USI: Low-Power Test Exemption for Coherent Electron Cooling Proof of Principle (CeC PoP) Experiment at RHIC

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Introduction

The Collider-Accelerator Department (C-AD) Chairman is requesting the Laboratory ESH Committee (LESHC), the Assistant Laboratory Director for ESH (ALD for ESH) and Head of DOE Area Office (BHSO) approve or recommend for approval, as applicable, a low-power beam test of the Coherent Electron Cooler (CeC PoP Experiment) devices at RHIC.

C-AD management requests that CeC PoP Experiment device testing be authorized under Exemption 3.c (2) in DOE O 420.2C. The test can be managed under the RHIC ASE[1], the C-AD SAD[2], the C-AD Conduct of Operations[3], C-AD OPM 2.5.2.2 Testing Safety Envelope Procedure for CeC PoP Experiment[4], and the SBMS requirements for standard industrial hazards. Reviews by the Radiation Safety Committee and Accelerator Systems Safety Review Committee were performed and a low risk was determined.

Low-power tests are needed to test the elements of the CeC PoP Experiment for final configuration during RHIC Run 16. Access to install equipment for final CeC PoP Experiment low power tests is limited to the remaining shutdown days prior to RHIC Run 16, which is planned to start in mid-January 2016 and the bi-weekly maintenance days during the RHIC run. Limited access for device modification will be problematic. These circumstances impede the ability to test the CeC PoP Experiment components with beam in their final configuration and significantly increase the risk of not meeting the project schedule for the Coherent Electron Cooling Experiment, which is planned to be finished before 2017.

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[1] C-AD ASE Note: Updated Version will apply when approved.
[2] C-AD SAD Note: Updated Version will apply when approved.
[3] C-AD Conduct of Operations Note: Updated Version will apply when approved.
[4] C-AD OPM 2.5.2.2 Safety Envelope for Coherent Electron Cooler Testing at Low Power in RHIC

Readiness for performing these tests will be reviewed by an IRR Team scheduled for December 21 and 22, 2015. Tests can be done with a very low bunch rep-rate, keeping total power below 1 W averaged over 1 hour, while providing vital information about the experimental setup.

Description of CeC PoP Experiment Device Tests

See Figure 1 for a layout of the CeC PoP Experiment in RHIC.

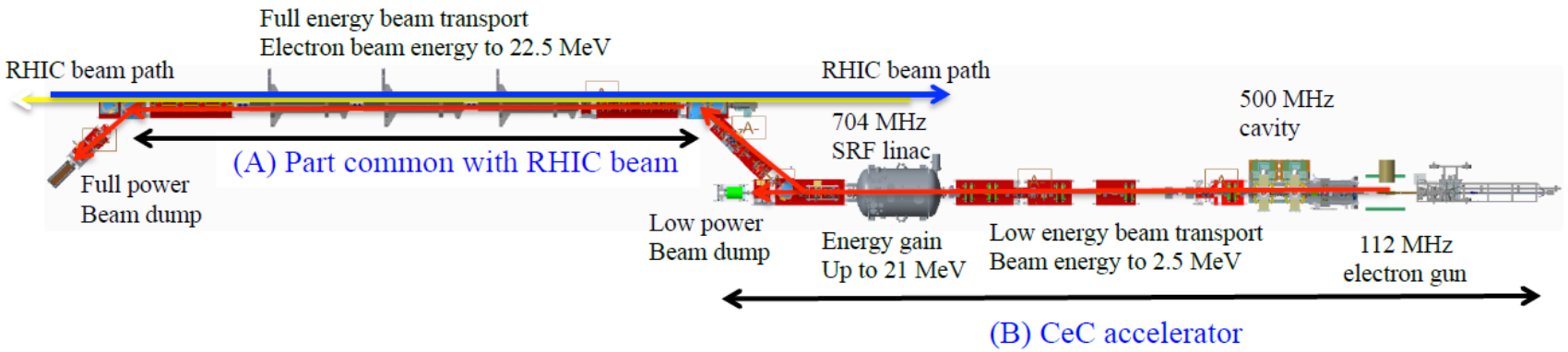

Figure 1 Layout of CeC system: (A) part common with RHIC beam; (B) CeC accelerator. Electron pulses will be generated in a 2-MeV 112-MHz SRF gun and then pass through two 300-kV 500-MHz bunching cavities and transported to the 704-MHz SRF linac for acceleration to full energy up to 25 MeV. The beam will be delivered to the RSC approved dump. Shielding and access controls have been designed for the future full power mode up to 8000 watts. Beam power in the low power test mode is less than 1 watt.

C-AD plans to complete the installation of CeC PoP Experiment equipment before the start of RHIC run 16 in order to be ready for the IRR and ARR. Some of the sub-systems, which do not produce radiological hazards using an electron beam, will be tested before the start of the RHIC run. They are water and power systems, power supplies, RF cavities, magnets, vacuum system and instrumentation.

