Jefferson Lab
Thomas Jefferson National Accelerator Facility

Operational Safety Procedure Form

(See ES&H Manual Chapter 3310 Appendix T1 Operational Safety Procedure (OSP) and Temporary OSP Procedure for instructions.)

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Title:	748.5 MHz Buncher Cavity Operation at the Upgraded Injector Test Facility		
Location:	Upgraded Injector Test Facility (UITF) located in the Test Lab High Bay Area, rooms 1125 - 1127	**Type:**	☒ **OSP** ☐ **TOSP**
Risk Classification (per Task Hazard Analysis attached) (See *ESH&Q Manual Chapter 3210 Appendix T3 Risk Code Assignment*.)		**Highest Risk Code Before Mitigation**	3
		Highest Risk Code after Mitigation (N, 1, or 2):	1
Owning Organization:	Accelerator Division	**Date:**	February 13, 2019
Document Owner(s):	Matt Poelker		

DEFINE THE SCOPE OF WORK

1. Purpose of the Procedure – Describe in detail the reason for the procedure (what is being done and why).

The purpose of this OSP is to assess to what extent the 748.5 MHz normal-conducting copper-cavity buncher installed on the keV beamline at the UITF poses an ionizing radiation hazard, as a result of inadvertent field emission, and to determine how much additional energy the buncher can provide the beam when it is mis-phased (note, under normal operation, the buncher does not accelerate beam, rather it is phased to "bunch" the beam, i.e., reduce the bunchlength).

This OSP describes two different measurements that can be scheduled many months apart:

1) Determine the onset of field emission when the buncher is powered by the solid state amplifier capable of providing 7 kW of RF power, and measure the x-ray levels near the buncher when field emission is present (x-rays may not penetrate the thick copper walls of the buncher).
2) Then pass electron beam through the buncher and deliver this beam to the keV spectrometer beamline. Crest the buncher to accelerate beam and measure the energy boost provided by the buncher as a function of applied RF power.

These measurements are needed to evaluate the efficacy of UITF shielding, and to determine to what extent the buncher represents a radiation hazard under normal operating conditions.

As described below, the buncher and solid state amplifier can only be energized when the UITF is swept clear of personnel and the PSS is utilized, i.e., no one will be inside the UITF when the buncher cavity is energized. The solid state amplifier can only be energized when Safety System Group-approved interlocks are made up.

The UITF can function as a gun test stand, where beam energy does not exceed the bias voltage applied to the photogun. Or it can operate as an accelerator when beam is accelerated to an energy that exceeds the potential energy applied to the gun. For this discussion, full blown accelerator operation describes ~MeV beam energies and is beyond the scope of this OSP. Although as stated above, the buncher can be mis-phased to accelerate beam, even under worst-case situations, this circumstance will not result in MeV beam and for this reason, this OSP describes "gun test stand" operation (see below).

For the purposes of hazard assessment, FSAD Rev. 8* considers all the hazards associated with the UITF and specifies required mitigations. Operations related to high-power RF commissioning of the QCM are governed by this OSP that addresses the relevant hazards and mitigations. Hazards associated with operation of the UITF as an accelerator require the use of credited controls. Those credited controls are identified in the FSAD Rev. 8 (and incorporated into the UITF Accelerator Safety Envelope (ASE)). The requirements for operating the UITF as an accelerator are incorporated in another OSP that addresses the relevant hazards and mitigations associated with both operation as a Gun Test Stand and as an operational accelerator as specified in the ASE.

* Final Safety Assessment Document Rev 8 https://jlabdoc.jlab.org/docushare/dsweb/Get/Document-160467/FSAD%20Rev8%2011%202018%20with%20signature.pdf

2. Scope – include all operations, people, and/or areas that the procedure will affect.

High Power RF Commissioning of the 748.5 MHz normal-conducting copper buncher cavity

The 748.5 MHz buncher and the solid state amplifier described in this OSP were originally purchased for an intended upgrade of the FEL injector, but the upgrade never happened. Because these items were not being used, it was decided to use the equipment at the UITF although the amplifier is considerably more powerful than needed for typical UITF operations.

The buncher and solid state amplifier are shown in Figure 1, left and right, respectively. The buncher cavity resides inside Cave 1 of the UITF enclosure, and is part of the evacuated keV beamline. The solid state amplifier resides above Cave 1, near the electronics racks. RF power from the solid state amplifier is delivered to the buncher using a rigid coaxial waveguide that passes through a penetration in the Cave 1 ceiling. More details related to facility description and shielding are provided in sections below.

Figure 1: (left) the normal-conducting copper-cavity 748.5 MHz buncher installed on the UITF keV beamline, and (right) the 7 kW solid state amplifier located above Cave 1 near the electronics racks. A rigid coaxial waveguide connects the two devices, with the waveguide passing through a penetration in the Cave 1 roof.

Although other hazards are addressed in this OSP, it is largely focused on the ionizing radiation hazards that the buncher might present, stemming from two mechanisms:

Field emission:

The solid state amplifier is considered to be "high power", comparable to klystron RF power supplies used at CEBAF. We do not intend to drive the copper buncher cavity to the point of generating field emission during normal operations, but it seems likely that such a condition can exist before reaching the power limit of the solid state amplifier. Field emitted electrons from the interior surface of the buncher cavity walls could be accelerated to high energy and these electrons will generate x-rays when they strike the vacuum chamber walls.

Buncher miss-phased to accelerate beam:

As the name implies, a buncher cavity is typically used to reduce the electron bunchlength. Bunching happens when electrons arrive at the buncher at a specific time, i.e., arrival time at a specific phase of the RF cycle – what we call "zero crossing". At zero-crossing, the head of the electron bunch is decelerated, and the tail of the bunch accelerated, producing a shorter electron bunch but providing no net acceleration overall. However, if the buncher phase is adjusted, it can be configured to provide acceleration. As shown in Figure 2, under normal UITF beam operating conditions, the buncher will be driven with ~ 40 W of power, and even when mis-phased, this would provide only a very small amount of acceleration, approximately 10 V. More relevant to this OSP, Figure 2 also shows a "worst-case" scenario: the buncher operating "on crest" and powered with the full 7 kW of RF power the solid state amplifier can provide. Under this condition, an electron beam gains 200 kV, effectively doubling the energy of the 200 keV input beam. This is considered a "worst case" scenario because the buncher was designed for 500 keV beam for the original FEL application. For a 200 kV input beam at UITF, the buncher will likely provide less acceleration because electron bunches will be longer and spanning a greater portion of the rf-phase.

