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Borexino Experiment
Process Procedure

Internal Source Insertion and Manipulation Procedure

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1 Revision History

Revision #	Revision Date	Author	Reason	Sections
1	February 9, 2003	Vogelaar	First writing for preliminary HazOp	ALL
2	February 15, 2003	Vogelaar	Update following preliminary HazOp	ALL
3	April 12, 2006	Vogelaar	Update for HazOp	ALL
4	April 15, 2006	Vogelaar	Update following HazOp	ALL
5	August 8, 2006	Vogelaar	Camera Control Manual	ALL
6	November 21, 2006	Hardy	Detailed Procedures	ALL
7	March 8, 2007	Rountree & Joyce	Modified settings after system testing	11.1.1 to 11.12.4
8	November 4, 2007	Hardy	Update following HazOp	ALL

2 System Purpose

2.1 Description of System

This system is designed to allow a source (or optical fiber) to be inserted anywhere within the inner vessel and located to within ± 2 cm. The radioactive sources are small quartz spheres similar to those used in the CTF. The insertion mechanism consists of several neutrally buoyant rigid rods that are subsequently coupled. One section has a hinge, which allows for motion off-axis. The off-axis motion is accomplished by pulling on a $\frac{1}{4}$ " (6 mm) Teflon tether tube that will swing the lower rod sections off to one side. The azimuthal position is set by rotating the rod assembly. Care must be taken to not rotate the rod by more than ± 180 degrees to avoid twisting the tether around the rod.

Since mechanical indexing using this method is not precise, an LED is attached near the source which, when lit, can be imaged using the seven cameras mounted on the SSS. Tests have shown that the HV for the phototubes does not need to be turned off during this process.

An unusual difficulty arises since the natural PC level in CR4 is set by the filling stations to be about 2 meters above the floor of CR4. To accommodate this, a load-lock method is employed to ensure that the ambient pressure above the PC is always sufficient to keep the liquid level from rising. This means that both the insertion rods and the Teflon tether tube must pass through sliding seals. The actual level of the PC only needs to be maintained to about ± 10 cm, even though the pressure in the vessels is regulated much more precisely. This is because the density of the gas above the liquid level is a factor of 1000 less than the liquid.

Radon and other gases are prevented from contacting the liquid by means of a glove-box which provides the first-order level of protection¹, and ultimately by the sliding seals. The seal around the rod is also purged since there are voids within the rod couplings which make continuous sealing impossible. Since one must couple the tether and the rod below the sliding seals, there is an access cross which acts as a load-lock. This cross is evacuated multiple times, and then backfilled to the required pressure with Low Ar and Kr Nitrogen (LAKN) before the gate-valve to the inner vessel is opened.

The coupling of the tether tube to the rod end is complicated since the angle between the two depends upon the hinge position. The primary mechanical termination is a pre-compressed Swagelok ferrule which registers into a mating groove in the split coupling (see Figure 7: Source Coupler). Secondary mechanical coupling is by means of a spring (whose upper end is captured and has a tang that registers and locks the spring into position) and a chemical bond.

The principle concerns are cleanliness, failure modes where PC would rise into this region, gross overpressure, inadvertent light leakage, inability to retract source due to tangling, and source breakage. Cleanliness is addressed in several fashions. First, the system resides in a Class 10 clean room (CR4) and second the rods are stored within the glove-box after a final cleaning. The glove box provides an ambient LAKN atmosphere, and has large, conductive, acrylic side plates for viewing. The PC should only be

¹ It is worth nothing that the glove-box was not designed to be, nor is it currently, hermetic.

exposed to LAKN using the load-lock system described above. Rn emanation from the gaskets is removed by the constant purging of the cross during operation.

The cleanliness specifications adopted by the Operational Group have been based on Military Standard 1246, and all equipment contacting the IV PC has been cleaned until certified to be Class 30 or better. The cleanliness specifications for the insertion system components entering the IV have followed the Operational Group's interpretation and implementation of this standard.

The insertion rods will be placed inside of a SS tube and detergent will be circulated. The rods will then undergo several DI water rinses until particle counting reveals a cleanliness level of at least class 30. A similar process, but on a smaller scale, has been performed for all other insertion system components entering the IV (bolts, collars, source coupler, etc.). The components will also be wiped down with reagent grade PC just prior to insertion².

Whenever the gate-valve to the IV (v1320) is open, the valves to the IV (v1321) and IB (v1421) filling stations are closed. The displaced volume (< 20 liters) due to the rod insertion is compensated by the OB filling station operation. However, this means that should pressure in the cross be lost, even though interlocks turn off the OB make-up pump, the volume of the OB header tank could flow into this region. To prevent this, the quartz windows are provided with back-up sealed acrylic windows. Likewise, the source coupler has a mechanical stop to prevent it from being accidentally withdrawn completely from the sliding seal, and the tether sliding seal has an alternative plug which can be inserted should the tube fail. The tether tube itself sometimes could have PC in it (PC collection mode), so it rises to a level above the header tanks before connecting to the laser or other device. There is also a catch basin in CR4 that will contain any spills.

Gross overpressure is avoided by means of a pressure relief valve on the cross feed line, whose operation is tested prior to each calibration campaign. No serious consequences of an overpressure would occur until the liquid level was forced down to the top of the inner vessel.

Light leakage is only a concern during the initial and final passage of the source past the gate-valve separating the calibration system from the IV (v1320) when the small viewing ports may be uncovered to allow visual inspection. During this time, CR4 will only be illuminated by low-level red, or yellow, light.

The liquid-alarm system has a sweep arm which can be used to ensure that there is nothing blocking the gate-valve, meaning that the gate-valve could in principle be closed without the visual inspection step.

The excess tube is stored in the tether storage drum in alternating right- and left-handed loops to prevent twisting. The insertion length is also determined with a roller meter. The scintillator sampling tube needs to be empty on the inside (i.e. no wires for LEDs), so it will only be used on the vertical axis.

Possible tangling of the source is minimized by procedures that prohibit the turning of the source system by more than ± 180 degrees. Rotational alignment is mechanically assured by the method of coupling rods. In addition, the hinge on the source rod can only bend 90 degrees before reaching a mechanical stop. It is also designed to have no protruding edges that could get caught at any steps in the upper

² However, one should keep in mind that the exposure time of these components to PC is much less than that for the fluid handling system.

pipes. Careful inventory of lengths of rod and tether, coupled with LED imaging, should allow us to keep track of what is going on inside. Should a problem develop, the HV could be turned off and normal photographs inside the SSS will help resolve questions.

Each rod will be weighed before and after insertion to check for any possible leaks.

The possibility of source breakage is minimized by spring-mounting of the source, and the fact that the source insertion rod has a larger diameter than the source itself. We are cognizant that sources were both broken (while still above the IV gate valve) and actually dropped into the CTF during the early CTF campaigns. The current design and procedures have been modified to minimize the chances of any such accident.

The internal calibration process can be cleanly separated into two phases. The first covers general preparation for a calibration process prior to the opening of V1320 which connects the calibration system to the inner vessel, and the second relates to operations immediately before, during, and after V1320 is opened. Therefore, there is significant flexibility in the order and detail of the procedures for the former, while the latter requires careful procedural controls – which are covered in this document. This document does *not* provide sufficient detail on its own to allow a new user of the calibration equipment to complete the following general preparation tasks. Such detail must be obtained by one-on-one training by members of the calibration group.

General preparations include:

- Camera image collection and calibration
- Gas control system calibration and functional tests
- Source preparation and quenching measurements
- Laser preparation (if called for) for internal laser calibration
- Assembly of component hardware and tools for calibration
- Installation and configuration of components in CR4
- Special cleaning steps
- Development of a calibration run strategy – including definition of which sources, and their locations, are to be used.

However, it *does* provide basic descriptions of the above, both directly, and in the cited references. It also specifies the safety hazards, precautions, equipment, and individual responsibilities associated with internal source insertion and manipulations during times when the Inner Vessel gate valve, V1320, is opened.

2.2 References

- CR4 filling station P&ID
- Detailed specification of gas system components
- Military Standard 1246 C

2.3 Attachments (appendices)

- A) Camera system operations manual (software)
- B) Camera system (hardware)
- C) Gas control system operations manual (software)

- D) Gas system (hardware)

3 Safety Hazards, Precautions and Equipment

3.1 Hazards for Personnel and the Environment

The primary hazard for this system is the loss of containment of the PC, or the ignition of the PC resulting in a fire. The fire hazard for personnel is that death, or injury, could occur due to smoke inhalation, burns, and asphyxiation due to consumption of underground oxygen. The hazards for the environment due to a loss of containment of the PC have already been well documented by the collaboration (see the documents “Information on the Principle Risks and Safety Procedures of Borexino” and “Safety and Environmental Measures for the Borexino Experiment” both available on the Borexino web page); additionally, loss of PC containment poses an increased risk of fire. Fortunately, the one pass air exchange rate in CR4 is very high (at least two exchanges per minute), so, the build up of potentially harmful (both to humans and as an ignition source) fumes is less likely than in other places in the laboratory. There is no risk of fire inside of the glovebox, since it will be a completely inert Nitrogen atmosphere devoid of Oxygen (less than 0.1%).

PC spillage can only occur if the pressure in the cross is lost while the gate valve is open. The valves to the IV (v1321) and to the IB (v1421) filling stations will be closed whenever the gate valve is open, and the OB make-up pump will be interlocked, so, in the event of pressure loss in the cross, the OB make-up pump will shut off and only the volume of the OB header tank could flow into the cross. The glovebox floor has a drain, which is connected to the PC waste tank through a check valve (and an emergency manual valve to bypass the check valve).

Pressure loss in the cross can occur for the following reasons:

- Teflon tether tube fails (breaks and slips through the tube seal). In the event that this occurs, there exists a plug for the tube seal that will always be kept in the glove box and needs only to be inserted into the tube seal to stop the pressure loss.
- An insertion rod falls through the rod seal. This is extremely unlikely because the rods themselves are neutrally buoyant, there are several O-rings through which they must pass that provide significant friction, there is a split ring lock that is always present on the rod above the rod seal, and two bolts – one of which is always in place. However, in the unlikely event that this does somehow happen, there will also be a plug for the rod seal available in the glove box that can be inserted to stop the pressure loss
- One of the quartz viewports ruptures, causing the pressure in the cross to be lost. To guard against this, there are thick acrylic covers that seal around the quartz viewports to prevent accidental breakage and provide secondary containment.

3.2 Hazard to the Experiment

- Rn contamination from inserted components
- Loss of radioactive source in detector

- Damage to vessels from items dropped into detector
- Leaking, or broken, radioactive source contaminating PC
- PC exposure to air (i.e. Oxygen, Krypton, Argon, Radon)

3.3 Safety Equipment

In accordance with safety regulations, there must be at least one portable breathing apparatus available in CR4, and an additional five in the control room. Each person must wear the provided safety clean room boots and there must be flashlights available in CR4 in the event of a power failure. All personnel entering the clean room are required to wear the specified clean room attire.

3.4 Safety Precautions

- All personnel must be trained
- Two people must be present when performing the insertion
- Mandatory check lists for each person performing the calibration. A third party in the control room will confirm the pressure in the cross before the gate valve is allowed to be opened
- The firemen should be notified that the gate valve will be opened, approximately when it is going to open, and for how long it will be open

4 Responsibilities

4.1 Calibration Director

Bruce Vogelaar

The Calibration Director is responsible for ensuring the safe execution of this procedure. Any problems encountered by the Calibration System Operators should be relayed to he/she as soon as possible. The Calibration System Operators shall confirm with the Calibration Director as well as the Operations Manager before operating the valves to the IV and IB, and operating the gate valve. The Calibration Director may wish to administer a verbal test of the Operators' knowledge of the emergency procedures.

4.2 Calibration System Operators

At least one from: Bruce Vogelaar, Steve Hardy, Steve Kidner, Matt Joyce, Christian Grieb, Henning Back

Operators perform the start up of the calibration system, source insertion, positioning, source removal, and system shut down. They are required to report any problems or questions to the Calibration Director, and must communicate with the guards and firemen if an urgent problem is encountered. One of the operators must contact the Calibration Director and Operations Manager before operating the valves to the IV and IB, and operating the gate valve. Before using the camera system for source location, they must notify the shift leader in charge of the DAQ. Additionally, they must be in very close communication with the DAQ shift leader during the opening of the gate valve to monitor

any increase in the PMT rates which might indicate a light leak. If a source needs to touch the inner vessel for any reason, the Calibration System Operators must first consult with the Vessels Expert. The system can be safely operated with one of the above people, and one other adequately trained person.

