planning is needed with substantial resources. These should not be insurmountable but experimenters are advised to consider those steps as soon as possible. One additional concern is the status of the SLAC collimator assembly and its availability for testing during the 2012 cycle.

**Experiment V: HRMT-06 “TPSG4”**  
**TPSG4 beam diluter- Jan Borburgh**

In this proposed experiment septa protection elements that have been already employed at the CERN SPS and whose designs have only been based on simulations will be tested. Analyses using worst-case scenario of LHC ultimate beam intensity have been performed. In the real system protection of the downstream equipment relies fully on the effectiveness of the beam diluters. Since all designs are based on simulation results, confirmation that will lead to full LHC beam extrapolation is needed. Updated high energy variants use carbon fiber composite (CfC) and graphite which exhibit non isotropic mechanical properties. Validation of the design is needed to quantify the effect of the anisotropic behavior of CfC, the exceedence of ductility in Ti and Inconel blocks and to demonstrate that the magnetic septa is properly protected by the TPSG4 as designed.

![Figure 4: TPSG Structure](image)

The board supports the TPSG4 experiment proposal as one of the HiRadMat experiments in 2012. Given the intensity of the LHC beam a clear understanding of the protective role and limits of these structures is paramount. The fact that these designs have to-date been based on simulations (integration of nuclear calculations and thermo-mechanical analyses) these experiments will provide an excellent forum for validation and benchmarking.

Specifically, the board feels that this being both a validating demonstration of the septa protection element design currently deployed in the SPS as well as an opportunity to obtain benchmark data for simulations beam excursion events – thus leading to improved designs for more demanding conditions- the test will be of great value.

It is noted however, that in the proposed configuration, the test components are large and heavy and appear to exceed the weight capacity of the HiRadMat equipment table. The TPSG and MSE are to be connected after placement in the HiRadMat tunnel. This could be done “hands-on”, but post experiment it seems this must be done remotely. The experimenters need to work out this detail, as well as more general installation and removal steps and preparations with the HiRadMat technical staff. A situation that prohibits removal of the equipment in reasonable time should not be permitted unless this is the very last HiRadMat experiment for the year. It is therefore recommended that this option be entertained.
Experimenters are also reminded to consider contamination release & exposure upon disconnection and inspection of the TPSG. The use of other diagnostics for the TPSG such as LDV was noted as *under discussion*. Such diagnostics are encouraged to maximize the value of the experiment; the data could be very useful to benchmark simulations.

It is further suggested for the experimenters to consider some technique for inspections that can be conducted between test cases; perhaps a video-borescope might be installed and remotely operated. The feasibility is unknown but the inspections might also quickly provide valuable data.

On the material side it is recommended, since the anisotropic behavior of C_C is a serious concern, to consider three dimensional weaved carbon composite structures in the array – perhaps insert 3D C_C by replacing anisotropic 2D C_C structures for comparison after the test.
**Experiment VI: HRMT-01 “TISD”**

Tests at HiRadMat of advanced SiC and Al₂O₃ as model targets for radioisotope beam production - Michal Adam Czapski

The main objective of this proposed experiment is to compare pulsed beam influence studies using data from 1.4 GeV beams (ISOLDE) and 450 GeV (HiRadMat) on new advanced model targets of tailored-made microstructures (following previous studies on nanostructured ceramics). The experimental study is to focus on the performance of silicon carbide (SiC) and aluminum oxide (Al₂O₃).

The experiment aims to test 8 samples (pellets Ø 2 cm x 2 cm) – 4 SiC & 4 Al₂O₃ using the following beam parameters:

- 450 GeV, 4.9x10¹³/pulse (7.2 µs/18s, 1 – 288 bunches), σ = 2.0
- Max. No. Cycles = 100 (desirable 10x more)
- Setup - 8 samples in a row as shown below

![Figure 5: TISD target arrangement](image)

SEM, EDS and XRD studies are being discussed for post-irradiation analysis of the targets to look at (a) irradiation assisted cracking, (b) microstructural changes, (c) micro-compositional effects and (d) diffusion and segregation of impurities.

Based on the material presented to the board and the readiness state that the proposed experiment is currently at, the board feels that the TISD is conditionally supported as a 2012 HiRadMat experiment.

Specifically, while the goals of the experiment (beam ageing studies of new isotope producing targets) are worthwhile the proposal lacked definition of a developed test apparatus and procedures that would safely achieve those goals.

No clearly defined concept was shown for a necessary enclosure to contain contamination in the test area. Further, no concept for transport of the samples out of the test area was shown.