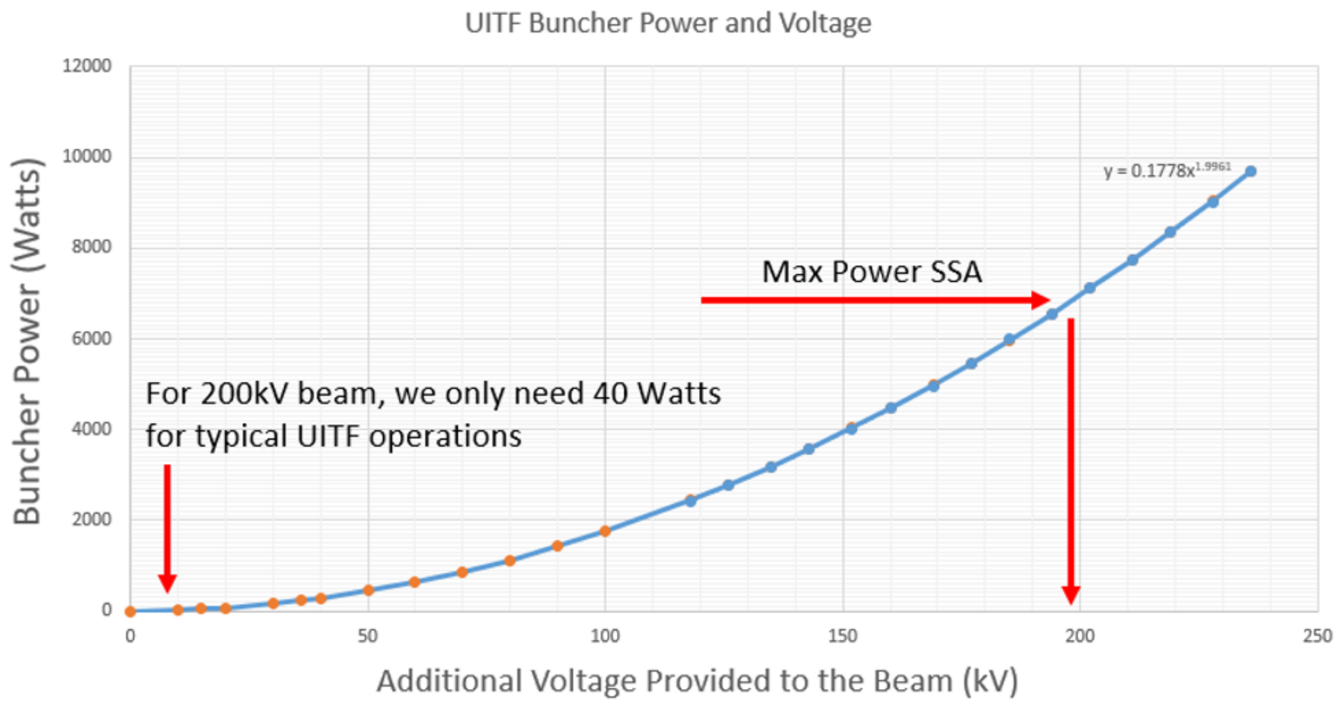

Figure 2: The possible acceleration capability of the normal-conducting copper-cavity 748.5 MHz buncher installed at UITF. When powered at 7 kW, a 200 keV input beam could gain ~ 200 kV (red arrows). This is considered a "worst case" scenario because it assumes electron beam parameters for the original FEL application (i.e., 500 kV input beam). For typical UITF beam operations, the buncher will operate at just ~ 40 W power and beam acceleration, even when mis-phased, will be very small, ~ 10V.

Buncher testing will be implemented in two parts, and these tests could be separated by months:

1) First, the buncher will be driven with RF power until field emission is observed, and this level of RF power will be compared to normal operating conditions.
2) Afterwards, the buncher will be tested using a 200 keV input electron beam, to determine the maximum acceleration the buncher can provide.

The affected area is the entire UITF enclosure composed of Cave 1 and Cave 2, and the region above Cave 1 where the solid state amplifier is located. All tests will be performed using the UITF PSS, with the UITF enclosure cleared of staff and the enclosure doors locked Closed. The solid state amplifier is connected to the PSS and can only be energized when SSG approved interlocks are made up, more below.

3. Description of the Facility – include building, floor plans and layout of the experiment or operation.

Global description of UITF composed of Cave 1 and Cave 2:

The location of UITF is the High Bay Area of the Test Lab building 58. Figures 3, 4 and 5 show the UITF layout and identify Caves 1 & 2, which are convenient designations referencing old and new test areas, respectively. The buncher resides in Cave 1, but operation of the buncher also affects Cave 2 because Cave 1 and Cave 2 form a common space. The solid state amplifier is located near the electronics racks above Cave 1. In Figure 5, for illustration purposes only, the roof of Cave 2 is shown removed.

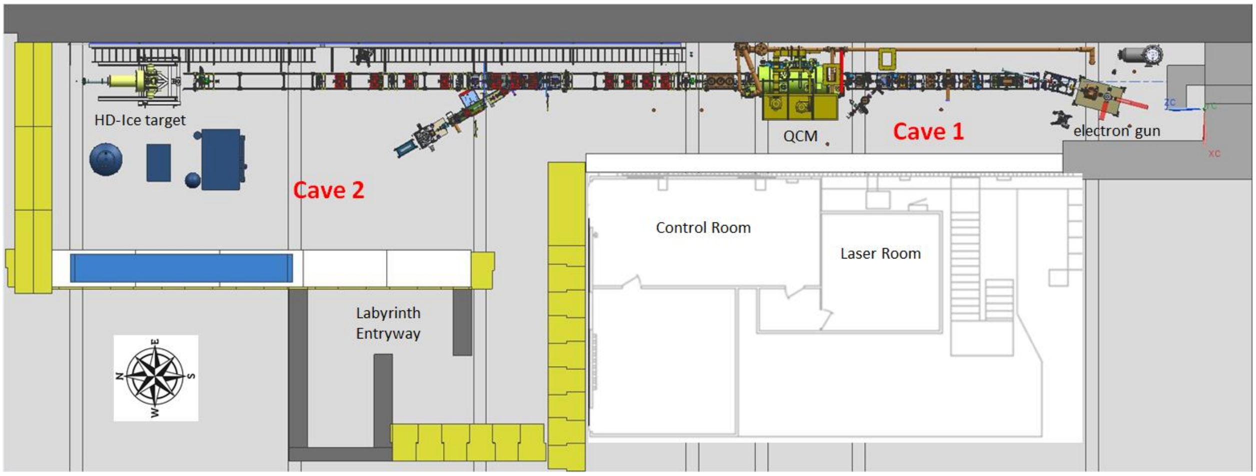

Figure 3: UITF enclosure composed of two "Caves". The buncher resides inside Cave 1.

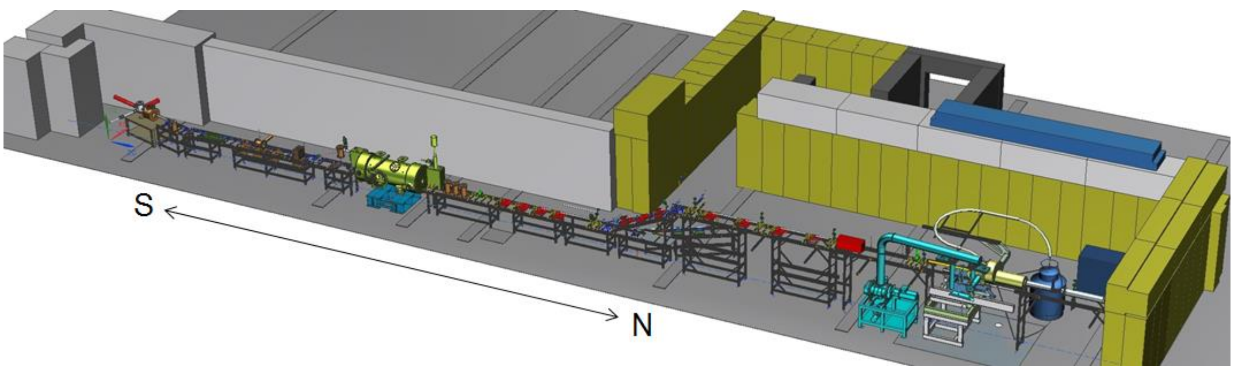

Figure 4: UITF layout showing the main exit towards the high bay area of the Test Lab and the MeV beamline and HDIce target. The MeV beamline is not relevant to this OSP but is shown for clarity.

