Argonne Bubble Chamber Test

1 Description of Test

The intent is to use the injector test area with a maximum beam energy of 10 MeV (9.5 MeV kinetic) to test the operational characteristics of the Argonne Bubble Chamber. The electron beam will be fully stopped by a water cooled copper dump/radiator. The chamber was tested at Duke where a high energy bremsstrahlung background adversely affected the results. The purpose of the test at JLAB is to determine the photon detection effectiveness in a low neutron background environment. Operating parameters (e.g. pressure, temperature, fluid, event rate, buffer fluid level) shall be adjusted within a safety envelope to improve photon detection and chamber recovery times. The active fluids for the test are N2O and C2F6.

1.1 Operational limits

Parameter	Limits
Bubble Chamber Pressure	0 to 1000 psig
Bubble Chamber Metal Temperature	-15 to 30 C
Beam Energy	4 to 10 MeV
Beam Current	0 to 10 µA
Detector Fluids	C2F6 and N2O
Active fluid temperature	-30 to 30 C
Bubble quenching pressure difference	500 psi max

1.2 Test Plan

The detector shall be tested within the limits listed above. For a detailed test plan see Section 11.4. Detailed procedures for operating the detector are given in Section 9.

2 Bubble Chamber Detector

2.1 General description

The Argonne Bubble Chamber was developed and tested at Argonne National Lab (ANL) by Brad DiGiovine et. al. The Chamber may be adapted for use with various super-heated target fluids. These fluids are contained in a glass vessel with a fluid volume of 40-60 ml depending on the fill configuration. There is an additional 150 ml of mercury (less than the 5 lbm Virginia state limit) that serves as a buffer fluid. The small bubble chamber vessel is contained in a larger (~7.5 liter) pressure vessel. The space between the two vessels is filled with a mineral oil based heat transfer liquid pressurized to a maximum of 1000 psi. The pressure in the glass vessel and the pressure vessel are commuted via a bellows assembly such that the differential pressure across the glass is very small. Should the inner vessel fail all fluids would be contained in the outer pressure vessel. See the figures below for more details. The system has two copper collimator/beam ports and two commercially supplied viewports. See Figure 1 below.

