

Procedure

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| Approved | Ed Folts |
| Title | Argonne Bubble Chamber Operations for Engineering Runs |
| Description: | <p>Procedures for test of ANL bubble chamber. The chamber is described in detail in PS folder PS-TGT-14-002. This document includes a system description, FMEA, safety data, and COO - conduct of operations (for test run). This document details the following procedures:</p> <ul style="list-style-type: none">• System prestart• Installation• Filling• Venting• Power loss• Fire• Basic user operation• Emergency Deenergizing |

Contents

| | | |
|---------|-----------------------------------------------|----|
| 1. | Revision History | 4 |
| 2. | Definitions | 4 |
| 3. | Purpose and Scope..... | 4 |
| 3.1. | Operational Restrictions | 4 |
| 3.2. | Test Plan..... | 4 |
| 4. | Facility | 5 |
| 5. | Authority | 5 |
| 6. | Controls..... | 5 |
| 6.1. | Engineered Controls..... | 5 |
| 6.2. | Special Fluid Materials | 5 |
| 6.2.1. | C3F8..... | 5 |
| 6.2.2. | Duratherm 450..... | 6 |
| 6.3. | Required Training..... | 6 |
| 7. | Bubble Chamber Detector | 8 |
| 7.1. | General description..... | 8 |
| 7.2. | Basic Theory of Operation | 9 |
| 8. | Electrical Safety..... | 11 |
| 8.1. | Maintenance Procedures | 11 |
| 9. | Radiation Safety | 12 |
| 10. | Material Handling | 13 |
| 11. | Pressure Safety | 14 |
| 11.1. | Major Subsystems | 14 |
| 11.2. | Component list..... | 14 |
| 11.3. | Canty Camera and Glass Windows | 16 |
| 11.4. | Vessel and chamber | 16 |
| 11.5. | Piping..... | 17 |
| 11.6. | Vacuum System..... | 17 |
| 12. | Procedures for bubble chamber operations..... | 19 |
| 12.1.1. | Installation | 19 |
| 12.1.2. | Prestart Checklist | 19 |
| 12.1.3. | Filling Procedure | 19 |
| 12.1.4. | Venting | 20 |

| | | |
|---------|---------------------------------------|----|
| 12.1.5. | Power loss | 20 |
| 12.1.6. | Fire | 21 |
| 12.1.7. | Basic User Operation..... | 21 |
| 12.1.8. | Emergency Deenergizing..... | 22 |
| 13. | Failure Modes and Effects..... | 24 |
| 13.1. | Failure of glass bubble chamber | 24 |
| 13.2. | Failure of pump cut off switch | 24 |
| 13.3. | Accumulator failure | 24 |
| 13.4. | Regulator failure | 24 |
| 13.5. | Refrigerator failure..... | 24 |
| 13.6. | Power failure..... | 24 |
| 14. | Beam Operations | 26 |
| 14.1. | General..... | 26 |
| 14.2. | 5D Beamline | 26 |
| 14.3. | Beam Dump/Radiator | 27 |
| 14.4. | General Test Plan | 27 |
| 15. | Conduct of Operations for Test | 29 |
| 15.1. | Organization and Administration:..... | 29 |
| 15.2. | Beam Operations | 29 |
| 15.3. | Injector Segment Access: | 30 |

1. Revision History

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|-------------|-----------|------------------------------------------------------|
| Revision: 0 | 4/24/2018 | Original |
| Revision: 1 | 5/1/2018 | Removed references to IH monitoring in process steps |

2. Definitions

- JLAB: Thomas Jefferson National Accelerator Facility
- MCC: Machine Control Center
- PEL: Permissible Exposure Limit; the permissible exposure limit (PEL or OSHA PEL) is a legal limit in the United States for exposure of an employee to a chemical substance or physical agent such as loud noise. Permissible exposure limits are established by the Occupational Safety and Health Administration (OSHA).
- PPE: Personnel Protective Equipment
- PSS: Personnel Safety System
- RCD: Radiation Control Department
- RWP: Radiological Work Permit
- SDS: Safety Data Sheet (Formerly MSDS)
- SSO: Safety System Officer

3. Purpose and Scope

The intent is to use the injector test area with a maximum total 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 fluid for the test is C3F8.