4.3 Operations Manager

Augusto Goretti

The Operations Manager is responsible for the safe and proper functioning of the Borexino equipment. Calibration System Operators must have his/her permission before operating the valves to the IV and IB, and operating the gate valve. He or she should be on call throughout the entire operation.

4.4 DAQ Shift Leader

One of the Shift Captains

The DAQ shift leader is responsible for the proper functioning of the DAQ system for Borexino. The Calibration System Operators are required to notify the DAQ Shift Leader before using the camera system for source location purposes. When the Calibration System Operators are first opening the gate valve, the DAQ Shift Leader must carefully monitor the PMT signal rates, any deviation from the accepted values should be relayed to the Calibration System Operators; the DAQ Shift Leader should be prepared to terminate the HV to the PMTs in the event that the signal rate rises unacceptably high.

4.5 Vessels Expert

One of the Princeton personnel

The vessels expert should be on call throughout the entire operation in the event that the source needs to come into contact with the IV itself (see Section 12.4). The vessels expert may also be called upon if a situation arises where it may be necessary to close v1521 (emergency procedure only).

4.6 Shift Leader

One member of the operational group

The shift leader is responsible for monitoring the status of the detector during a calibration campaign³. The shift leader will be called upon to report the current pressure of the PC in the Inner Vessel several times. In the event that the calibration campaign spans several shifts, an overlap period should be scheduled between shift leaders so that they can be adequately informed of the current status.

³ The shift leader may designate one of the shifters to this task

5 Insertion System Hardware

The following section will describe, in moderate detail, the major hardware components of the glovebox system. For a complete assembly drawing (minus gloves), see Figure 12; see Figure 13 for a section view.

5.1 Glovebox

The glovebox panels (Figure 1) are constructed out of four 44" (111 cm) by 43" (109 cm) by 1/16" (1.5 mm) stainless steel panels, and two 3/8" (9.5 mm) thick static dissipative acrylic sheets. To provide structural rigidity, the bottom glove box panel attaches to a frame (1" (2.5cm) square SS tubing) that itself is attached to the cross via two 8" (20 cm) U-bolts⁴. Due to height restrictions in CR4, the top glovebox panel has a hole for a "Top Hat" (approximately 15" (38 cm) tall) which extends up into a recess in the CR4 ceiling to allow space for the one-meter long insertion rods to be coupled together above the rod seal. On the bottom panel is a hermetically sealed load cell that will be used to weigh the insertion rods before and after they are inserted into the detector in order to check for any leaks in the insertion rods. One of the side panels of the glovebox has a 12" (30.5 cm) diameter hole for the tether storage drum, and also a plate where the tether measurement system will mount. The acrylic panels will have six *glove* ports (three on each panel)⁵.

The gloves for the glovebox are 32" (80 cm) long Butyl rubber isolator box gloves that will have a 14" (35 cm) long Nitrile⁶ glove over the hand and forearm of each Butyl glove. The decision on this glove combination was motivated by the desire to keep Rn emanation and diffusion very low (while Viton is approved for PC usage, tests by H. Simgen indicate that its Rn emanation was four orders of magnitude larger than Butyl rubber). Since Butyl rubber is susceptible to damage by PC, a PC resistant outer glove is required. We are currently working with some glove manufacturers on creating a layered glove that provides both low Rn emanation and diffusion characteristics, and PC resistance⁷.

⁴ In order to comply with earthquake restrictions, the glovebox is not rigidly attached to CR4 in any way

⁵ The third glove port is used to operate the tether storage drum since operating it from the other glove positions proved to be awkward

⁶ The Nitrile glove is certified for use with PC. We have plans to try Silver Shield gloves as another alternative

⁷ The KamLAND collaboration is currently pursuing a similar course of action after bad experiences with Viton gloves.

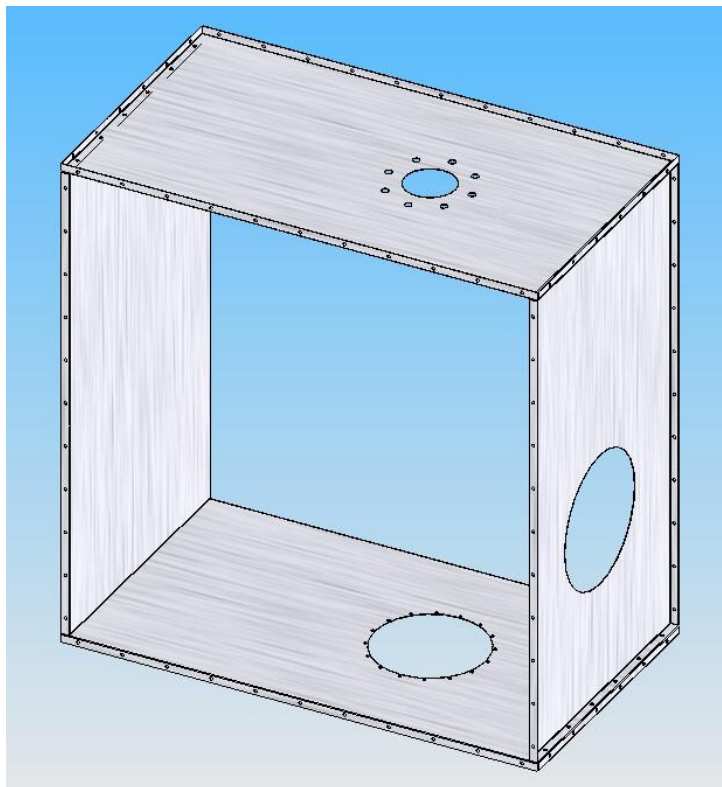


Figure 1: Glovebox Panel Assembly

5.2 Six-Way Cross

As previously stated, the six way cross (Figure 2) is the load lock between the IV and the glovebox. The cross flanges are sealed with copper conflat gaskets -- 10" (25 cm) on five of the sides, 6" (15 cm) on the gate valve mating side -- the flange on the top has been machined to accept the rod and tube seals, as well as the liquid level monitor and sweeper arm assembly, and one of the four horizontal flanges houses all of the feed-throughs for pressure monitoring, gas input and exhaust. Since the sources cannot be allowed to pass through the rod seal, they must be coupled to the source coupler while inside of the cross (one must also attach the tether tube to the source coupler in the cross since they cannot both fit through the rod seal); for these reasons two of the cross flanges will be temporarily removed while these tasks take place⁸.

To allow for visual inspection of the system during the initial insertion and removal stages, two of the flanges are equipped with quartz view ports. Due to concerns about inadvertent breakage of these windows, there are thick acrylic covers that surround the quartz viewports. During all but the aforementioned times, the acrylic viewport covers will be covered by opaque materials to prevent light from entering the detector. To ensure the safety of the PMTs, CR4 will be illuminated by low-level red light during any time in which the covers are removed and v1320 is open.

⁸ These flanges are equipped with handles to allow for safe and easy removal and installation

Before the operators of the system close the gate valve, it is important to ensure that there is nothing still in the closure path of the gate valve. Additionally, since the windows on the cross are normally covered during the time that the gate valve is open, an alternate means to determine if the liquid level has risen into the cross is required. Both of these concerns are solved with a liquid monitor assembly that resides in the cross. The liquid monitor is a tube that contains a very small reed switch, and a float with an internal magnet which sits around the tube. If the liquid level rises, the float will rise with it, and cause an alarm in the system. The bottom of this device also has a sweeper arm that can be rotated from side to side from inside the glovebox; unimpeded passage from one side to the other (indicated by fiducial marks placed on the liquid monitor seal in the glove box) indicates that it is permissible to close the gate valve. See Figure 3 for a section view of the cross with the liquid monitor, and also the rod and tube seals which are discussed in sections 5.6 and 5.7 respectively.

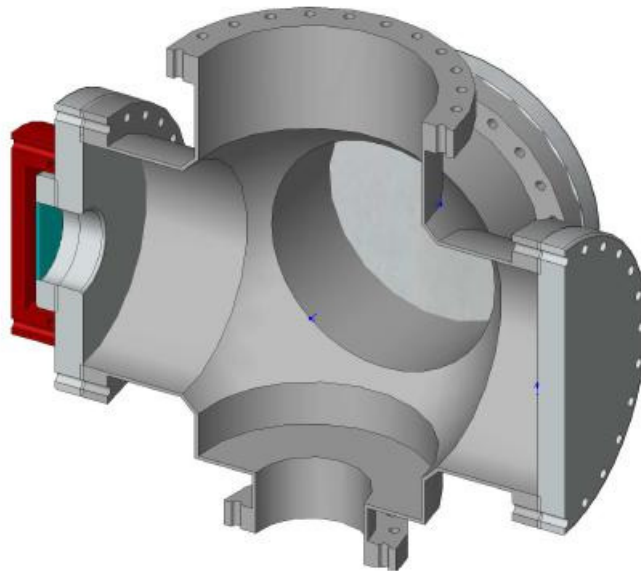


Figure 2: Cross Assembly

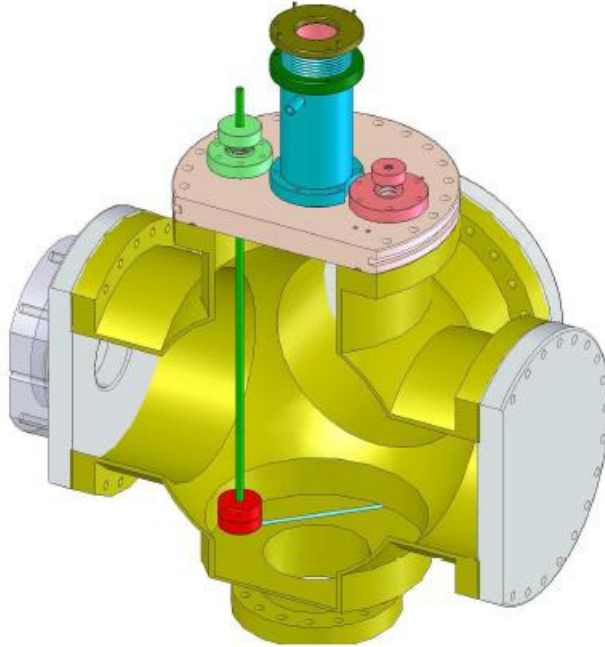


Figure 3: Cross with Hardware

5.3 Insertion Rods

The insertion rods are one-meter long, 1.5” (3.75 cm) diameter, electropolished Stainless Steel sections that can be coupled together above the rod seal, and then lowered through the IV fill tube to position the source inside of the inner vessel. The rods couple together as shown in Figure 4. The couplers were designed to minimize the possibility that rods decouple while inside of the IV (in order for this to happen, a sleeve with holes has to rotate to align with the heads of two bolts, which then must both back out before the section could fall). The female end of the coupler on every rod has a hole that is used to insert sections of thin rod to tune the weight of the rods so that they will be neutrally buoyant in both PC and in water. This hole is normally plugged with a screw with a small amount of PC safe epoxy under its head to prevent liquid ingress. The couplers have been orbital welded onto the stainless tubing that comprises the body of the rods and then He leak checked; all insertion rods had leak rates better than 10^{-9} mbar/L/s.

To allow for off axis motion of the source, there is also a hinge rod (see Figure 5 for the hinge coupler), which is simply another one meter long rod that has a hinged section in the middle that allows for motion up to 90 degrees. The Teflon tether tube is coupled to a source holder at the end of the last rod, and pulling on this tube allows one to raise the hinge to any angle between zero and ninety degrees. The operators can turn the entire rod assembly ± 180 degrees manually. Procedures prohibit turning by more than 180 degrees in one direction or the other to avoid tangling of the tether.