The CeC PoP Experiment cryogenic system, both 2K and 4K, can be tested only when RHIC cryogenic system is fully operational at the start of RHIC Run 16 scheduled for mid-January 2016. The specific CeC PoP cryogenic system has been reviewed for safety by the BNL Cryogenic and Pressure Safety Sub-Committee.[5, 6, 7]

The laser delivery system and interlock system will be tested using an approved laser SOP and using trained and qualified personnel. Laser operation will commence only after the laser area is secured according to laser safety requirements.

Conditioning of CeC PoP Experiment's three RF systems (112 MHz SRF gun, two 500 MHz bunching cavities and 704 MHz SRF linac) will generate X-rays. Conditioning will be conducted within the RHIC tunnel radiation enclosure after a sweep is completed and the PASS system is operational. Interlocks will block these systems from being turned on if PASS is not operational or if a gate access is attempted. Exposure rates up to 5 R/h are anticipated in the vicinity of CeC PoP Experiment RF cavities during conditioning.

A draft CeC PoP safety analyses and a draft version of a new RHIC ASE are available.[8] Prior to the IRR and following BHSO concurrence on the CeC PoP Experiment safety analyses and approval of RHIC ASE changes, the CeC PoP Experiment safety analyses will be appended to the C-AD SAD, and the new RHIC ASE will be flowed down into a newer version of OPM 2.5.2 Accelerator Safety Envelope Credited Controls and Supports for RHIC. Additionally, a separate ASE procedure for low-power testing will be effective during the low-power test exemption period; OPM 2.5.2.2 Testing Safety Envelope Procedure for Coherent Electron Cooler (CeC) Testing at Low Power (≤1 W) in RHIC. The Internal Readiness Review (IRR) will occur on December 21 and 22, 2015 and the IRR Team is charged to review both the proposed CeC PoP Experiment's readiness for commissioning, and to review the readiness for low-power testing. An ARR will occur in February 2016. Thus, there will be a period of six to eight weeks of independent RHIC operations when low-power testing of the CeC PoP Experiment could be performed.

A Low-Power Test Plan has been developed for this purpose.[9] Electrons will be generated in the 2 MeV 112 MHz SRF gun, pass through 300 kV bunching cavities and transported to the 704 MHz SRF linac for acceleration to full energy up to a nominal 21 MeV.

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[5] LESHC PCSS 15-03, Review of the CEC POP 704 MHz 5-Cell Cavity Cryostat and 2K Cryo Subsystem (password is oper8)
[6] LESHC 13-14 Review the 112 MHz SRF Cavity Gun Cryostat System and Cryogenic Supply Cryostat and Distribution System at RHIC's IP2 (password is oper8)
[7] LESHC 13-09 Initial Review of the 704 MHz 5-Cell Niobium Cavity Cryostat System for the Coherent Energy Cooling (CeC PoP) Project in IP2 (password is oper8)
[8] Links to Safety Basis Documents and Safety Review Progress for C-AD Accelerator Projects
[9] CeC PoP Low Power Test Plan

Low power beam tests will be conducted at low repetition rate, typically 1Hz. Bunch charge will not exceed 10 nC and will typically be 3 nC. The low-power beam testing will be conducted without significantly interacting with RHIC hadron beam. The average electron beam power will not exceed 1 W in 1 hour during any low-power test. The beam will be propagated either to the first beam dump, which is located at the end of the accelerator section, or to a second beam dump, which is located at the end of the CeC PoP Experiment beam line. The maximum beam energy for propagating to either dump will be less than 25 MeV. Beams less than 20 MeV are planned to be transported only to the first dump but an inadvertent lower-energy beam transport to the second dump will not impact safety.

The 3.c (2) exemption for low power beam testing is planned for up to 7 months, from January 1, 2016 through June 30, 2016, or up to BHSO authorization to commission CeC PoP Experiment, whichever comes first. C-AD will conduct the CeC PoP Experiment low-power tests only when the relevant RHIC access control system is operational.

Low-power testing allows for development of an operational CeC PoP Experiment, early detection of any malfunctioning equipment and taking corrective actions. Allowing the CeC PoP Experiment to do low-power testing under Exemption 3.c (2) during the period between the IRR and ARR/BHSO approval is low-risk and is appropriate because of the developmental nature of an experiment.

C-AD bases the safety during testing on the limited power and the low-level radiation hazard it could create.

The gun is capable of producing maximum beam energy of 2.5 MeV, which is limited by the available heat load on the liquid helium system. The beam-accelerating capability of the each 500 MHz buncher cavity is less than 300 kV, which is an experimentally determined value. The energy gain in the 704 MHz linac is up to 21 MeV or about a factor of 10. That is, equipment capability for CeC PoP Experiment devices limits the maximum beam energy to 24.1 MeV.

