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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:** | QCM Operation at the Upgraded Injector Test Facility (UITF) | | |
| **Location:** | Upgraded Injector Test Facility (UITF) located in the Test Lab High Bay Area, rooms 1127-1129 | **Type:** | X **OSP**<br>☐ **TOSP** |
| **Risk Classification**<br>(per Task Hazard Analysis attached)<br>(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:** | Center for Injectors and Sources, Accel. Div. | **Date:** | February 9, 2019 |
| **Document Owner(s):** | Matthew 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 describe in detail the procedures for safely applying high power RF to the cold Quarter Cryomodule (QCM) at the UITF (but not accelerating beam). There are two main concerns: prompt ionizing radiation as a result of field emission inside the QCM, and ODH conditions that result from cryogenic conditions required to operate the SRF accelerating cavities.

The UITF can function as a gun test stand. But when beam is accelerated to an energy that exceeds the potential energy applied to the gun, the UITF is considered an operational accelerator (beyond this OSP).

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 specific 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 QCM (no beam acceleration)***

Apply high power RF energy to the cold QCM located inside the UITF enclosure using two klystrons. One klystron drives a unique 2-cell accelerating cavity described as an rf-capture section, and the other drives a 7-cell cavity similar to those used in C100 cryomodules at CEBAF. Compare RF performance at UITF to performance previously measured at Cryomodule Test Facility (CMTF). This is a necessary first step before using the QCM to accelerate an electron beam.

At UITF, liquid nitrogen at 80K is used for the shield line, and not helium at 35K, which is the typical cryomodule configuration. This reduces the cryogenic burden on the Cryogenic Test Refrigerator (CTF). But if QCM performance at UITF is inadequate, the shield line might also be operated with helium in the shield circuit.

Besides evaluating the performance of the QCM, we will be commissioning a brand new cryogenic system (the QCM connected to CTF with new controls and piping), and a new high power RF system (new high power amplifier and klystron racks). The klystrons used at UITF represent "CEBAF spares" and are expected to operate at 5 kW maximum power (typical CEBAF operating condition). Based on QCM performance observed at the CMTF, and based on the beam energy requirements of UITF (5 to 10 MeV), the QCM is not expected to operate in a field emission regime. The purpose of this OSP is to verify the absence of field emission under expected operating conditions.

The implementation of this OSP also represents the first tests of the cold and energized QCM interfaced to a new PSS system.

The affected area is the entire UITF enclosure composed of Cave 1 and Cave2, and the region above Cave1 where the electronics racks are located (See figure 1)

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

The location of UITF is the High Bay Area of the Test Lab. Figure 1 shows the UITF lay out and identifies Caves 1 & 2. This OSP covers QCM operation with RF (no beam acceleration) which occurs in Cave 1, but also affects Cave2 because Cave1 and Cave2 form a common space. The names "Cave1" and "Cave2" are convenient designations, referencing old and new test areas, respectively. Figures 1 and 2 show the labyrinth, which is the main access to UITF. Figure 3 shows UITF with concrete shielding over the roof of Cave 1. Electronics racks are located above Cave1. In Figure 3, for illustration purposes only, the roof of Cave2 is shown removed.