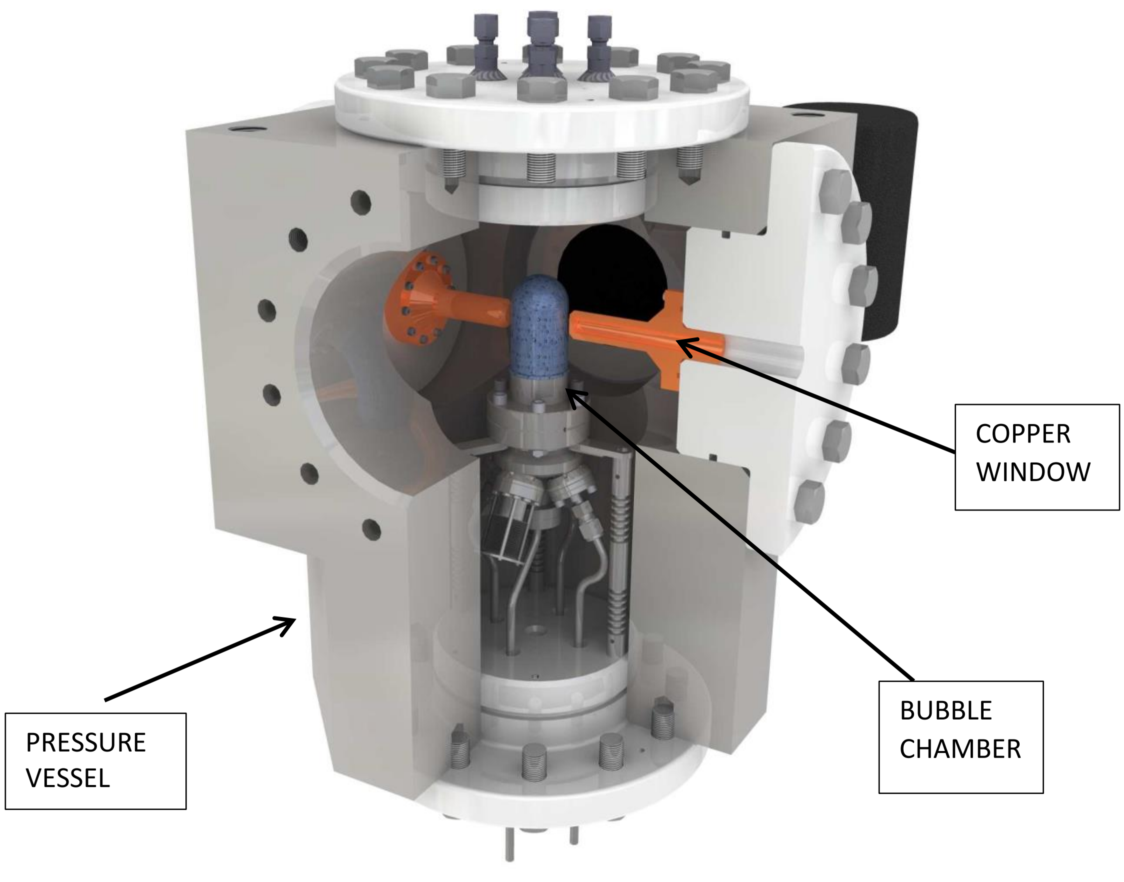

Figure 1: Bubble chamber and pressure vessel cut away view

2.2 Basic Theory of Operation

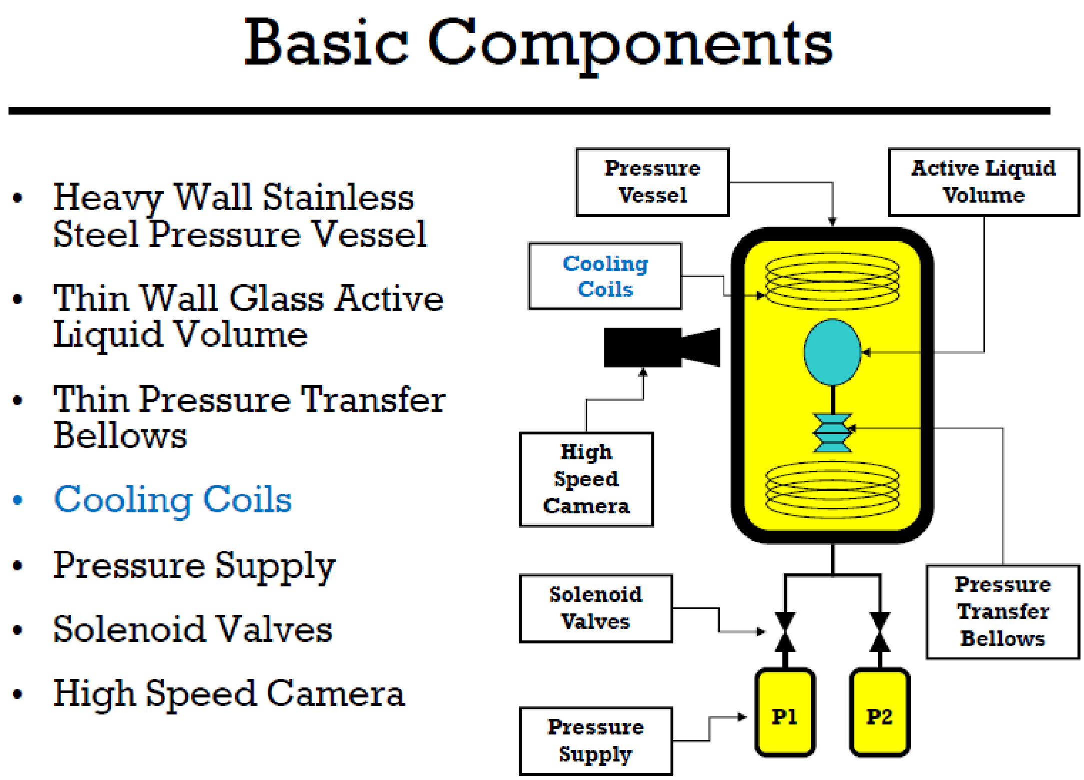

Figure 2: Basic Components

This system is designed to prepare the active fluid of choice into a metastable superheated state to act as an active target for low energy nuclear astrophysics research. There are two main volumes, the first is a small clean volume containing the active fluid and buffer fluid. This volume is built of stainless steel and glass and is contained within the heavy wall stainless steel pressure vessel. An edge welded bellows is incorporated into this clean volume to facilitate volumetric changes due to changes in operating temperature, as well as to equalize pressure between this clean volume and the outer hydraulic volume. Surrounding this clean volume within the heavy wall vessel is a hydraulic working fluid. This fluid provides for thermal stability of the active fluid, and is directly connected to the pressure supply system external to the vessel. The pressure supply system is a hydraulic system which controls the system pressure by the actuation of solenoid valves allowing the system to cycle between superheat pressure (low) and recovery (high) pressure (points 3 and 4 in the Figure 3). The active volume is backlit and observed by a fast machine vision camera operating at 100Hz. The data acquisition and control computer analyzes these images, determines if an event has occurred, stores the event, logs instrumentation data, and signals the system to pressurize to the default recovery state from the active superheated state. Once the system recovers, the computer signals to decompress to the superheated state and the system goes live again. Temperature control is accomplished via an external chiller and flow control system which is manually operated. This system feeds heat exchange coils within the hydraulic volume, this has replaced an existing heating system which is no longer present, but sometimes referenced in older documentation.

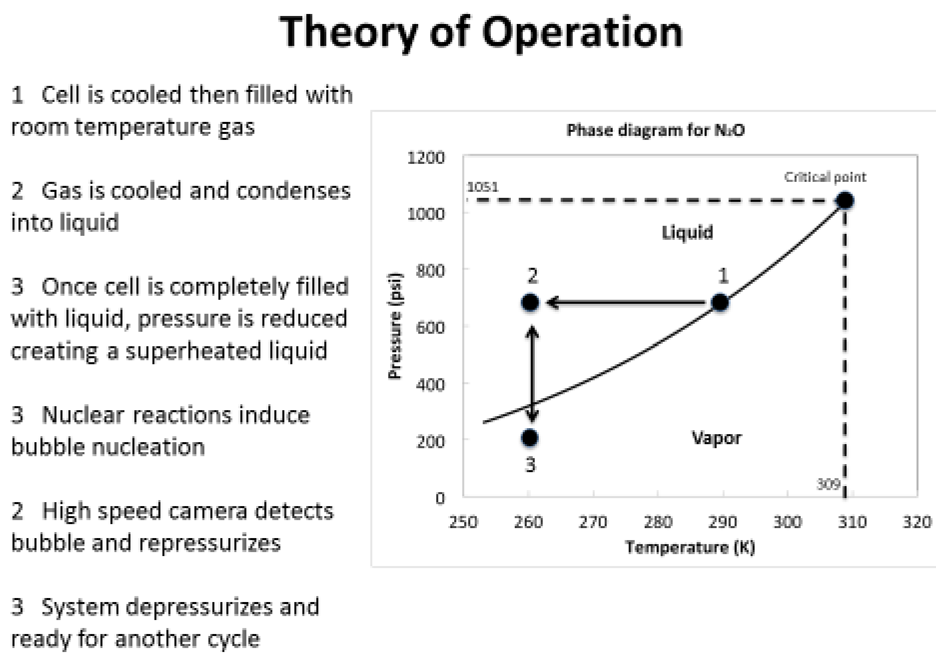

Figure 3: Phase Diagram and Theory of Operation

3 Hazardous Materials

3.1 Mercury

There is roughly 150 ml of mercury contained in the inner vessel. This fluid serves as a buffer fluid for the active target fluid. The mercury has been preloaded into the inner vessel at Argonne National Lab (ANL). Pump and purge cycles performed on this volume with small quantities of the target fluid are required to ensure a pure liquid sample. To prevent a mercury (droplets or vapor) release, two filters are installed (see P&ID). Filter F-001 is installed upstream of the vacuum pump and will prevent droplets from reaching the vacuum pump. Filter F-002 is installed on the outlet of the pump to prevent mercury vapor from escaping the system. While these safe guards are in place, mercury can still be released through human or mechanical failure. Mechanical failure is extremely unlikely given that the fluid systems have been designed and fabricated in excess of ASME Code requirements.

Hazards associated with long term or acute mercury exposure are:

- Neurological symptoms:
  - Headache, short term memory loss, incoordination, weakness, tremors, etc.
- Kidneys may also be affected
- Intense exposure to vapors can lead to severe respiratory damage.