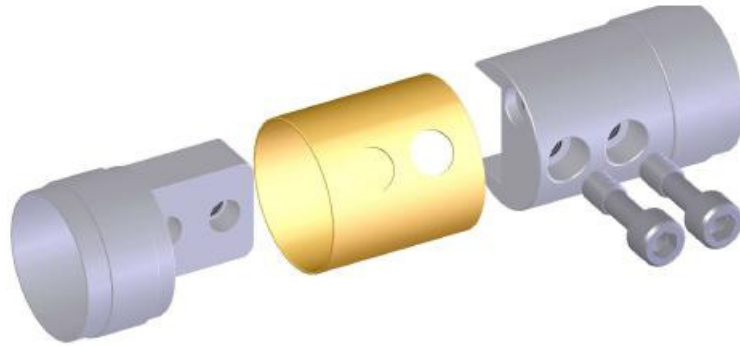


Figure 4: Rod Coupler

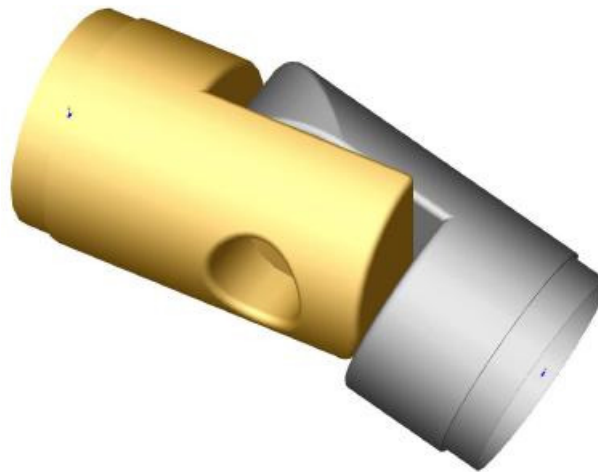


Figure 5: Hinge Coupler

5.4 Tether

The tether tubes, of which there are three (one for a radioactive source, one for a fiber optic source, and one for scintillator sampling), are 1/4" (6 mm) diameter, 1/32" (0.8 mm) wall, 20 meter continuous lengths of Ultra Pure PFA Teflon tubing. The specifications for each tether are given below:

- Radioactive Source Tether
 - Pre-compressed Swagelok ferrule at source end
 - +5V and ground wires for location LED
 - 3/16" (4.7 mm) Quartz plug tube with LED (diffuse on inside)
- Fiber Optic Source Tether
 - Pre-compressed Swagelok ferrule at source end
 - +5V and ground wires for location LED
 - Fiber optic cable

- Sealed to a quartz ampoule containing the location LED and the fiber optic filter
- Scintillator Sampling Tether
 - Pre-compressed Swagelok Ferrule
 - Will only be used on axis

To avoid twisting the sources, and possibly damaging the terminations at the CR4 end, a storage system (see Figure 6) has been employed that will keep the tether neatly stored in alternating right and left handed loops inside of a 12" (30 cm) diameter drum assembly¹⁰ which mounts on the side of the glovebox. Most of the time, the tether tubes will not be in use, so, they are kept inside of their respective storage drums which are filled with LAKN and then capped. When in use, the tether will pass through a roller meter that will measure the length of the tether that has passed through it¹¹.

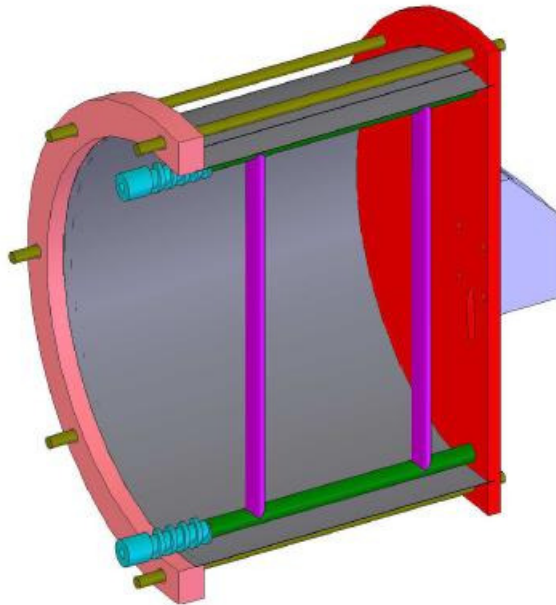


Figure 6: Tether Storage Drum

5.5 Calibration Source

There are two types of calibration sources that will be used, radioactive and fiber optic; they both couple to the insertion rods in the same fashion.

The radioactive sources are contained in a 1" (2.5cm) diameter spherical quartz vial with a short quartz neck, which then transitions to Pyrex and then to a 3/16" (4.7 cm) diameter Stainless Steel tube that is then crimped shut and sealed. There is an externally threaded split Teflon ring that goes around this tube, and a SS extension spring that

¹⁰ There are three storage drums, and three tube seal assemblies, one for each tether since the items on the IV end of the tethers are too large to pass through the tube seal

¹¹ Placing the tether meter directly atop the tube seal will give the precise distance of the tether below the tube seal.

threads onto it, this spring then attaches to the source adapter recess and is locked in place via a tang at its other end. The tether tube for the radioactive sources contains the wires for the location LED that is attached to the source coupler. As previously mentioned, the tether has a precompressed Swagelok ferrule on it that registers into the mating slot in the source coupler. Please see Figure 7 for a visual aid, as these features are very important.

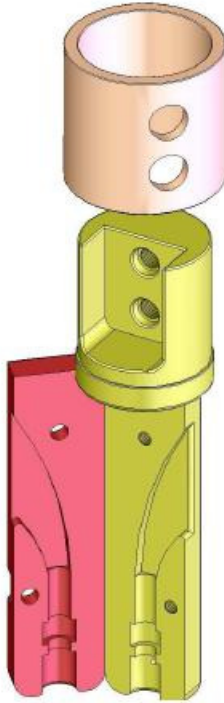


Figure 7: Source Coupler

The fiber optic source is contained in a small quartz ampoule which is adhered to the Teflon tube via a special chemical bond. The ampoule contains the fiber optic termination and filter, as well as the LED for source location. Figure 8 and Figure 9 show sample sources created at VT.



Figure 8: Prototype Fiber Optic Source



Figure 9: Radioactive Calibration Source

5.6 Rod Seal

The rod seal (see Figure 10) is designed to act as a sliding seal through which the insertion rods will pass during source insertion and removal. It mounts to the flange on top of the cross with an O-ring seal under its base. The rod is inserted into the seal, and then a series of clamps¹² apply pressure to the rod seal cap which compresses the two internal O-rings. It is also equipped with LAKN input and output ports and a honeycomb shaped insert that allows the region around the insertion rods (and more importantly the couplings between the rods) to be purged during operation. The constant flow of N₂ will help to remove Rn emanated by the o-ring seals. The pressure of the seal gas is matched to the internal cross pressure to prevent any flow past the lower o-ring.

¹² Note that there are also holes in the rod seal compression cap and the threaded ring, if the clamps were to become difficult to operate, or break, one can use bolts to apply the compression

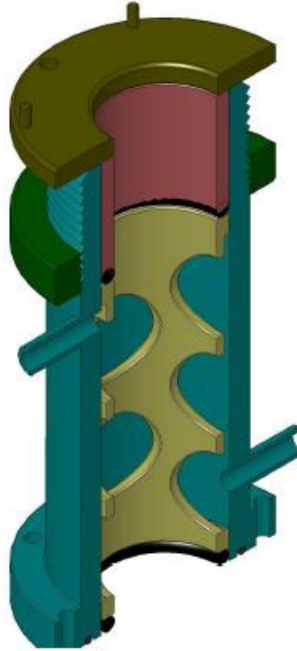


Figure 10: Rod Seal Assembly

5.7 Tube Seal

The purpose of the tube seal (Figure 11) is very much akin to the rod seal, with the Teflon tether tube taking the place of the insertion rod. O-rings on the base of the tube seal provide the seal to the glovebox. However, one should note that there is no LAKN purge on the tube seal since the tether has no voids that need to be purged (Teflon has an intrinsically low Rn emanation rate). There are actually three tube seals (one for each tether tube) since the items on the ends of the tether have OD's that are larger than the 1/4" (6 cm) diameter of the feed thru on the tube seal (the tube seals are stored under a LAKN blanket, along with the tether in the tether storage drums, of which there are also three). The operation of the seal is very simple; one just turns the cap until it is tight¹³. When inserting or removing the tether it will be necessary to loosen the cap slightly to lessen the compression on the tether. Pushing too hard on the tether tube can cause it to kink.

¹³ Tests at VT found that slightly more than a one eighth turn past finger tight proves to be sufficient; it is important not to over tighten due to the risk of seizing.

