Response to feedback from the Resource Loaded Schedule Review panel and the MICE Project Board

The project team welcomes the reports from the Resource Loaded Schedule Review panel and the MICE Project Board following their meetings in April 2015. This document provides the project team's response to each of the RLSR panel's and the MPB's recommendations.

Resource Loaded Schedule Review

Recommendations

1. **The project should undertake a cost-benefit analysis to determine replacing the Lithium Hydride secondary absorbers with plastic.**
   The baseline configuration for the demonstration of ionization cooling specifies two retractable discs of lithium hydride (LiH) to be used as secondary absorbers. This specification was adopted because of the flexibility that it provides. By retracting either or both secondary absorbers the apparatus can be operated in a variety of conditions. This flexibility will be essential to understand the optics and the evolution of the transverse and longitudinal phase-space.
   - **Cost and schedule:** The company "Y12" in the USA is the sole supplier of sintered lithium-hydride of the quality required for MICE. The company has quoted that two lithium-hydride discs to form the secondary absorbers can be supplied at a cost of $140k. We estimate that the lead time from placement of contract to delivery of the discs will be six to nine months. The linear-drive systems required to move the secondary absorbers into and out of the beam are estimated to cost £10k. The construction of the linear-drive systems are believed to be low risk since they are a copy of those built and tested for the lead radiation-shutters. So, the long lead-time items are the lithium-hydride discs themselves. The disc procurement should therefore be launched as soon as possible.
   - **Benefit:** The flexibility introduced by the ability to move the secondary absorbers remotely restores some of the flexibility of the original Step V lattice. This will be important in understanding the optics of the cooling cell and the way in which the transverse and longitudinal phase-space occupied by the beam changes along the channel.
     The MICE measurement programme has been planned to deliver measurements of the cooling effect for which the precision is limited by systematic uncertainties. The ability to vary the absorber configuration regularly during operation will be critically important to demonstrate that the systematic effects are understood and that the related uncertainties can be reduced to a level commensurate with the statistical power of the experiment.
   - **Risk:** The alternative to installing retractable LiH secondary absorbers will be to install plastic discs in the bores of the two spectrometer solenoids. The interventions required to remove or insert these discs will be such that a configuration change will be possible only in an ISIS shutdown and will require partial removal of the Partial Return Yoke (PRY) and one or both of the Single Cavity Modules (SCMs).
     Failure to install retractable LiH secondary absorbers therefore places at risk the ability of the experiment to deliver measurements at the level of precision required to fully characterise the cooling cell. Such a failure would represent a substantial loss of scientific impact from the MICE programme.
     Experience with Y12 indicates that it is essential to place the contract early to mitigate the risk that the material arrives after it is required by the experiment.

- **Contingency:** At the current exchange rate, an expenditure of £102k is required to produce the retractable LiH secondary absorbers. This investment would mitigate the risk of loss of scientific impact outlined above. The additional investment is a small fraction of the cost to the UK of delivering the cooling demonstration. As a fraction of the global investment in the project, the additional investment required to deliver the retractable, LiH-absorber system is much less than 1% of the total project cost.

The project team therefore believes that the retractable, LiH-absorber system should be used in the cooling demonstration. In view of the risk to the schedule implied by late placement of order with Y12, the project team proposes to move forward with the procurement straight away.

2. **The project needs to maintain a very close scrutiny on the staffing requirements in the MICE Hall for the installation and commissioning of the equipment for Step IV and Cooling Demonstration to maintain schedule.**

   The project team welcomes and agrees with the panel's recommendation. During this critical phase the Project Manager (R. Preece, STFC/RAL) and Project Engineer (A. Nichols, STFC/RAL) are in close consultation with the Hall Manager (J. Govans, STFC/RAL), the Operations Coordinator (S. Boyd, Warwick) and the Operations Engineer (C. Macwaters, STFC/RAL). Issues are dealt with as they arise or are escalated as appropriate within the Laboratory or collaborating institutes. The status of the project is captured in the bi-monthly report that accompanies this response to the feedback.

