Committee Report: eHDice Experimental Readiness Review

Review held November 19, 2019
Report dated December 10, 2019

Committee Members

1. Alexandre Deur
2. Camille Ginsburg
3. Chris Keith (chair)
4. George Perry
5. Tony Riley
6. Eric Sun
7. Michael Tiefenback
8. Celia Whitlatch
9. Lorenzo Zana
10. Ed Folts (*observer*)
11. Javier Gomez (*observer*)

Executive Summary

The committee commends the HDice and UITF collaborations for their well-organized and informative presentations and tour of the facility. Overall, we find that the HDice group is on path to begin testing the target with a low-energy electron beam shortly after the initial, commissioning run of the UITF facility (referred to as “Run 0”). However, for reasons that are outside the direct control of the HDice group, we have reservations that these tests can be completed within the timeframe presented at the review, January to May of 2020. First, the collaborations expressed concerns that sufficient personnel exist to operate the UITF facility on an around-the-clock basis. Second, other demands on the Cryogenic Test Facility, which provides coolant to the UITF, may severely limit the latter’s operational schedule. Coordination and agreement between the Accelerator and Physics Divisions will be necessary to resolve these problems.

The committee reviewed nine charge items, addressed separately below.

Charge Item 1. What is the status of the UITF towards operation?

Findings:

It was stated at the ERR that the UITF accelerator is built and ready to use. Based on a tour of the facility, the committee agrees that it is in good shape to begin its initial, commissioning run in the near future. The electron gun is currently undergoing high voltage processing and the keV portion of the beamline has been commissioned. The new Booster cryomodule has been cooled and successfully tested with full RF power. It is currently scheduled to be removed from the UITF and installed in the CEBAF injector beginning in May 2020. A replacement quarter-cryomodule from CEBAF will be installed in the UITF at some later date.

The UITF has passed several reviews, and all important safety documents have been approved by JLab management. Final approval from the Jefferson Lab Site office is required to begin commissioning the accelerator and produce MeV electron beams. This is expected shortly, after which the UITF may be operated as a user facility for the HDice tests, etc.

Comments:

Removal of the Booster cryomodule in May, coupled with a shortage of personnel to operate the UITF and possible cryogen conflicts with the LCLS-II program (see Charge Items 6 & 7), casts doubt that the HDice tests can be completed within the scheduled time frame. The UITF and HDice collaborations are encouraged to pursue an alternative schedule that extends the possible tests through September 2020. This will require coordination with both Accelerator and Physics divisions.

Charge Item 2. What are the goals of the HD-Ice tests?

Findings:

As stated in the introductory presentation, the central goal of the HDice electron tests is to "***identify the beam and target parameters for which the target spin-relaxation time is ~2 weeks***". The spin-relaxation time, T_1, is the time after which the target polarization has decayed to 1/e of its initial value, while every two weeks is approximately the maximum frequency that target changes could be accomplished during experiments with CLAS12.

Comments:

1. The goal T_1 of two weeks (14 days) is significantly shorter than the value specified by PAC39 to satisfy C1 approval:

   > **"One has to achieve at least WITHIN a factor of two of the figure-of-merit required by the physics program (I = 1nA and 60% polarization), and a spin relaxation time of 50 days or longer with a 1 nA electron beam on the target before CLAS12 experiments with the transversely polarized HDice target can be fully approved." [PAC39 Final Report, p. 22]**

2. Waiting to replace the target when its polarization has dropped to 1/e (37%) of its initial value may not be the most efficient use of beam time. In this scenario and assuming exponential decay, the average polarization throughout a target cycle is about 63% of the starting value. More importantly, the average Figure-of-Merit for the target, P^2, is only 43% of the starting value, meaning the experiment must run more than twice as long to achieve the proposed statistical uncertainties.

<u>Charge Item 3.</u> *What is the status, and if not completed, the plans and schedule for:*

a) IBC status: Dec. 2018 quench & repair
b) IBC pressure vessel certification
c) Beam Dump solenoid and vacuum vessel certification

<u>Findings:</u>

The main and transfer superconducting magnets inside the In-Beam Cryostat (IBC) were damaged by a quench that occurred during tests in 2018, when both magnets were simultaneously energized to their full currents. These share the same, vapor-cooled feedthrough inside the IBC, which was insufficient to carry away the heat of all eight, normally-conducting leads. During the subsequent quench, leads for the main solenoid arced and damaged multiple sections of the transfer coil. The magnets have been repaired using new leads on the main coil and replacing the damaged sections of the transfer coil. Additional precautions were taken to stabilize the leads and to reduce the current at the feedthrough from 17 A per lead to 10 A per lead. Finally, a thermal shield was added around the transfer coil's 4 K bath to help keep it cold when the bath level drops. Following these repairs, the coils were successfully ramped to full field using only half the maximum lead cooling flow. The magnets were stable at full field for several minutes. While the lead voltages of both the main and transfer solenoids are monitored by the IBC control software, there are no hardware interlocks on these readbacks. The repairs were made using the original certified pipe and weld designs, and documented in accordance with the JLab Pressure Systems Safety program.