3.1. Operational Restrictions

| Parameter | Limits |
|--------------------------------------|-----------------|
| Bubble Chamber Pressure | 0 to 1000 psig |
| Bubble Chamber Metal Temperature | -15 to 30 C |
| Total Beam Energy | 4 to 10 MeV |
| Beam Current | 0 to 50 μ A |
| Detector Fluids | C3F8 |
| Active fluid temperature | -30 to 50 C |
| Bubble quenching pressure difference | 500 psi max |

3.2. Test Plan

The detector shall be tested within the limits listed above. For a detailed test plan see Section 14.4. Detailed procedures for operating the detector are given in Section 12.

4. Facility

This procedure shall be performed in the CEBAF Injector Area.

5. Authority

The authority to use this procedure is limited to the personnel listed below:

System Experts:

1. Brad Digiovine
2. Kevin Bailey
3. Thomas O'Conner

System Users

1. Riad Suleiman
2. Brad DiGiovine
3. David Meekins
4. Roy Holt
5. Ernst Rehm
6. Claudio Ugalde
7. Joe Grames
8. Matt Poelker
9. Alicia Hoffler
10. Dan Moser
11. Mike McCaughan
12. Seamus Riordan
13. Jay Benesch
14. Whitney Armstrong
15. Brandi Cade

6. Controls

6.1. Engineered Controls

The bubble chamber is a JLAB pressure system (PS-TGT-14-002) built at Argonne Nation Lab. The piping system meets all applicable Codes and Standards. A detailed analysis of the vessel (which contains hydraulic fluid with a low stored energy) also shows that this component is operated well within acceptable limits.

6.2. Special Fluid Materials

6.2.1. C3F8

Octofloropropane (C3F8) shall be used as an active fluid in the bubble chamber; the chamber shall contain 85 ml of liquid C3F8. At STP this quantity of C3F8 expands to roughly 2.5 liters. There is no PEL

for C3F8 exposure; for conservatism an exposure limit of 1000 ppm is assumed. It is not considered toxic or flammable.

Should all of this gas escape the system, the concentration in the injector area would be less than 50 ppm which is much less than the imposed limit (see TGT-CALC-18-005). This limit could be exceeded if the contents of a large supply bottle are released. This bottle shall be valved closed at all times other than when the filling procedure is being performed (this is a manual process that shall be performed by system experts only). The bottle shall be stored outside the Injector area in a designated gas bottle storage area.

The hazards associated with C3F8 over exposure:

- Difficulty breathing from oxygen deficiency.
- Asphyxiation. Note: does not pose ODH risk with the limited quantities needed for the bubble chamber.

The following mitigating steps shall be employed:

- Only the system experts, shall be allowed to perform the filling and venting operations using the procedures given in Section 12.
- 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 C3F8 into the system piping.
- Valve close and lock C3F8 bottle when not in use.

The SDS for C3F8 is filed in the pressure system folder PS-TGT-14-002.

6.2.2. 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.

6.3. 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 a system expert who is considered fully trained. All users, prior to operating the DAQ system require a short briefing, given by a system expert. The following is a list of additional general training required for experts and users:

- SAF 801 Rad worker I
- SAF 103 ODH
- SAF 123 Oil Spill Training (not required for all personnel and only if needed)
- SAF 130A Pressure System Awareness Training (Staff/Users)
 - User version is available online
 - Only required for system experts (i.e. those working with pressurized fluids)

- SAF 132 Tunnel worker safety
- SAF 801kd RWP for tunnel access
- SAF 100 General safety

7. Bubble Chamber Detector

7.1. 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 up to 150 ml depending on the fill configuration. 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.