The following mitigating steps shall be employed to limit exposure or loss of mercury:

- Only the system expert, Brad DiGiovine, shall be allowed to perform the filling and venting operations using the procedures given in Section 9.
- Fluid systems that are designed and fabricated in excess of ASME Code requirements.
- Documented TOSP including specific procedures for bubble chamber fluid handling operations.
- Perform leak tests of the system prior to introducing active fluid into the system piping.
- Monitor personnel/room air for mercury; SKC Elemental Mercury Passive Sampler
- Secondary spill containment under the bubble chamber.
- Limited amount of mercury 150 ml.
- Spill kit placed in injector

The MSDS or MDS for Mercury is filed in the pressure system folder PS-TGT-14-002.

3.2 N2O

Nitrous Oxide (N2O) may be used as an active fluid in the bubble chamber. If selected as the active fluid, the chamber shall contain 40 to 60 ml of liquid N2O. Note that the N2O is a liquid at the high operating pressure even at room temperature. At STP this quantity of N2O expands to roughly 17 liters. The occupational limit for N2O exposure (based on 2000 hour/year exposure) is 50 ppm. Should all of this gas escape the system, the concentration in the injector area would be 25 ppm which is below the limit (see TGT-CALC-502-002). This limit could be exceeded if the contents of the supply bottle is released. This bottle shall be valved closed at all times other than when the filling procedure is being performed. While N2O is not flammable it does rapidly decompose to release oxygen which can accelerate or reignite fires.

This material presents the following hazards from an acute overexposure:

- Dizziness
- Drowsiness
- Poor coordination
- Oxidizer can accelerate or reignite fire.

The following mitigating steps shall be employed:

- Limited quantities do not present ODH/asphyxiant hazard.
- Only the system expert, Brad DiGiovine, shall be allowed to perform the filling and venting operations using the procedures given in Section 9.
- Fluid systems that are designed and fabricated in excess of ASME Code requirements.
- Documented TOSP including specific procedures for bubble chamber fluid handling operations.
- Perform leak tests of the system prior to introducing N2O into the system piping.
- Monitor personnel/room air for N2O exposure using Assay Technology 575 N2O sampler
- N2O is an oxidizer; therefore all flammable gases in the CEBAF Injector shall be stored at least 20 ft from the N2O bottle. This is typically not an issue in the Injector.
- Removal of N2O bottle when not in use. Store bottle in locked storage area.

The MSDS or SDS for N2O is filed in the pressure system folder PS-TGT-14-002.

3.3 C2F6

Hexaflouroethane (C2F6) may be used as an active fluid in the bubble chamber. If selected as the active fluid, the chamber shall contain 40 to 60 ml of liquid C2F6. Note that the C2F6 is a liquid at the high operating pressure even at room temperature (see Section 5). At STP this quantity of C2F6 expands to roughly 1 liter. The occupational limit for C2F6 exposure (based on 2000 hour/year exposure) is 1000 ppm. Should all of this gas escape the system, the concentration in the injector area would be much less than the limit (14 liters at STP or 20 ppm) (see TGT-CALC-502-002). This limit could be exceeded if the contents of the supply bottle are released. This bottle shall be valved closed at all times other than when the filling procedure is being performed.

The hazards associated with C2F6 over exposure:

- Difficulty breathing
- Does not pose ODH risk with the limited quantities needed for the bubble chamber.

The following mitigating steps shall be employed:

- Only the system expert, Brad DiGiovine, shall be allowed to perform the filling and venting operations using the procedures given in Section 9.
- Fluid systems that are designed and fabricated in excess of ASME Code requirements.
- Documented TOSP including specific procedures for bubble chamber fluid handling operations.
- Perform leak tests of the system prior to introducing C2F6 into the system piping.

Removal of C2F6 bottle when not in use.

The MSDS or SDS for C2F6 is filed in the pressure system folder PS-TGT-14-002.

3.4 Duratherm 450

The hydraulic fluid in the space between the inner and outer vessels is a mineral oil based heat transfer fluid. This fluid is not considered hazardous material. An MSDS/SDS is filed in the pressure system folder. The fluid is considered non-toxic and environmentally friendly. It poses no ill effects to worker safety. Duratherm 450 is flammable with a flash point slightly above 290 F.

The MSDS or SDS for Duratherm 450 is filed in the pressure system folder PS-TGT-14-002.

4 Required Training

The following training is required for operation of the detector and for installation and removal activities. Filling and relief procedures shall only be performed by the system expert Brad DiGiovine who is considered fully trained. All users, prior to operating the DAQ system require a short briefing, given by B. DiGiovine. The following is a list of additional general training required for users:

- SAF 801 Rad worker I
- SAF 103 ODH
- SAF 130 Oil Spill Training (not required for all personnel and only if needed)
- SAF 132 Tunnel worker safety
- SAF 801kd RWP for tunnel access
- SAF 100 General safety

5 Electrical Safety

The detector and all ancillary equipment was developed and assembled at Argonne National Lab. Detailed schematics can be found in the pressure systems folder (PS-TGT-14-002). The system was inspected by both Argonne and JLAB SMEs and found to be sound.

5.1 Maintenance Procedures

Maintenance shall only be performed by Brad DiGiovine (ANL) after disconnecting the power source (at the plug) obviating lock tag and try procedures. Work shall not be performed on exposed equipment when energized.

6 Radiation Safety

The electron beam has a maximum energy of 10 MeV for the test. The CEBAF Injector area shall be radiologically surveyed prior to any access when beam energies exceed 8 MeV. The survey is considered good practice; no activation of material in the CEBAF Injector is expected.

7 Material Handling

The chamber has engineered lift points that are centered over the center of gravity. The weight of the chamber is less than 500 lbm and shall be lifted by trained (crane and rigging) JLAB staff under the direct supervision of Brad DiGiovine from ANL. There is no lift procedure required for these operations. The chamber must be lifted about 3 ft. off the floor to be installed onto and removed from the cart. Note that the flanges are heavy and caution must be taken when removing and installing them.

8 Pressure Safety

The pressure systems documentation is filed in the pressure system folder PS-TGT-14-002 on DocuShare. There is extensive documentation for the original ANL system including reviews performed at ANL. This includes the review alteration of the system to operate with N2O and C2F6 with mercury as a buffer fluid. ANL documentation requirements for low stored energy systems is not as extensive as JLAB requirements. The total stored energy of the system is less than 1000 ft-lbf (1300 J) and is therefore considered low risk. Additional calculations confirming the design of the system have been performed by the JLAB DA for the system (Dave Meekins). These calculations indicate the system is safe to operate within the following parameters.

