MICE Liquid Hydrogen System Operational Review

15th and 16th January 2015, Electron Building, Science and Technology Facilities Council, Rutherford Appleton Laboratory, Didcot, OX11 0QX, UK

Review Panel:

John Thomason (STFC) – Chair, Gary Allen (STFC), Mo Chowdhury (STFC), Matt Dickson (STFC), John Dowell (University of Birmingham), David Findlay (STFC), Duncan Francis (STFC), Jonathan Gulley (CERN), David Haynes (STFC), David Jenkins (STFC)

Introduction

The goal of the MICE project is to provide a working demonstration of muon ionisation cooling. Such a demonstration is a vital precursor for future accelerator systems using muons. The experiment is being carried out on behalf of the International MICE Collaboration, using the proton beam at STFC's ISIS facility to generate muons.

The experiment is split into discrete R&D phases that are presently described as 'Step IV' (which will use either a liquid hydrogen or a lithium hydride absorber cell with no re-acceleration of the muon beam) and 'Cooling Demonstration' (which will use only lithium hydride absorber cells and will include re-acceleration).

Previous reviews of the R&D stages, extensive MICE-ISIS working group activities and HAZOP studies have ensured MICE liquid hydrogen system safety to date, but the present review seeks to establish the compliance with all relevant safety frameworks of the actual liquid hydrogen system installation and methodology that will be used in operation of Step IV.

Findings

1) The MICE Liquid Hydrogen team should be congratulated on their substantial achievements to date, the quality of the liquid hydrogen system installation and the obvious expertise that has been built up within the team.
2) The basic safety philosophy looks to be sound. This is borne out by the successful running in 2012 and also observation of the development of the plant by ISIS experts and by what the review panel members saw during this review.
3) All of the reviews, HAZOP studies, *etc.* done to date have been done well.
4) The configuration and scope of the MICE experiment has changed over the past 1–2 years. The key changes are that only one liquid hydrogen absorber will be used (instead of three), and that there will no longer be thin-wall, high-power RF cavities in close proximity to liquid hydrogen in thin-window vessels. The duration of the experimental running programme has also been much

shortened. Overall, therefore, all other things being equal, any operational risks should be reduced.

5) The control system and software are largely unchanged from the R&D system.

Comments

1) Most of the liquid hydrogen hardware to be used in the forthcoming MICE experimental programme is the same as was used in the July–August 2012 operational "R&D" programme, and so much of the hardware has already been run and proved itself suitable for purpose (although in a review, held in early 2013, of the 2012 operational programme a number of improvements were identified). In the future the hydride bed will no longer be used as a hydrogen store; instead the absorber will always be filled with hydrogen directly from a hydrogen cylinder pack and so any risks directly associated with the hydride bed will be removed. However the key change for the future is that liquid hydrogen will now be contained in a vessel with thin aluminium windows (180 µm (absorber window) and 210 µm (safety window) on axis) instead of in a thick-walled cryostat.

2) The hydride bed seems to be something of an unknown quantity, its capacity has been degrading, and the reabsorption rate noted in 2012 was very slow. Also, depending upon the getter material in the bed, it could overheat, or burn, if inadvertently exposed to air.

3) The MICE recommendation for removal of the hydride bed from the system is welcomed. For MICE operations as now foreseen, the bed is an unnecessary complication, and filling the system from a cylinder pack outside R5.2 is a better solution.

4) Operating from a cylinder pack will increase the need to vent hydrogen to atmosphere but as the residual gas from the buffer had to be vented even when operating with the hydride bed, this is not seen as a big change or a problem.

5) Very few code changes will be required in the control system and software to accommodate the proposed system changes.

6) Given that the hardware it will be used with was effectively proved to be satisfactory in 2012, the thin-wall absorber vessel presents the MICE team with an opportunity to re-confirm the calculated results of window failure, especially leakage of hydrogen into the neighbouring interspace.

7) The panel expressed a preference for removal of the relief valve from the absorber insulation vacuum system, as the bursting disc should be adequate protection on this system (making the relief valve an unnecessary complication and source of possible leaks). However, as MICE staff preference is to keep the valve, and the installation of a check valve downstream will prevent any possibility of air back-streaming into the cold system, there is no objection to them operating in this way.

8) Of the actions generated during the reviews, HAZOP studies, *etc*. to date it was not clear which had been completed or were still relevant.

9) Responsibilities for safety have been established (run coordinator, shift leader, GLIMOS, *etc.*), but should perhaps be presented in a diagram. However, it is less clear that responsibilities and procedures for emergency drills, building evacuation and housekeeping have been fully defined.

10) MICE liquid hydrogen operations are overseen by 'expert' personnel, but it is not clear how this expert status is attained.