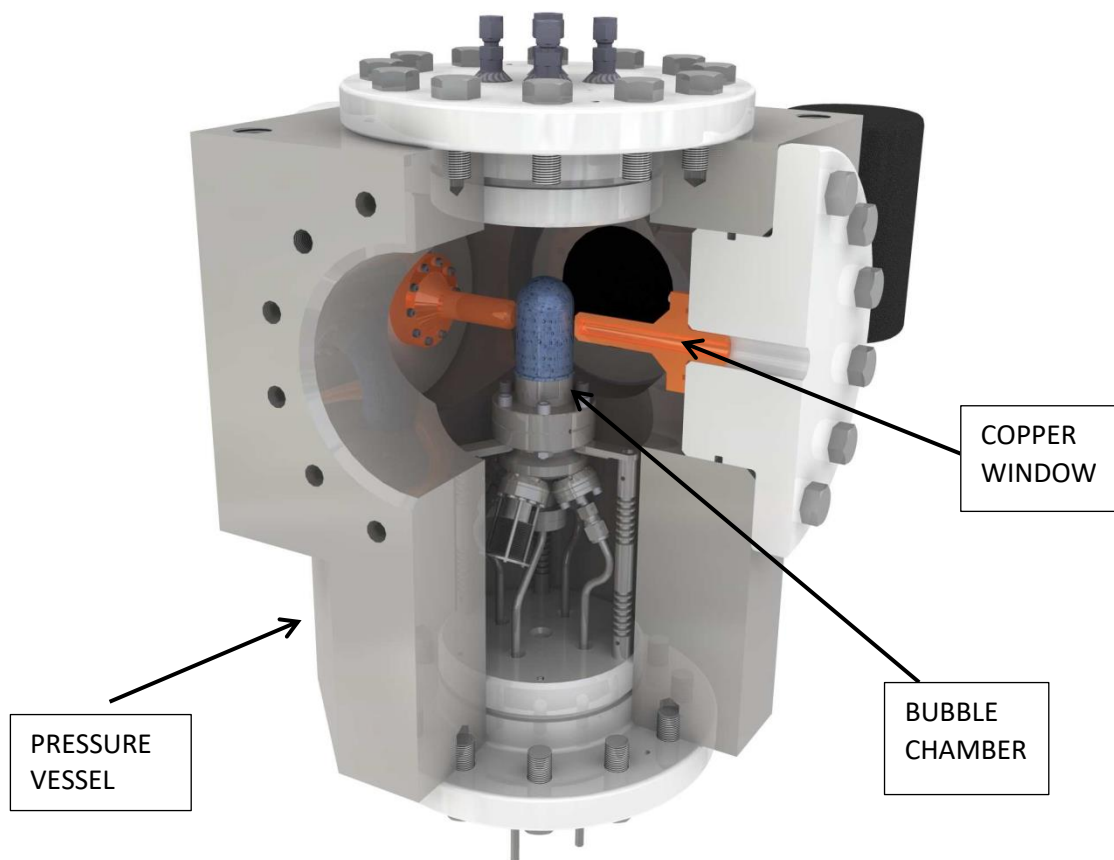


Figure 1: Bubble chamber and pressure vessel cut away view

7.2. Basic Theory of Operation

Basic Components

- Heavy Wall Stainless Steel Pressure Vessel
- Thin Wall Glass Active Liquid Volume
- Thin Pressure Transfer Bellows
- Cooling Coils
- Pressure Supply
- Solenoid Valves
- High Speed Camera

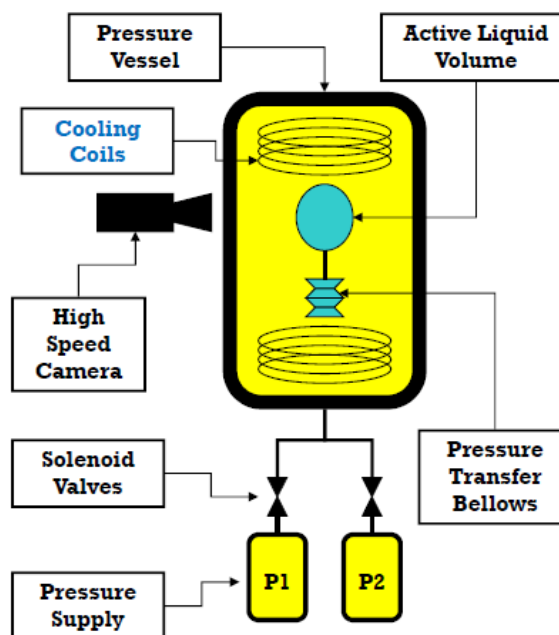


Figure 2: Basic Components

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 2 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.

Theory of Operation

1 Cell is cooled then filled with room temperature gas

2 Gas is cooled and condenses into liquid

3 Once cell is completely filled with liquid, pressure is reduced creating a superheated liquid

3 Nuclear reactions induce bubble nucleation

2 High speed camera detects bubble and repressurizes

3 System depressurizes and ready for another cycle

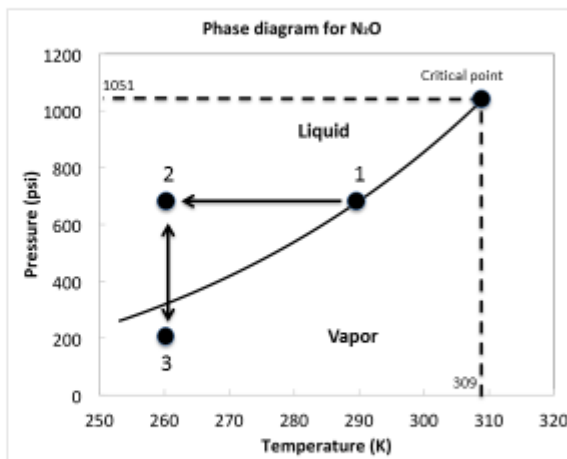


Figure 3: Phase Diagram and Theory of Operation. Note actual operating pressures and temperatures for C3F8 are much lower than those shown in the figure.