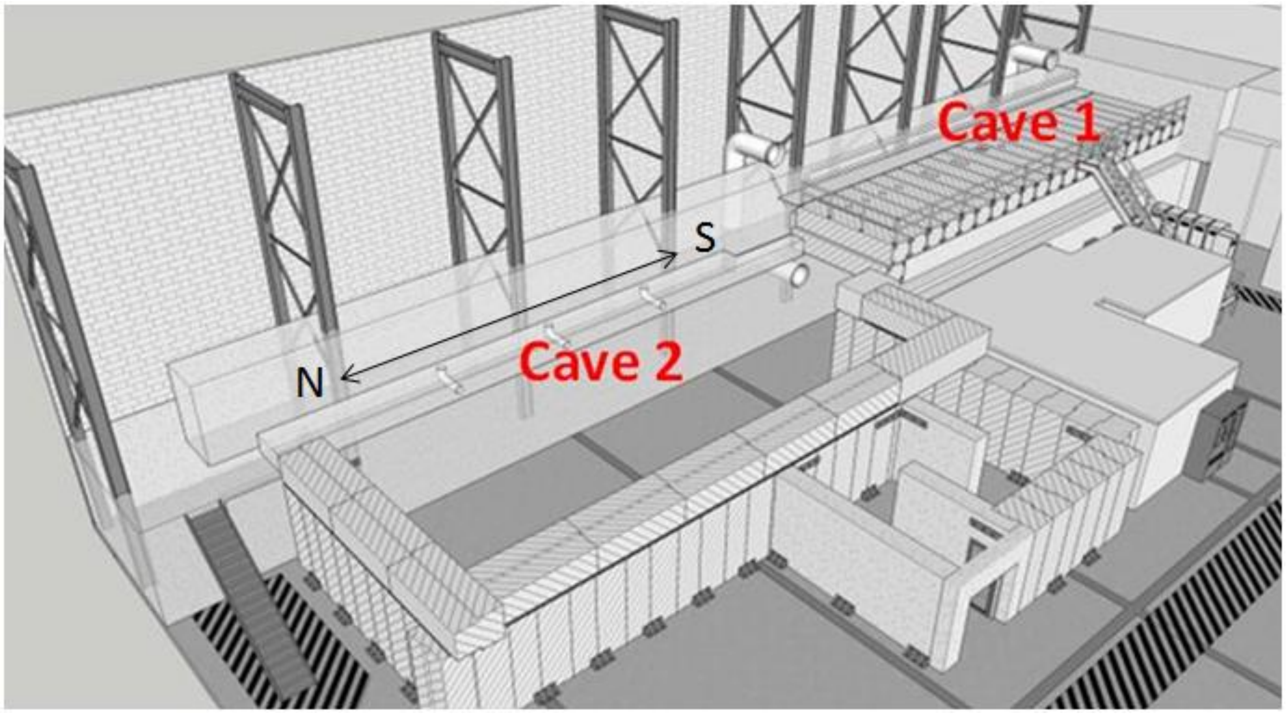

Figure 5: UITF layout showing the main entrance Labyrinth and shielded roof of Cave 1. Klystron racks, electronics racks and the buncher solid state amplifier are located above Cave 1.

Close-up view of keV beamline in Cave 1

The buncher is designed to provide a longitudinal beam waist (i.e., a bunchlength minimum) at the location of the two-cell capture cavity within the quarter cryomodule (QCM). Typically, a buncher is placed equidistant from the photogun and the location of the longitudinal waist, but as can be seen from Figure 6 below, the buncher is slightly closer to the QCM than the photogun, however this is not expected to pose a significant problem for beam delivery.

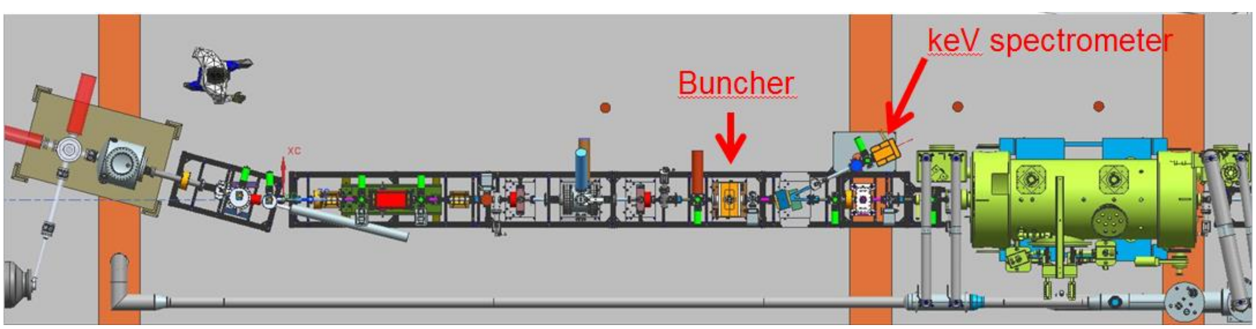

Figure 6: The schematic layout of the photogun and the keV beamline located inside Cave 1 of the UITF enclosure. The buncher and keV spectrometer are labeled.

Figure 7 shows a photograph of the buncher positoned on the keV beamline, looking toward the photogun. RF power is supplied via a rigid coaxial waveguide. The buncher cavity is maintained at constant temperature using a dedicated "water skid" that also includes temperature interlocks. The buncher cavity was baked to provide ultrahigh vacuum, but we anticipate the need for "vacuum conditioning" when first energized, i.e., we will slowly apply RF power while monitoring and maintaining relatively good vacuum. Vacuum outgassing will diminish with extended operation of the buncher.

Figure 7: Photograph of the buncher installed on the keV beamline at UITF, looking toward the photogun.

For the first test of the 748.5 MHz buncher – to assess the onset of field emission – no electron beam is required. Afterwards, low current electron beam (viewer-safe beam, nanoAmpere average current) will be passed through the buncher and directed to the beam dump in the keV spectrometer line, to evaluate the accelerating capabilities of the buncher. Procedures related to both measurements are outlined below.

ANALYZE THE HAZARDS and IMPLEMENT CONTROLS

4. Hazards identified on written Task Hazard Analysis

Refer to attached Task Hazard Analysis Work Sheet for details and mitigation. The following lists the hazards.

1. Ionizing Radiation
2. RF Non-ionizing Radiation
3. Electrical
4. Pressure / Vacuum
5. Oxygen Deficiency (the buncher does not pose an ODH hazard but tests are performed inside the UITF

where ODH hazards exist)

5. Authority and Responsibility:

5.1 Who has authority to implement/terminate

- **Facility Manager** – This responsibility is assigned by the Accelerator Division Associate Director. This individual has ownership of the facility and has overall responsibility for safe configuration and operation of the facility. Matt Poelker is the present UITF Facility Manager, but others in the Center for Injectors and Sources could be assigned this designation too.

- **Principal Investigator (PI)** – The PI is assigned by the Facility Manager. The PI has overall responsibility for a given test plan or experiment. The PI is responsible for planning and executing the test plan, ensuring that operations are carried out in a safe manner, directing the activities of system operators while they are on shift, and insuring that the facility is properly staffed. The PI must be cognizant of the status of the facility and any device under test in the facility for the duration of the test. The PI must have a thorough understanding of the configuration and operation of the relevant systems required for the execution of the planned experiments. For most routine operation, the Facility Manager may also serve as the PI. Presently, PIs are members of the Center for Injectors and Sources, the Injector Group of the Operations Department and the RF Group of the Engineering Division.

5.1 Who is responsible for key tasks

- **Principal Investigators (PI's)** have to demonstrate to the Facility Manager that the test is appropriate. The PI must ensure that tests can be performed in a safe manner. The PI or approved designee must be on-call while the respective test is being performed.

- **RF System Operators:** They are members of the Engineering Division familiar with RF control systems and power amplifiers. They assist the Principal Investigators in the execution of tests and the changing of RF system configurations. They must have a thorough understanding of the configuration and operation of the PSS and MPS systems, as well as the configuration of the MPS and RF systems required for the execution of the planned experiments. They should also have a general understanding of the interactions of the cryogenic systems with the specific RF tests. They are responsible for safe operation of the facility and have the authority to stop any experiment if they feel that there is unnecessary potential to damage equipment or if there is an elevated level of risk of injury.

- **UITF Operator:** UITF Operators are people familiar with electron beam generation, delivery and acceleration. Presently UITF Operators are members of the Center for Injectors and Sources, and the Operations Department.

- **The Radiation Control Department (RCD)** insures that all radiation safety requirements, e.g. shielding configuration and postings, are met for this specific running mode. RCD will provide radiation survey support as well as maintenance support of any radiation monitoring equipment that is associated with Personnel Safety.

- **Industrial Hygiene** shall provide RF survey assistance upon request.

- **The Group Leader of the Safety Systems Group** (SSG) or his designee is the owner of the Personnel Safety System (PSS).

5.2 Who analyzes the special or unusual hazards including elevated work, chemicals, gases, fire or sparks (See ES&H Manual Chapter 3210 Appendix T1 Work Planning, Control, and Authorization Procedure)

Task Hazard Analyses (THA's) for any Test Plans that require operation of the facility in a manner that is outside the scope of this OSP and existing THA's will be executed by the Facility Manager acting in concert with the relevant Subject Matter Experts (SME's):

SME's will include but are not limited to the following individuals or their designees:

- Jerry Kowal - Safety Systems Group Leader – PSS, MPS and ODH Monitoring
- Rick Nelson – RF Safety
- Keith Welch – Radiation Control Department
- Harry Fanning – Accelerator Division Safety Officer
- John Hansknecht – Safety Warden
- Jennifer Williams – ODH and Industrial Hygiene

6. Personal and Environmental Hazard Controls Including:

6.1 Shielding

The 748.5 MHz normal-conducting copper-cavity buncher installed on the keV beamline at the UITF can be driven with sufficient RF power to produce ionizing radiation via inadvertent field emission. And the 748.5 MHz normal-conducting copper-cavity buncher can be phased in such a way as to accelerate electron beam passing through it. Although the performance of the buncher has not yet been evaluated, the Radiation Control Department (RCD) has recommended and evaluated the shielding at UITF to mitigate radiation hazards.