Parameter	**Limits**
Operating pressure	1000 psi
Operating Temperature	-30C to 30C
Cycle depth for quench	500 psi max
Hydraulic pump	1 GPM
Design Pressure	1100 psi
Applicable Code	ASME B31.3 2010

Note that care must be taken when filling and relieving to prevent damage to the glass bubble chamber. Should the chamber rupture, the glass would be contained in the outer vessel but the detector assembly would need to be returned to ANL for repair. For this reason, only the system expert Brad DiGiovine may perform the fill or relief procedures. See Section 9 for details.

8.1 Major Subsystems

The system consists of the following subsystems

- Hydraulic fluid system
  - Outer vessel and beam ports
  - Hydac hydraulic pump
  - Gas and hydraulic fluid handling control panel.
  - Ancillary piping for hydraulic and nitrogen gas fluids (nitrogen is used to charge the accumulators)
  - Camera with Canty glass windows.
- Target fluid system
  - Inner vessel (actual bubble chamber)
  - Ancillary piping for gas handling
- Refrigerator system
  - Commercially supplied refrigerator and insulated flex lines
- DAQ and control system

8.2 Component list

The following is a general list of components for the entire system. These components are rated by the manufacturer to have working pressure limits in excess of the operating pressures for the system.

1. Commercially supplied
    a. Hydraulic pump 1 gpm
    b. Low, high and supply accumulators Hydac SB 200 and SB 210 series.
    c. Hand and solenoid actuated valves
    d. Relief valves.
    e. 0.25” and 0.375” nominal tubing; SST 0.035” wall.
    f. Pressure regulators
    g. Various relief valves (hydraulic and pneumatic)
    h. Phase separator
    i. Pressure gauges and transducers
    j. Flow controller/valves
    k. Filter, strainer, and check valves
    l. Camera and high pressure window
2. The following components are custom
    a. Beam ports (copper subject to compression loading).
    b. Bubble chamber (glass vessel fully contained in the larger pressure vessel).
    c. Pressure vessel (because of limited size <6 inch bore this component is not required to meet the ASME BPVC). The most applicable ASME Pressure Code is ASME B31.3 2012.

The commercially supplied components have maximum working pressure ratings of 1500 psi or higher. Fittings are Swagelok with non-welded connections (i.e. there are no welded joints outside of the commercial components boundaries). Commercially supplied components are accepted without further calculations. The fully assembled (without camera) system is shown in Figure 4.

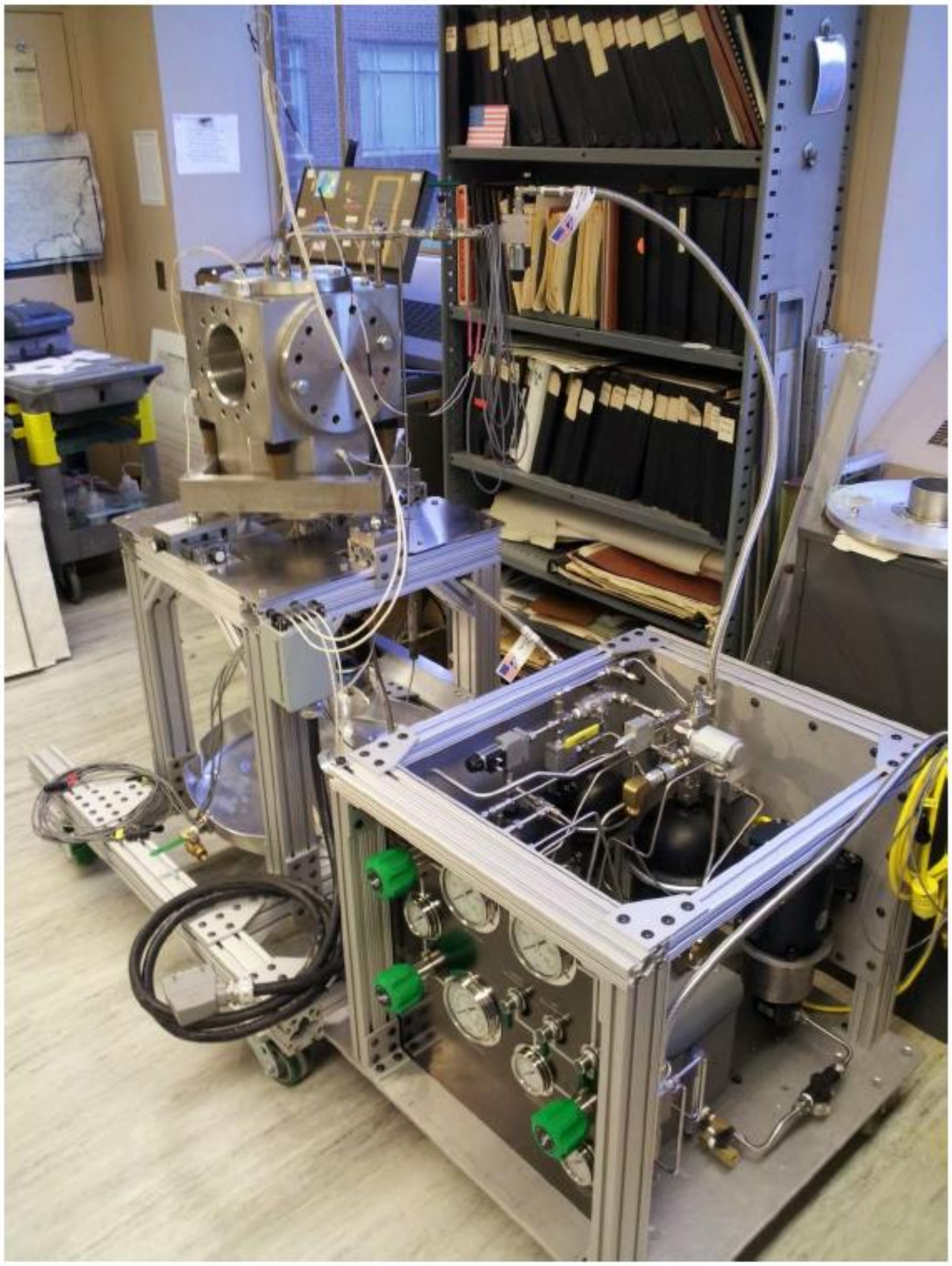

Figure 4: Fully assembled system

8.3 Canty Camera and Glass Windows

The camera and window are commercially supplied and have operating pressure ratings of 1300 psi as indicated in the drawing below (see Figure 5). These components have technology considered proprietary by the manufacturer and do not have additional documentation beyond this certification. This drawing can be found in the pressure system folder. These components are accepted without further analysis. See Figure 5.