8. 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 prior to the September 2015 run and found to be sound. The system shall be re-inspected by JLAB SME prior to operation.

8.1. Maintenance Procedures

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

9. Radiation Safety

The electron beam has a maximum total energy of 10 MeV for the test. No radiation hazards are expected when the beam is off. In August 2015, one of the rapid access probes in the Injector was relocated above the copper radiator/dump in the bubble chamber beamline. This ensures that rapid access will function as intended in this configuration and operation of the bubble chamber will not require RadCon surveys as the electron beam energy is gradually raised. If the radiator/dump gets activated, the probe will alarm at 1.4 mrem/h at 1 foot, i.e. a safety factor of ~3.5 below the radiation area limit. Therefore, as long as the Rapid Access beacon activates when the button is depressed, no survey is required for Controlled Accesses or prior to going to Restricted Access.

10. 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 (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.

11. 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 of the alteration of the system to operate with C3F8. 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 50C |
| 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 shall perform the fill or relief procedures. See Section 12 for details.

11.1. 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 Cauty 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

11.2. 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.

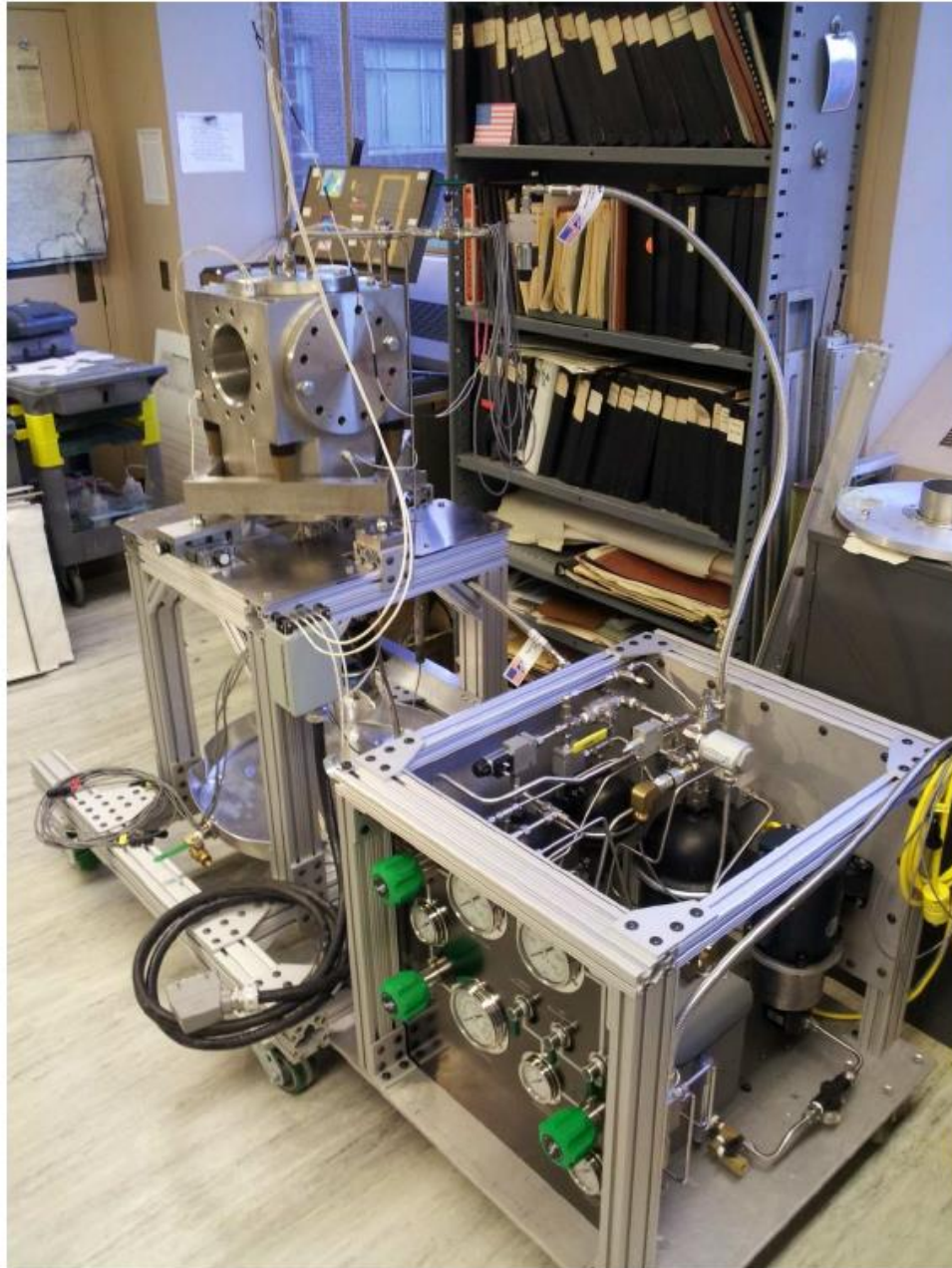


Figure 4: Fully assembled system

11.3. 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.

11.4. 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.

11.5. 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.

11.6. 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.

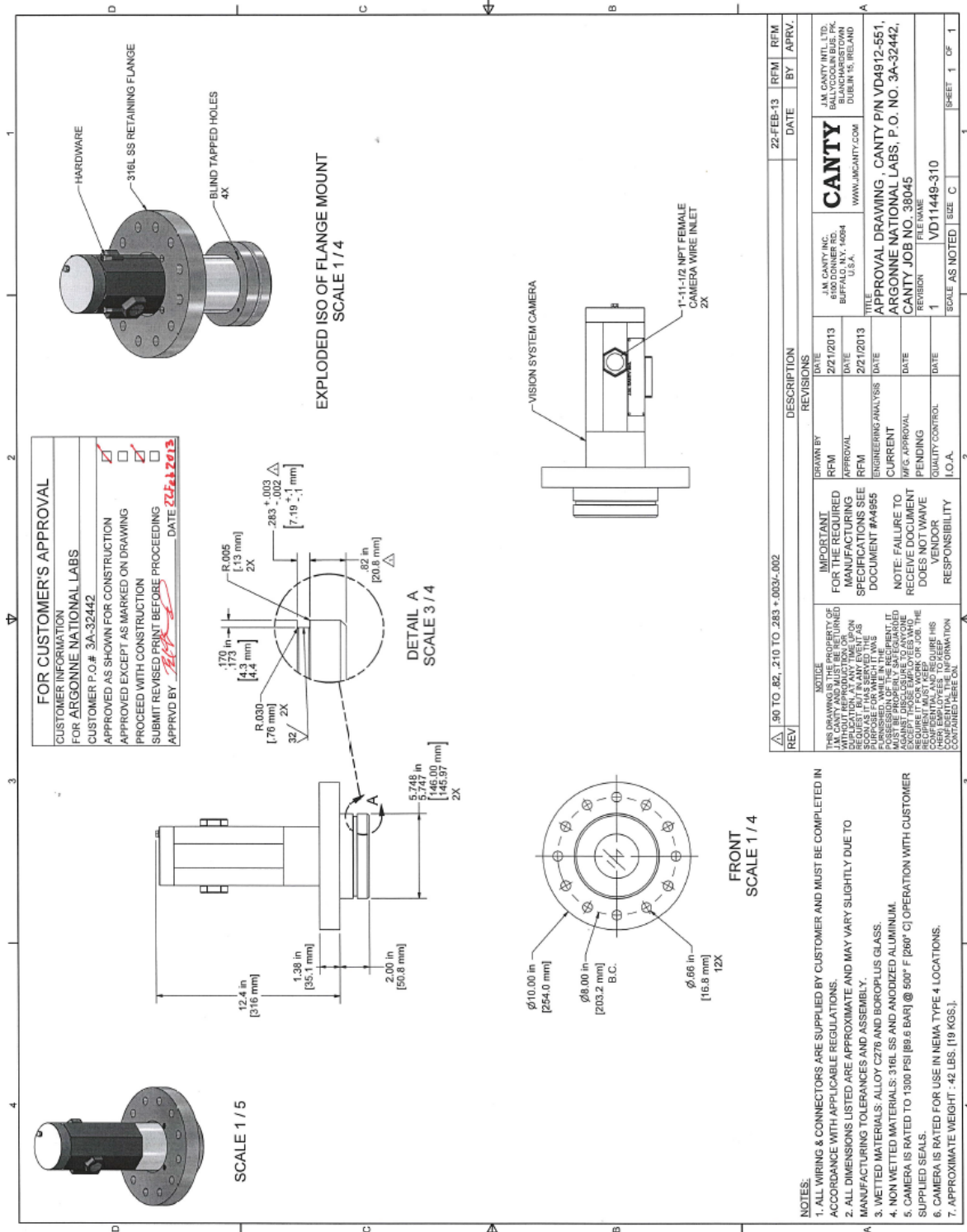


Figure 5: Cauty camera and window assembly.