Key Shielding Features:

The east wall of the UITF enclosure (see figure 1) is many meters thick and is an effective radiation barrier. The west wall of Cave 1 is 55" thick to a height of 103" (i.e., approximately 8.5'). Above 103", the wall thickness is approximately 27 to 28" thick. Cave 1 has 30" concrete shielding on the roof. There are nine penetrations in the Cave 1 ceiling. Six circular penetrations (~ 10" diameter) provide a means to pass cables to connect beamline devices to the controls located in the electronics racks above. One rectangular penetration serves to pass the RF coaxial waveguide to the buncher cavity and also provides a means for helium gas to escape the UITF enclosure (see section 6.5 Ventilation). All of the penetrations, except for the one used for RF waveguides to the quarter cryomodule, have 3.5" iron shielding directly beneath (Figure 8, below). The penetration used to attach the quarter cryomodule to the klystrons is filled with sand.

Figure 8: The rigid coaxial RF waveguide passing through a rectangular ceiling penetration in Cave 1, connecting the buncher cavity to the solid state amplifier. The iron plate hanging below the penetration provides radiation shielding.

Two penetrations serve as helium vent holes should the Cave 1 enclosure fill with helium gas. Above the cave, these penetrations have "chimney stacks" attached (more in Section 6.5 Ventilation), to direct the light helium gas safely above the heads of occupants who might be working atop the Cave 1 enclosure. Bags of gravel placed at the base of each chimney-vent stack provide additional shielding at these penetrations although these are not considered credited controls.

Floor Trenches: The floor trenches provide a means to pass electrical conduit and control cables from the UITF enclosure to the Test Lab High Bay, the Drive Laser room, the UITF control room, etc., But the trenches also represent pathways for ODH gasses and radiation. To address these concerns, the trenches were filled with layers of foam to prevent ODH gasses from leaving the UITF enclosure, and with lead brick and gravel bags to provide radiation shielding. Additional layers of lead brick shielding are placed on top of the iron plate that cover the trenches. This trench shielding is an important credited control for UITF and is labelled as such, and cannot be moved without RCD permission. Examples of trench foam and lead shielding are shown in Figure 9 below;

Figure 9: floor trench preparations to address ODH and radiation shielding concerns: the top images show foam installed inside the trench to restrict the flow of ODH gas, and the bottom images show lead brick and gravel-bag shielding inside the trench and lead brick above the iron trench plate. This shielding is a vital credited control and is under RCD control and cannot be removed without permission. Credited control signage is located at each trench, although not shown in the photos above.

Although the 748.5 MHz normal-conducting copper-cavity buncher is located in Cave 1, the entire UITF enclosure (Cave 1 and 2) will be swept and made clear of personnel. The main entrance labyrinth and the south access labyrinth prevent line of sight exposure to x-ray radiation for people working in the main high bay area outside the UITF enclosure.

An assessment by the Radiation Control Department (RCD) indicates Cave 1 is adequately configured with sufficient shielding to mitigate radiation hazards. The link to the shielding calculations can be found at: https://misportal.jlab.org/doc_validation/processes/13 and at https://misportal.jlab.org/doc_validation/processes/29

The top of the UITF Cave 1 roof is accessible during buncher operation but the area is considered a Radiologically Controlled Area (RCA) with signage provided by RCD indicating access restrictions and dosimeter requirements. Signage will be posted at the bottom of the stairs leading to the Cave 1 roof (see Figure 10). RCD will monitor radiation levels and add, modify or remove postings as appropriate based on prevailing conditions. It is presently assumed that the minimum posting level of the Cave 1 roof will remain RCA for the duration of buncher commissioning and subsequent commissioning of the accelerator.

Figure 10: During UITF operations, the top of UITF Cave 1 roof is a Radiologically Controlled Area and dosimetry is required to access the roof.

During initial buncher commissioning, RCD will conduct radiation surveys of accessible areas outside the UITF enclosure to verify shielding effectiveness and establish final operational limits, alarm thresholds, and postings.

Activation
Buncher operation presents no possibility for activation of nearby materials, even at the highest achievable RF powers.

6.2 Barriers (magnetic, hearing, elevated or crane work, etc.)

The buncher is under vacuum. During field emission testing (no beam delivered to the buncher), beamline valves on either side of the buncher will be closed, but with epics control maintained. It could be advantageous to open the valves to provide additional pumping if significant outgassing is observed.

The doors to UITF represent barriers, and these will be closed and locked using the UITF PSS. See below in

Section 6.3 Interlocks

Some of the ceiling tiles above Cave2 are designed to be removable to permit installation/removal of large equipment like the HDIce target and the QCM. These ceiling tiles are located near a helium vent described in Section 6.5 Ventilation. There is a grating installed near this vent to prevent personnel from entering the UITF enclosure (see Figure 11). When the roof tiles are removed for installation/removal of equipment, the grating must also be removed. The grating is an essential configuration-control device and must be in place before UITF is operated in any mode that can generate radiation. The grating must be confirmed in-place during the Pre-Sweep process.

Figure 11: the grating at the Cave2 helium vent that prevents entry into the UITF enclosure. Attached signage designates the grating as UITF credited control but is not shown in this photograph.

6.3 Interlocks

The UITF's Personnel Safety System (PSS) ensures that personnel cannot access the UITF enclosure when prompt radiation hazards are possible. And the PSS will turn OFF radiation sources when unacceptable radiation levels are detected by CARMS placed outside the enclosure at locations designated by RCD. Radiation exposure is prevented through both administrative (sweep procedures, locked gates, postings) and engineered means (shielding, interlocks, radiation monitoring, etc.). UITF (see Figure 12) is a completely enclosed area. No one is allowed inside the enclosure when RF is applied to the buncher cavity, or during the production of electron beam from the photogun.

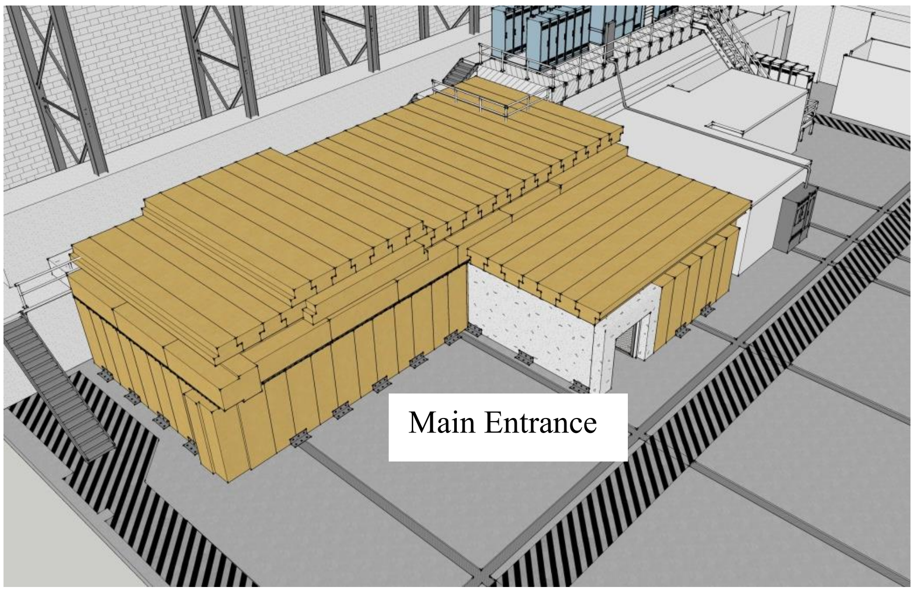

Figure 12: UITF with concrete shielding in place

As mentioned above, there are two entry/exit ways at the UITF. The main entrance/exit is from the high bay area through a labyrinth the leads to Cave 2. The secondary entrance/exit into the high bay is from the southern-most location of the keV section in Cave 1. Both doors have Personnel Safety System interlocks and emergency exit switches on the nearby walls (Right). Warning beacons exist at both entrance/exit ways. Photographs of the entry/exit ways are shown in Figures 13 and 14, along pictures of the run safe box, signage, and the warning beacons.