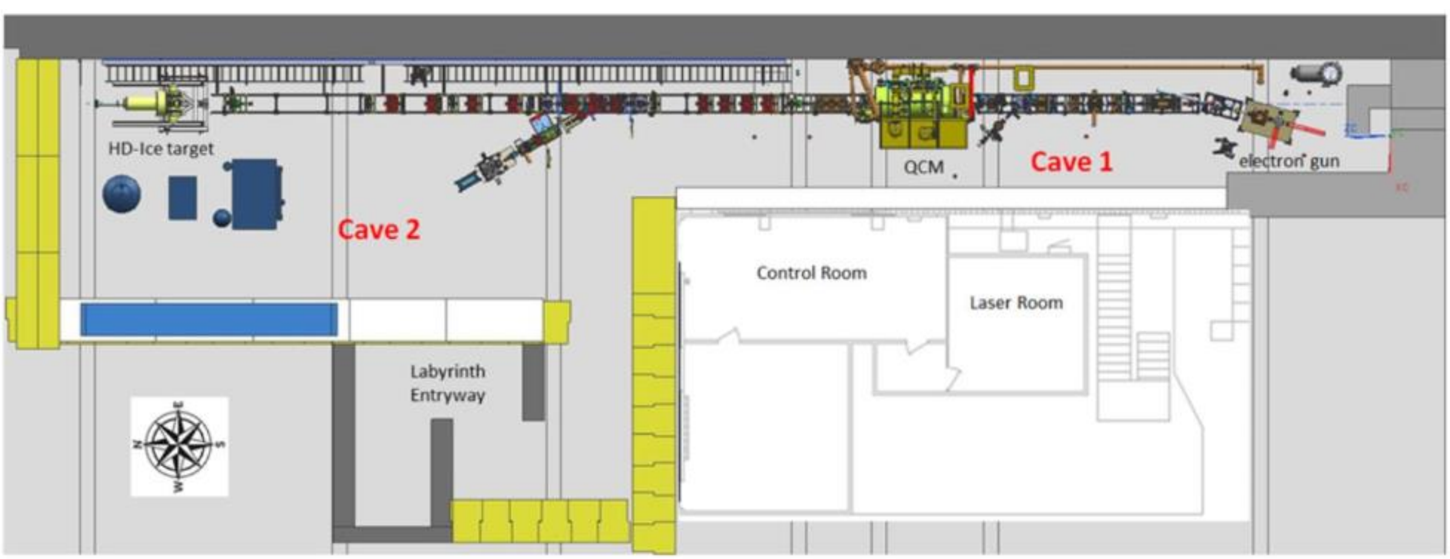



Figure 1 UITF beamline layout showing the two Caves. The QCM is inside Cave 1

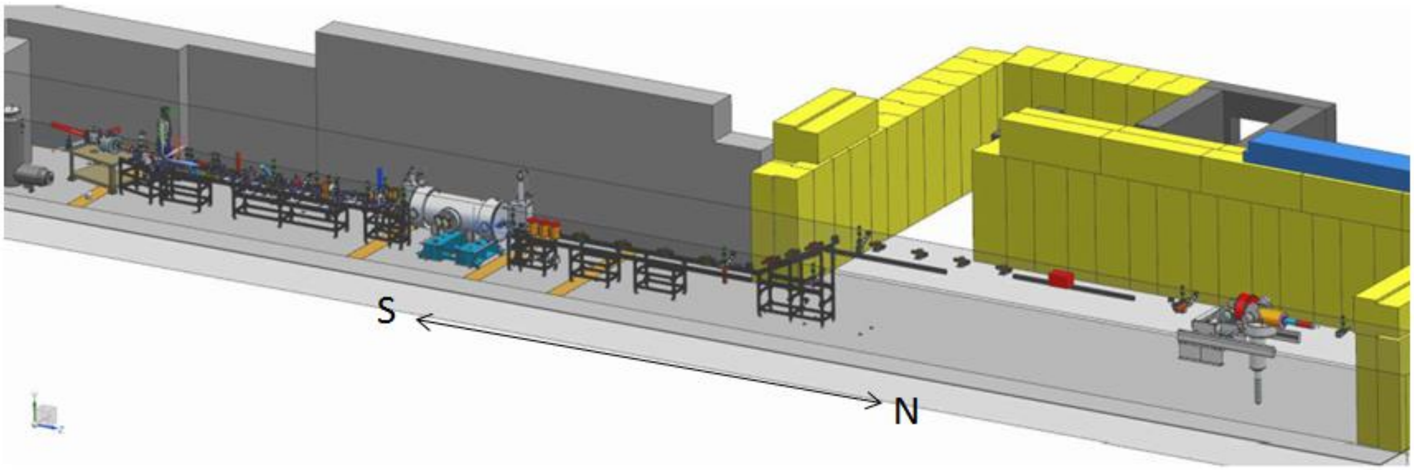



Figure 2 UITF layout showing the exit to main entrance through labyrinth towards the high bay area

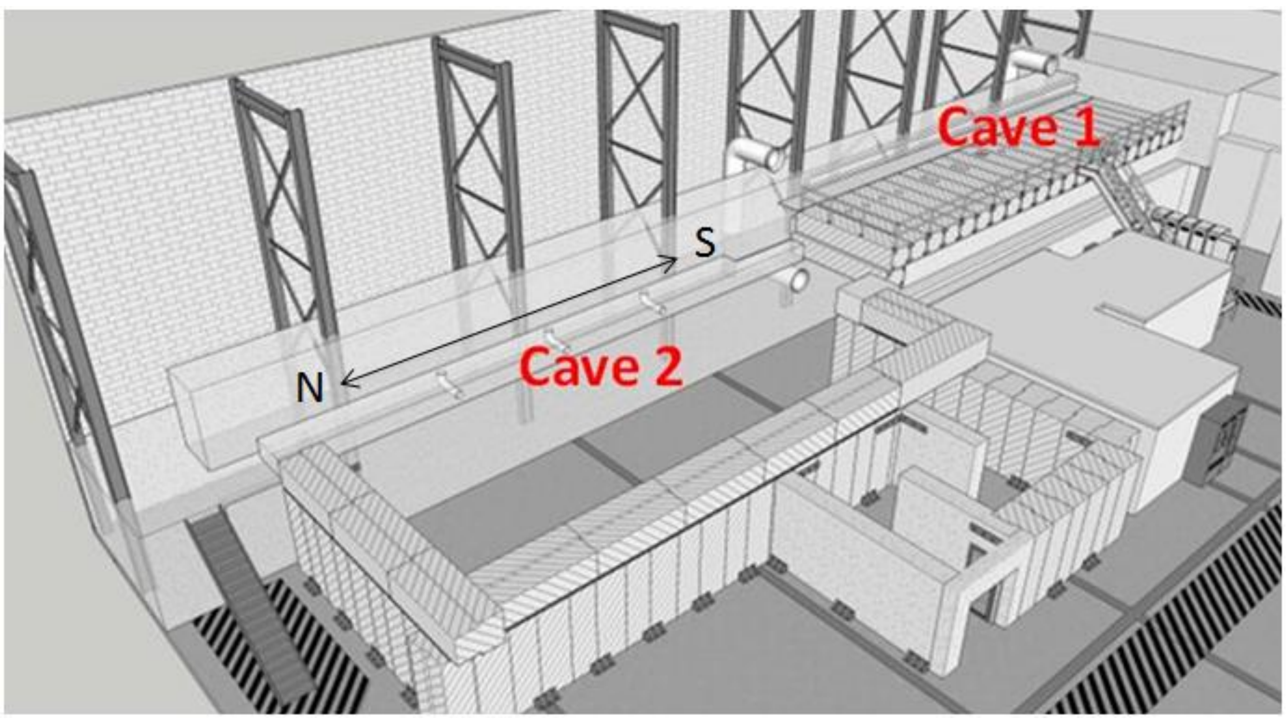



Figure 3 UITF layout showing the main entrance Labyrinth and shielded roof of Cave 1. The klystrons and RF controls are located above Cave1. Cryogens are delivered to UITF from the CTF via piping that enters at the south end of Cave1.

## 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. Oxygen Deficiency
4. Electrical
5. Pressure / Vacuum

## 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 SRF Institute, and the Injector Group of the Operations Department.

### 5.2 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. Members of the SRF Institute will be considered PIs during initial cooldowns and for RF commissioning.
- **RF System Operators:** They are members of the Engineering Division familiar with warm 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.
- **Cryogenic System Operators:** They are members of the Cryo Group, within the Engineering Division. They assist the principal investigators in the execution of tests and the changing of cryogenic system configurations. They must have a thorough understanding of the configuration and operation of the cryogenic systems required for the execution of the planned experiments. They should also have an understanding of the interactions of the specific RF and SRF tests with

operations of the cryogenic systems. 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.

- **SRF System Operators:** They are members of the SRF Institute within the Accelerator Division familiar with commissioning of SRF cryomodules and the operation of SRF cryomodules like the QCM. They are responsible for safe operation of the QCM and have the authority to stop work 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 posting, 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).

**5.3 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:

- Swapnil Shrishrimal – Cryogenic Safety
- 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/Imani Burton – Oxygen Deficiency
- John Fischer – SRF cool down procedure
- Mike Drury – SRF commissioning/operation of the QCM

**5.4 What are the Training Requirements** (See http://www.jlab.org/div_dept/train/poc.pdf)

UITF Operators must have the following Training

- SAF 100 – ES&H Orientation
- SAF 307 – Ladder Safety
- SAF603A – Electrical Safety Awareness: Classes, Modes, etc.
- SAF 103 – Oxygen Deficiency Hazard
- SAF 104 – Lock, Tag and Try
- SAF 801– Rad worker

- SAF130AU – Pressure Systems Safety Awareness for Users
- Read and sign this OSP

## 6. Personal and Environmental Hazard Controls Including:

### 6.1 Shielding

The accelerating cavities inside the QCM can be driven with sufficient RF power to initiate field emission, which will produce X-rays. And field emission accelerated to sufficiently high energy (> 8 MeV) can make some materials radioactive. 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 Cave1 is 55" thick to a height of approximately 7'. Above 7', the wall thickness is approximately 27 to 28" thick. Cave 1 has 30" concrete shielding on the roof. There are nine penetrations in the Cave1 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 RF waveguides from klystrons to the QCM. And two rectangular penetrations provide a means for helium gas to escape the UITF enclosure (see section 6.5 Ventilation). All of the penetrations, except the one used for RF waveguides, have 3.5" iron shielding directly beneath (Figure 4, below). The RF waveguide penetration is filled with sand (Figure 5).