Regarding the post-irradiation analysis which carries most of the weight of this experiment, while listed the desired examinations to be performed, very few or no details were given on how samples would be moved and to where or identify laboratories equipped to analyze irradiated targets.

Much experiment planning seemed yet to be done. If the experimenters can provide developed plans in sufficient time that satisfy the HiRadMat technical and safety boards, then support for proceeding would be given.
Experiment VII: HRMT-15 “RPINST”

Test of radiation protection instrumentation in HiRadMat - Marco Silari

The proposed experiment is prompted by the need for radiation detectors able to efficiently measure in pulsed neutron fields (strong limitations due to dead-time). In particular, this represents a major issue for CERN accelerators (γ-n pulsed fields: beam losses in accelerators and beam line elements, around targets and beam dumps). Most of commercial instruments show severe underestimations of the neutron ambient dose equivalent. In recent studies it has been found that there is a common behavior/finding namely detector saturation and severe dose underestimation.

The proposed experiment will test radiation detection instruments for prompt dose response accuracy and evaluate some newly developed instruments. It has three major objectives, namely:

- Test of the performances of the detectors used for the RAMSES system
- Inter-comparison of radiation detectors
- Experimental verification of the FLUKA simulated neutron spectra

It is assessed by the proposing team that a number of limitations, (i.e. lack of a reliable way to produce strongly pulsed fields with good reproducibility) that have been experienced in previous studies will be overcome using HiRadMat experimental station.

The board strongly supports the RPINST experiment to be included in the 2012 HiRadMat experiment schedule. It addresses a very important aspect which can benefit the accelerator community in general. Instruments capable of prompt response typical of pulsed accelerators such as the LHC will improve safety and diagnostic capabilities at CERN facilities and beyond.

The experiment appears simple to conduct with little hazard or post experiment consequences.

The board notes that while the main experiment scope should be conducted as an independent experiment with its own time slot in the schedule, the overall scope can take advantage and be supplemented by parasitic testing along with other HiRadMat experiments.
APPENDICES – Board Member Inputs
1. **HRMT-10 “NTHIMBLE” (Tristan Davenne & Peter Loveridge)**

NTIMBLE is supported as a HiRadMat experiment in 2012. The proposed investigation addresses a key issue for the innovative high-power pulsed target concept, namely flowing powder metal targets. The stability of such targets needs to be understood & controlled for eventual acceptance and utilization by future research facilities. Current engineering simulation methods require benchmarking against test data from experiments with prototypically high energy density beam pulses.

In the flowing powder metal concept a motivating gas (e.g., helium) is required. NTHIMBLE will use tungsten powder in a static trough setup to investigate whether heating of the gas directly from the beam and / or conducted from the metal particles occurs in such a way that rapid gas expansion moves the metal particles. Observation of free surface of the tungsten powder trough by high-speed video is the direct measure of powder motion; this is complimented by laser Doppler vibrometer tracking of the inner (tungsten powder) trough as well as the outer trough that is intended to simulate a target container.

The experiment progresses from modest energy density levels towards higher values. Disturbance of the free surface is expected (based on current simulations) to occur at some threshold of power density range. It is recommended to the experimenters that some method of observation of the powder free surface is added so that its status can at least be qualitatively assessed prior to successive pulses. The condition of the free surface should be well known for benchmarking simulations; it is quite possible that the high-speed video misses the surface motion or malfunctions on a given test pulse. If this happens, the initial condition for successive pulses could be misunderstood thus invalidating the benchmark.

2. **HRMT-12 “LPROT” (Juan Blanco Sancho)**

LPROT is supported as a HiRadMat experiment in 2012. The investigators are developing a softly coupled simulation approach to modeling the damage that LHC beam excursions might cause. The so-called tunneling effect presents the simulation challenge that calculated energy deposition fields should include the rapidly changing density changes that occur from material damage (melting, vaporization, ejection, etc.). LPROT aims to capture the extent of the tunneling effect in three long, segmented copper targets to which different intensity beams are to be directed.

The experimenters rely heavily on indirect indication of the tunneling in near real-time by particle detectors. These were complimented by vaguely defined post irradiation inspections of the copper target segments. While the detection method may work it was not clear to what level of precision; their innovative nature may not be robust. Extraction of the full value of the experiment will depend on thorough post irradiation examination of the segments. Visual examination of the segment ends seems significantly impaired by the highly angled view to the cylinder ends through the 1 cm segment gaps.

It is recommended to the experimenters that improved and more developed post irradiation methods are included in their plans. Direct photography of the end faces of the cylinders should be possible after some months cool-down by removal from the enclosure. Longer term, some subset of the segments could be sectioned and microscopy done that would accurately reveal the extent of the beam tunneling; this would be excellent data for benchmarking the coupled simulation approach.