Figure 13 (Left) Main entrance/exit through the labyrinth of UITF, (Middle) Secondary entrance/exit from the

southern-most location of the keV section in Cave 1. Both doors have Personnel Safety System interlocks and emergency exit switches on the nearby walls, (Right) Beacons exist at both entrance/exit ways

Figure 14 (Left) Exit door into high bay from Cave 1 near the electron gun (Middle) Run/Safe Box (Right) Crash Switch for exit. Run/Safe Boxes and Crash switches are at both the entrance/exit ways

There are four PSS states: OPEN, SWEEP, READY and RUN. OPEN state is the safe state, when doors are open and the UITF enclosure can be occupied by personnel. The RUN state issues "permits" to RF sources, the Gun High Voltage power supply and PSS laser shutters. "Permits" allow these devices to be energized.

There are radiation monitors – referred to as CARMs – that are interlocked to the PSS system. CARMs are used to detect radiation outside the UITF enclosure. CARM placement is determined by the RCD, see Figure 15 for approximate CARM locations above Cave 1. An additional interlocked probe is located in the Control Room. When CARMs detect unacceptable levels of radiation in Run state, the PSS will drop to READY state, removing all the permits.

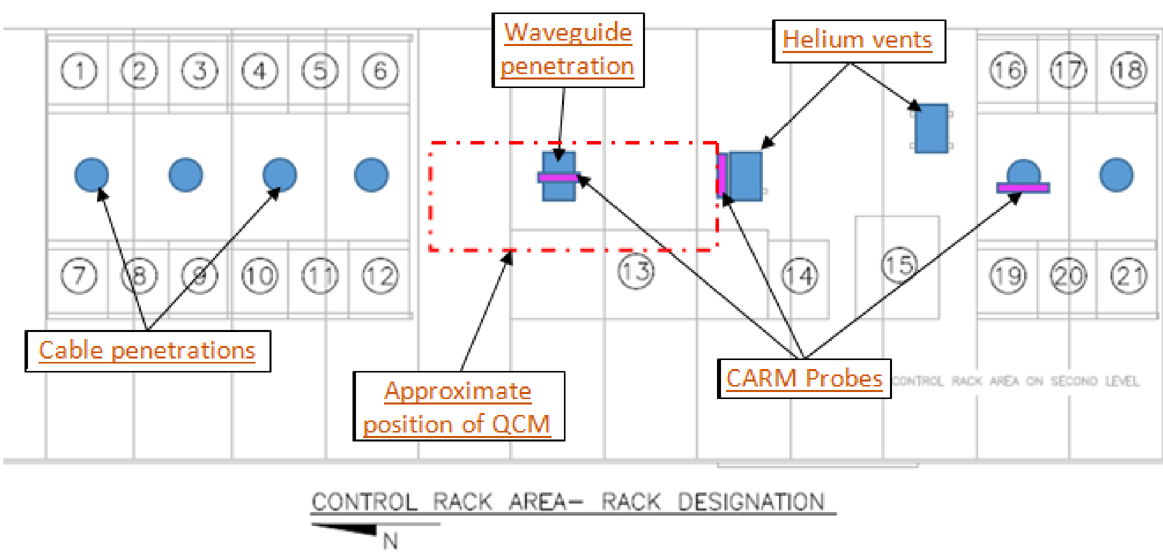

Figure 15, schematic layout of the electronics racks above Cave 1 showing approximate location of CARM probes on the Cave 1 rooftop. There is also a CARM in the Control Room.

In OPEN state, the main entrance/exit will be in use. The secondary exit door can be used as needed, but is primarily considered an emergency exit. The main and secondary entrance/exit doors are part of the PSS, with magnetic locks that engage and prevent entry when the UITF enclosure is swept and the PSS is set to the RUN state. When door interlocks are breached while the PSS is in the RUN state, it will drop to OPEN state and turn OFF all radiation sources.

Additional details related to the PSS interlocks:

There are signals warning about potential prompt radiation:

a) Magenta Beacons are active as soon as UITF PSS Controller is switched to SWEEP State and these beacons stay ON for all higher States. Beacons are located at both doorways and above Cave 1 near the electronics racks

b) 30s siren is turned ON, when UITF is about to switch to RUN State. This means the RUN State is delayed by 30s while the warning siren sounds

In addition, when a CARM is tripped, it drops the UITF PSS Controller from RUN State to READY (safe) activating latched audible and visual alarm indicators in the UITF Control Room. The audible alarm can be silenced when RESET pushbutton is pressed once. If the cause of alarm is not present anymore, then the RESET pushbutton, when pressed 2nd time, will clear the visual alarm. It is not necessary to clear the latched alarms to return to RUN State as long as there is no active CARM trip. Trip of the CARMs will trigger radiation alarm (audible and visual) at the UITF Control Room independently of the PSS State.

Relevant to this OSP, solid state amplifier used to power the buncher is interlocked to the PSS and can only be energized when the UITF enclosure is swept, cleared of personnel and taken to the RUN state. The PSS will turn OFF the applied RF to the buncher when UITF enclosure door interlocks are breached or when CARMs indicate excessive radiation measured outside the enclosure.

The solid state amplifier is located near the electronics racks above Cave 1, see Figure 1. Besides the vendor-supplied interlocks used to prevent damage to the solid state amplifier, there are JLab-provided interlocks that help to ensure personnel safety and machine protection. These include:

a) AC power interlocks (contactors) controlled and monitored by PSS
b) Enclosure door interlock that prevents opening of the solid state amplifier while it is energized.
c) Cooling water flow interlocks
d) Vacuum interlock to prevent energizing the buncher when beamline pressure is unacceptably high

Configuration Control related to high power RF:

All PSS cables, conduits, and control devices are either labeled or placed in locked enclosures. Only Safety Systems Group personnel may access these devices.

The RF interface devices that are owned by the Safety Systems Group:

a) AC Contactors located in rack ITF14 near the klystron racks above Cave 1 (locked rack)

Certain devices that are critical for safe UITF operation, such as RF high power amplifier power supplies, are interfaced to the PSS but are not owned by the Safety Systems Group. The safety function of these devices still falls under PSS configuration control.

Devices not owned by the safety systems group but under PSS configuration control:

a) 5kW / 1497 MHz klystron power supply PSS interlock chain
b) Wave Guide pressure interlock for the quarter cryomodule

The devices listed above shall have a PSS configuration control sticker. The sticker instructs anyone that may want to disconnect the device to first contact a member of the Safety Systems Group. As an alternative to the automated safety interlock system, the Safety Systems Group may maintain configuration control through the use of administrative lock and tag and the PSS jumper request system. Administrative lock and tag may only be used to render a device Off/Safe. Administrative lock and tag and jumpers used for bypassing the normal PSS configuration of a device may only be applied by a member of the Safety Systems Group.

6.4 Monitoring systems

There are three monitoring systems related to safety at the UITF:

1) The PSS, explained above, provides access control to the UITF and protects personnel from prompt ionizing radiation associated with UITF operation. The PSS monitors the configuration of the doors, open or closed. CARMs are part of the PSS, used to detect radiation outside the UITF enclosure. When radiation levels exceed values specified by RCD, a laser shutter closes and terminates beam delivery. Similarly, CARMs will turn OFF high power RF when radiation levels exceed specified values, for example during buncher commissioning related to this OSP. CARM alarms are indicated inside the Control Room.

2) There is an ODH monitoring system, which alarms when the oxygen level in the UITF enclosure drops below 19.5%. There are three sensors for helium and one sensor for nitrogen. Helium sensors are located near the ceiling, and spaced roughly equidistant along the length of the enclosure: one helium sensor head near the expected location of the HDIce target, one near the QCM and the other near the keV beamline. The nitrogen sensor is located close to the floor, near the QCM. ODH alarms are located at each door and also in the Control Room.

3) The third monitoring system relates to the pressure within the SF6 tank that houses the Glassman gun high voltage power supply. There is a digital pressure gauge that monitors SF6 pressure, and can be configured to "alarm" when pressure falls below a User specified level. The alarm is a Yellow LED that illuminates at the SF6 tank. The alarm is also an EPICS signal. The alarm is triggered when pressure drops from 60 to 58 psi. Finally, there is an Ashcroft pressure switch that will shut off the Glassman HV power supply when SF6 pressure falls below 45psi. Note: the photogun high voltage power supply will NOT be energized during the implementation of this OSP and is only listed here for completeness sake.