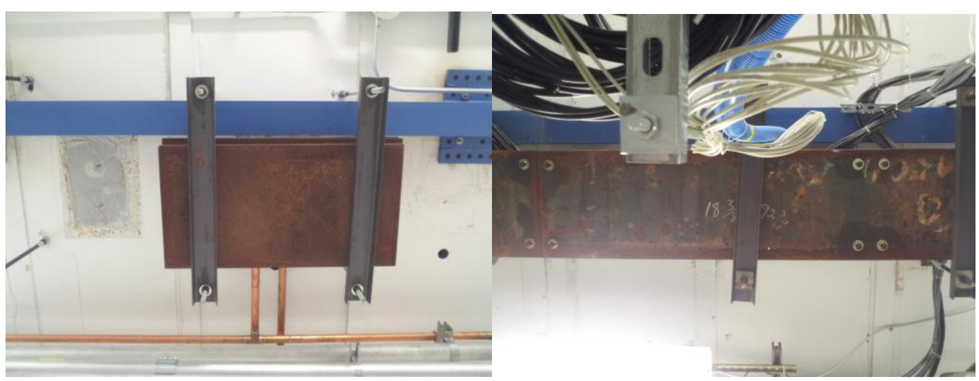


Figure 4: Steel plates covering penetrations in Cave 1. Cables pass through the penetrations linking the electronics racks and beamline elements.


Figure 5: images of RF waveguides passing through a ceiling penetration in Cave1, connecting the QCM to klystrons. Left: view from inside the UITF enclosure, Right: view from cave rooftop, near the klystron racks.

Two penetrations serve as helium vent holes should the Cave1 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 Cave1 enclosure. Bags of gravel placed at the base of each chimney-vent stack provide additional shielding at these penetrations but gravel bags are not required credited controls mandated by RCD.

**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 6 below;

Figure 6: 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 sand bag shielding inside the trench and 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 QCM is located in Cave1, the entire UITF enclosure (Cave1 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 Cave1 is adequately configured with sufficient shielding to mitigate radiation hazards posed by QCM rf commissioning.

The top of the UITF Cave1 roof is accessible during QCM 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 Cave1 roof (see Figure 7). 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 QCM commissioning and subsequent commissioning of the accelerator.


Figure 7: During UITF operations, the top of UITF Cave1 roof is a Radiologically Controlled Area and dosimetry is required to access the roof.

During initial QCM 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**

High-gradient accelerating cavities such as the 7-cell cavity used in the QCM have shown the potential to produce radioactivity when operated at high power. Under certain conditions, the energy of the photon field produced by field emitted electrons may exceed the threshold for giant resonance photo-nuclear interactions. These interactions result in the emission of neutrons and the production of residual radioactivity. This phenomenon is difficult to predict. However, the onset of the condition is easily detectable by means of neutron radiation monitoring in the vicinity of the cryomodule or direct survey after shutdown. See section 6.4 for specific procedures related to this.

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

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 8). 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 8: 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.

**QCM beamline Valves:** The QCM is under vacuum, and for this test, the valves to the adjoining beamline are closed, with epics control of the valves disabled. The connectors for valve electronic control are disconnected from the valve body and placed in LTT boxes. Because the valves are closed, there is no possibility of injecting and accelerating a beam through the QCM.

Besides vacuum valves and the grating at the helium vent, other barriers at UITF include:

1. Vacuum windows: The UITF beam line is under vacuum. If work involves thin windows (which is not anticipated), there will be signage warning personnel entering UITF that hearing protection is mandatory for entrance. Hearing protection will be available in well-marked containers.
2. Magnetic Fields: The magnets at UITF can be energized when the UITF is OPEN but these magnets have fields that drop off to less than 5 gauss within a few inches from the magnet. If there are cases where the field is > 5 gauss at a foot or more, there will be barriers to prevent personnel from exposure to the magnetic field.
3. The magnets have electrical terminals which are either insulated or have protective covers to prevent accidental contact.
4. The doors to UITF represent barriers, these are described below in Section 6.3 Interlocks

Note, when the UITF ceiling tiles are removed to install a large device such as the HDIce polarized target, all radiation generating sources must be locked out, as described in a separate OSP titled "UITF Cave2 roof tile removal". Specifically, the photogun high voltage power supply and the high power RF sources must be locked out when Cave2 ceiling tiles are removed.

## 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 located outside the enclosure. Radiation exposure is prevented through both administrative (sweep procedures, locked gates, postings) and engineered means (shielding, interlocks, radiation monitoring, etc.). UITF (see Figure 9) is a completely enclosed area. No one is allowed inside the enclosure during beam operations, or gun high voltage conditioning, or when high power RF is applied to the buncher or the QCM.

There are interlocks associated with the high power RF klystrons. These include enclosure interlocks that prevent exposure to electrical hazards within the klystron racks and waveguide pressure interlocks that ensure RF energy does not leak from the waveguides.

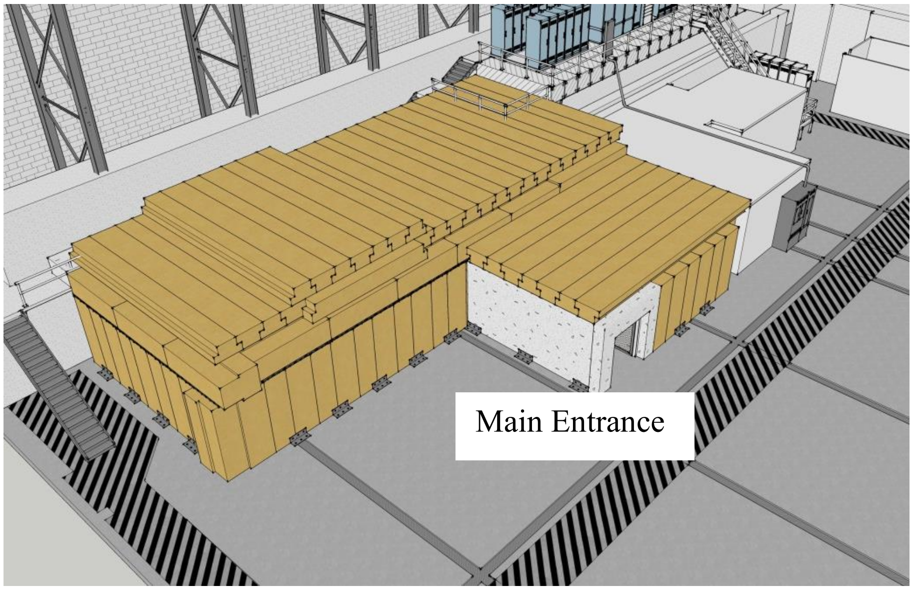



Figure 9: UITF With concrete shielding in place

Figures 8 and 9 show the two entry/exit ways to and from the UITF, the run safe box, signage along with the warning beacons.