A new 0.25 T, normally conducting solenoid will focus the electron beam into a small beam dump downstream of the IBC. The solenoid was designed to work with an existing power supply. Its components were procured or manufactured at JLab, and it was wound by a local vendor, Electric Motor & Contracting Co. of Chesapeake VA. The solenoid was installed in the UITF cave and successfully tested to 350 A (0.275 T). The upgraded LCW system in the Test Lab was able to provide sufficient coolant to the magnet along with all other coolant needs for the UITF. The stray field of the solenoid is expected to produce some broadening of the HDice target's NMR signals.

The vacuum vessel that houses the beam dump extends through the solenoid and attaches to the IBC. This vessel was engineered and constructed in accordance with the lab's Pressure System Safety program.

<u>Comments:</u>

1. There are no active quench detection and protection mechanisms for the superconducting magnets. The risk should be assessed to determine if these mechanisms are necessary.
2. There is no dump resistor to extract energy from magnets during quench.
3. The committee commends the JLab Magnet Group for designing the beam dump solenoid in a timely and cost-effective manner.

<u>Recommendations:</u>

1. Interlock the voltages of the current leads of the IBC superconducting magnets with the power supplies.
2. Investigate the effects of eddy currents (heating and induced forces) of 4K copper shields of the superconducting magnets to see what are the appropriate ramping rates.

<u>Charge Item 4.</u> *What is the status of the following equipment, including ownership and control during beam operations? If still not completed please present plans and schedule:*

a) Cave-2 beam line optics design
b) Beam transport through the HD-Ice IBC
c) Low currents monitor with a Rogowski coil
d) Beam Halo counters
e) Device to prevent delivery of high currents to the HD-Ice target

<u>Findings:</u>
The cave beam line optics design is complete. Beam transport through the HDice In Beam Cryostat will be complicated by the low rigidity of the 10 MeV beam coupled to the IBC's internal magnetic fields, and by divergence produced at a thin thermal shield inside the IBC. This has been modelled extensively, and the collaboration has confidence that a satisfactory beam spot can be tuned onto the target. The length of the target has, in fact, been shortened to 12.5 mm to avoid expected "nodes" in the beam profile. A field map inside the IBC, presumably on-axis, has been made at room temperature with small currents through the transfer and main coils.

A four-segment Rogowski coil will be placed upstream of the IBC and used to measure the beam spot during low-current running. The coil has been characterized using AC currents through copper wires down to 0.1 nA, and the results match the predicted behavior with better than 1 mm accuracy.

The beam position at the target location (up- and downstream) will be monitored by sets of plastic scintillators mounted to the outside of the IBC. These are in place and have been tested using a ^{90}Sr source. These, along with a copper aperture target, will be used in Run 1 to test the beam transport through the IBC (see Charge Item 5).

The first of two beam line apertures will be used to define the beam position upstream of the raster magnets. The second aperture will limit the diameter of the rastered beam on the target.

<u>Comments:</u>
1. The performance of the Rogowski coil looks very impressive. It could prove to be very useful in other low current experiments at the lab.
2. An accurate measure of the beam charge, and by association the beam current, is crucial to the success of these tests. The sum of the four Rogowski coil signals may provide a better measure of very low beam currents than the Faraday cup.
3. During Runs 2 and 3, it is especially important to put only *rastered* beam of the maximum diameter on the HD target. Under-rastered beam will obfuscate the NMR measurements of the target polarization.
4. Archiving all beam current/charge and raster information will be critical for data analysis.

<u>Recommendation:</u>
1. Interlock the raster with an FSD.
2. Provide the impact on beam transport due to magnetic field uncertainties and misalignments.

<u>Charge Item 5.</u> What is the sequence of the HD-Ice tests?

a) Beam tuning sequence

b) Cave-2 roof tile removal for target loading. Have all the EHS&Q requirements been considered?

<u>Findings:</u>

A detailed description of beam-tuning through the elevated portion of the UITF beam line was presented at the ERR. During Run 1, this will be performed with the In-Beam Cryostat in place, cold, and with magnets energized. A 2 mm thick copper target with a 2 mm aperture will be used in lieu of a solid HD target. Viewers and a Faraday cup will be used to establish the beam conditions just upstream of the IBC. At this time, the sensitivity of the Rogowski coil will be investigated for beam position and current, starting at 20 nA and working down to 0.2 nA.