12. Procedures for bubble chamber operations

12.1.1. Installation

Installation shall proceed under the direct supervision of B. DiGiovine and D. Meekins. An electrical inspection shall be performed by Todd Kujawa.

12.1.2. Prestart Checklist

Perform the following prestart checklist prior to filling and operating the detector for the first time or after down period exceeding 1 month:

1. Post area as "Test in Progress: Keep Out"
2. Visually inspect all mechanical supports and ensure that the position of the chamber is acceptable.
3. Ensure that shielding is in place for beam dump
4. Ensure that electrical inspection has been performed
5. Visually inspect all mechanical connections on flex lines and tubing
6. Ensure that the fill level of the hydraulic reservoir is acceptable
7. Ensure that power is supplied to equipment rack
8. Visually inspect insulation

12.1.3. Filling Procedure

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

1. Operate a 1000 cfm fan to recirculate air in the injector and provide mixing.
2. Ensure that the correct personnel monitoring equipment for exposure to the target fluid (e.g. Assay Technology 575 N2O sampler) is in place. Note this monitor is not required if N2O is not to be used in the system.
3. Make sure LabVIEW is online and temperature/pressure data is available and accurate.
4. Connect filling manifold to detector fill port with new VCR gasket, connect dry pump, connect gas supply bottle.
5. Perform a leak down vacuum test of filling manifold
6. 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.
7. Pump out filling manifold and open valve to detector phase separator to pump.
8. Open valve to detector upper fill line to pump active volume of detector.
9. Connect hydraulic fluid reservoir to fill port on the heavy wall vessel, connect vacuum pump to pump port on top of vessel.
10. Pump and fill hydraulic volume of vessel
11. Turn on chiller system, adjust temperature and flow control valves to appropriate values based on active fluid and threshold calculations.
12. Once fluid temperature has reached operating conditions filling can begin
13. Close detector upper fill valve and use regulator on filling manifold to set fill pressure to 3 atm

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.
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 and remove from the Injector area to be stored outside.
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.

12.1.4. Venting

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

1. Operate a 1000 cfm fan to recirculate air in the injector and provide mixing.
2. Ensure that the correct personnel monitoring equipment for exposure to the target fluid (Assay Technology 575 N2O sampler) if applicable.
3. Verify filling manifold is still properly setup, if not, install manifold and pump.
4. Turn on pump, pump out manifold
5. Open valve to detector phase separator and pump
6. Begin lowering hydraulic pressure slowly to vapor pressure at temperature
7. Wait for gas bubble to form in active volume, leave pressure so little change in gas bubble volume occurs
8. Slowly open detector upper fill valve and begin bleeding liquid into phase separator
9. Once all liquid is gone continue bleeding until differential pressure across glass is close to 1atm, close detector upper fill valve
10. Lower pressure in hydraulic system to equalize differential pressure
11. 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.
12. Close detector upper fill valve, close detector phase separator valve; turn off pump.
13. Power down chiller, and shut down hydraulic system, electronics and DAQ can now be powered down if necessary.

12.1.5. 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.

12.1.6. 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.

12.1.7. 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.

12.1.1.1 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.

12.1.1.2 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

12.1.1.3 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

12.1.1.4 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 will stop the DAQ Run and return the system to the high pressure condition. This limit is adjustable however, it shall only be adjusted by a system expert.

12.1.8. 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 off 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.

13. Failure 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.

13.1. 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 releases C3F8 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. Procedures to perform the disassembly shall be agreed upon by IH and the system expert.

13.2. 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.

13.3. 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.

13.4. 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.

13.5. 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-1 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.

13.6. Power failure

Should a power failure occur while the detector is in operation or standby mode, the solenoid valves will go to the normal state with control valve CV-1 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.

14. Beam Operations

14.1. 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 50 μA
- The total beam energy shall be varied up to 10 MeV
- Vary bubble chamber operating parameters as required inside limit envelop given in Section 12.

Note that the beamline with the dump was commissioned in 2014. It is now approved for 1000W.

14.2. 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 $^{16}\text{O}(\gamma, \alpha)^{12}\text{C}$. The beamline is formally described in the Song Sheet ACC2008000-1100. The line currently has an operational limit of 1000W. 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.