Figure 10: (Left) Main entrance/exit from high bay area through the labyrinth of UITF (Middle), Secondary exit into the high bay from the southern-most location of the keV section. Both doors have Personnel Safety System interlocks and emergency exit switches on the nearby walls (Right). Beacons exist at both entrance/exit ways


Figure 11: (Left) Exit 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 12 for approximate CARM location above Cave1. 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.

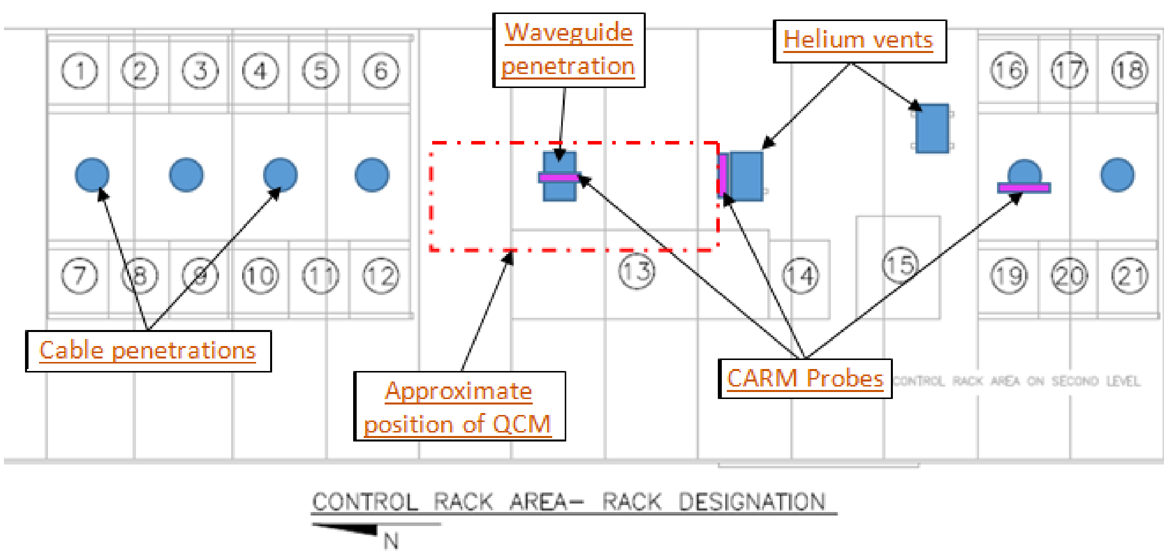



Figure 12: schematic layout of the electronics racks above Cave1 showing approximate location of CARM probes on the Cave1 rooftop. There is also a CARM in the Control Room.

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:

- 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 Cave1 near the electronics racks
- 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, the klystrons and HPA are 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 QCM when UITF enclosure door interlocks are breached or when CARMs indicate excessive radiation measured outside the enclosure.

The klystrons and HPA are located within electronics racks positioned above Cave1, see Figure 13. Waveguides attached to the klystrons deliver RF energy to the QCM located below within the UITF enclosure, through a penetration in the roof top shielding that is filled with sand.

There are interlocks associated with the high power RF klystrons (see Figure 14). These include electronics rack door/panel enclosure interlocks that prevent exposure to electrical hazards within the klystron racks and waveguide pressure interlocks that ensure RF energy does not leak from the waveguides. The waveguides are filled with air at 1.5 psi above ambient.

Figure 13: the UITF klystron racks also known as the High Power Amplifier (HPA)

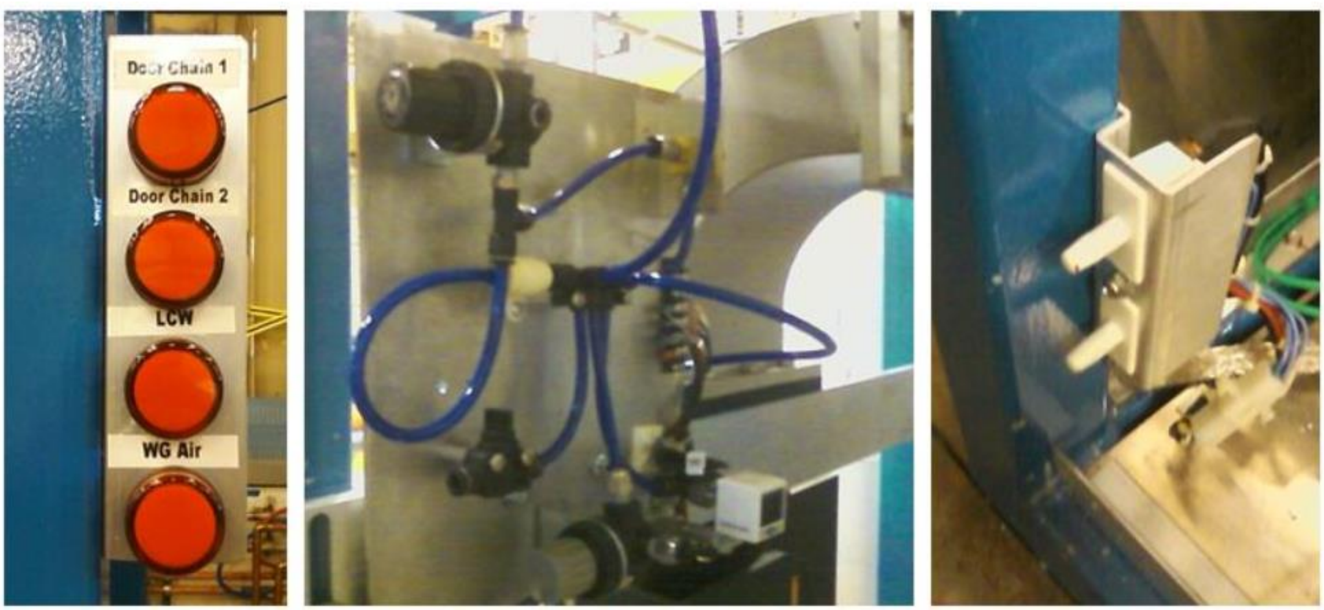



Figure 14: (left) Photograph of the indicator lights related to the electronics rack door/panel enclosure interlocks, low conductivity water flow, and waveguide air pressure, (middle) the waveguide air pressure manifold and interlock sensor, (right) one of the electronics racks door interlock sensors.

## Configuration Control related to high power RF:

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

Devices that are owned by the Safety Systems Group

- AC Contactors located in rack ITF14 near the klystron racks above Cave1

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:

- 5kW / 1497 MHz klystron power supply PSS interlock chain
- Wave Guide pressure interlock

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 QCM 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 together with audible alarm that can be heard inside Cave1. 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.