8.4 Vessel and chamber

The vessel is machined from a single forged block of SST 304. The design pressure is 1700 psi (1100 psi for beam ports). The maximum operating pressure is 1000 psi. This is determined by the relief valve PSV-4. This valve is not an ASME valve but does have a capacity higher than the pump can deliver. The vessel is protected by a Flow Safe ASME liquid relief set at 1100 psi with a capacity far greater than the pump can supply. It is JLAB policy that piping less than 6 inch in diameter need not be protected from fire. The relief device is a Flow Safe S8L2P-05FN-05FN-SS-SS-KVN.

8.5 Piping

All piping components are commercially available from the following suppliers.

- Swagelok: Fittings, valves, flex lines, and tubing
- Parker: small hand valves
- Hydac: hydraulic pump, fittings, relief/check valves, and accumulators
- Kunkle relief valves
- Wika pressure gauges

All components have a working pressure rating (with the exception of the lower range pressure gauges) in excess of the relief device set points. The N2 piping is protected by an AMSE relief valve: Kunkle 1000 psi 207 SCFM.

8.6 Vacuum System

The vacuum system is temporarily connected when filling and venting (relieving) the system. There is a vacuum pop-off installed on the vacuum line that will prevent an accidental overpressure of the vacuum system due to operator error. Note that only the system expert is allowed to perform procedures requiring the vacuum subsystem.

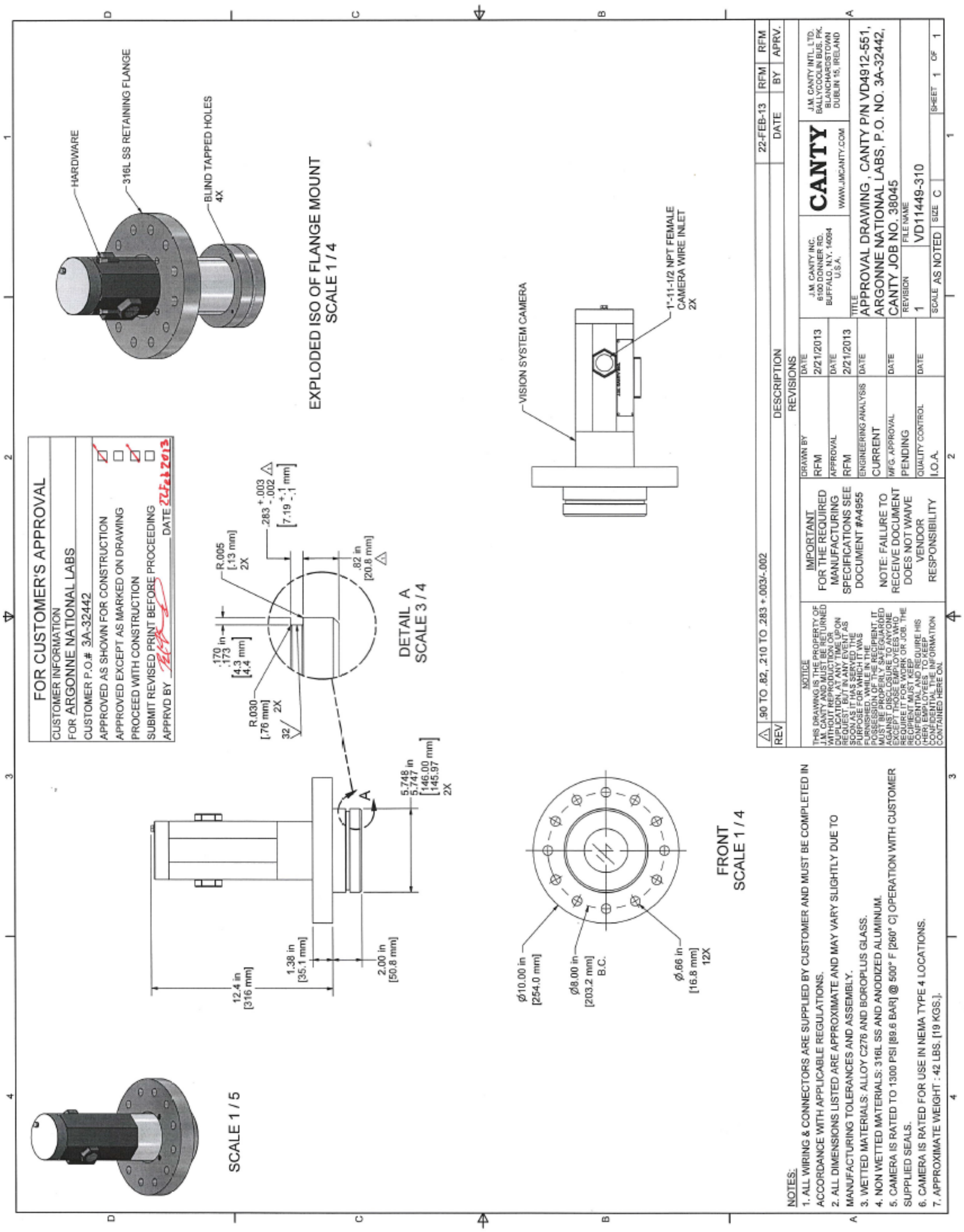

Figure 5: Canty camera and window assembly.

9 Procedures for bubble chamber operations

9.1.1 Installation

Mercury (Hg) was preloaded into the bubble chamber space at ANL in a clean room environment. There shall be no handling of Hg at JLAB outside of extreme emergency situations. If necessary, the chamber shall be shipped back to ANL for any and all Hg handling. Installation shall proceed under the direct supervision of B. DiGiovine and D. Meekins. An electrical inspection shall be performed by Todd Kujawa.

9.1.2 Filling Procedure

The following procedure shall be used for all filling operations. Only Brad DiGiovine from ANL shall perform this procedure.