The issue of potential galvanic corrosion should be taken seriously, especially for long-term protection of the copper target segments. Months (or years) of storage in the aluminum
enclosure should be avoided. If direct photography of segment end faces can be arranged in a
couple of months, this would seem an opportune time to store the segments in a protective and dry
environment.

3. **HRMT-14 “LCMAT” (Alessandro Bertarelli)**

LCMAT is supported as a HiRadMat experiment in 2012. This extensive experiment will test
conventional and innovative materials used / considered for beam interrupting devices under
extreme beam pulse conditions that simulate LHC beam accident scenarios. Both real-time data
and post irradiation examination is included in the scope. Substantial simulations have been
carried out that will greatly benefit from benchmarking.

The real-time data acquisition plan is impressively broad in technique, which is to be
commended. Much pre-irradiation testing has been done (LDV, HSV, etc), and having multiple
physics-based sensing provides a level of robustness suitable for difficult and expensive
experiments. However, dynamic strain measurements in high radiation, large pulsed electro-
magnetic fields can present difficulties. The experimenters had not considered EM field
vulnerability in their sensor selection; they are encouraged to find an opportunity with a preceding
HiRadMat experiment to verify sensor functionality near the beam.

Post irradiation examination (PIE) can provide invaluable data not possible by other
means. Such work requires careful and determined planning and resources to complete.
Experimenters are strongly encouraged to more fully develop PIE plans at the earliest time.

4. **HRMT-09 “LCOL” (Stefano Redaelli)**

LCOL is supported as a HiRadMat experiment in 2012. This experiment tests two beam
collimator design assemblies under extreme conditions approximating LHC beam accident
scenarios. The first design is an actual TCTA collimator for which test data can verify the
robustness of the design and provide benchmark data for simulations. The second design tests
the prototype rotating collimator under development with SLAC for similar data. The latter test
further confirms the rotation functionality after severe beam incidents.

Many of the experiment goals had a clear path for achievement, e.g., verifying water
coolant integrity and verifying rotation function. However methods for measurement of damage /
melting / deformation were less clear. In particular, direct measurement of damage implied
accessing the activated / contaminated collimator interior, but plans for this were not well defined.
These may present special difficulties for which advance planning is needed with substantial
resources. These should not be insurmountable but experimenters are advised to consider those
steps as soon as possible.

5. **HRMT-06 “TPSG4” (Jan Borburgh)**

TPSG4 is supported as a HiRadMat experiment in 2012. This a both a validating demonstration of
the septa protection element design currently deployed in the SPS as well as an opportunity to
obtain benchmark data for simulations beam excursion events – thus leading to improved designs
for more demanding conditions. The test components are large and heavy and appear to exceed
the weight capacity of the HiRadMat equipment table. The TPSG and MSE are to be connected
after placement in the HiRadMat tunnel. This could be done “hands-on”, but post experiment it
seems this must be done remotely. The experimenters need to work out this detail, as well as
more general installation and removal steps and preparations with the HiRadMat technical staff. A
situation that prohibits removal of the equipment in reasonable time should not be permitted unless
this is the very last HiRadMat experiment for the year. Experimenters are also reminded to
consider contamination release & exposure upon disconnection and inspection of the TPSG. The
use of other diagnostics for the TPSG such as LDV was noted as under discussion. Such
diagnostics are encouraged to maximize the value of the experiment; the data could be very useful to benchmark simulations. Further suggested is to consider some technique for inspections done between test cases; perhaps a video-borescope might be installed and remotely operated? The feasibility is unknown but the inspections might also quickly provide valuable data.

6. **HRMT-01 “TISD” (Michal Adam Czapski)**
   
   *TISD is conditionally supported as a 2012 HiRadMat experiment.* While the goals of the experiment (beam ageing studies of new isotope producing targets) are worthwhile the proposal lacked definition of a developed test apparatus and procedures that would safely achieve those goals. No concept was shown for a necessary enclosure to contain contamination in the test area; no concept for transport of the samples out of the test area was shown; plans for post-irradiation studies were only mentioned in terms of desired analyses but little though seemed given on how samples would be moved to necessary laboratories. Much experiment planning seemed yet to be done. If the experimenters can provide developed plans in sufficient time that satisfy the HiRadMat technical and safety boards, then support for proceeding would be given.