**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 10, 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 Test Coordinator and Principal Investigator 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 or Assigned Radiation Monitors 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 QCM 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) shall notify RCD through the duty phone 757-876-1743 and discuss the operational activities that preceded the alarm. The Facility Manager should also be notified. RCD staff may require a supplementary radiation survey as radiation producing activities recommence. An ARM, if available, may conduct the radiation survey and report the results to the Radiation Control Staff. RCD staff will address the results of the radiation survey with the Principal Investigator and discuss the mitigating measures, if necessary, for continued operation. The Facility Manager will then determine when operations may resume.

**Neutron CARM Alert Response**

One neutron radiation detector in the cave is configured to produce an "alert level" alarm in the control room. This alarm will occur if the neutron levels in the vicinity of the cryomodule exceed 0.5 mrem/hr. This alarm is not interlocked to the PSS and will NOT terminate the test. The operator may acknowledge the alarm to silence the audible annunciator. When this condition occurs, the operator shall place signage prominently at the PSS console stating "**Contact RadCon at 876-1743 Survey required**" and make an appropriate elog entry copied to hamlette@jlab.org and welch@jlab.org and to the Principal Investigator. Furthermore, the Operator will place identical signage on the QCM during the next available access.

## 6.5 Ventilation

Cryogenic gasses and fluids are delivered to the QCM from the CTF refrigerator, cold nitrogen and helium gas, liquid helium (LHe) and liquid nitrogen (LN2). The ODH assessment is attached to this OSP and can be found at:
https://misportal.jlab.org/railsForms/oxygen_deficiency_reviews/74180/edit

The QCM will be cooled to LHe temperature only periodically at UITF. Anticipated operation of the QCM will likely not exceed three periods of operation per year, with each period lasting approximately 3 weeks. During the majority of time, when the QCM is not being operated, the QCM will be at room temperature with no cryogenic gasses or fluids delivered to UITF.

The QCM will be connected to the CTF refrigerator using two sets of u-tubes. One set of u-tubes is located at the CTF refrigerator, and the other set is located inside Cave1 of the UITF enclosure. As described by the ODH assessment, the UITF enclosure was assigned ODH0 status EXCEPT for elevations above 9' (signs are posted), and when u-tubes are removed or stabbed. When u-tube operations occur, the Cryo group will perform these operations per "CRY-15-54131-OSP - Bayonet Installation and Removal". The Cryo Group and UITF Facility Manager will coordinate u-tube operations, and it is the responsibility of the Facility Manager to restrict access to the UITF enclosure to only authorized personnel (i.e., those with proper ODH training).

Vent piping (on the circle seal relief), a sheet metal deflector (on the parallel plate relief) and a 90 degree elbow (on the burst disc) serve to protect the relief ports from damage during u-tube operations.

There are two fans on the east wall of Cave 1 (Figure 15). 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.

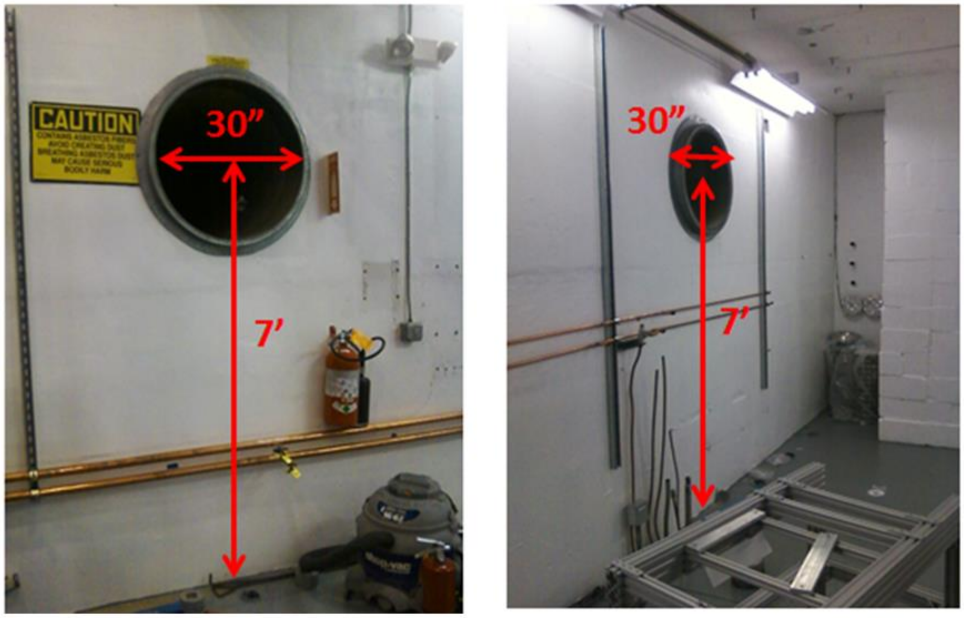



Figure 15: (Left) Fan with a capacity of 7400 CFM vents air into the high bay area, (middle) fan with a capacity of 4400 CFM vents air to outside the test lab

As mentioned above in the section related to Shielding, two penetrations serve as vent holes should the Cave1 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 Cave1 enclosure (Figure 16). 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 Cave1 rooftop provide foam removal instructions.