Next, beam will be transported to the copper target, where it will be centered based on count rates on the Halo counters, and centered on the beam dump by adjusting the position of the beam dump solenoid. The copper target is then removed, requiring use of the transfer cryostat in a manner identical to loading a polarized HD sample. Beam is again centered upstream of the IBC using the Rogowski coil and transported to the beam dump viewer. The beam transport simulations are checked/verified by offsetting the beam in X & Y, and by adjusting the IBC and beam dump magnets. Finally, the raster behavior is checked with the beam centered on the dump viewer.

A similar beam-tuning sequence will be used for Run 1 (unpolarized HD) and Run 2 (polarized HD), except the beam will be centered and qualified using an empty IBC, before the samples are loaded.

Loading and unloading samples from the IBC requires removal of shielding tiles from the roof of the UITF cave. The procedure is described in **OSP 87551**, which has been reviewed and approved by the relevant Subject Matter Experts and Safety Officers.

<u>Comments</u>

Additional, off-axis apertures in the 2 mm copper test target may be beneficial during the initial beam-tuning sequences.

<u>Charge Item 6.</u> *Are the responsibilities for carrying out each job identified, and are the manpower and other resources necessary to complete them on time in place?*

<u>Findings:</u>

Eight trained personnel are currently available to operate and maintain the HDice target system at JLab. However, the number of personnel is anticipated to shrink to only three full-time and one part-time persons after September 2020.

There are currently seven individuals approved to operate the UITF. This is insufficient to support 24/7 operations.

<u>Comments:</u>

1. Loss of key HDice personnel after September 2020 makes completion of the electron tests prior to this date imperative.
2. Continued development and operation of the HDice target beyond September 2020 will require new personnel, either from Jefferson Lab, the CLAS12 user community, or new institutions.
3. The inability to run the UITF around the clock will severely reduce the efficiency of the HDice electron tests as they are currently scheduled and will interfere with a recommendation given under Charge Item 7. The collaboration should therefore seek additional trained operators, perhaps from the CEBAF operations pool. This seems more feasible if the test schedule is extended beyond May 2020.
4. If necessary, the CLAS collaboration should provide additional target operators for the tests.

<u>Charge Item 7.</u> *What is the experiment plan, the target status and the requested UITF schedule? Specifically discuss possible conflict with LCW and cryogenics.*

<u>Findings (experimental plan):</u>
Under ideal circumstances, four experimental runs with the IBC in the test cave could be used to complete the tests. Due to the compressed schedule of the UITF, only three runs were presented. The first is a commissioning run and will utilize a copper target with a 2 mm aperture for beam positioning studies. Run 2 will use an unpolarized solid HD sample with a relatively short spin-relaxation time and will focus on the performance of the dilution refrigerator with beam on target and possible interplay between the electron beam and target NMR. This sample will gain a slight degree of polarization (~2%) when it is cooled inside the IBC and exposed to the 1 T holding field. Run 3 will utilize one or more fully polarized and aged HD samples to explore the response of proton polarization to varying beam currents and holding fields. If time allows, Run 4 will expand upon Run 3, and perhaps examine the performance of polarized deuterons in the target sample.

Instead of the 50 mm long HD samples described in the CLAS12 proposal, 12.5 mm long samples will be used at the UITF (Charge Item 4). The reduced heat load on the sample will be supplemented by a heater attached to the target refrigerator.

<u>Comments (experimental plan):</u>
1. The cooling power of the DR, which can be tested with a heater, is perhaps less of a concern than the temperature of the HD sample. Beam heating of the latter was identified as a source of depolarization during the initial G14 electron tests, and a new target cell and a new raster were built to combat this issue. Run 2 is an ideal time to test these modifications because the thermal equilibrium NMR signal of an unaged HD target can be used to measure the sample temperature as a function of beam current and raster speed.
2. Heating the refrigerator is not equivalent to applying the same heat to a longer HD sample. One can expect a higher sample temperature in the latter case. This is another reason to measure the sample temperature directly.
3. Radiation damage, in concert with beam heating, is another important source of target depolarization. However, radiation damage is a cumulative effect, and the rate of depolarization is expected to accelerate as paramagnetic species continue to build up within the target. It may not be possible to accurately predict the performance of the polarized target in a long-term physics measurement from only a few hours of beam exposure or intermittent beam exposure.
4. Polarization measurement via continuous NMR sweeps can lead to some polarization loss from RF saturation or RF heating of the aluminum coolant wires, so it is prudent to consider sweeping the RF periodically. The minimum safe time between NMR sweeps can be determined by systematically decreasing the period until an apparent drop in T_1 is observed.
5. Any run plan should take into consideration the efficiency of UITF operation. This can only be estimated after the commissioning run (Run 0).
6. For post-run analysis, it is obviously critical to properly archive all beam and target parameters. This includes both beam current and total charge.