7. **HRMT-15 “RPINST” (Marco Silari)**

RPINST is supported for inclusion in the 2012 HiRadMat experiment schedule. The experiment will test radiation detection instruments for prompt dose response accuracy and evaluate some newly developed instruments. Instruments capable of prompt response typical of pulsed accelerators such as the LHC will improve safety and diagnostic capabilities at CERN facilities and beyond. The experiment appears simple to conduct with little hazard or post experiment consequences. The basic experiment scope should be conducted as an independent experiment but this could be supplemented by parasitic testing along with other HiRadMat experiments.
1) Direct contact between dissimilar metal combinations that may result in a galvanic couple should be avoided. Examples are copper targets in the "Aluminum enclosure" in experiment HRMT-12; graphite supports and spacers in contact with sample holder in EN-AW 6082-T6 and with copper-based materials (Copper-diamond MMC, Glidcop®) mentioned in the list as candidate materials to be tested in experiment HRMT-14. To assess the relevance of possible corrosion phenomena, the full history of the exposure and environments should be taken into account (before installation in the experiment, during and following the experiment).

2) Concerning experiment HRMT-01, some background or prediction of behavior of the materials to be tested in the specific conditions of the HiRadMat experiment compared to the Isolde ones should be provided. Indeed, the stress cycling and the response under the pulse conditions of HiRadMat experiment might result in crack growth or mechanical damage (production of debris?) on the samples of the materials to be tested, that might also be relevant for RP aspects.

3) For the experiments foreseeing post-mortem analysis of samples, the campaigns of non-destructive and destructive tests on the materials to be tested should be more precisely addressed by the proposers (test matrix; techniques and equipment involved; tests foreseen at CERN or in dedicated hot labs; in the latter case defined agreements with specialized external labs and availability of time slots, etc.).

The reviewers addressed the 2 main subjects of the review:

1. Is the design of the facility sufficient to reach the scientific mandate of the HRM project?
2. Have the safety aspects of the installation and associated infrastructure been sufficiently addressed?

The scope review of the facility did not include the irradiation modules proper which need to be subject of another review.

1. Facility Design

On the first subject, the reviewers concluded that the HRM represents a very strong case. A certain number of scientists have expressed their interest to conduct experiments at this facility, which will be able to operate at the scientific frontier. HRM will provide the ability to CERN to operate under LHC like conditions and will provide the scientific community with experimental conditions that are almost unique in the world.

The impact of shock waves on solids, alloys, composites is in the interest of a large scientific community which will also study the effects on the materials on a microscopic scale using the information and acquired data in, for example, light sources. The review panel therefore considers this facility as a tool that will serve this purpose.

These statements come with the understanding that CERN will make this facility available to the scientific community at large.
On the short term, the objective is to commission the facility and to conduct a first set of experiments, almost uniquely in the interest of CERN users and the LHC. It is nevertheless important to establish a mutual understanding with the CERN management that physics scope will broaden at a later stage using the experimental data and operational experience that will be accumulated. This may result in requests to upgrade the facility. While the initial focus remains CERN and the LHC upgrade, scientifically more advanced experiments in the future should not be excluded.

On technical matters of the facility, the review panel debated the following points:

**Switchyard**: it could be of interest to study a switchyard close to the experiment to provide an intermediate step before a full intensity beam is sent on target. At the moment, a switchyard is not available which means that samples have to be moved out of the beam when the beam needs adjustments or when the beam is set up.

**Experimental setup**: The panel has noted that this facility will probably only be accessible by collaborations from large experimental laboratories which have access to a certain infrastructure in their home laboratory. This will put certain restrictions on the experimental teams. The experimental setup of HRM is complicated to use, experiments will need help from inside CERN to increase the probability of a successful radiation test. The panel also noted that user diagnostics in the target area (cameras, sensors, aligning tools) will probably need to be improved with time when the physics scope of the experiments will broaden.

**User Selection Panel (USP)**: It is recommended to reinforce the USP at the scientific level to be able to confirm scientific experiments on a more solid ground. The USP should also address the impact of an experiment on CERN resources, clarifying the contributions that the organization is expected to make to the proposed experiment and the commitments of the collaboration to the experiment, safety requirements included. The quality of scientific publications in peer reviewed journals will be one of the measures of the degree of success of an experiment in HRM. In summary, a more balanced decision making must be pursued taking into account HRM operation, science, safety and the required resources.

**Liquefied gasses and liquid targets**: There is presently no infrastructure for liquefied gasses and liquid targets. Perhaps this can be considered for upgrades.

**Upgrading**: In the first years of operation, it is important to note how the operation of HRM is articulated with the operation of the rest of the CERN accelerator complex. Once this point has been addressed to its full extent, increasing the facility performance and expanding the scope of the experiments can be considered. The use of gasses in confined spaces is of particular concern here.

**Resources**: The panel recommends estimating the running costs in terms of manpower and budget for the next few years and to present this to the extended CERN management for approval.