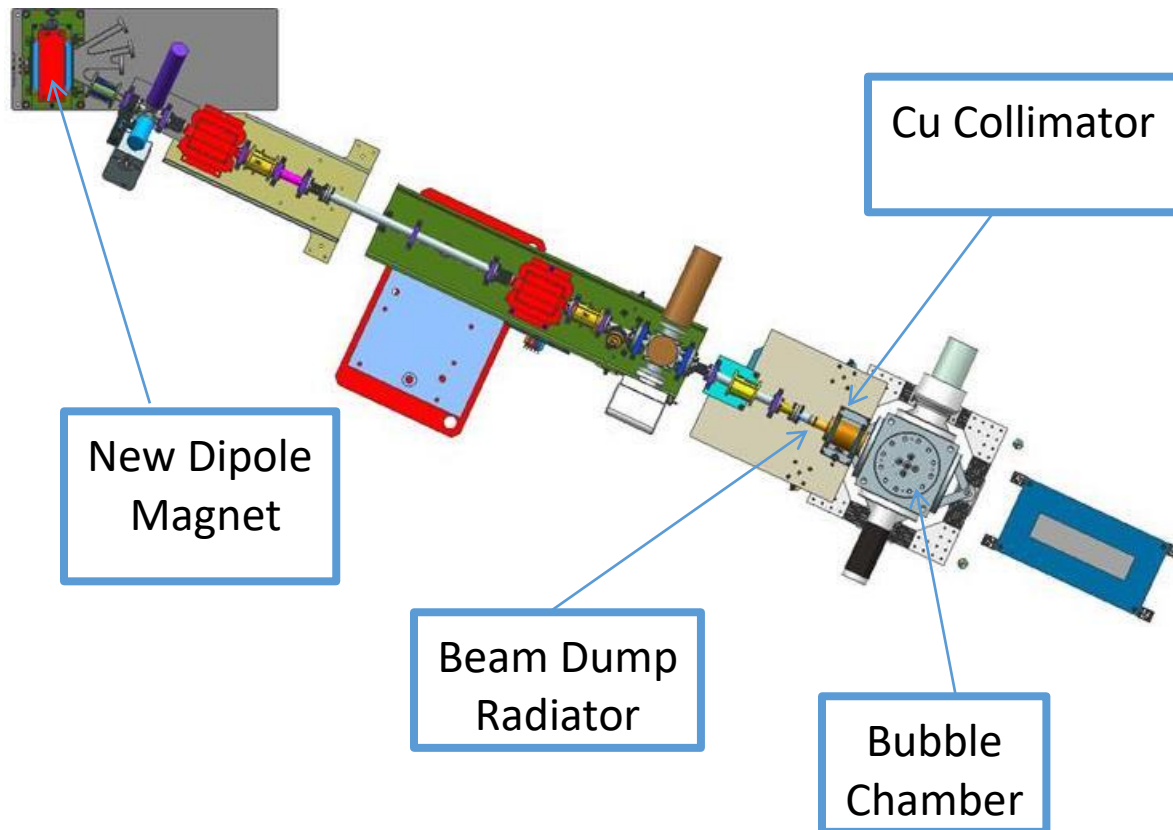


Figure 7: 5D Beamline Schematic

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 $\frac{1}{4}$ cryomodule in the injector. This provides a layer of protection in the unlikely event that the copper dump fails.

14.3. 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. This analysis can be found in the pressure system folder PS-ACC-14-003. A summary of the analysis is given in Figure 8. This dump was commissioned in 2014. A GEANT4 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 at much lower energies. These electrons are not expected to have any measurable effect on the detector.

Results – 9.5 MeV

- In the plot below the resulting steady-state temperature is plotted on the model. Note that the display is sectioned through the central horizontal plane. Beam current is 105 microA.
- Probe results:
 - 627.3 K (354.2°C)
 - 567.8 K (294.6°C)
 - 455.5 K (182.4°C)