Radiation Mitigation

Penetrations through the roof of Cave 1 create potential for localized elevated radiation levels, even under normal operating conditions. All but one of these penetrations is equipped with shadow shielding to mitigate the condition, but these locations remain potential sources of exposure. As shown in Figure 15, interlocked CARM probes are placed adjacent to several penetrations and in the UITF Control Room. Administrative controls (e.g. posting as a Radiologically Controlled Area or Radiation Area) may be applied to limit access to portions of the roof until radiation monitoring proves that they are otherwise unnecessary. Additional shadow shielding will be used, if needed, to reduce the intensity of radiation oriented towards the labyrinth on the northeast end of the test area. An active area radiation monitoring system, surveys, and operations log reviews will be conducted to ensure that the doses to monitored and unmonitored personnel are less than the JLab design goals and ALARA. Passive integrating dosimeters at key locations will be used to provide additional verification that doses outside the shielded enclosure are kept ALARA. If exposure design goals appear to be in jeopardy of being exceeded, further controls will be established or documented justification to exceed them will be produced. The access points will be posted and controlled in accordance with the Jefferson Lab EH&S Manual and Radiation Control Manual.

Some scattered radiation (through cable trenches, penetrations, etc.) may be present outside even the thickest parts of the shielding. Consequently, the Radiation Control Department will evaluate the need for shielding and/or active radiation monitors outside the test area where there are trenches, joints or cracks between concrete walls, doors, etc. or other shielding discontinuities. Careful placement of shielding and/or interlocked radiation monitors will be used to prevent a "Radiation Area" condition from occurring outside the UITF. Any removable shielding is inspected and posted as configuration controlled shielding. RCD verifies the configuration of interlocked radiation monitors and shielding semi-annually.

On-line interlocked radiation monitors (CARMs) and associated warning devices (magenta beacons) are installed at access points to the UITF, and on top of the UITF roof near the electronics racks and penetrations. On-line radiation monitoring is part of the operating procedures. If the radiation level outside the shielding should exceed administrative trip points, the radiation monitor will open the guard line that interrupts RF delivery to the UITF. All radiation detectors associated with the on-line monitoring system shall be properly maintained, calibrated at least annually, and tested during each PSS certification. RadCon, in coordination with the Principal Investigator and UITF Operator on duty, will perform these actions. Portable survey meters will be used to periodically survey areas outside of the test area. Routine and special surveys will be taken by RCD staff and will be coordinated with the operations staff to ensure that the surveys are appropriately coupled to operating conditions. Copies of these surveys will be made available to UITF operations staff.

For the buncher testing conducted under this OSP, four locations are monitored by interlocked CARM probes as described in Section 6.3. Trip of the CARMs will trigger radiation alarm (audible and visual) at the UITF Control Room independently of the PSS State. Resetting of alarms is described above. Response to CARM alarms is discussed below.

CARM Alarm Response

CARM alarms will terminate radiation-producing activities in the UITF. In the event of a CARM alarm, the Principal Investigator (PI) or UITF Operator shall notify (RadCon) through the duty phone 757-876-1743 and discuss the operational activities that preceded the alarm. RCD staff may require a supplementary radiation survey as radiation producing activities recommence. RCD staff will address the results of the radiation survey with the PI and/or Operator and discuss the mitigating measures, if necessary, for continued operation. The PI will then determine when operations may resume.

6.5 Ventilation

Cryogenic gasses and fluids can be delivered to the quarter cryomodule (QCM) from the CTF refrigerator, gaseous N2, gaseous He, liquid helium (LHe) and liquid nitrogen (LN2). In addition, gaseous nitrogen “boil off” is provided to the UITF. Because the buncher employs no cryogenic fluids, only a brief description of UITF ventilation is provided here. For a full description of ODH hazards, please see the approved ODH assessment found at: https://misportal.jlab.org/railsForms/oxygen_deficiency_reviews/74180/edit

There are two fans on the east wall of Cave 1 (Figure 16). In addition, there are three 0.15 m (6”) diameter vent holes on the west wall near the ceiling and two 0.3m x 0.3m (12”x12”) square vents. These square vent holes have chimneys attached to them on the ceiling. The height of the chimneys is about 7 ft. which will mitigate any hazard in the unusual event of cryogenic gas release in Cave 1. The existence of these fans is included for completeness of information, however the ODH assessment of UITF does not take credit for the existence of these fans.

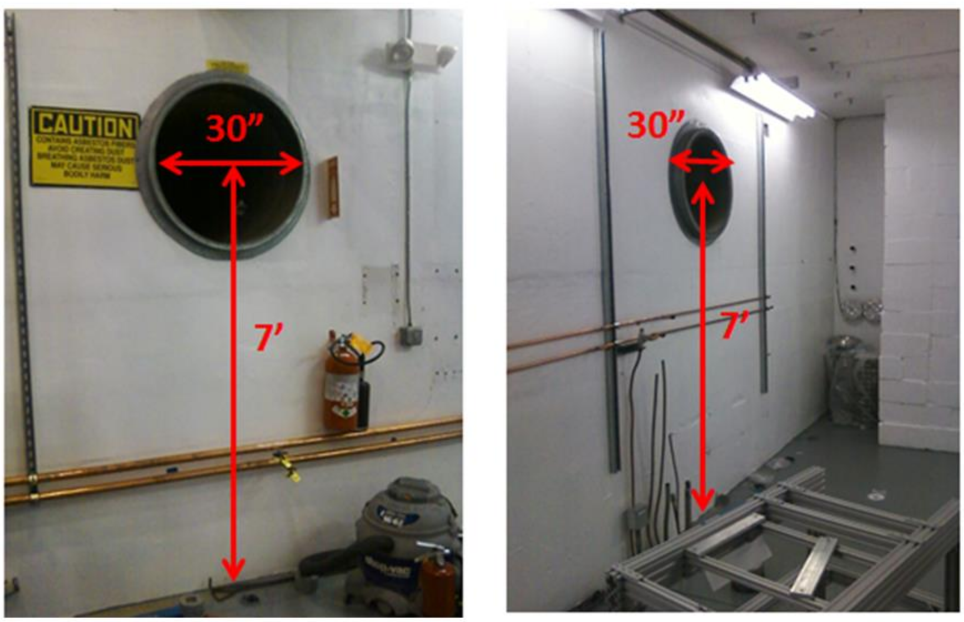

Figure 16: (Left) Fan with a capacity of 7400 CFM vents air into the high bay area, (Right) fan with a capacity of 4400 CFM vents air to outside the test lab

As mentioned above in the section related to Shielding, two penetrations serve as vent holes should the Cave 1 enclosure fill with helium gas. Above the cave, these penetrations have “chimney stacks” attached, to direct the light helium gas safely above the heads of occupants who might be working atop the Cave 1 enclosure (Figure 17). So called “memory foam” fills the remaining penetrations, to block the free flow of helium gas to the electronics racks located above, where personnel might be working. The foam can be removed from penetrations, for example to provide additional cabling to the UITF enclosure, but only after consulting with the Facility Manager to determine if foam removal creates an ODH hazard. If liquid helium is present within the QCM, the ODH level of the rooftop region becomes ODH1 when the foam is removed from penetrations, and the Safety Systems Group will be required to provide local oxygen monitoring throughout the duration of the work. If there is no liquid helium inside the QCM, the foam can be removed without taking extra ODH precautions. The Facility Manager will inform personnel as to the cryogenic state of the QCM. Signs placed near the penetrations on the Cave 1 rooftop provide foam removal instructions.