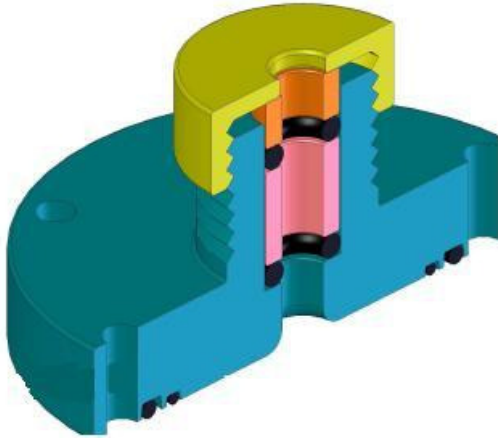


Figure 11: Tube Seal Assembly

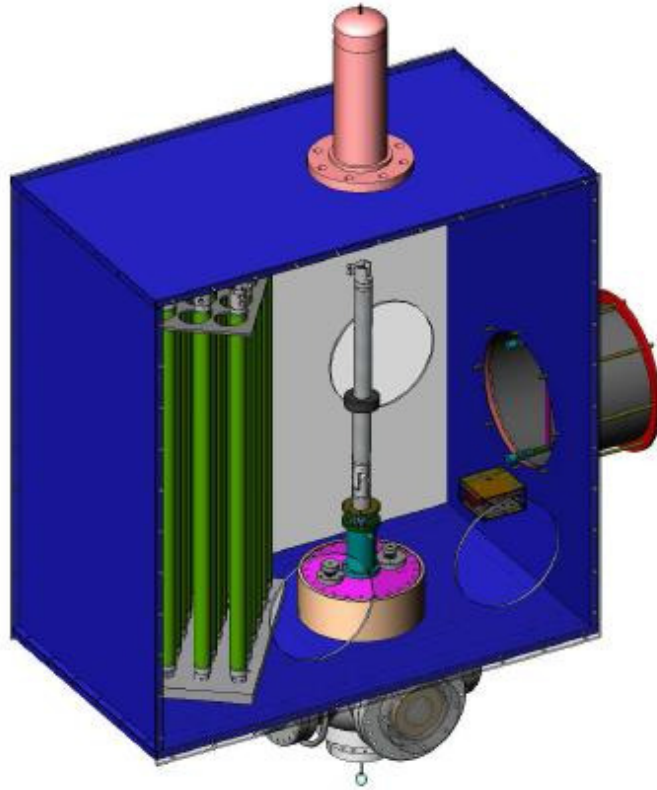


Figure 12: Glove Box Assembly

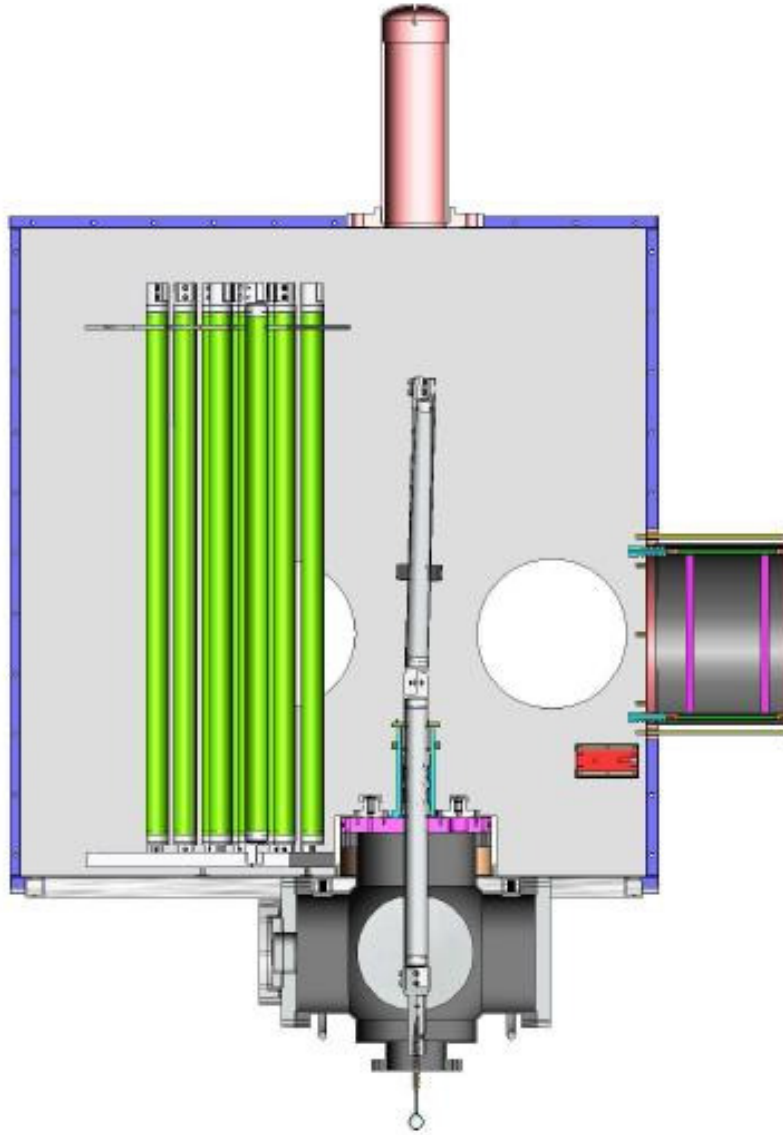


Figure 13: Glove Box Assembly Section View

6 Gas Flow System

This section will provide a brief summary of the components of the gas flow system. Nearly all of the components are computer controlled via the PERL program `gascontrol.pl`. The communication with the system components is through a fiber optic link between the computer in CR4 and a National Instruments data acquisition system with analog and digital I/O and a relay¹⁴ module.

¹⁴ All relays used in this system are non-latching

The interconnecting tubing for all of these items is Stainless Steel tubing that has been cleaned with high purity Nitrogen under high pressure (80 psi, 5.5 bar)¹⁵. All components are located inside of a Nema 7 enclosure (the gas box) that mounts on the head tank support structure in CR4; all of the cabling for the components exits this box through a short length of conduit through the wall and into the electronics box that houses all of the power supplies, terminal blocks, the DAQ system, etc. The gas box is fed with air from one of the CR4 supply ducts, and is exhausted through the electronics box, and then exhausted through the computer cabinet.

As previously mentioned, the glovebox provides the second level of protection against dust (CR4 being the first), and also provides a natural LAKN atmosphere for the components that will be inserted into the IV; additionally, it has a steady flow of LAKN (4 lpm) to remove any Rn emanated by the various seals, gloves, etc. The glovebox is equipped with an Oxygen monitor which is used to indicate when the glovebox atmosphere is sufficiently free of natural air (if it is devoid of Oxygen, it is presumed to be devoid of Kr, Ar, Rn, etc.). Since the pressure in the cross will be equal to the over-pressure of the PC in the IV, there are two sliding seals for the rods and tether tube. The rod seal is continuously purged with LAKN at the same pressure as that in the cross; this ensures that the pressure difference across the lower seal of the rod seal is zero. Since there are voids in the rod couplings that could trap gases, these couplers will be left in the rod seal for a minute or so to ensure an adequate purge.

6.1 Brief Description of Components

The system components are briefly summarized below. For a complete description of all of the components, including data sheets, please reference the attached Appendix D, "Detailed Parts Specifications". See Figure 14 for a photo of the "gas box"; the solenoid valves are on the top row, vacuum pumps on the second, the O₂ monitor and the flow meters are on the third row, and the bottom row contains the pressure transducers, the regulators and needle valves are visible on the right wall. Figure 15 is a photo of the electronics box, which contains the DAQ system, power supplies, and interconnecting wiring¹⁶.

- Valves
 - Eight solenoid valves (V1-V8) controlled, via relays, by the computer system
 - Five manual needle valves (NV1-NV5), these are primarily for throttling purposes. Care must always be taken to never close these valves down tightly
 - Five check valves (CV1-CV5) provide pressure relief in the event of over, or under, pressurization
 - One metering valve (MV1) used to make sure the flow through FM4 does not exceed its maximum rating of 4 lpm.
- Flow control and feedback instruments
 - Three pressure regulators (R1-R3), whose control knobs protrude through the control box, control the pressure to various parts of the system

¹⁵ The LAKN tubing that feeds the system underwent the same cleaning process

¹⁶ The box has also been wired to facilitate replacement of the current camera control circuit

- Five flow meters (FM1-FM5) provide feedback to the computer system on flow rates through various regulators
- Six pressure transducers (G1-G6) provide the pressure measurements in various areas.
- Vacuum
 - A relay controlled diaphragm pump (P1) is used to feed the Oxygen monitor from the glovebox
 - An identical pump (P2) is used to evacuate the cross before backfilling it with LAKN
- There is one Oxygen monitor (OM) which provides information on the percentage of Oxygen in the glovebox atmosphere.
- One liquid level monitor (LM) is used to alert the users if the liquid level rises into the cross¹⁷

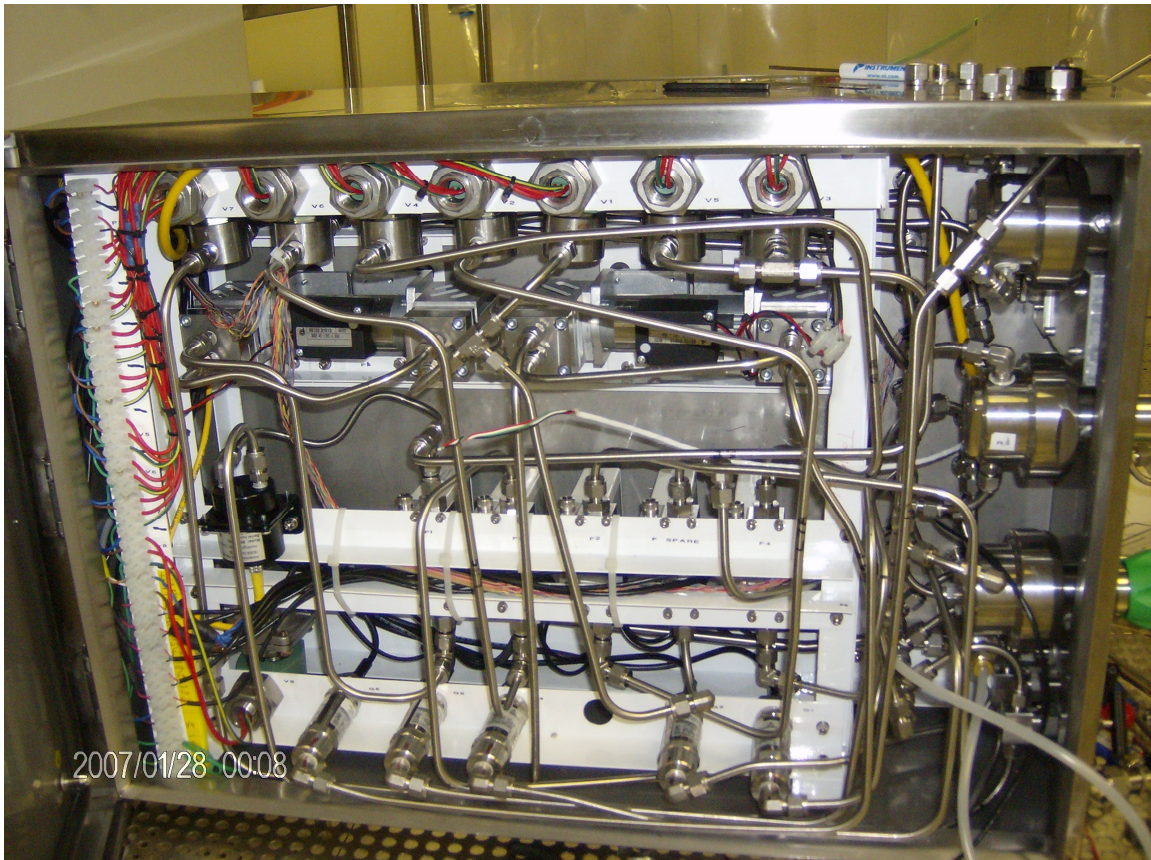


Figure 14: The "Gas Box" that houses all of the instrumentation for the glove box system

¹⁷ Recall that visual inspection of the cross is not possible during the majority of the operations

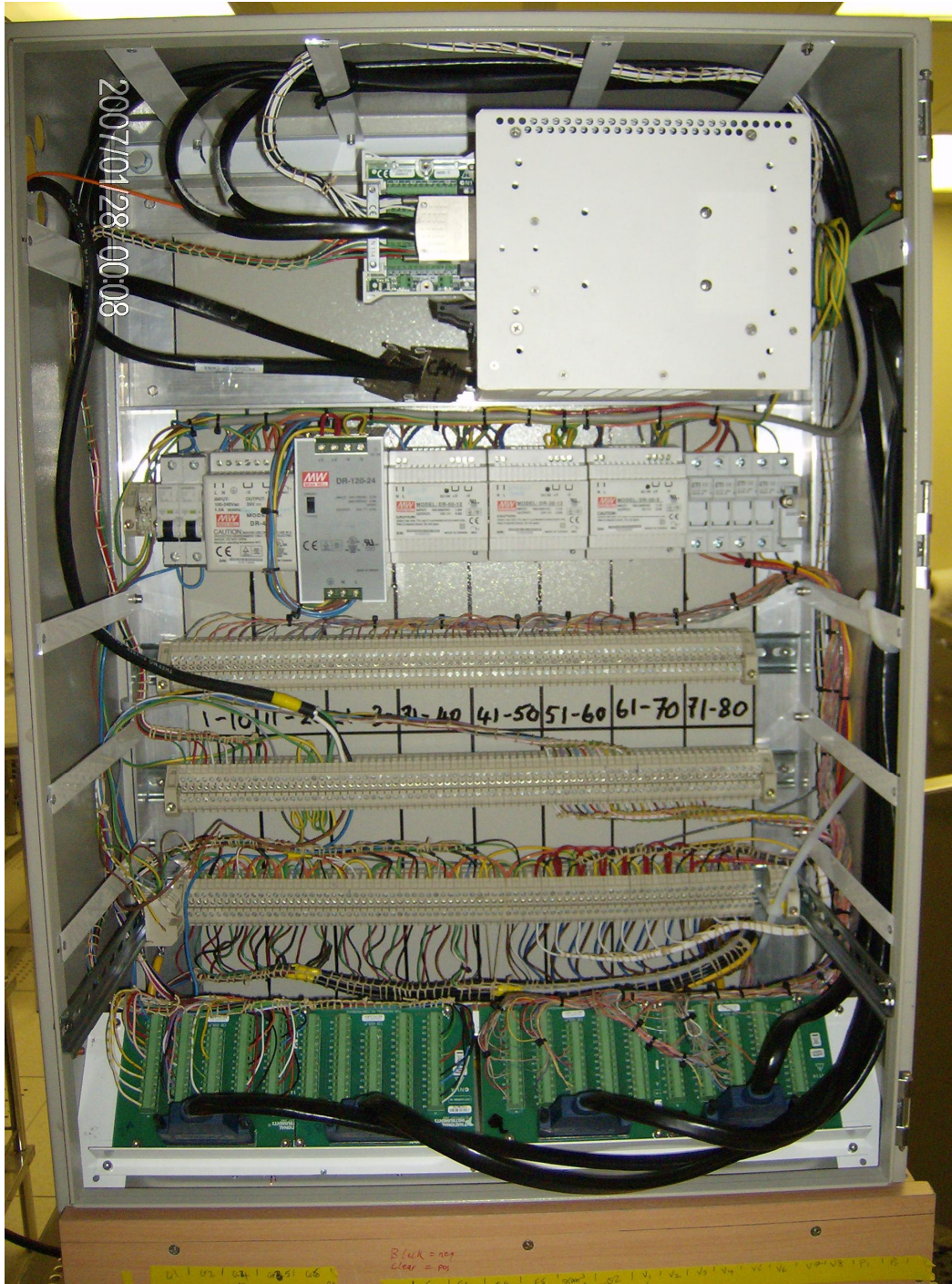


Figure 15: The electronics box. Some temporary power connection wiring is visible entering the box in the upper left