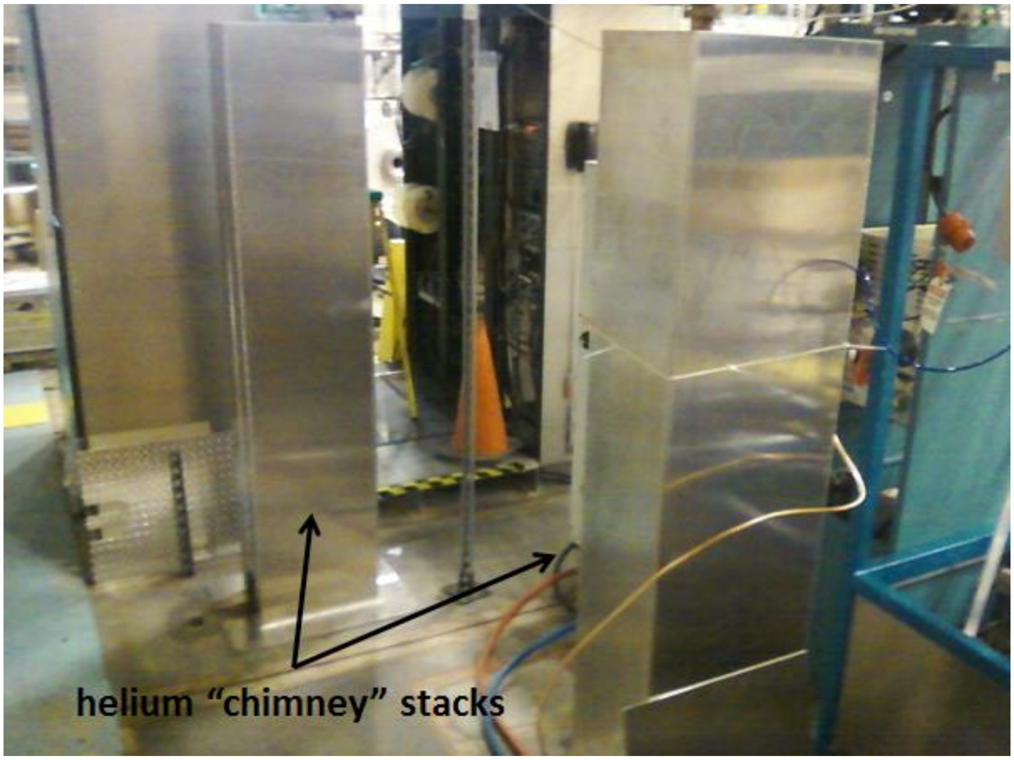
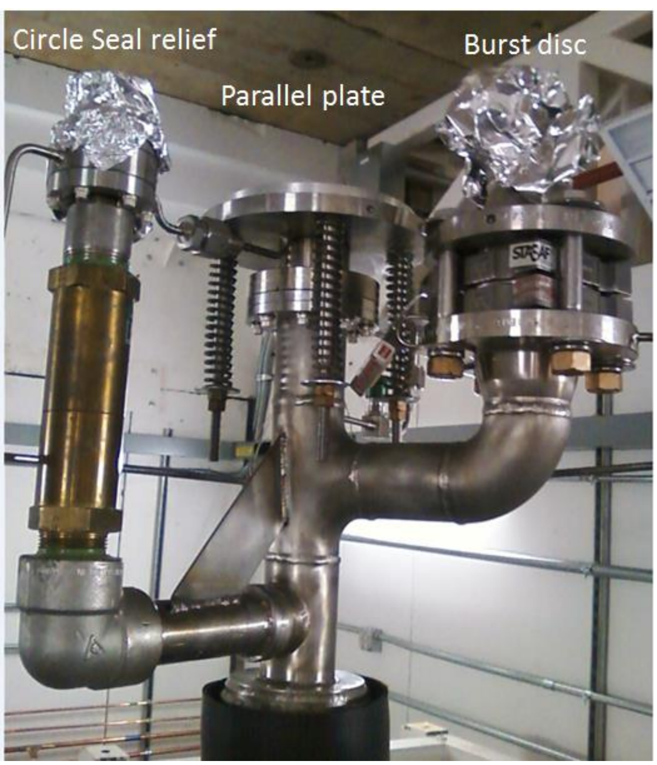


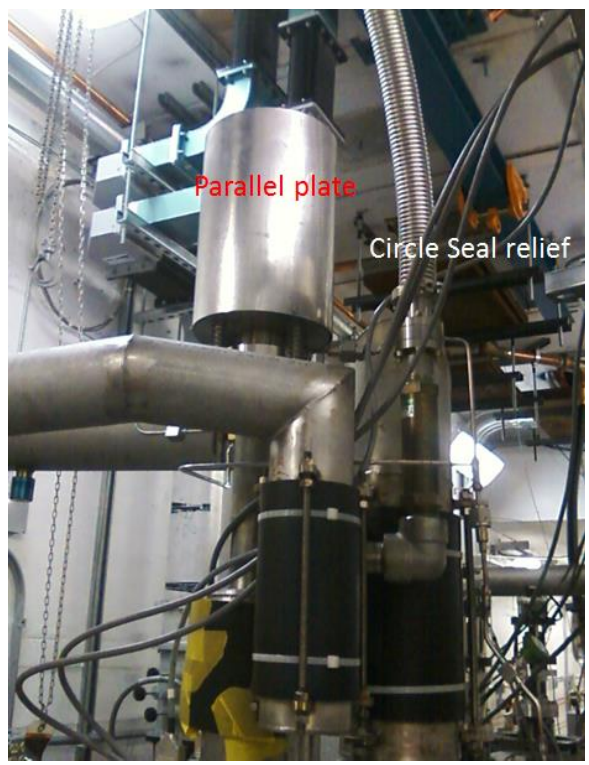

Figure 16. Two helium "chimney" stacks attached to rectangular penetrations in the ceiling of Cave1. If helium gas is released inside the UITF enclosure, these chimneys will direct helium gas above the heads of staff members working near the electronics racks above Cave1.

There is a passive 5.6 $m^2$ vent beneath the raised roof of Cave 2 (Figure 17) 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 17: (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 Cave2, for lighter than air cryogenic gases to escape.

There are three main vent pathways by which helium gas can escape from the QCM, and each vent pathway is located on the QCM vent stack: a) circle seal relief which Opens at 17 psi, b) a parallel plate relief valve which Opens at 45 psig and c) a burst disk which Opens at 51 psig. See Figure 18, below. If a vent incident should occur, the circle seal relief would OPEN first. For this reason, the exhaust of the circle seal relief is piped outside of the UITF enclosure. Sheet metal wrapped around the parallel-plate relief serves to direct gaseous helium upward, and not toward personnel walking near the QCM.