3. **The US should ship the RF modules sequentially in order to maintain maximum contingency in the schedule for the Cooling Demonstration.**

   The final long-lead-time item required in the fabrication of the RF modules (the collars that retain the RF couplers) have been obtained. The team responsible for the delivery of the SCMs is therefore on track to deliver the cavities on schedule. The team is aware of the benefit of advancing the date at which the cavities are shipped to RAL and is vigilant in seeking opportunities to advance the schedule.

Actions

1. **The STFC Executive should urgently identify solutions to resolve the RF Engineering staffing effort shortfall, so that proper planning can be undertaken by the project.**

   The RF system required for the MICE demonstration of ionization cooling requires two amplifiers each driving a single tuned cavity. The feedback and control system is slightly simpler than would have been required at Step V and the total voltage is 8.8 MV (ignoring transit time effects).

   Two members of the ASTeC RF Engineering team have recently left DL. Specifically, these two staff were responsible for the development of the Xilinx Spartan FPGA software for the LLRF-4 boards. As one of these departures was foreseen, steps were put in place to recruit a replacement who is now in post. This appointee does not immediately replace the FPGA programming expertise, but does bring relevant skills which minimise the dependence on this capability. DL are presently advertising a position to replace the FPGA programming expertise. Fortunately, the software developed at DL had been transferred to ISIS for development of a 201 MHz system driving an amplifier chain similar to that to be used at MICE. Positive meetings with the ISIS RF teams have resulted in a 201 MHz LLRF-4 system being operational at DL. Moreover, on-site training at DL is being organised by the builder of the LLRF-4 boards. We therefore propose the following system for the LLRF controls. The LLRF-4 control software, developed by DL and further developed by ISIS, will be used to control the amplifier chain to provide the required feed-forward control and set amplitude, frequency and phase. This software is extant but will need to be adjusted and refined and implemented on analogue hardware to be provided by DL (the LLRF hardware expertise remains in place at DL). To simplify the Xilinx programming we plan to implement all "housekeeping", including monitoring temperature and signal levels and control of the tuners on a NI Labview system. This exploits the expertise of the recently appointed RF Engineer at DL and also has

synergy with the US RF team's system since the current software in use in the US for tuner control is NI-Labview based. This system will need to have an interface to the overarching EPICS control system. This will be facilitated by the EPICS programming expertise extant at DL. The project team notes that, should it become necessary, additional expertise can be brought to bear from Tessella, the software house with which a contract is being negotiated to support the finalisation of controls-and-monitoring system for Step IV (see the response to MPB recommendation 1). Tessella is a NI partner organisation.

Summary of resolution of the LLRF staffing:

- Minimise the demands on the Xilinx subsystem by moving all non-speed-critical aspects to NI system—this exploits NI programming expertise appointed at DL;
  - Elements to move to NI include housekeeping, monitoring of RF signals and tuner control;
  - Key elements that must remain in Xilinx are RF-drive phase, frequency and amplitude, including ramp of RF amplitude.
- Exploit synergy with ISIS where (at the same frequency) the critical Xilinx features are being implemented—exploit this software with minimal modification. This system is operating on the bench.
- Training in the Xilinx system is to be arranged for the DL LLRF staff. A post for Xilinx expertise at DL has been advertised, however it is likely this post will need to be filled by training rather than appointment.

A document containing a full discussion of the arrangements that have been made to deliver the RF-power project has been prepared and will be presented to the MIPO at its next meeting (8^{th} June 2015). Once agreed by the MIPO, the document will be published for future reference on the MICE wiki.