11) The panel accepts that, during operation of the MICE experiment for physics, expert attention to the hydrogen system outside normal working hours will be on an 'on call' basis. The 'shift leader in matters of safety' will be responsible for calling an expert. Appropriate training in recognising a problem will be needed.

12) The sign-off system to allow liquid hydrogen R&D operations in 2012 worked well and should be maintained for first introduction of liquid hydrogen into the Step IV system, *i.e*. signatures required from:

    ISIS Accelerator Division Head

    MICE Project Manager

    PPD Director

    ISIS Director

13) While the liquid hydrogen team are happy that they can make the progress necessary to meet the MICE timescales satisfactorily, success does depend on the willingness of Technology Department to continue to maintain and support the team.

Recommendations

1) Now that the future MICE experimental configuration and operational programme seem clear, it would probably make sense to re-confirm that the consequences of interactions between the totality of the liquid hydrogen system and the totality of the environment in and around R5.2 raise no worries (it is not clear that all of this was covered in previous reviews). Risk assessments for other systems or co-activities should take into consideration the presence of the hydrogen system. For example, what happens if hydrogen bursts into the neighbouring muon trackers? Is the present R5.2 building fire risk assessment fully compatible with the new MICE configuration? Is crane operation adequately integrated with the liquid hydrogen system? Are there circumstances in which the ISIS Crew could be asked to provide help to MICE?

2) A manifolded cylinder pack of hydrogen should be easily sufficient to cover all of the MICE hydrogen requirements for Step IV (~3 absorber fills plus test runs); the only recommendations are that hydrogen supply lines in the MICE Hall must be double contained with nitrogen purge over the primary containment, that only enough cylinders from the pack should be on line at any one time to achieve a complete fill (one fill takes ~1.5 cylinders) and that the system should be fitted with purge gas flowmeters and cylinder pack pressure and post regulator flow gauges (although these may not be needed for the relatively short proposed run with liquid hydrogen).

3) Failure of a 180 μm aluminium absorber window will result in the release of liquid hydrogen into the interspace behind the 210 μm safety window. Is the safety window and relief system on the interspace capable of coping with the large pressure rise that will be generated by the rapid boil-off of liquid hydrogen to gas (~ 1:845)? The original (Mike Green *et al.*) calculations on this should be revisited by ISIS pressure systems engineers. In particular the design philosophy calculations for the hydrogen vent scenarios should be reviewed by Stephen Harrison (ISIS Instrument Design Group Leader), who has current knowledge and experience of this type of analysis from his work designing cryogenic systems for superconducting magnets.

4) Although the additional burst testing of the windows is not seen as an absolute requirement it would certainly be useful for gaining further knowledge and confidence in their design and manufacture. Equally, the reverse pressure test on the window suggested by Wing Lau has similar value and the panel endorses the MICE proposal to carry it out.

5) MICE are sure that pressure relief systems are adequate and this has been verified by several re-checks of the calculations. However, all relief devices should be test lifted and all bursting discs should be replaced before operations are restarted. This work should be documented.

6) Written Schemes of Examination (WSEs) will be required for the pressure systems that MICE are operating: the RAL competent person is currently Lloyds British Ltd. ISIS experience with Lloyds is that they will probably want to carry out internal inspections of equipment (buffer vessels, *etc.*) and this could be very disruptive to the commissioning schedule. To avoid the possibility of wasting time during commissioning, testing or running, MICE should open discussions now with RAL SHE Group and Lloyds engineers, and carefully consider and collate all the relevant design information that might be required for the WSE.

7) Findings from previous HAZOPs should be examined for consistency with the new MICE configuration and programme. The MICE team are encouraged to hold a "mini-HAZOP" exercise covering changes to the system (such as the introduction of a thin-window liquid hydrogen vessel). In principle such a mini-HAZOP could usefully be chaired by the chairman of the previous HAZOP exercise (October 2012).

8) The MICE Liquid Hydrogen Working Group should establish a plan to deal with actions still outstanding from previous reviews, HAZOP studies, *etc*. Work carried out under the plan should be documented. Completed HAZOP and DSEAR studies should be reviewed in light of ‘significant changes’ to a part of the design.

9) Ensure risks from maintenance/servicing are addressed and evaluated (apparently these were not addressed in the HAZOPs).

10) Establish a documented maintenance schedule for all items, equipment, *etc.* requiring maintenance/inspection/testing (*e.g.* relief valves), although it is recognised that maintenance need not be scheduled beyond the end of MICE operations.

11) Define operating procedures for specific operations including; purging and means of establishing that pipe work and vessels are adequately purged; interventions on the system requiring use of PPE; work/intervention in a declared ATEX zone (*e.g*. use of anti-static clothing/footwear).