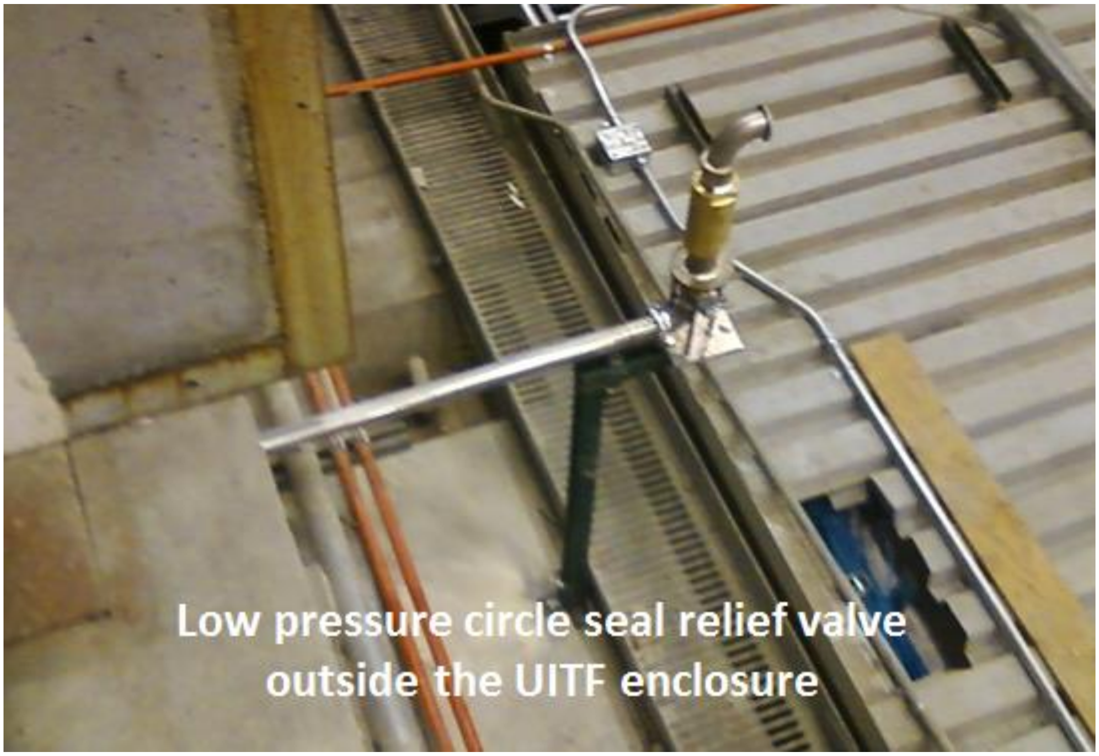



Figure 18: top left shows the three relief ports of the QCM vent stack. Top right shows the deflector sheet metal attached to the parallel-plate relief which would direct gasesous helium upward and not toward occupants inside the UITF enclosure. This figure also shows piping attached to the exhaust port of the circle seal relief which would direct vented gas out of the UITF enclosure, bottom photo.

## 6.6 Pressure / Vacuum

The QCM pressure system documentation can be found in Docushare at:
<https://jlabdoc.jlab.org/docushare/dsweb/View/Collection-15912>
File folders and subfolders include: "Project Status and Information", "Engineering", "Manufacturing" and "Testing"

1. Under "Project Status and Information", there is a brief summary of the QCM status with an emphasis on pressure safety
2. The PS-1 form can be found under the Engineering root directory
3. Drawings can be found under Engineering>Drawings; Specifications can be found under Engineering>SOW
4. In-process weldmaps can be found under Manufacturing>Welding-brazing (for in-house fabrication)
5. PS-5 forms are combined into one file and stored under Manufacturing>Fabrication.
6. PS-7 form for QCM pressure test is stored under Manufacturing>Inspections-Examinations
7. Memos and Readme's are written to brief the status and whereabouts of some documentation
8. Vendor submitted documents are found in relevant subfolders under either Engineering or Manufacturing

Category 2 vacuum systems are described in the EH&S manual at the link below:
https://www.jlab.org/ehs/ehsmanual/Pressure%20and%20Vacuum%20Systems%20Supplement/PSS%20Part%207%20Vacuum%20Systems.htm

In section 7.2.3 of the EH&S manual, Category 2 vacuum systems are described as:

*"Vacuum systems attached to or containing a credible pressure source that can exceed 15 psig and are protected from pressurization exceeding 15 psig through engineering controls (e.g. pressure relief devices). Insulating vacuums for cryogenic systems shall be considered Category 2 vacuum systems. Examples of Category 2 vacuum systems include cryostats, cryogenic transfer lines, cold boxes, and target scattering chambers."*

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

See above, Ventilation section. The ODH assessment for the UITF is attached. This assessment can be found at: https://misportal.jlab.org/railsForms/oxygen_deficiency_reviews/74180/edit

The potential hazards associated with the UITF operations include electrical/electrocution, non-ionizing radiation (RF), ionizing radiation, vacuum, ODH, and material handling concerns related to u-tube operations. These hazards and their mitigation are covered in the attached Task Hazard Analysis.

## 7. List of Safety Equipment:

### 7.1 List of Safety Equipment:

1. Safety glasses when performing mechanical work, as needed
2. Gloves depending on mechanical or shielding work
3. Hard hats and/or steel toed boots depending on materials handling needs
4. Laser safety goggles, as required by LOSP (ACC-17-64784-LOSP)

### 7.2 Special Tools:

n/a

## 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 valves on either side of QCM are forced CLOSED, with controls disabled and locked-out to prevent opening of valves

*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 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

## DEVELOP THE PROCEDURE

### 9. Operating Guidelines

The UITF's QCM 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 QCM 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 11.

**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)
3. Perform walkthrough of the following areas: UITF control room and Cave 1 roof where the electronics racks are located.