MICE Project Board

Technical systems

1. **Strengthen the team preparing the controls and monitoring system.**
   A search for appropriately skilled software effort was conducted within the DL Controls Group, ISIS Department and the Particle Physics Department. No suitable personnel were identified. Therefore, contact was made with Tessella "an international analytics, software services and consulting company". Tessella has contracts with ISIS, CLF and Diamond as well as with DL. For ISIS, Tessella is managing the EPICS-based instrument-controls system upgrade.
   These discussions culminated on the 29^{th} May 2015 with a meeting between MICE and Tessella in which it was agreed to recruit one full time software engineer from Tessella to work with MICE for an initial period of four months. This arrangement was judged to be sufficient to complete the controls-and-monitoring system required for Step IV and to provide additional support for the critical commissioning and shake-down periods.
   Contractual negotiations are now underway under the "Contingent Labour 1" arrangements.
2. **Work together with the suppliers of the RF system in order to advance full testing with cavities in the MICE hall. (Also see RLSR recommendation).**
   With the receipt of the RF-coupler retaining collars at LBNL, the SCM-construction activity is being pushed forward as a matter of urgency. The recent review of the SCM was successful and procurement of the vacuum vessel and other components is now underway. An RF system review will take place in July 2015. Through the preparation for this review, and by implementing the recommendations that it

produces, the project team seeks to make the robust arrangements necessary to advance the RF-system commissioning and test activity in the MICE Hall.

3. **Carefully monitor the status of the decay solenoid system and consider implementing a deeper study to the possible cause of its quenching.**
   The decay solenoid was been energised with a current of 200 A and was stable for a number of weeks. Following a ramp-down initiated automatically from the control system, an investigation was started to identify the unexplained ramp down. The magnet was used for operation in the first days of ISIS User cycle 2015/01a. The behaviour of the refrigerator remains is under investigation as a matter of urgency. At present the instabilities of the refrigerator are not impeding the commissioning of the experiment.

Data acquisition, simulation and reconstruction

4. **Review the requirements for accurate end-to-end simulation (e.g. G4beamline) of the full beam-line, and quantify the effects on final analysis of using an approximate simulation. This should form part of the review of the Accelerator Physics beam dynamics programme recommended below.**
   The collaboration's response to this recommendation is presented under item 8 below.

Commissioning, operations and data analysis

5. **Maintain momentum in the implementation of the practical safety and operational steps required between now and the start of Step IV data taking.**
   Formal oversight of safety for MICE is carried out by the MICE-ISIS Safety Committee. This Committee has the responsibility to ensure that MICE complies with STFC's SHE policy.
   The MICE-ISIS Safety Committee has joint membership from MICE and ISIS and is chaired by J. Thomason (ISIS Accelerator Division Head). All safety matters relating to both the construction and experimental aspects of MICE are dealt with at regular meetings and a mechanism exists for actions to be reviewed and approved at Director-level where necessary. The Committee usually meets at six-weekly intervals, but meetings have been more frequent as the construction period has become more intense.
   Within the remit of the MICE-ISIS Safety Committee, more specialised working groups for activities such as liquid hydrogen and RF, have been formed, with more targeted and specialist membership. These groups work in much the same way, but necessarily contain more technical detail, and also have Director-level sanction.
   A series of Step IV readiness reviews have successfully been held for the major safety-related subsystems. These reviews each generated an action list, which have formed the basis of a comprehensive project "sign-off", which will be carried out by the GLIMOS, the Run Co-ordinator and representatives from ISIS in June 2015. As well as authorising safe completion of the MICE Step IV construction project, this exercise will also document and approve the operational safety practice for the beginning of Step IV.
6. **Continue the beam-line optics studies in order to further optimise the process of transfer matrix measurement and incoming beam channel matching.**
   The optics of the MICE Muon Beam (MMB) was extensively studied in Step I and satisfactory settings were obtained that allowed the various beams required by the MICE programme to be delivered. The effort to optimise the beam further and to ensure good matching to the cooling cell at Step IV is ongoing. In particular, MMB settings need to be improved to take into account the as-built diffuser parameters. A dedicated optics is required that maximises the rate of particles traversing the experiment for tracker commissioning without magnetic field in the spectrometer solenoids or focus coils.
   In the dedicated pre-commissioning phase, which started on 21$^{\mathrm{st}}$ March 2015, the MMB hardware was proven to be working reliably. Several Step I settings were remeasured and new, test settings were used. The data collected are now being analysed and further modelling using MAUS, G4Beamline and MAD-X continues to further optimise the settings. Further experimental studies are planned in June–July 2015

(cycle 2015/01a). These studies will exploit the full track reconstruction. This will allow a direct test of the matching conditions for the Step IV cooling cell.