6.2 Gas Flow Schematics

The following color-coded schematics show gas flow during various operations:

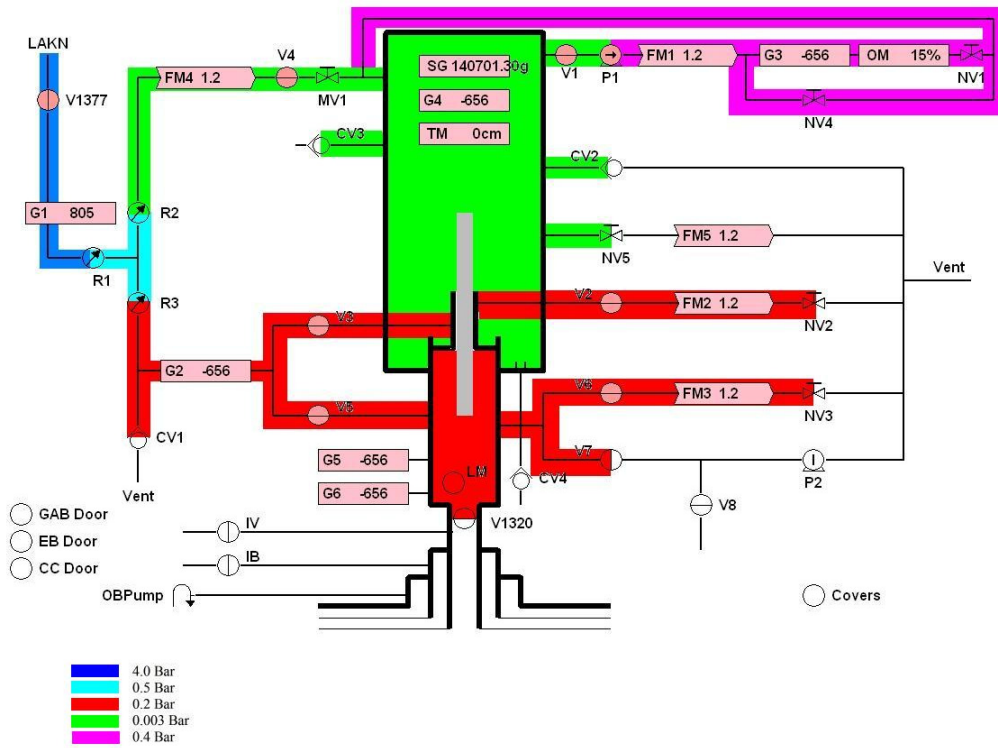


Figure 16: Basic Gas Flow

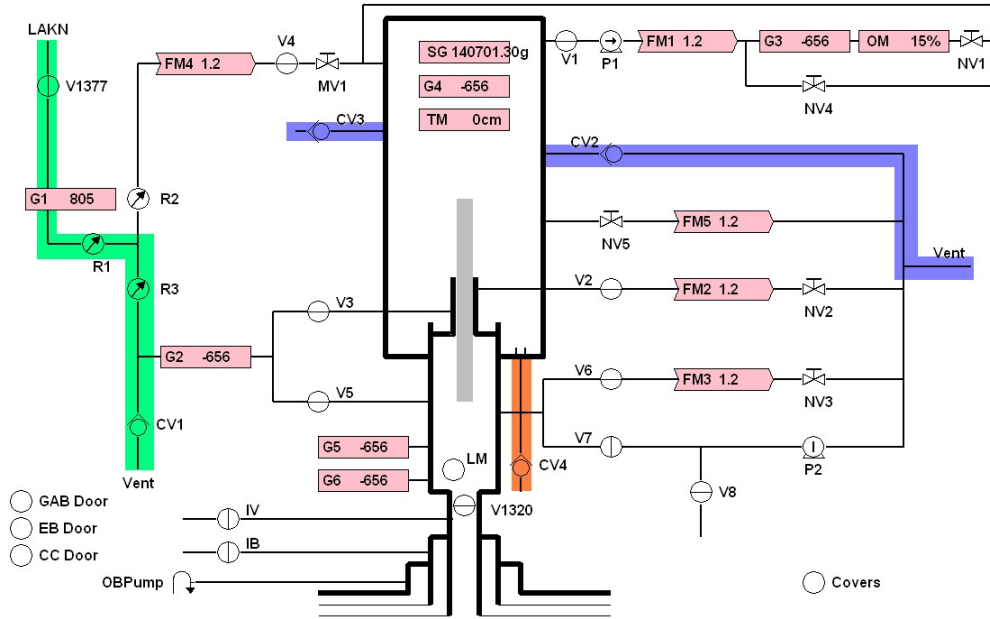


Figure 17: Some special features; Green: Path to check for functionality of CV1; Blue: Backup over/under pressure relief for glove box; Orange: liquid drain from glove box

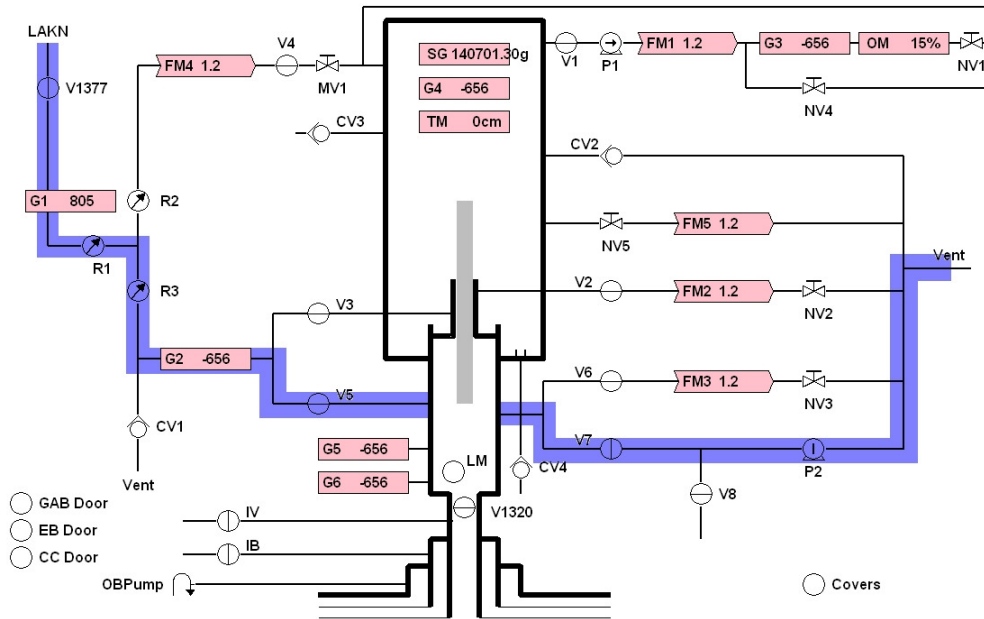


Figure 18: Gas control path to allow pumping/purging of the cross

7 Software

As previously mentioned, the software for the control of the gas system is a PERL program (gascontrol.pl – see Appendix C¹⁸) with a graphical interface written in TK. Functions are executed by the DAQ system by calling one of several routines contained in the DAQ interface code which is written in C¹⁹. Communication between the two programs is through a byte pipe which allows fast data transfer between the two sets of code in a way that avoids disk access. A screen shot of the interface to the code can be found in Figure 19. Preset upper and lower limits for the outputs of the feedback devices can be loaded in via the function buttons on the left panel. Values out of this range cause either a minor (local to the calibration system), or a major (in both CR4 and in the control room) alarm. See Figure 20 for a screenshot of the alarm definition window. Changing the state of one of the relay controlled items (solenoid valves V1-V8, or either of the pumps P1 or P2) is done by simply clicking on the item²⁰. Operators of the system will

¹⁸ Maintainer: Bruce Vogelaar

¹⁹ Maintainer: Steve Hardy

²⁰ Clicking on an item actually puts a red outline around the other devices that depend on it; right clicking on the device will then cause the relay to operate

learn to use this software during their training. The software allows the users to customize what triggers an alarm based on the current calibration.