Recommendations (experimental plan):

Formulate a run plan for Runs 1-3 that includes the following:

- the resolution required for the proposed measurements, and the resolution available from existing diagnostics tools;
- a measure of the HD sample temperature versus beam current and raster frequency;
- prolonged (suggested minimum 7 days) around-the-clock electron test performed on a polarized HD target using nominal 1 nA beam current;

Findings (target status and UITF schedule):

The HDice in-beam cryostat is currently installed on the UITF beam line and seems to be in good shape for taking beam in the coming weeks. The anticipated heat load on the target refrigerator is approximately ½ mW per nA of beam, which should result in a refrigerator temperature of about 100 mK at 1 nA. There is currently one polarized target of solid HD ready for beam, and it is highly probable that two additional samples can be ready for use in Run 3 of the experimental schedule.

Three possible run periods between January and May of 2020, with a total of 52 days, were identified in which cryogens from the CTF would be available for UITF operations. However, one of the reviewers, Tony Riley, commented that the CTF schedule was still in flux, and the number of UITF days could be considerably lower.

Comments (target status and UITF schedule):

The time between this ERR and the anticipated start date of the tests is much shorter than is typical. Also, the number of days to complete the desired program is very tight. It is therefore critical to complete all remaining work in an efficient and timely manner.

The apparent scheduling conflict between UITF operations and LCLS-II testing must be resolved before any meaningful experimental run plan can be developed. This should be dealt with at the division or institutional levels.

Recommendations (target status and UITF schedule):

Generate Gantt Charts for completing outstanding beam line and target work in order to initiate Run 1 in Feb. 2020 and complete Run 3 by May, 2020.

<u>Charge Item 8.</u> What is the status of the HD-Ice COO and OSPs documents. Are the specific documentation and procedures to operate safely and efficiently the equipment, in place and adequate?

<u>Findings:</u>
Drafts or final versions of the following documents were made available for review prior to the ERR:

- UITF Shielding design: Radiation Safety Aspects of the Upgraded Injector Test Facility (JLab-TN-18-020): [1]
- UITF ODH assessment (ODH Review 74180): [2], [3]
- IUTF Cave2 ceiling roof tile removal (OSP 87551): [4]
- Cool and Operate HDice IBC and its super-conducting magnets in cave-2 of UITF (OSP 80380): [5]
- Transferring (loading/removing) targets to/from the HD-Ice IBC in cave-2 of the UITF (OSP 94834): [6]
- HD-Ice Dump Solenoid (OSP 94612): [7]
- Conduct of Operations (COO) [8]
- Experimental Safety Assessment Document (ESAD) [9]
- Emergency Response Guidelines (ERG) [10]

A draft of the RSAD was provided just before the close-out of the ERR.

<u>Comments:</u>

1. The documentation provided to the ERR committee was sufficient to satisfy the review committee.
2. The HDice group should add P&ID (process and instrumentation diagrams) to their operation manuals. This will benefit reviewers as well as operators of the systems.
3. The operation manual for the *Juelich Transfer Cryostat* should be updated to remove references to the "SPHICE target group at BNL" (p. 11) and confirm that drawing numbers referenced therein point to JLab drawings, not BNL.
4. Upon approval of all required safety and operations documents, the committee feels Charge Item 8 has been successfully satisfied.

<u>Recommendation:</u>
Complete all documentation required to pass this ERR.

<u>*Charge Item 9.*</u> *Are the radiation levels expected to be generated in the cave acceptable? Is any local shielding required to minimize the effects of radiation in the equipment?*

<u>Findings:</u>
A draft RSAD was made available to the committee at the conclusion of the ERR and reviewed by one committee members L. Zana. All the information contained in it is current. It is based on simulations done by V. Vylet and documented in JLAB-TN-18-020. This simulation, as mentioned in the RSAD and at the presentation during the ERR, will be re-evaluated with measurements, first during the Run 0 commissioning test of the UITF. Additional tests will be performed following major changes to the UITF beamline or HDice IBC in the beamline.

During the ERR the beam dump design was evaluated, since it was upgraded from the design described in the technical note (a single layer of Copper). It will be constructed of consecutive layers of Aluminum (22mm), Nickel (28mm), Lead (17mm). This configuration is not expected to create activation in the dump, nor to create neutron flux from it, with the expected beam energy at 9.5 MeV utilized during the eHDice tests.

Local shielding will be added around the lock-in amplifiers used for the Rogowski coil and at the entrance of the HDice cryostat for the halo monitors.