1. Ensure that the correct personnel monitoring equipment for exposure to the target fluid (Assay Technology 575 N2O sampler) and mercury (SKC Elemental Mercury Passive Sampler) is in place.
2. Make sure LabVIEW is online and temperature/pressure data is available and accurate
3. Connect filling manifold to detector fill port with new VCR gasket, connect dry pump, connect gas supply bottle.
4. Perform a leak down vacuum test of filling manifold
5. Open the bottle supply valve and bleed a small amount of gas from supply into filling manifold and pump out, several times to purge system.
6. Pump out filling manifold and open valve to detector phase separator to pump.
7. Open valve to detector upper fill line to pump active volume of detector.
8. Connect hydraulic fluid reservoir to fill port on the heavy wall vessel, connect vacuum pump to pump port on top of vessel.
9. Pump and fill hydraulic volume of vessel
10. Turn on chiller system, adjust temperature and flow control valves to appropriate values based on active fluid and threshold calculations.
11. Once fluid temperature has reached operating conditions filling can begin
12. Close detector upper fill valve and use regulator on filling manifold to set fill pressure to 3atm
13. Open valve to detector lower fill and fill upper volume with appropriate amount of mercury
14. Close valve to lower detector fill and open valve to upper detector fill to begin letting gas into inner volume, constantly check the pressure differential across glass.
15. Once the pressure differential is close to 1atm, begin to increase hydraulic pressure to equalize the pressure differential.
16. Repeat 13 and 14, increasing gas and hydraulic pressure until vapor pressure is reached at temperature, gas will begin to liquefy. Continue to fill with liquid active fluid until there is no remaining gas volume and the mercury meniscus has been displaced down several millimeters.
17. Close valve to upper detector fill, close valve to detector phase separator, close valve to gas bottle
18. Let system sit and settle for some time to allow thermal equilibrium to be reached.
19. **Ensure that the bottle valve is fully closed**. Disconnect from system.
20. Verify proper setup and operation of LabVIEW system, verify proper operating pressures and temperatures.

21. Set system into standby for users to take over operation.

9.1.3 Venting

The following procedure shall be used for venting. Only Brad DiGiovine shall perform this procedure.

1. Ensure that the correct personnel monitoring equipment for exposure to the target fluid (Assay Technology 575 N2O sampler) and mercury (SKC Elemental Mercury Passive Sampler) is in place.
2. Verify filling manifold is still properly setup, if not, install manifold and pump.
3. Turn on pump, pump out manifold
4. Open valve to detector phase separator and pump
5. Begin lowering hydraulic pressure slowly to vapor pressure at temperature
6. Wait for gas bubble to form in active volume, leave pressure so little change in gas bubble volume occurs
7. Slowly open detector upper fill valve and begin bleeding liquid into phase separator
8. Once all liquid is gone continue bleeding until differential pressure across glass is close to 1atm, close detector upper fill valve
9. Lower pressure in hydraulic system to equalize differential pressure
10. Open detector upper fill valve and repeat 7&8 until system is completely vented and pumped, hydraulic system pressure should be 1atm, inner volume FV.
11. Close detector upper fill valve, close detector phase separator valve; turn off pump.
12. Power down chiller, and shut down hydraulic system, electronics and DAQ can now be powered down if necessary.

9.1.4 Power loss

In the event of a power loss, place the remote override box into its default position as described in the general user section. The system automatically switches to recovery (high) pressure to prevent any active fluid boiling. The chiller system will of course fail due to loss of power so the system will begin warming up. The bellows in the active volume will provide the necessary expansion volume for the possible excursion to room temperature, and the hydraulic system relieving regulators (and backup relief valve) will provide the necessary relief for the inevitable expansion of the hydraulic fluid. The hydraulic supply system also has a large supply accumulator which will provide the necessary hydraulic supply pressure for weeks in system standby. A system expert must inspect and determine the proper course of action once power is available again, ideally the system will be able to be cooled back down to operating temperature and returned to service with minimal disruption.

9.1.5 Fire

In the case of a fire, place the remote override box into its default position as described in the general user section. Do not approach the system, it is designed to relieve excess pressure in events like this, but due to the chemical hazards present from operating fluids, and possible thermal decomposition, the composition of the venting material will likely be hazardous. Stay away.

9.1.6 Basic User Operation

Any user not considered an expert is limited to the start/stop of runs, and the placement of the system into and out of standby. The main interface of the system for standard user is a LabVIEW interface and control panel. This panel allows for the naming of runs, specifying data storage locations, and the start/stop function.

The system will be available for users once it is prepared and placed into standby by an expert. This means that the system will be at operating temperature and pressurized to its recovery (high) pressure. The LabVIEW system will be online but not running.

9.1.6.1 Start Run

Step 1. Enter (or verify) the storage location of data files in the “path” textbox

Step 2. Enter run number in the appropriate textbox

Step 3. Click the run (arrow) button

The system will decompress to the active pressure and become live, the acquisition and control system will automatically recognize events, log data, pressurize the system to recover, and decompress to the active pressure to go live again.

9.1.6.2 End Run

To end a run and place the system in standby

Step 1. Click the red “STOP” button on the LabVIEW interface

Step 2. Verify system pressure has increased to recovery (high) as indicated by LabVIEW

9.1.6.3 DAQ Failure

A remote override box is available to users, this is only necessary in the event of acquisition failure, emergency, or as a redundant backup for standby mode. A user must verify proper position of override switches before enabling the box with the toggle switch in the upper left corner. The switches should be left in this orientation to facilitate a fast enabling of override.

The default standby positions are:

- Heater Power: Disabled
- Hydraulic Supply Pump: Enabled
- Valve High: Open (Green)
- Valve Low: Closed (Green)
- Valve Bleed: Closed (Green)
- Valve Inner: Closed (Green)

These switches are found on the System Override Box shown in Figure 6.

Figure 6: System Override Box

9.1.6.4 Control System Alarms

The user interface is simple to use as there are few functions for the interface to perform. The following is a list of the control functions:

- There is an alarm on the temperature which indicates possible failure of the refrigerator. This will stop the DAQ Run and return the system to the high pressure (stable) condition.
- Backlight failure alarm. The alarm and interlock Stops the DAQ Run and returns the system to the high pressure condition.
- Differential pressure alarm: this alarm indicates that the DP limit between the inner and outer vessel has been exceeded. The interlock with stop the DAQ Run and return the system to the high pressure condition. This limit is adjustable however B. DiGiovine is the only authorized person for setting this limit.