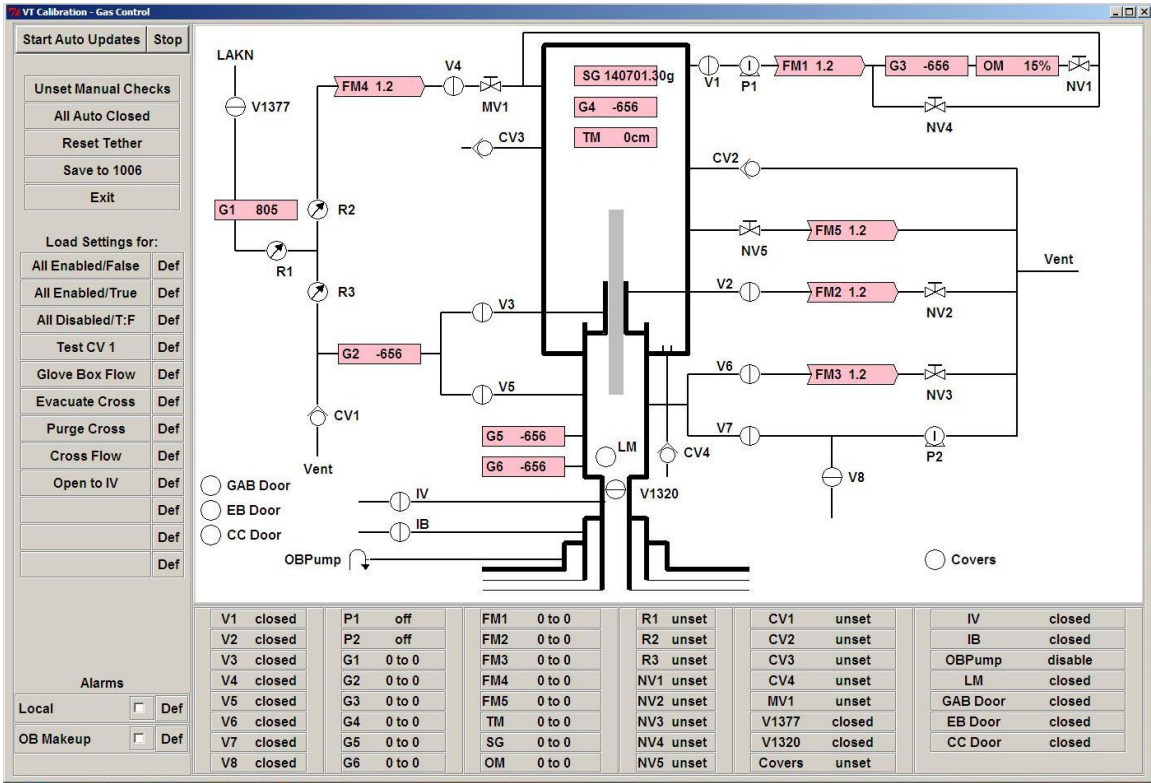


Figure 19: Gas Control Software

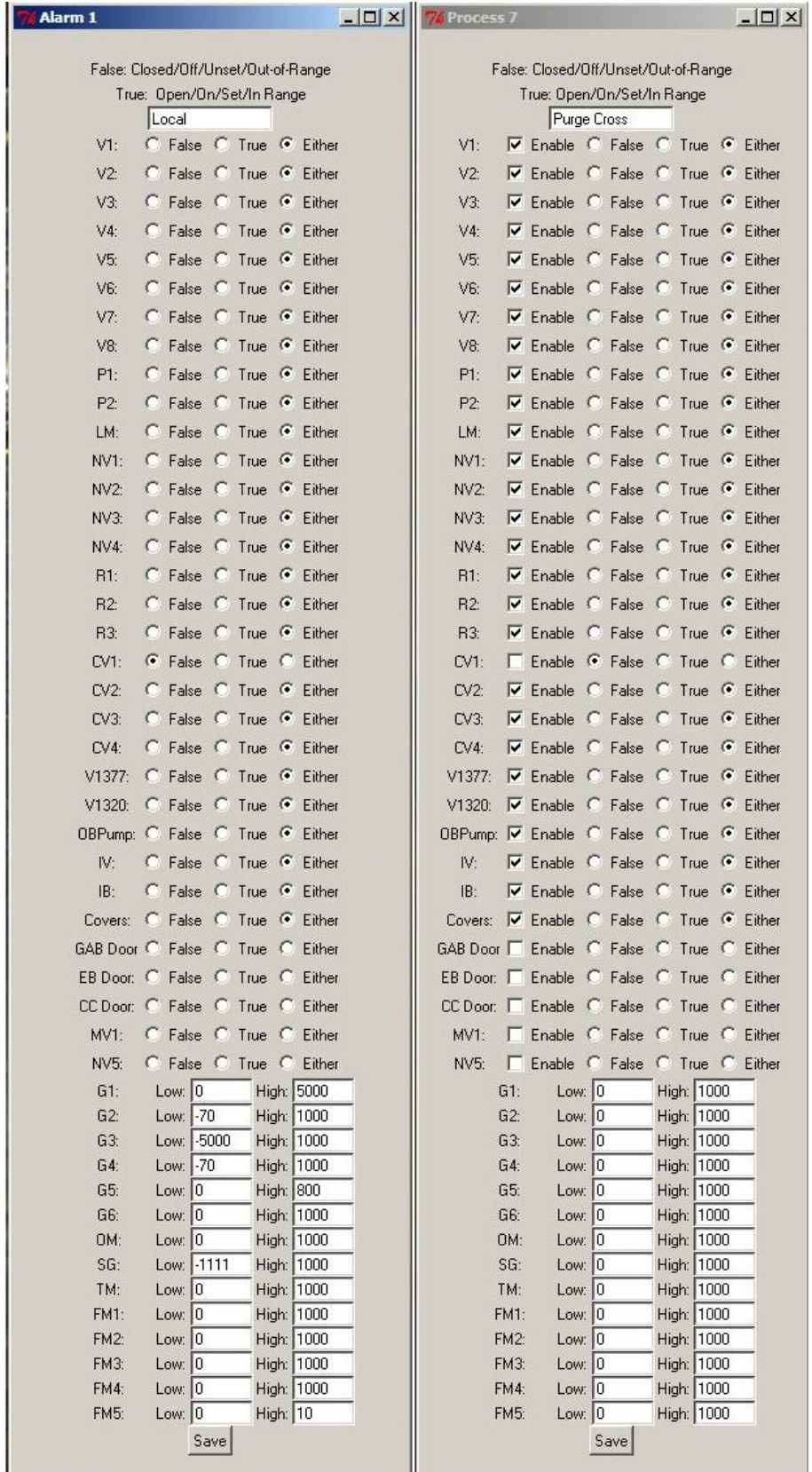


Figure 20: Panel to set process and alarm definitions

8 Calibration System Prerequisites

Before the source insertion process can begin, all components of the system must be in a state to function safely, and within their specified values. All personnel directly involved must notify the required people (see Section 4), all personnel performing these tasks must be properly trained, and all managers and shift workers must be notified of the planned operation, its starting time and expected duration. Additionally, the Calibration Director should verify that the normal site services (electricity, etc.) will remain operational for the duration of the calibration process.

As mentioned above, the calibration system must be verified to be in a condition to operate safely, with specific attention to the following items:

- The ensuing calibration has been approved by the Steering Committee
- The firemen have been notified of the intention to open the gate valve, and the possibility for loss of PC containment
- The Operations Manager and Shift Leaders have been notified of the impending operations
- Local fire extinguishers and portable Oxygen canisters are available
- The UPS power to CR4 associated equipment is connected and in service
- The emergency exit door in CR4 is unobstructed on both sides
- The floor has been cleared of any tools or items which could be tripped upon
- The GLIMOS has authorized the use of the calibration system
- The charcoal exhaust filter is in place and unobstructed

Certification by Calibration Director:

The calibration of Borexino can begin on _____. The prerequisites above have been confirmed to be satisfied by the Calibration System Operators.

Bruce Vogelaar
Calibration Director

9 Personnel Prerequisites

- The personnel performing the source insertion operation (the Calibration System Operators) have been adequately trained to perform the tasks required of them in a manner that is safe for personnel and equipment. In particular, these individuals have knowledge of normal operating procedures, system startup and shutdown procedures, and emergency shutdown procedures.
- The schedules and shifts have been planned, and the personnel on shift during the insertion process have been trained for the tasks they must perform during the calibration operation and made aware of their responsibilities. Additionally, all personnel that will be on call have been notified and their telephone numbers and calling sequence have been established and posted in CR4, the control room, and the electronics room.
- A sufficient quantity of LAKN is guaranteed for the expected duration of the calibration campaign.

Certification by Calibration Director and Operations Manager:

The calibration of Borexino can begin on _____. The prerequisites above have been met.

Bruce Vogelaar
Calibration Director

Augusto Goretti
Operations Manager

10 Site Prerequisites

The site manager is responsible for the following:

- Essential services in Hall C are expected to continue through the calibration period (electricity, air ventilation, shuttle transportation).
- The LNGS director (if he/she requests such notification) and people responsible for the services have been informed that the calibration for Borexino will start, and in particular, that the gate valve will be opened
- All necessary safety systems are in working order
- Firemen have been given any necessary special instructions

Certification by Site Manager:

The calibration of Borexino can begin on _____. The prerequisites above have been met.

Augusto Goretti
Site Manager

11 Procedure

The following sequences need to be completed for any calibration campaign. These should be checked off as they are completed or as having already been done (although 11.1.5 should be done at least once per campaign or once a month during a campaign), and are described in more detail in specific sections of this document as indicated.

1. Training
 - a. Train personnel about calibration features and documentation
 - b. Train personnel in emergency / abnormal procedures (Section 12)
2. Configure software control
 - a. Calibrate cameras (See Appendix A)
 - b. Define processes in gas control software (See Appendix C)
 - c. Define alarms (See Appendix C)
3. Define calibration plan based on physics needs
 - a. Define source type
 - b. Fabricate source (if needed)
 - c. Define source location target positions within detector
 - d. Define duration of data collection at each point
 - e. Determine how to integrate source data with Borexino DAQ run logs
4. Configure hardware (Section 11.1)
 - a. Perform any final cleaning procedures
 - b. Install required items into glovebox
 - c. Install required items into cross
 - d. Ensure required items are available in CR4
 - e. Establish generic gas control settings
(Note: if staying strictly on-axis, the tether items can be skipped, and the tether hole in the top of the cross simply plugged)
5. Administrative controls
 - a. Ensure approved procedures
 - b. Ensure approved manpower
 - c. Obtain sign-off by cognizant personnel (Sections 8, 9, 10)
6. Preparation
 - a. Establish proper gas environments (Sections 11.2, 11.3, 11.4 *in that order*)
 - b. Establish interface to other systems (Section 11.5)
 - c. Engage alarms (Section 11.5.4)
7. Insert source
 - a. Complete any administrative checklists
 - b. Open calibration system to inner vessel (Section 11.6)
 - c. Manipulate source into position (Sections 11.7, 11.8)
 - d. Confirm position with cameras (Appendix A)
 - e. Acquire data
 - f. Repeat step 7 as required
8. Remove source (Sections 11.9, 11.10, 11.11)
9. Set system to standby (Section 11.12)
10. Abnormal / emergency procedures (Section 12)

11.1 Preparing the System for Use

11.1.1 Goals

The goal of the tasks described below is to ready the system for the source insertion and removal operations. These tasks include: collection and positioning of all necessary items, testing the functionality of CV1, and bringing the Oxygen monitor online.

11.1.2 Manpower

At this stage, the only personnel required are the Calibration System Operators. However, the Operators should give the Calibration Director and Operations Manager a notification of the completion of this section of the procedure if no problems are encountered. Communication with other personnel is only required during the final steps before the gate valve is opened.

11.1.3 Prerequisites

- Computer Status:
 - The gas system control software has been started in CR4 and functioning
- Present in Glovebox
 - The plugs for the rod, tube, and liquid level monitor seals
 - Two glove port plugs
 - The custom wrench for the rod seal
 - Nitrile outer gloves
 - The allen wrenches for tightening the bolts on the following:
 - Rod couplers (1/4" hex key)
 - Rod slip lock (3/16" hex key)
 - Rod seal cap (3mm hex key)
 - Two bolts and a collar for each insertion rod
 - The rods to be used during source insertion
 - Clean room wipes and a small bottle (~500 ml) of pure PC
 - The wrenches for tightening the bolts on the following:
 - Tether drum (9/16")
 - Rod, tube, and liquid level monitor seals (8mm)
- Present in CR4
 - The light blocking covers for the cross
 - The source to be used (radioactive or fiber optic)
 - The source coupler, bolts, and sleeve
 - The catch tray insert for the cross
 - Two new 10" (25 cm) copper conflat gaskets
 - The wrenches for tightening the bolts on the cross flanges (12 pt wrench)
 - Allen wrenches for tightening rod coupler bolts and source coupler cover (1/4" and 5/32" hex keys)
 - The handles for the cross flanges
 - The wrench for the glove ports (7/16")

- The nut driver for the hose clamps used to seal the gloves (5/16")
- The key for the gas box
- The wrench for the tether drum (9/16")
- Visually inspected
 - The glovebox gloves (this includes both the Butyl gloves and the outer gloves) – look for any tears, punctures, or other damage
 - The acrylic panels – check for any visible crazing or cracks (pay particular attention to the areas around bolt holes)
 - The two quartz viewports – look for any signs of stress or breakage

11.1.4 General Operating Notes

- Calibration of flow meters and gauges should be done off-line. They need to be rechecked if there have been any related hardware changes.
- Once the glovebox is pressurized, never try to quickly insert, or withdraw, one's arms from the gloves, especially the latter. There are check valves on the glovebox that prevent both over and under pressurization so there is no possibility of damage to the glovebox. Simply move slowly and do not force your arms into or out of the glovebox. The gas flow will make up for the change in volume quickly. Rapid insertion will overrun P1 (capable of 6 lpm) and rapid withdrawal is limited by line impedance and the setting of R1. (The unused glove will also act as a buffer volume.)
- Valves v1321 and v1421 are diaphragm valves, when reopening them at the end of a calibration run, open all of the way, and then close approximately ¼ of a turn. Leaving a diaphragm valve completely open to the top of the stem can cause it to seize or distort under stresses due to temperature fluctuations.
- All pressures in this document are gauge pressures, except where noted explicitly.
- Following the guidelines set forth in ADMIN-BX-001 (the procedure for writing Borexino Procedures), any deviation from this procedure must be approved by the Calibration Director. Any such deviations should be marked as such in the log book / execution log, and a detailed description of the reason for the deviation and what was entailed in the deviation should be noted in the log. However, if the deviation alters the intent or scope of this procedure, or has an effect on any of the aforementioned safety issues, the Calibration Director must get the approval of at least one Reviewer *and* the Approver of the procedure.
- Recall that turning a regulator knob clockwise is "opening" the regulator (increasing the outlet pressure). When the procedure says to fully close a regulator, turn the knob completely counterclockwise.
- If you are not sure about the current state of a valve, it is almost always safer to try to close it first rather than to open it. Closing an open valve rarely has a significant effect, but opening a closed valve can have a very significant effect.
- Since bare stainless steel components entering the IV must be electropolished, all bolts used in these components will be nickel or copper plated stainless steel to reduce the chance of galling.
- The default position (or power-off) for all calibration valves is 'closed' and all calibration pumps is 'off', unless explicitly set in the procedures below. Provided

V1320 is closed, there is no harm or danger in closing any valve at any time, except that the Oxygen meter should not be on if G3 is below about 0.4 bar.

- When tightening the bolts on the 10 inch flanges (maximum torque of 15 ft-lbs) use the following procedure:
 - Pass 1 – Tighten the bolts loosely by hand in the first instance, according to the bolt pattern scribed on the flanges, then hand tighten them evenly
 - Pass 2 – Using the torque wrench, torque the bolts to a maximum of 30% of the full torque, according to cross bolting pattern. Check that the flange is bearing uniformly on the gasket
 - Pass 3 – Torque to a maximum of 60% of the full torque, according to the cross bolting pattern
 - Pass 4 – Torque to the full 15 ft-lbs, according to the cross bolting pattern
 - Pass 5 – Again torque to the full 15 ft-lbs in a clockwise direction on adjacent fasteners

11.1.5 Functionality Test of CV1 and Setting R1 Pressure

To prevent possible over-pressure in the cross, and thereby forcing the liquid level down into the Inner Vessel, there are several fail-safe systems. The first is to set v1377 such that even if R1 and R3 fail, CV1 will open sufficiently so that the pressure at G2 will not become excessive. We also want to set R1 so that it *just* clips this gas flow-rate, since we want its output pressure to be high enough to provide sufficient flow through R2 into the glove-box.