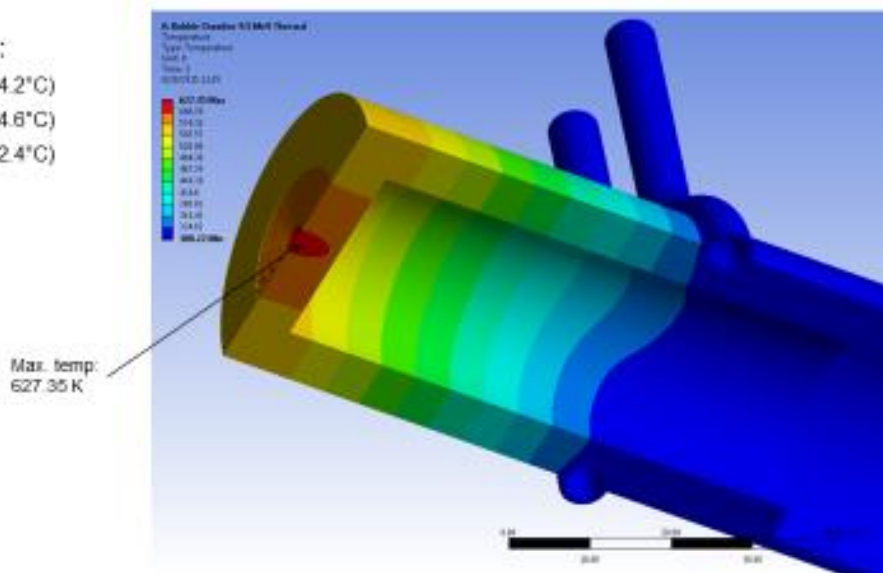


Figure 8: Beam dump/radiator temperature rise

14.4. General Test Plan

The test plan shall use C3F8 as an active fluid to determine its effectiveness. The following is an outline plan for the test:

- Phase 1:
 - 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 kinetic 8.5 MeV. Use neutron detectors in Injector area to measure neutron production rate.
- Phase 2:
 - Ensure that the DAQ and hydraulic systems are functioning properly.
 - Measure rate to calibrate detector using Penfold-Leiss unfolding analysis. This can be compared to the neutron rich data from Duke.

15. Conduct of Operations for Test

15.1. Organization and Administration:

Accelerator Program Deputy: (cell: (757) 876-7997)

Accelerator Physics Experiment Liaison: Alicia Hofler (phone: 7171)

Accelerator Work Coordinator: Steve Suhring (phone: 7670)

Bubble Chamber Shift Crew:

1. Riad Suleiman (cell: [\(757\) 254-7895](tel:7572547895))
2. Brad DiGiovine (cell: [\(815\) 780-7777](tel:8157807777))
3. David Meekins (cell: (757)-968-9076)
4. Roy Holt
5. Ernst Rehm
6. Claudio Ugalde
7. Joe Grames
8. Matt Poelker
9. Alicia Hoffler
10. Dan Moser
11. Mike McCaughan
12. Seamus Riordan
13. Jay Benesch
14. Whitney Armstrong
15. Brandi Cade

The Bubble chamber will be operated from the MCC.

We will use a computer electronic logbook, which serves as the record of the experiment. All relevant activities are to be recorded, including all changes of experiment conditions and equipment failures. The log book assigned to this experiment is: <https://logbooks/book/bubblelog>

The bubble chamber proposal, detailed test plan, and all other documents and references are available online at: https://wiki.jlab.org/ciswiki/index.php/Bubble_Chamber

15.2. Beam Operations

All beam operations will be conducted from the MCC. To contact the Crew Chief please dial 7045. The phone number to reach the MCC Operator is 7048. The experiment will be staffed 24/7.

For any issue related to the bubble chamber, please contact Riad Suleiman (cell: [\(757\) 254-7895](tel:7572547895)) or Brad DiGiovine (cell: [\(815\) 780-7777](tel:8157807777)).

To limit access to the bubble chamber when Injector in Restricted Access, an exclusion zone will be marked with a ribbon and cones. The area shall be posted "TEST IN PROGRESS PLEASE DO NOT

DISTURB”.

Riad Suleiman will represent the collaboration at the 8:00 am meetings in the MCC during the work week. Daily work planning will occur at this time.

15.3. Injector Segment Access:

Access to the injector segment will be governed by the JLab beam containment policy, and work in designated radiation areas will be carried out in accordance with the JLab RadCon Manual. The injector segment is not a posted Radioactive Materials Area.

During bubble chamber test, the injector segment will normally be in Beam Permit. When temporary access to the area is needed the shift crew can ask the MCC to bring the injector segment to Controlled Access. If long term access to the injector segment is required, the shift crew may request the injector segment be brought to Restricted Access.

Restricted Access is a state where delivery of beam and/or accelerating RF power is not permitted, and entry to and exit from the injector segment is not controlled by the Personnel Safety System (phone 7050). This is the normal state of the area when the accelerator is off and no experiments are running. Access is “restricted” only in the sense that the injector segment is not open to the general public. Well-defined check-list procedures are to be followed whenever the injector segment is brought to and from Restricted Access.