9.1.7 Emergency Deenergizing

This procedure shall only be performed in cases of emergency. Performing this procedure will likely cause damage to the bubble chamber glass vessel. Damage to this vessel does not pose a personnel risk but, will require that the chamber is shipped back to Argonne National Lab for repair.

1. Turn off hydraulic pump.
2. Turn of refrigerator.
3. Open HA-18 bypass valve.
4. Close PRV/RV 1 This is a pressure relieving regulator that will relieve pressure as the setpoint is lowered.
5. Close PRV/RV 2 This is a pressure relieving regulator that will relieve pressure as the setpoint is lowered.
6. Close PRV/RV 3 This is a pressure relieving regulator that will relieve pressure as the setpoint is lowered.
7. After pressure is relieved (verify on gauges PI

8. Power down chiller, and shut down hydraulic system, electronics and DAQ can now be powered down if necessary.
9. Do not attempt to open vessel or valves or disconnect lines on the system. The system expert shall disassemble the system for shipment to ANL for repair and inspection.

10Failure Modes and Effects

This section details the possible credible failure modes and their effects as well as mitigations to reduce risk to personnel and equipment.

10.1 Failure of glass bubble chamber

Failure of the glass vessel will be detected with the camera during operations mode. At all other times manual observation is required to detect the failure. This failure mode released N2O/C2F6 and mercury into the hydraulic fluid. The integrity of the system is still maintained and is safe as long as the system is not disassembled. The system must be shipped back to ANL for repair. Industrial Hygiene shall be required to cover the disassembly of system for shipment back to ANL. Procedures to perform the disassembly shall be agreed upon by IH and the system expert.

10.2 Failure of pump cut off switch

The pump is controlled by the pressure switch PS-1. Should this switch fail the pump would run continuously and supply a steady flow of 1 gpm. Multiple Hydac relief devices and control regulators should ensure that the pressure in the vessel and piping do not exceed the design pressures. However these devices are not ASME. Should these all fail, relief valve PSV-8 with a set pressure of 1100 psi ensures that the pressure in the vessel does not exceed the design pressures beyond Code limits.

10.3 Accumulator failure

Should the accumulator fail and allow N2 into the hydraulic system, there will be no effect aside from the system DAQ and control issues. The amount of N2 stored in the accumulators is negligible. The N2 bottle is disconnected after the charging procedure is complete. This event is considered extremely unlikely as these devices have a working pressure rating of 3000 psi.

10.4 Regulator failure

Should the N2 regulator fail on the accumulator charging line, an ASME relief valve will protect the system from overpressure. The orifice at the bottle connection ensures that the Cv is known and that the valve has adequate capacity. See TGT-CALC-502-003 for more details.

10.5 Refrigerator failure

Should the refrigerator fail without a full power failure while in operation or standby mode, the DAQ system will alarm and interlocks will open CV-2 and close CV-4. This returns the chamber and vessel to the stable condition. The active fluid will stay in the liquid state at room temperature and no damage to the bubble chamber will occur. The system may then be manually relieved in a safe and controlled manner with no damage to the bubble chamber and no additional risk to personnel. The consequences of this failure mode are minimal.

10.6 Power failure

Should a power failure occur while the detector is in operation or standby mode, the solenoid valves will got to the normal state with control valve CV-2 open and CV-4 closed. The bubble chamber and outer vessel are then set to the high pressure which is the stable condition for the fluid. This will prevent boiling of the fluid even with a full warm up to room temperature. The refrigerator will also fail during a full power failure. The system may then be manually relieved in a safe and controlled manner with no damage to the bubble chamber and no additional risk to personnel. The consequences of this failure mode are minimal.

11Beam Operations

11.1 General

The chamber will be operated remotely from the MCC control room. The control shall be separate from the beam control. Beam operations shall be limited to the following:

- Beam current shall be varied up to 10 µA
- Beam energy shall be varied up to 10 MeV
- Vary bubble chamber operating parameters as required inside limit envelop given in Section 1.1.

Note that the beamline with the dump was commissioned in 2014. It is approved for 10 MeV and 10 µA.

11.2 5D Beamline

The 5D beamline is in the injector region and was used for the PePpo experiment. The line was modified in 2014 to accommodate the future experiment E12-13-005 $^{16}O(\gamma,\alpha)^{12}C$. The beamline is formally described in the Song Sheet ACC2008000-1100. The line currently has an operational limit of 10 µA and 10 MeV (9.5 kinetic). The dump on this line shall also serve as a radiator to produce photons for the test of the bubble chamber detector. A Schematic of the beamline is shown in the figure below.