Assuming the following parameters:

0.008	bar	nitrogen header tank pressure
100	cm	bottom of gate valve to liquid level in OB header tank (approximate)
243	cm	bottom of gate valve to top of SSS
685	cm	radius of SSS
425	cm	radius of IV
870	kg/m ³	density of PC

→ Total column of PC above IV north pole = 603 cm, giving a pressure of 0.51 bar.

- Close V3, V4, V5, V1377
- Fully back off (counterclockwise, closed) R1, R2, R3
- Open v1377
- Record G1 (should be at least 2 bar)
- Tighten R3 fully (clockwise, full open)
- Tighten R1 fully (clockwise, full open)
- CV1 should now be bypassing gas (it is full open at 0.21 bar)
- Close v1377 slowly until G2 reads at or below 0.30 bar
- Back off R1 until G2 reads at or below 0.29 bar
- Fully back off R3 (counterclockwise)
- G2 pressure should now drop to about 0.17 bar (pressure where CV1 fully closes)

V1377 and R1 have now been set so that either one of them will limit the flow through CV1 sufficiently that G2 will not exceed 0.30 bar, thus giving a 0.21 bar safety factor before gas can enter the inner vessel.

11.1.6 Setting of NV1

The oxygen monitor requires a minimum pressure and below a maximum flow to read properly. This is accomplished by setting NV1 appropriately.

- Close NV4, open V1, NV1
- Turn on P1
- Close NV1 and open NV4 as necessary until G3 reads 1.0 bar and FM1 reads between 0.5 and 1 lpm
- Record G3
- Close V4, V1, and turn off P1

11.1.7 Removal of Tether Installed in Glovebox

If the tether to be used in the ensuing calibration is already installed in the glovebox, the operators need only visually verify that the following steps have been completed before moving on.

- If tether is to be changed, decouple tether from insertion rod inside cross, and dismount roller meter if used
- Loosen compression on the tube seal cap until it is free from the base
- Remove the six bolts that hold the tube seal to the cross
- When all six bolts have been removed, carefully lift the tube seal off of the top flange (taking care that the o-rings stay with the tube seal), and place it inside of the tether storage drum.
- Ensure that the cap for the installed tether drum is within easy reach of the glovebox
- The CR4 end of the tether should be disconnected from any power supplies or lasers, and coiled near the tether drum.
- Operator 1 should support the weight of the installed tether drum, while Operator 2 removes the nuts that hold the tether drum onto the glovebox
- Once the tether drum is free, Operator 2 should place the cap on the tether drum, and tighten the bolts as soon as Operator 1 removes it from the glovebox
- The now capped tether drum should be stored safely in CR4
- The hole in the glove box should be covered if the new tether is not to be mounted immediately

11.1.8 Tether Installation

After identifying the correct tether drum to use for the calibration, the operators should retrieve it and place it near the mounting location on the glovebox

- Loosen the bolts that hold the cap onto the tether drum and reposition the gasket if necessary
- Operator 2 should position his/her hands inside the glovebox gloves and gather the necessary tools to tighten the nuts on the tether drum

- Operator 1 should position the tether drum onto the mounting location of the glovebox, taking care to align the dowel pins into their holes
- Operator 2 should tighten the nuts securely
- Operator 2 will retrieve the tube seal from the storage drum and position it over its mating hole on the top flange (taking care that the o-rings remain in their grooves) and then insert and tighten the mounting hardware
- While Operator 2 is performing the above task, Operator 1 can connect the CR4 end of the tube to any power supplies, lasers, or other devices required by the ensuing calibration

11.1.9 Source Attachment

- If a plug is present in the rod seal, remove it and store it out of the way in the glove box.
- Select an insertion rod, or the hinge²¹, and place it into the weighing location. Record its weight and then insert it through the rod seal until it can be easily accessed through the cross
- Reapply the compression to the cap, and place the rod lock around the rod (place it just above the rod seal cap) and tighten
- Remove the light blocking covers from the acrylic viewport covers on the cross flanges and store them safely out of the way
- Remove the two cross flanges with the viewports and discard the old copper gaskets; *do not attempt to reuse them*
- Place the catch cup in the bottom of the cross
- Remove the cover plate from the source coupler
- Place the (large diameter) collar over the top of the source coupler and attach it to the mating coupler on the rod inside of the cross, do not over tighten the bolts, and rotate the collar so that the holes in the collar no longer line up with the bolt heads
- Loosen the tube seal cap and insert enough of the tether tube so that the precompressed Swagelok ferrule can reach the mating slot in the source coupler
- If using the radioactive source:
 - Attach the split Teflon ring to the neck of the source, being sure that the ring is on the Quartz itself, not the quartz/pyrex transition
 - Thread the spring (the end without the tang) onto the Teflon ring
 - Place the tang of the spring in the hole in the groove of the source holder
- Put the tether tube into the groove, making sure that the ferrule rests in its mating slot
- Put the cover onto the source holder and tighten the two bolts
- One operator should apply power to the location LED while the other operator verifies its functionality
- Visually check the cross for any bolts, washers, tools, debris, etc. that may have accumulated in the cross and remove if necessary
- Remove the catch cup

²¹ Whether the first rod is the hinge rod or not will be determined by the desired source location, although it is envisioned to never have the hinge be the first insertion rod.

- Check to make sure the recess where the quartz viewports reside is free of any washers, nuts, dirt, debris, etc. Check them again to ensure that no damage has occurred during these operation
- Open two new copper gaskets and reinstall the two flanges. Inspect the now mated flanges for any variations in their spacing which would indicate nonuniform compression of the copper gasket. Fix as necessary
- Make one more final inspection of the gloves for any tears, punctures, or other damage
- Alert the Calibration Director that this stage of the operation has been completed

At this point, the system is completely sealed, one of the regulators is set to the required value, and all instruments have gone through their calibrations²². The system is ready to proceed with the purging of the glovebox and cross.

11.2 Purging the Glovebox

11.2.1 Goals

The goal for this section is to begin a LAKN flow to the glovebox and displace air from the glovebox volume. When the glovebox is not in use, the LAKN flow will either be set very low, or off completely, so a period of purging must take place to remove any Rn, Kr, or Ar (presumed proportional to the Oxygen content) in the glovebox itself²³.

11.2.2 Manpower Requirements

During this operation, only the Calibration System Operators are required. The gate valve will remain closed throughout this operation.

11.2.3 Purging the Glovebox

- Steps in 11.1 should have been completed first
- Fully close R2, close V1, and MV1
- Open V4
- Open R2 approximately one eighth of a turn
- Adjust MV1 so that FM4 reads no higher than 4 lpm.
- Adjust R2 as necessary until G4 reaches 2 mbar (Go slowly, waiting for G4 to stabilize after each adjustment). You may have to adjust MV1 after each such adjustment to R2 since at very low pressures the regulators provide a large impedance to the flow.
- Have one operator slowly place his/her arms into a pair of gloves while watching G4, it should peak between 3 and 4 mbar as CV2 opens, if the pressure does not peak, stop and slowly withdraw gloves, notify the Calibration Director, and cease the operation until the source of the problem has been determined, and the situation fixed.
- Turn on P1
- Open V1

²² This step is done when the gas control system is started

²³ If the tether drum was changed in earlier steps, the glovebox volume was open to CR4 for a short period of time during which cleanroom air may have entered the glovebox

- Open NV5 until FM5 reads about 4 lpm
- Do not proceed until the Oxygen monitor reads less than 0.1%

If all of these steps have been successfully completed, the glovebox itself is ready for source insertion operations. The next section will deal with preparing the cross atmosphere for source insertion.

11.3 Purging the Cross

11.3.1 Goals

Since the cross was opened to atmosphere during the source attachment operation, its volume will need to be purged, and the rough leak tightness checked before continuing.

11.3.2 Manpower

This operation only requires the CSOs; the gate valve will stay closed during this entire operation. The cross will be evacuated and backfilled three times, and then left to sit for 30 minutes to watch for any decrease in pressure (indicating a leak).

11.3.3 Purging the Cross

- See Figure 15 for reference
- Contact the shift leader, and get the current value of the over pressure needed in the cross, P_{ref} (typically 120 cm of PC, or 0.10 bar – see section 11.1.5)
- Ensure that V3, V5, V6, V7, V8, and NV3 are all closed, and that P2 is off
- Open V5 and V7 and turn on P2, and allow it to pump until G2 reads slightly below atmosphere, then close V5, V7 and turn off P2
- Slowly close R3 (clockwise rotation) until G2 reads P_{ref}
- Check to make sure rod and tube seals are firmly tightened to top flange, and that the rod and tube seal caps are sufficiently tightened
- Open V7 and turn on P2
- Pump for approximately 10 minutes, record G5 and G6 (if not below 100 mbar *absolute*, fix leak or seek advice)
- Turn off P2 and then close V7
- Open V5 to let the cross up to P_{ref}
- Once G5 and G6 read within 20 mbar of P_{ref} , close V5
- Open V7 and then turn on P2
- When G5 and G6 read approximately 100 mbar *absolute*, turn off P2 and close V7
- Open V5
- When G5 and G6 read within 20 mbar of P_{ref} , close V5
- Open V7, and turn on P2
- When G5 and G6 read approximately 100 mbar *absolute*, turn off P2 and close V7
- Open V5
- When G5 and G6 read P_{ref} (this time adjust R3 to obtain P_{ref}), close V5

- Record the exact reading of G5 and G6
- Wait for 30 minutes
- If G5 and G6 read lower than before the 30 minutes:
 - Perform a visual check of the cross flanges and look for any gaps that may indicate insufficient tightening of bolts, if so, retighten and try again.
 - Check to make sure the rod and tether seals are sufficiently tightened
 - Open V5 until the cross is back at atmosphere, and then close V5
 - Replace conflat gaskets on flanges
 - Evacuate cross and backfill with LAKN three times as in above procedure
 - If G5 and G6 still read lower than previously recorded value, halt operation and contact Calibration Director for further advising
- If G5 and G6 have kept approximately the same readings, open V5 again
- Open V6
- Slowly open NV3 until FM3 indicates a flow rate of 1 lpm
- Wait half an hour to allow further purging of cross

At this stage:

- 1) The glovebox
 - a) Has less than 0.1% Oxygen²⁴
 - b) Is under positive pressure
 - c) And, is being continuously purged with LAKN
- 2) The Cross
 - a) Has pressure equal to that of the PC about 20 cm below the gate valve
 - b) Is leak tight
 - c) Is being continuously purged with LAKN
 - d) And, contains a calibration source attached to the first insertion rod and associated tether tube.

11.4 Purging the Rod Seal

11.4.1 Goals

The goal of this operation is to start the LAKN flow through the rod seal in preparation for the source insertion process. The gate valve will stay closed during this entire operation; however, the Operators should notify the Calibration Director of their progress and intention to begin the LAKN flow through the rod seal. The pressure in the rod seal will be brought up to P_{ref} so that the pressure difference across the lower seal of the rod seal and the interior of the cross is zero, additionally a 4 lpm flow will begin through the rod seal to facilitate its purging. This is especially important during the passage of the rod couplings.

11.4.2 Manpower

This section requires only the CSOs

11.4.3 Starting LAKN Flow Through the Rod Seal

- Fully open NV2, and ensure that V2 and V3 are closed

²⁴Compared to air

- Open V3 and V2
- Slowly close NV2 until a 4 lpm flow rate is observed in FM2

At this point, the insertion system is pressurized to the appropriate levels, adequate flow has been established through all critical components, and the calibration system is ready for source insertion to proceed. In the next step of the procedure, the interfaces to other system will be brought online, alarms will be armed, and a final cross check of all components will take place.