12) Produce documentary evidence defining responsibilities and procedures for emergency drills, building evacuation and housekeeping.

13) Liaise with on-site and off-site emergency intervention personnel to agree on and define intervention procedures for certain key foreseeable accident scenarios (*e.g.* a small or large fire inside R5.2).

14) Define prerequisites for competency of 'expert' staff (*e.g.* specific DSEAR course, experience/on the job training and safety awareness training, use of fire extinguishers, *etc.*) and formally sign off competency.

15) Establish a formal "Change Request Notice" system where proposed operational changes are agreed and signed off by the GLIMOS.

16) The panel would like to see the MICE liquid hydrogen team set a consistent pressure unit convention throughout their documentation (*e.g.* bara, bar absolute).

17) Steve Watson should provide a regular update on commissioning to the MICE Liquid Hydrogen Working Group.

18) Director approval should be obtained (as before in 2012) before any hydrogen is introduced into the system.

19) Before sign off for Step IV operations to begin there must be a pre-operations review to ensure that the entirety of the integrated MICE system (including liquid hydrogen) is safe and fit for purpose. MICE should consider some kind of procedure similar to ISIS OPI 207 "Procedure for a New Beamline to take Neutrons or Muons" that arrives at the final sign off document.

Appendix

Review Charge:

"To review the installation and operational methodology of the MICE liquid hydrogen system for its compliance with all relevant safety frameworks."

Agenda:

Thursday 15th January 2015

0900 – 0915	-	Chairman's briefing, closed session
0915 – 0930	-	Introduction (Steve Watson)
0930 – 1000	-	Summary of hardware details (Steve Watson)
1000 – 1015	-	Coffee
1015 – 1045	-	Summary of control and software (Phil Warburton)
1045 – 1100	-	Review history (David Findlay)
1100 – 1145	-	Risk management policy (Andy Nichols)
1145 – 1230	-	Tour of MICE facilities
1230 – 1330	-	Lunch
1330 – 1415	-	Absorber/window design (Wing Lau)
1415 – 1445	-	System modifications (Steve Watson)
1445 – 1600	-	Coffee and general discussion/questions

Friday 16th January 2015

0900 – 0915	-	Chairman's briefing, closed session
0915 – 1000	-	Commissioning and testing plan (Steve Watson)
1000 – 1015	-	Coffee
1015 – 1045	-	Approval mechanism proposal (Steve Watson)
1045 – 1115	-	Open discussion / questions
1115 – 1200	-	Panel closed session
1200 – 1300	-	Conclusions and preliminary recommendations (John Thomason)

Documents for consideration by the review:

Response to 2005 review recommendations
http://micewww.pp.rl.ac.uk/attachments/2595/Response_to_Review_PanelV4.doc

Response to 2009 review recommendations
http://micewww.pp.rl.ac.uk/attachments/2596/MICE_LHreview_Response.doc

Operating instructions for R&D tests
http://micewww.pp.rl.ac.uk/attachments/3195/Operating_Instructions_R_D.pdf

R&D test report
http://micewww.pp.rl.ac.uk/attachments/2594/R_D_test_report.doc

Process and instrumentation diagram (R&D)
http://micewww.pp.rl.ac.uk/attachments/3201/Hydrogen_System_Baseline_Layout_18June12.pdf

HAZOP 1 (design)
http://micewww.pp.rl.ac.uk/attachments/2597/HAZOP_Report_Issue_1.pdf

HAZOP 2 (operations)
http://micewww.pp.rl.ac.uk/attachments/2598/STFC_RAL_MICE_Hazop_Report_Issue_1.pdf

LOPA study (SIL assignment)
http://micewww.pp.rl.ac.uk/attachments/3196/X589_TR_001___2.0_.pdf

LOPA study (SIL assessment)
http://micewww.pp.rl.ac.uk/attachments/3197/X589_TR_002___1.0_.pdf

Letter from TDS regarding SIL reassignment
http://micewww.pp.rl.ac.uk/attachments/3194/STF1201LTR01.pdf

DSEAR risk assessment
http://micewww.pp.rl.ac.uk/attachments/3198/Overall_DSEAR_RA_MICEH2-RA-110906.doc

DSEAR zone drawing
http://micewww.pp.rl.ac.uk/attachments/3199/MICEH2-DSEAR_zone_dwg.pdf

Control system specification
http://micewww.pp.rl.ac.uk/attachments/3200/H2CtrlSpec_V2.pdf

Control system Atex-rated equipment
http://micewww.pp.rl.ac.uk/attachments/3193/H2Ctrl_Ex_Equip.doc