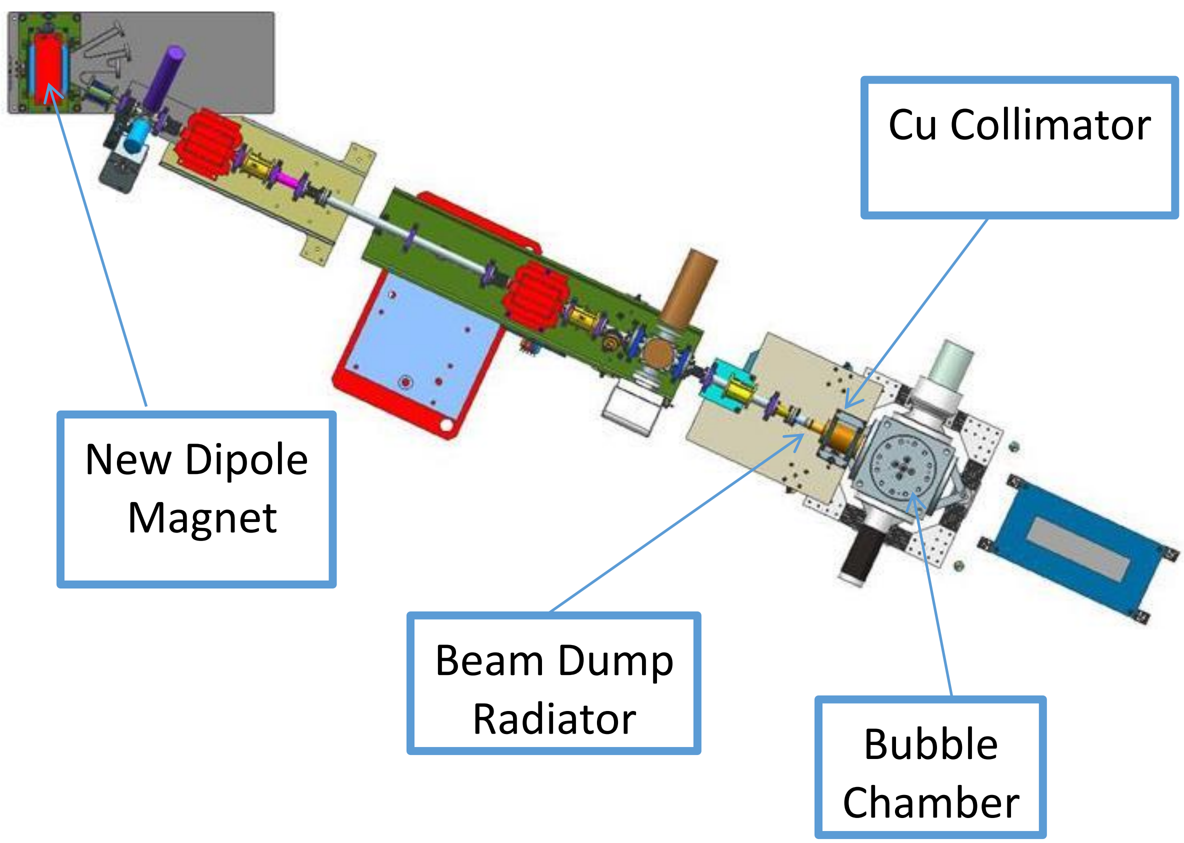

Figure 7: 5D Beamline Schematic

A new fast acting gate valve has been added to the beamline upstream of the 5D line. This valve closes when pressure is high in the downstream line thus protecting the ¼ cryomodule in the injector. This provides a layer of protection in the unlikely event that the copper dump fails.

11.3 Beam Dump/Radiator

The beam dump for the 5D line shall also serve as the radiator (source of photons) for the test. A thermal analysis using conservative assumptions was performed by J. Matalevich. This analysis can be found in the pressure system folder PS-ACC-14-003. A summary of the analysis is given in Figure 8. For the input power of 100 W the temperature rise on the beam dump is acceptable, about 100 C. This dump was commissioned in 2014. A GEANT simulation indicates that electrons from the beam will not penetrate the radiator/dump but knock on electrons produced by the incident photon shower will escape a much lower energies. These electrons are not expected to have any measurable effect on the detector.

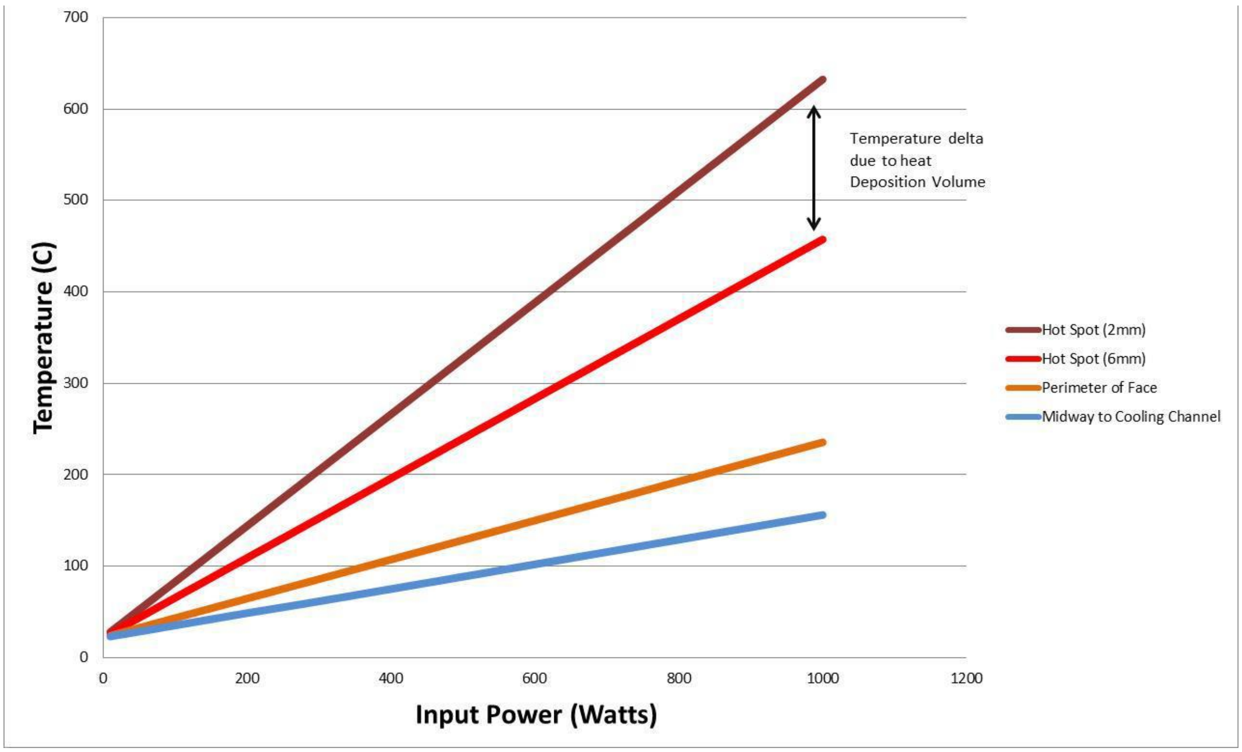

Figure 8: Beam dump/radiator temperature rise

11.4 General Test Plan

The test plan shall consist of two phases. The first where the chamber is filled with N2O as the active fluid and the second where this fluid is C2F6. The following is an outline plan for the test:

- Phase 1:
    - With no beam on the chamber test operation with neutron source. Ensure that the DAQ and hydraulic systems are functioning properly.
    - With beam on the dump operate the detector.
        - Check counting rates especially multiple bubble production

    - Measure bubble distribution in the chamber.
    - Background measurements:
        - Measure beam off background
        - Measure beam on background by examining outside the fiducial volume
        - Measure background with beam on Faraday Cup.
        - Measure neutron events in chamber when beam energy is above 8.5 MeV. Use neutron detectors in Injector area to measure neutron production rate.
- Phase 2:
    - Test system operation of the chamber with neutron source (after detector is down for ~1 month).
    - Measure rate to calibrate detector using Penfold-Leiss unfolding analysis. This can be compared to the neutron rich data from Duke.