In all tests, beam power is planned to be within an operations envelope of 0.90 W in order to remain below the safety envelope of <1 W in 1 hour. Radiation-safety analysis has assumed much greater beam power, and protections are designed to shield against the radiation hazards at full power.[10, 11, 12]

The hardware limit on the beam power (2.5 kW) is set by the available RF power from the 2 kW amplifier with 25% added due to possible acceleration of the electron beam in the bunching cavities. With full energy gain in the 704 MHz linac, the maximum beam power is equipment-limited to about 20 kW. The control of the beam power at or less than 0.90 W in 1 hour will be done through the setting of the photocathode drive laser, pulse energy and repetition rate. The RSC has reviewed the engineered system for limiting the experiment to less than 1 W.[12]

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[10] RSC Memo, CeC PoP Beam Test, March 20, 2014
[11] RSC Memo, Radiation Issues Related to the CeC PoP Low Power Beam Dump, September 14, 2015
[12] RSC Memos, November 13, 2015

Diagnostic equipment is available for the low-power beam tests. For the beam passing through the CeC PoP Experiment devices, the following instrumentation will be tested.

1. Charge monitors and associated electronics
2. Six profile monitors and controls
3. Pepper-pot
4. Beam position monitors
5. Faraday cups (FC)
6. Energy measurement devices
7. Timing and synchronizations
8. Triggering of cameras, oscilloscope, BCM, BPM electronics
9. Oscilloscope
10. Machine Protection Systems (MPS)
11. Beam loss monitors
12. IR diagnostics
13. Spectrum analyzer

Safety Basis for Exemption Request for Low-Power Testing

To test the CeC PoP Experiment at low power, C-AD management will adhere to an updated and approved RHIC Safety Envelope Procedure (OPM 2.5.2). In OPM 2.5.2, C-AD defines a relevant set of limits:

- Electron kinetic energy shall be limited to 25 MeV
- Shield blocks in or around penetrations and local beam line shielding will be properly in place and configuration controlled
- Relevant portions of the ACS must be functional if they are preventing access to CeC PoP Experiment beam radiation or CeC RF-generated x-rays inside enclosures, and the ACS must remove beam, or turn off RF, when excessive beam loss or x-ray dose occurs
- Relevant portions of the ODH engineered protection systems (interlocks, sensors, fans and alarms) must be in place to minimize the likelihood of injury/illness from a release of inert gas if they are preventing exposure to CeC PoP Experiment ODH hazards in the RHIC tunnel or in Building 1002A
- RHIC may operate Yellow ring simultaneously with CeC PoP Experiment with up to 12 ion bunches with nominal intensity not exceeding 10^9 ions per bunch and total intensity of $12x10^9$ ions
- With CeC in commissioning or exempt mode and CeC injection only into the abort gap, the on-duty Operations Coordinator shall allow simultaneous RHIC operation

Additional Controls

1. The CeC PoP Experiment Physicist must ensure the updated RHIC ASE procedure, OPM 2.5.2 Accelerator Safety Envelope Credited Controls and Supports for RHIC, and CeC ASE Procedure, OPM 2.5.2.2 Testing Safety Envelope Procedure for Coherent Electron Cooler (CeC) Testing at Low Power (≤1 W) in RHIC, are implemented during CeC PoP Experiment low-power testing.
2. The CeC PoP Experiment Physicist must ensure control of the beam power at or less than 0.90 W averaged over 1 hour through the setting of the photocathode drive laser, pulse energy and repetition rate. These settings must be under configuration control.

Evaluation of Radiological Issues during Low-Power Testing

The CeC PoP Experiment relies on bulk shielding of the RHIC tunnel and the relevant portion of the RHIC Access Control System for radiation protection. Cableways have been blocked with additional shielding. Cooling water and the electron beam dump may be activated by photo-neutrons. The low power beam dumps have been evaluated for a series of radiological issues at 2 MeV and 22 MeV. These include dose rate outside the enclosure, beam dump heating, ozone production, air activation, soil activation, and residual activity. The results are well below any exposure or environmental limits.[13, 14, 15]

Specific Assurance Methods for Low-Power Testing

C-AD management has employed the following assurance methods specific to this test:

1. The existing RHIC tunnel shielding will be used
2. The CeC PoP Experiment Physicist and engineered-safety-system owners shall sign the Radiation Safety Check-off list prior to enabling low-power tests
3. The CeC PoP Experiment Physicist shall be required to be present during any period of testing with low-power electron beam
4. Radiation surveys shall be performed during the testing
5. The IP2 experimental area shall be subject to the C-AD RHIC sweep search procedures, and equipment operation will be subject to the relevant RHIC PASS interlocks during CeC PoP Experiment testing

[13] C-AD Radiation Safety Committee, Memorandum from D. Beavis, September 16, 2015
[14] C-AD Radiation Safety Committee, Memorandum from D. Beavis, March 20, 2014
[15] C-AD Radiation Safety Committee Minutes, 11-12-15 (1) and [15] C-AD Radiation Safety Committee Minutes, 11-12-15 (2)