7. **Report, in a MICE note to the collaboration, the definitions and methods used for the determination of the betatron functions and emittances.**
   A MICE Note in which the relevant definitions are documented and the methods by which betatron functions and emittances are calculated is in preparation. It will be "published" as MICE Note 465.
8. **Carry out an independent review of the beam dynamics analysis using this as an opportunity to renew contacts with the Accelerator Physics community. The aim is to ensure that the best set of techniques and tools are used in cross-checking the analysis of the muon dynamics, so that best value is extracted from the experimental data.**
   The collaboration welcomes this recommendation which, together with recommendation 4, will encourage a timely and detailed discussion of the challenges presented by the MICE programme. Possible formats for the review have been discussed and a list of possible reviewers, observers and chair-persons has been drawn up. A proposal for the conduct of the review was discussed by the MICE Executive Board at its meeting on the 5^{th} June 2015. Further feedback will be solicited before potential review-panel chairs are approached.
   Presently, it is felt that the initial analysis of some Step IV data would be valuable to inform discussion at the review. ISIS User Cycle 2015/02, which starts at the end of August 2015, has been adopted as the scheduled start of production data taking for physics in the Step IV configuration. Ideally, therefore, the beam-dynamics, analysis and simulation review should take place in October 2015. If possible, the review will be arranged in advance of the next RLSR and MPB reviews of the project.
9. **Define strategies to provide online feedback, quickly, to ensure end-to-end efficiency and quality given the restricted time available.**
   A number of procedures have been put in place to provide rapid feedback to the run planners and shifters. These include:
   - *Online Monitoring:*
     Each of the sub-detectors provide a set of diagnostic histograms containing information which can be used to diagnose problems in the system. It is the primary job of the shifters to monitor these histograms and to call system experts if they think that a particular quantity does not conform to what is expected. A set of standard histograms generated when the sub-detectors are operating normally is available for comparison.
   - *Online reconstruction:*
     The data from each particle passing through the channel is reconstructed on an almost-real-time basis. This allows physics measurements (such as the transverse emittance) to be calculated in the control room as the run progresses and the preliminary outcome of the measurement to be monitored. To feed the results of this reconstruction back into the run plan, the analysis group has implemented the concept of a "physics shifter". This is a named physics expert whose task is to monitor the results of the online reconstruction and provide feedback on the quality of the data within 24 hours of it being recorded.
     In order to bring these streams of information together the operations group will have daily operational-review meetings during running periods. The goal of these meetings is to receive reports from shifters on the health of the system which can then be disseminated to sub-system experts. The physics shifter will also provide a report on the previous day's running and the run plan for the following 24 hours will be modified, if necessary, so that the data required to meet the physics goals of the experiment are taken in an efficient manner.
10. **MICE management to request Professor Womersley to write to Jim Siegrist (DOE) and a represen-**

tative from the NSF (C. Denise Caldwell or F. Fleming Crim) to point out the opportunity for U.S. physicists to engage fully in the operations, data-taking and analysis of this unique experiment, and to fully exploit the significant capital investment, during the Cooling Demonstration.
MICE management is in discussion with the STFC Science Programmes Directorate over the most effective means by which Professor Womersley may make the case for the benefits that will accrue to US physicists, and the MICE collaboration, from continued DOE and NSF support for the experiment. The text of a letter to go to NSF has been drafted. A briefing meeting between MICE management and Professor Womersley will be requested in the near future.