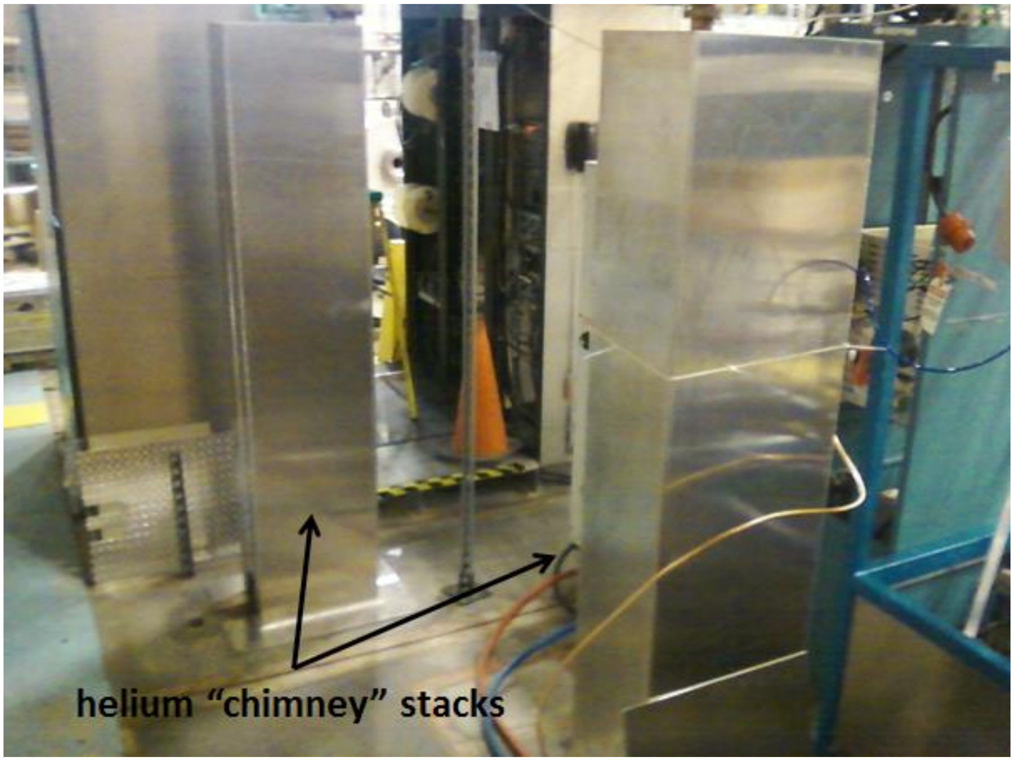

Figure 17. Two helium "chimney" stacks attached to rectangular penetrations in the ceiling of Cave 1. If helium gas is released inside the UITF enclosure, these chimneys will direct helium gas above the heads of staff members working near the electronics racks above Cave 1. Before energizing the QCM with high power RF energy, sandbags will be positioned at the base of each "chimney".

There is a passive 5.6 m^2 vent beneath the raised roof of Cave 2 (Figure 18) to vent lighter than air cryogens into the high bay area in the unlikely event of an equipment failure of experimental targets (e.g. HD-Ice).

Figure 18: (top) Shielded elevated-roof section of Cave 2, which will be used for experimental targets, including cryogenic targets. (bottom) 5.6 m^2 Vent area beneath the elevated roof section of Cave 2, for lighter than air cryogenic gases to escape.

6.6 Other (Electrical, ODH, Trip, Ladder) (Attach related Temporary Work Permits or Safety Reviews as appropriate.)

Rigid coaxial RF waveguide – ensure that all connections are made up and secure, to prevent non-ionizing radiation from leaking out of the coaxial waveguide

Dangerous levels of non-ionizing RF radiation can be produced by the solid state amplifier. Approval to energize the solid state amplifier must be given by the Subject Matter Expert in the RF Group, who will verify that all the necessary coaxial waveguide connections have been made up and are secure, to ensure RF radiation does not leak out.

7. List of Safety Equipment:

7.1 List of Safety Equipment:

1. Portable radiation monitoring equipment, as deemed necessary by RCG. If deemed necessary, it would be used by RCG in addition to the radiation monitoring equipment permanently installed at UITF and described above.

7.2 Special Tools:

1. As mentioned above, RCG might use portable radiation monitoring equipment
2. CIS will monitor radiation emanating from the buncher using a system called DecaRad, composed of 10 Gieger Muller tubes.
3. The keV spectrometer beamline represents a "tool" used to measure beam energy. The spectrometer dipole magnet was mapped before installation. By noting the current required to steer beam to the spectrometer dump, we can infer the beam energy, and the energy boost provided by the crested buncher.

8. Associated Administrative Controls

- Safety Systems Group staff is responsible for:
  - PSS administrative and engineered controls
  - Training on access controls and sweep procedures

- Radiation Control Department staff is responsible for:

- Maintenance and calibration of fixed interlocked and hand held radiation monitors
- Area and personnel dosimeters
- Configuration control of moveable shielding
- Radiation surveys
- Determining and posting the appropriate radiological control signage, boundaries and barricades
- Assigned Radiation Monitor Training (if needed)

- Center for Injectors and Sources (CIS) staff is responsible for:
  - Ensuring that vacuum is adequately monitored during buncher rf commissioning and that the Decarad system is functioning properly, to note onset of field emission and to quantify field emission levels
  - Thread beam to the spectrometer dump for energy gain measurements

*Administrative controls includes: Authority/responsibility, Procedures, Postings, and PPE

- CIS personnel are responsible for safe operation of the UITF.
- UITF's PSS logic manages the two entry/exit door switches and the Run/Safe Boxes to provide an "Area Secure" signal to the PSS logic
- The CARMs/radiation probes are interlocked to the PSS.
- High power RF (for buncher and ¼ cryomodule) is interlocked to the PSS

9. Training

9.1 What are the Training Requirements (See List of Training Skills)

1. Trained in performing a sweep to arm the PSS
2. Trained in operating the solid state amplifier, to power the buncher
3. Trained in monitoring the keV beamline vacuum
4. Trained in delivering beam to the keV spectrometer dump

All of this training will be provided by Subject Matter Experts, and by members of the Center for Injectors and Sources.

DEVELOP THE PROCEDURE

10. Operating Guidelines

The UITF's buncher commissioning procedure is described by this Operational Safety Procedure, which addresses hazards associated with maintenance and operation and their mitigations through engineered and administrative controls. Fault conditions in the UITF can produce only local work area impacts.

Staffing

The UITF can be swept and operated by a single trained and authorized user (typically the personnel conducting gun and/or beam studies).

UITF Operation

PSS state for the UITF is either: OPEN (open access), SWEEP, READY or RUN State. READY State is an internal (logical) state confirming that all interlocks are ready for transition to RUN State.

Prior to buncher commissioning, the Laser Bypass key must be returned to the PSS console in the Control Room in order to energize the gun high voltage power supply. In addition, the UITF must be placed in OPEN State using the Personnel Safety System (PSS) and the doors must be properly configured (i.e., closed). The sweep procedure is described in Section 12.

UITF Operator Requirements
In addition to the training listed in section 4.4, the UITF operator must:

1. Read and understand this OSP that includes PSS sweep procedures,
2. Receive the practical training on this OSP and on UITF operational procedures from system owner (Matthew Poelker or designee)

Perform walkthrough of the following areas, verify shielding is in place: UITF control room and Cave 1 roof where the electronics racks are located.

11. Notification of Affected Personnel (who, how, and when include building manager, safety warden, and area coordinator)

Safety: UITF Safety Warden, John Hansknecht 269-7097
UITF system owner: Matthew Poelker, office 269-7357, cell. 757-897-9408

12. List the Steps Required to Execute the Procedure: from start to finish.

Step 1: **Determining the Onset of Field Emission from the 748.5 MHz Normal-Conducting Copper-Cavity Buncher**, which requires that the UITF enclosure be cleared of personnel:

Procedure:

Inside the UITF

1. Verify that valves on either side of the buncher are CLOSED and note the beamline vacuum as determined by the buncher ion pump current. The valves can remain in EPICS control, and the valves can be OPENED if deemed beneficial by the PI.
2. The following is an overview of the PSS sweep, which can be performed by a single individual. Use the complete detailed sweep procedure and map attached to this OSP. A copy will also be maintained in the Control Room.
   - i) Before applying RF to the buncher, consult with RCG and the RF group to schedule this test. RCG will advise on the radiation monitoring equipment used for this test and the RF group will educate the PI on the correct method for apply RF to the buncher.
   - ii) Inform all occupants to leave the UITF enclosure, inform occupants of Cave1 rooftop of impending tests and that personal dosimetry is required to remain on the rooftop, verify the presence of the grate at the helium vent in Cave2
   - iii) Close both doors
   - iv) Go to control room and turn key to SWEEP
   - v) Enter the enclosure through the back door, close door behind you upon entry
   - vi) Arm RunSafe Box601 in the hallway
   - vii) Sweep the enclosure, walking all the way to the north wall of Cave 2
   - viii) Verify the Faraday Cup is locked in place, and the valve to the ¼ cryomodule is locked CLOSED
   - ix) Arm RunSafe Box602 near labyrinth exit

x) Exit through the labyrinth closing screen gate door completely

xi) Return to control room, turn key to RUN to arm the Personnel Safety System

In the Control Room:

xii) Apply RF in small increments, starting from zero. Note the forward and reflected RF power levels, the buncher temperature, the buncher beamline vacuum (i.e., ion pump current), and measured radiation levels.

xiii) Continue to increase applied RF power until a significant radiation signature is detected, indicating the presence of field emission. Or until vacuum pressure exceeds 1 uA current on the buncher ion pump.

xiv) If pressure reaches 1 uA on the ion pump (and assuming radiation levels are permissible as determined by RCG), let the buncher "soak" at constant RF power until the pressure no longer rises, but begins to decrease. At this point, the RF power can be increased.

xv) Continue increasing RF power applied to the buncher until radiation levels reach the maximum permissible RCG recommendation, or until pressure is deemed too high to continue.

xvi) Post the result to UITF electronic logbook. Comment on RF power levels achieved, compared to the expected power level of normal operation.