### 10. 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

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

**QCM in position at Cave1**

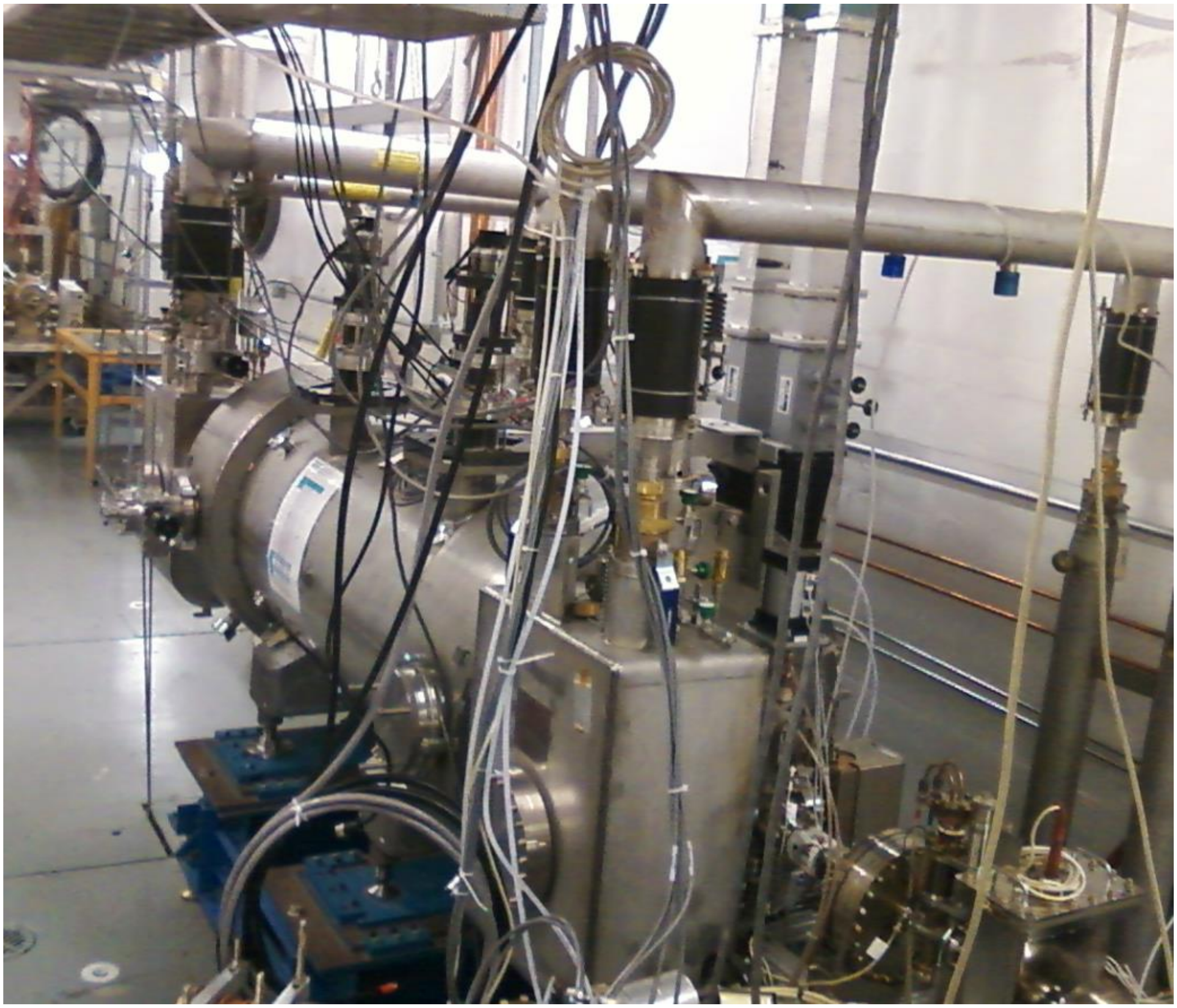


Figure 19: top and bottom: The QCM in position at Cave1 of the UITF, with u-tubes "stabbed" and waveguides connected.

**General Operating Protocol, as described by SRF System Experts:**

The following are general operating guidelines to be followed when using the test area for radiation producing experiments. Refer to the Conduct of Operations document for details.
One qualified SRF System Expert must be present in the facility during all high power RF operations. Their name or names displayed on the control desk and entered in the UITF electronic logbook.

1. Only authorized personnel shall be permitted to enter the test area to make changes to the QCM apparatus. Authorization must be obtained from the SRF System Expert or Facility Manager.
2. The SRF System Expert is responsible for ensuring safe operation in accordance with the OSP during attended high power RF operations. All personnel entering any Radiologically Controlled Areas shall carry Personal Dosimetry – specifically, the top of Cave1.

3. Any staff member has the responsibility to report to the SRF System Expert or the Facility Manager on issues of safety. If the issue cannot be resolved relatively quickly, operation shall cease until such time as the issue is resolved with the help of other experts.
4. Response to any emergency, accident condition, or injury shall be coordinated with the site security, phone extension 5822.
5. The control room must be attended when high power RF is on. High voltage operations may be left unattended for brief break periods. (See Table 5 for Staffing Requirements.)
6. One-person operation of the cryomodule test facility is permitted from the control room or in the cave when the cave ODH status is ODH 0.
7. The SRF System Expert or his designee must be on call for emergencies.

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The following describes the **QCM Cool Down Procedure**, which can happen with the UITF enclosure OPEN, if RF commissioning is not performed, i.e., there is no radiation hazard. This procedure may be revised following the initial cool down, based on lessons-learned. Members of the Cryo Group and SRF Institute coordinate this work.

Cooldown of UITF cryomodule:

Preconditions:

- Cryomodule shield and primary U-Tubes are installed.
- Shield and primary circuits have been pumped and backfilled and have been left under positive pressure.
- All insulating vacuums have been pumped and are holding proper vacuum.
- Cryomodule temperature diodes are active and reading correctly.
- Turn on the superconducting liquid level probe (AMI box)

LN2 Shield Cooldown

- Install the supply and return bayonets of the UITF Thermosiphon.
- Ensure EV27SH is locked fully open.
- Set the LN2 liquid level control to auto.
- Ensure positive pressure remains on the primary circuit during shield cooldown.
- Open EV249BY in UITF Transferline to keep PR2 under positive pressure.

Primary Cooldown

- Shut off Kinneys and repressurize Kinney suction
- Lower CPI2440 to 1.3 atm
- Close UITF EV27JT, EV27RT, and EV249BY
- Install PR then PS utubes
- Repressurize CPI2440 and turn Kinneys back on
- Open MV27BY on UITF HX can
- Set EV27RT to control CPI2732 at 1.05 atm, range=-10 to 100
- Set main compressor discharge pressure range from 12 to 15
- Ensure that CB3 injection valves are set to automatic and that CB4 HP supply MV2CB4 is open
- Give controls for CM JT to SRF during cooldown.

- Recovery suction pressure CPI284 shall remain below 1.2 atm during cooldown
- Kinney suction pressure CPI2091 shall remain below 0.05 atm during cooldown

- Once CM is cold, close MV27BY
- When CM is ready to pump down to 2K, slowly manually open EV27RT in ~0.3 increments
  - Keep Kinney suction CPI2091 below 0.09 during this time
  - Once CM pressure reaches ~0.04, put max and min of EV27RT to 100

**Cryo Ops Contacts**: Swapnil Shrishrimal, Sasa Radovic, Thilan Wijeratne, and Joe Wilson

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The following describes **Commissioning the cold QCM with RF** procedure, which requires that the UITF enclosure be cleared of personnel:

**Procedure:**

**Inside the UITF**

1. Shielding Verification: In advance of QCM commissioning, contact the Radiation Control Group to verify acceptable UITF shielding
2. Verify that valves on either side of the QCM are CLOSED and cannot be opened via EPICS (i.e., the compressed air line is NOT attached to the OPEN spigot of the valve)
3. 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) Inform all occupants to leave the UITF enclosure, inform occupants at the electronics racks above Cave1 about the day's activities and that personal dosimetry is required by roof top occupants
   ii) Verify the barrier is installed at the Cave2 helium vent and that required lead shielding is properly positioned at the Cave1 trenches
   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 Cave2
   viii) Verify the two valves on either side of the are locked CLOSED and disabled from epics control
   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:**

Following QCM cool down, RF can be applied to the QCM. **An appendix describes the RF commissioning**

**procedure for C100 cryomodules**. Similar steps will be followed for the QCM, and performed by SRF Institute staff, with CIS staff observing. After the first few RF commissioning trials, a dedicated RF commissioning procedure will be written for the QCM and CIS staff will apply RF to the QCM in the future.

**12. 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 QCM RF from EPICS control screens
- Switch the PSS State key to "OPEN"

**13. Special environmental control requirements:**

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

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

**13.3 Abatement steps** (secondary containment or special packaging requirements)

**14. 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, 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 that produces an audible alarm that can be heard inside Cave1 in the vicinity of the photogun and SF6 pressure vessel
4. Potential prompt radiation (magenta strobe beacon and 30 second siren), located at each doorway and near the electronics racks on Cave1 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. Radiation alarms cleared by Radiation Control Group

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 Cave1. 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, a very thin layer less than 1" thick. In this case, personnel are not allowed to work on the floor, i.e., on hands and knees, 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, confer with Facilities to restore ventilation.

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

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

**16. Inspection Schedules**

PSS certification will happen twice per year, scheduled by SSG

**17. References/Associated/Relevant Documentation**

Task Hazard Analysis
UITF ODH assessment
QCM vacuum vessel design and analysis can be viewed in Docushare Pressure System Folder
C100 RF commissioning procedure

**18. 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 1.4 – 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 | 06/20/16 | 06/20/19 | 1.4 |

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