Step 2: **Determining the energy boost that the 748.5 MHz Normal-Conducting Copper-Cavity Buncher can provide to the beam, when phased on crest**, which requires that the UITF enclosure be cleared of personnel:

Procedure:

Inside the UITF

1. Perform Presweep steps as outlined above in Step 1. Sweep the UITF enclosure, and ensure there are no personnel inside the UITF, and engage the PSS as described above in Step 1.

In the Control Room:

i) Turn ON the gun high voltage

ii) Load the nominal optics file and look for beam on viewers (viewer limited mode, very low duty factor), working from the gun to the dump, using steering magnets as necessary. Adjust solenoid fields to obtain the desired beam size along the beamline. With buncher OFF, thread beam to the keV spectrometer dump using steering magnets

iii) Energize the buncher at low power setting and observe the impact the buncher has on the viewer image in the spectrometer line. Adjust the buncher phase to determine "bunching" and "cresting" conditions.

iv) With the buncher RF phase set to "bunch", increase the RF power to obtain the smallest beam size in the horizontal plane, and note this RF power level.

v) Now set the buncher RF phase for the "crested" condition. Increase the buncher RF power incrementally, while adjusting the dipole magnet setting to maintain the beam spot centered on the spectrometer viewer. Record dipole magnet setting versus RF power. Continue increasing the buncher RF power until the onset of field emission is reached. At this point, halt the study.

13. Back Out Procedure(s) i.e. steps necessary to restore the equipment/area to a safe level.

At any time during UITF operations, the PSS can be brought to OPEN State, in case there is a need for accessing the enclosure or to conclude high voltage operations.

Returning the PSS to OPEN State in normal operating conditions:

- Turn off the buncher RF from EPICS control screens
- Switch the PSS State key to "OPEN"

14. Special environmental control requirements:

14.1 List materials, chemicals, gasses that could impact the environment (ensure these are considered when choosing Subject Mater Experts) and explore EMP-04 Project/Activity/Experiment Environmental Review below

There is SF6 inside the gun high voltage power supply pressure vessel, see section 15 below.

14.2 Environmental impacts (See EMP-04 Project/Activity/Experiment Environmental Review)

14.3 Abatement steps (secondary containment or special packaging requirements)

15. Unusual/Emergency Procedures (e.g., loss of power, spills, fire, etc.)

Returning the PSS to OPEN State in case of emergency or any other abnormal conditions

At any moment the PSS Safety Crash buttons can be depressed. This action will cut off the gun high voltage power supply, turn OFF high power RF, and will close the laser shutter if those systems are operational. It will also crash the sweep and will force unlock the doors.

Since ionizing radiation is present in the enclosure only when the gun is at high voltage, or when high power RF is applied to the buncher or QCM, depressing any of the PSS RunSafe or Control Room crash buttons will restore the area to a safe level. NOTE: the emergency exit crash switch will only release the local door lock.

The following is a list of currently installed alarms:

1. ODH (blue strobe + buzzer), located at each door and in the Control Room
2. Fire (white strobe + high pitch)
3. SF6 pressure sensor on Glassman high voltage power supply SF6 tank
4. Potential prompt radiation (magenta strobe beacon and 30 second siren), located at each doorway and near the electronics racks on Cave 1 rooftop.

The expected response to any of the alarms is to evacuate the UITF enclosure immediately and proceed to the high bay area of the Test Lab

Return to normal operations occurs when alarms are cleared by the following personnel:

1. ODH cleared by SSG or CIS Staff
2. Fire cleared by Facilities Management
3. SF6 CIS staff, SF6 custodian, UITF Safety Warden responsibility
4. CARM alarms, contact RCD and follow their instructions

Comments regarding SF6 hazards: The 45 lbs of SF6 that resides inside the high voltage power supply vessel would occupy 3.2 cubic meters if it were instantaneously released, compared to 207 cubic meter volume of Cave 1. Since SF6 is about 5 times heavier than air, it will accumulate on the floor when released from the high voltage power supply vessel. It would reside within a layer less than 1” thick on the floor. However, if it fully mixed with air in Cave 1, the oxygen concentration would fall to ~ 20.5% which is not deemed hazardous (normal oxygen content of 20.8%). Accounting for the 4400 cfm exhaust fan, it will take ~ 45 minutes to remove all SF6 from the cave (assuming good mixing in the Cave). This time interval does not allow enough time for personnel to exceed the 8-hour exposure limit of 1000ppm. The estimated 8-hour average exposure concentration would be ~ 572ppm.

If the ventilation fan is not operating inside the UITF enclosure, the SF6 will remain along the floor. In this case, personnel are not allowed to work on the floor in case of known leaks.

The pressure vessel assessment of the high voltage power supply SF6 tank can be found in Docushare, Folder PS-ACC-17-001

Other emergency procedures not covered by alarms are:

a. Ventilation failure. Expected Response is to evacuate area immediately and convene at muster point.

b. Personnel inside UITF enclosure AND the doors are locked. **NOTE: This event should never occur if proper sweep procedures are followed.** Expected response is to proceed to the nearest Run/Safe Box and press the crash button. Each door has a local crash out button the will release its lock to allow exit. Opening the door will drop the PSS to OPEN State.

c. Electrical Power failure and in case of personnel trapped inside UITF enclosure. **Personnel Entrapment should never occur if proper sweep procedures are followed.** PSS system will unlock the doors (Electrical power maintains the locks, loss of power unlocks – fail/safe mode)

Notifications:
UITF Safety Warden, John Hansknecht 269-7097
UITF system owner: Matthew Poelker, office 269-7357, cell. 757-897-9408
ODH, Fire: Guard gate 269-5822
Other Emergencies: Guard gate 269-5822

16. Instrument Calibration Requirements (e.g., safety system/device recertification, RF probe calibration)

PSS certification will happen twice per year, scheduled by SSG

17. Inspection Schedules

PSS certification will happen twice per year, scheduled by SSG

18. References/Associated/Relevant Documentation

- Task Hazard Analysis
- UITF Sweep procedure, found on Docushare website: https://jlabdoc.jlab.org/docushare/dsweb/View/Collection-27533
- UITF ODH assessment found at: https://misportal.jlab.org/railsForms/oxygen_deficiency_reviews/74180/edit
- Shielding assessment and specifications from RCD at: https://misportal.jlab.org/doc_validation/processes/13 and https://misportal.jlab.org/doc_validation/processes/29
- The operations manual for the SigmaPhi 7 kW solid state amplifier, pdf version

19. List of Records Generated (Include Location / Review and Approved procedure)

Operations logbook (electronic)

Click
To Submit OSP
for Electronic Signatures

Distribution: Copies to Affected Area, Authors, Division Safety Officer
Expiration: Forward to ESH&Q Document Control

Form Revision Summary
Revision 1.5 – 04/11/18 – Training section moved from section 5 Authority and Responsibility to section 9 Training
Revision 1.4 – 06/20/16 – Repositioned "Scope of Work" to clarify processes

Qualifying Periodic Review – 02/19/14 – No substantive changes required
Revision 1.3 – 11/27/13 – Added "Owning Organization" to more accurately reflect laboratory operations.
Revision 1.2 – 09/15/12 – Update form to conform to electronic review.
Revision 1.1 – 04/03/12 – Risk Code 0 switched to N to be consistent with 3210 T3 Risk Code Assignment.
Revision 1.0 – 12/01/11 – Added reasoning for OSP to aid in appropriate review determination.
Revision 0.0 – 10/05/09 – Updated to reflect current laboratory operations

ISSUING AUTHORITY	FORM TECHNICAL POINT-OF-CONTACT	APPROVAL DATE	REVIEW DATE	REV.
ESH&Q Division	Harry Fanning	04/11/18	04/11/21	1.5

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