11.5 Alarms, Interlocks, and Interfaces to Other Systems

11.5.1 Goals

The purpose here is to ready any other systems involved in the calibration process, to bring online all interlocks and alarms, to perform a final check of all components, and to allow the GLIMOS, Operations Manager, or any other designee to inspect the system before authorizing the opening of the gate valve.

11.5.2 Manpower

All of the operations in this section will be performed by the Calibration System Operators, but any persons wishing to inspect the system before the opening of the gate valve should be notified that the Operators are performing the final preparations to ensure that the designees are available to perform the inspection. This step will require frequent communication with the persons monitoring the vessels and associated systems.

11.5.3 Interfaces to Other Systems

- Contact the Operations Manager and verify that it is permissible to close v1321 (IV to header tank) and v1421 (IB to header tank)
- Contact personnel in Control Room to verify operation of OB header tank system
- Slowly close v1321 and mark IV as closed in the gas control software
- Slowly close v1421 and mark IB as closed in the gas control software
- Verify that the DAQ inhibit cable is connected to the camera control box
- Contact the DAQ Shift Leader and verify that the DAQ inhibit signal from the camera control box is connected to the DAQ system

11.5.4 Arming Alarms

- Click on the checkbox labeled "Local" in the alarms section of the gas control software
- Wait several seconds, if the alarm goes off, check screen for where the problem occurred. Notify the Calibration Director of problem encountered, and do not proceed until fixed
- Click on the checkbox labeled "OB Makeup" in the alarms section of the gas control software
- Wait several seconds, if the alarm goes off, check the screen for where the problem occurred. Notify the Calibration Director of the problem encountered, and do not proceed until fixed

11.5.5 Final Checks and Authorizations

- Contact the Calibration Director and Operations Manager to inform them that the system is fully prepared for the gate valve to open
- Contact personnel in the Control Room and ask for the current value of P_{ref} , adjust R3 if necessary until G5 and G6 equal the new P_{ref}
- Contact the DAQ Shift Leader and verify that the DAQ system and those in charge of it are prepared for the gate valve to open
- Contact the GLIMOS and any other persons wishing to inspect the system before authorizing the opening of the gate valve and inform them that the Operators are doing their final checks and await their inspection and authorization before opening the gate valve
- Contact the firemen and alert them that the gate valve will be opened soon
- Contact the control room and verify that the OB makeup pump interlock is operational
- Check v1321 and v1421 to ensure that they are fully closed
- Verify that the light blocking covers for the cross windows are nearby
- Perform a visual check of the source again
- Check the viewports of the cross again and verify that they are not showing any signs of damage
- Place the light blocking cover over the rear window (Hall C side) of the camera control window if not already present
- Allow inspections by the GLIMOS and any other designees
- Once the Calibration Director, Operations Manager, and the GLIMOS have authorized the opening of the gate valve proceed onto the next step of the procedure

11.6 Opening the Gate Valve

11.6.1 Goals

The purpose of this section is to open v1320, the gate valve between the IV and the six way cross of the insertion system. By this point, the system is fully prepared to open the gate valve, the necessary personnel are on hand and have been notified, and the authorization to open the valve has been obtained by the required personnel.

11.6.2 Manpower

These operations will be performed by the Calibration System Operators, but the Calibration Director, Operations Manager, DAQ Shift Leader, and the Shift Leader in the control room must all be reachable quickly. Close communication between the Calibration System Operators, and the DAQ Shift Leader must be maintained to monitor for any light leaks that might be observed by the DAQ system. Additionally, the Operators must also stay in close communication with the Shift Leader in the control room to monitor the condition of the vessels and overall detector well being.

11.6.3 Prerequisites

- G5 and G6 concur with the most recently reported value of P_{ref} , the pressure of the PC about 20 cm below the gate valve

- Both Local and OB Makeup Pump alarms have been armed
- The GLIMOS, Operations Manager, and Calibration director have authorized the opening of the gate valve
- The DAQ Shift Leader and DAQ Shifters are monitoring the PMT rate and are prepared to kill the HV if the rate rises out of specs.
- The light blocking covers for the cross are within easy reach of the operators
- Light blocking covers are in place over the outer window of the camera control cabinet

11.6.4 Opening the Gate Valve

- Turn on low level red lighting in CR4
- Turn off CR4 fluorescent lights
- Operator 2 should get a verbal confirmation that the DAQ personnel and Control Room personnel are prepared for the gate valve to be opened.
- Operator 2 will give a "3-2-1" count down and then open the gate valve
- If Operator 1 indicates that PC is rising into the cross²⁵, or, if G5 or G6 drops more than briefly (as liquid directly below the gate-valve is pushed down about 20 cm), Operator 2 should close the gate valve. The OB makeup pump will have already been turned off by the interlock. The operation should be halted and the source of the problem determined before continuing.
- If the DAQ Shift Leader indicates that the PMT rate has increased out of the normal range, Operator 2 should close the gate valve. The source of the problem must be identified and fixed before continuing.
- Place light blocking covers on the cross windows, tighten retaining rings, and mark as installed in gas control software
- Alert the DAQ Shift Leader that the CR4 lights will be turned on and they should continue monitoring for increased PMT rates
- Turn on CR4 fluorescent lights
- If the DAQ Shift Leader indicates that the PMT rate is out of range, Operator 2 will close the gate valve until the source of the problem is identified and fixed.
- Turn off low level red lights

11.7 Source Insertion Along Z Axis

11.7.1 Goals

Now that the gate valve has been opened, the insertion of the source may proceed as planned.

11.7.2 Manpower

This operation can be completed with just the Calibration System Operators, but the Shift Leader in the control room should keep an eye on the status of the detector and report any concerns to the Calibration System Operators.

²⁵This will be indicated by the liquid level monitor also

11.7.3 Source Insertion

There will be many instances where the Operators will take pictures with the source LED illuminated during this process. Prior to each photo, one of the Operators should notify the DAQ Shift Leader of the intent to take a photo. During the insertion of the tether tube, Operator 2 should carefully check the tether tube for any damage as it is inserted, if any damage is found, immediately stop the operation, evaluate, and perhaps retract the source.

- Operator 1: Grasp the rod that is in the rod seal firmly. Operator 2: Loosen the bolt on the slip lock
- Operator 2: Slide the slip lock up near the top of the rod and then retighten the bolt
- Operator 2: Loosen the compression on the rod and tube seal caps while Operator 1 holds the rod and tether.
- Operator 2: Check the flow through FM2, if below 2 lpm, add compression to the rod seal until the flow rate increases
- Operator 1: Slowly insert the rod through the rod seal while Operator 2 feeds the tether through the tube seal at the same rate, pausing when necessary to unwind more of the tether from the drum
- If this first rod is the hinge, pause for 30 seconds as the hinge coupler passes through the rod seal to ensure a good purge
- When the slip lock has been reached, recompress the rod and tube seal caps
- Obtain another insertion rod place it into the weighing station hole (in the rod holder) and record its weight
- Wipe rod down with PC
- Put the rod up into the top hat and lower it back down onto its mating connector and collar, tighten the two bolts securely, and rotate the collar out of alignment
- Operator 1: Grasp the rod firmly. Operator 2: Loosen the bolt on the slip lock
- Operator 2: Slide the slip lock half way up the rod and retighten the bolt.
- Operator 2: Loosen compression on the rod and tube seal caps while Operator 1 holds the rod and tether.
- Operator 2: Again check FM2 for low flow (< 2 lpm), add compression to rod seal if too low
- Operator 1: Insert rod through rod seal while Operator 2 feeds the tether through the tube seal. Pause for 30 seconds as the coupler passes through the rod seal.
- Repeat this process²⁶ of inserting the rod and tether until the source LED is first expected to enter the IV (from the inventory of rods and the tether, and Camera Software, you should know exactly when this will occur)
- Alert the DAQ Shift Leader that the source is expected to have just entered the IV and you will be taking a picture with the reference LED
- Take a picture with the camera system; ensure that the LED is visible, if not:
 - Check your logs and verify that the LED should actually be visible at that point.
 - Check connection of LED illumination wires in CR4

²⁶Adding the hinge where necessary if it is being used

- Proceed with slight further insertion and take a photo with the cameras
- If still not found, follow the source retraction procedure and analyze situation further once the gate valve has been closed
- If LED is visible, proceed with insertion, taking a picture after every meter is inserted, until the desired Z axis position of the source is reached²⁷
- After tightening the rod slip lock for the last time, align the rotation marks on the rod slip lock and the rod seal cap (these will be shown to the Operators during their training)
- Tighten the rod and tube seal caps and ensure adequate flow through FM2
- During this process, update the logbook, noting that the tether insertion matches the rod insertion.

11.8 Off Axis Motion of Source

11.8.1 Goals

The goal of this part of the procedure is to move the source off the Z axis by bending the hinge rod, and then by rotating the assembly azimuthally until the desired position is reached. At the conclusion of this step, the detector will be ready to take the calibration data.

11.8.2 Manpower

The CSOs are the only personnel required to perform this task, however, they should notify the Calibration Director and the Operations manager of their progress.

11.8.3 Moving Hinge to Desired Position

It is important that one never pulls hard on the tether tube while the rod is significantly off axis. Recall that the IV pipe is only four inches in diameter, so, it is very easy to put a sharp bend in the tether where it enters the IV. This could be especially harmful if the tether with the fiber optic cable is being used. Again, there will be numerous times where photos must be taken with the source LED illuminated. Alert the DAQ Shift Leader prior to each such process.

- Take one initial reference image with the cameras
- Dismount the tether measuring device from the glovebox side panel and place it directly atop the tube seal and record this measurement in the log book
- Remount tether measurer on side of glovebox
- Loosen compression on the tube seal cap slightly
- Retract approximately 5 cm of the tether tube into the glove box. *DO NOT* force the retraction. If retraction of the tether tube is difficult:
 - It is possible that the IV fill tube is not truly vertical; in which case it may be necessary to rotate the rod 180 degrees before the tube will retract willingly. *NEVER* rotate the rods by more than 180 degrees in either direction.

²⁷There may be some slight disagreement if the hinge is within the IV, slight off axis motion is expected, the agreement should be to within 10 cm

- The operators should loosen compression on the rod seal cap and begin to rotate the assembly. Record the amount, and direction, of the rotation in the log book
- Once the tether tube starts to retract, withdraw 5 cm of it
- Return the rod seal assembly to its original angle (re-align the rotation marks)
- Reapply compression to tube seal cap
- Take a photo with the camera system and ensure that the reconstructed LED position agrees with the expected position
- Release compression on tube seal cap and retract tube approximately 5 cm
- Reapply compression on tube seal cap
- Take another picture with the cameras, check the agreement of the reconstructed and expected positions
- Continue to extract the tether tube in approximately 5 cm increments until desired hinge angle is obtained (long arms at large angles can take larger steps)

11.8.4 Rotating Rod Assembly to Desired Azimuthal Angle

During this procedure, the Operators should continue to notify the DAQ Shift Leader before each photo is taken. Any images that need to be taken after an azimuthal rotation should be taken after a few minutes have elapsed to allow any motion of the rod assembly to cease.

- Determine which direction the rod assembly must be rotated
- Release compression on the rod seal cap (monitor flow through FM2)
- If the rod assembly needs to be rotated by less than 30 degrees from the current location, rotate directly to that position
- Otherwise, rotate the rod assembly by 30 degrees in the necessary direction, and reapply compression to the rod seal cap
- Record the rotation in the log book
- Allow motion to cease and take reference image
- Continue to rotate rod assembly to desired position in 30 degree increments, recording each such rotation in the log book and imaging with the cameras
- When the final position has been reached, apply compression to the rod seal cap
- When motion has had time to stabilize, take final reference image
- Do a final check of all of the gauges and verify that they are operating in range
- The Operators should notify the Calibration Director, Operations Manager, Shift Leader in the Control Room, and DAQ Shift Leader that the source is inserted into the detector in its final position (for the current run) and the calibration data run can now begin.

The Operators should check in with the Shift Leader in the Control Room at least every hour to ensure that P_{ref} has not changed considerably. If several data runs are required with this source in different locations, the Operators should follow the above procedure

for rotating it to its new location. If the new position requires lowering the hinge, then reference section 11.9 on returning the source to the Z axis²⁸.

11.9 Returning the Source to the Z Axis

11.9.1 Goals

The goal of this section is to let the hinge rotate back down to being parallel with the rest of the rods above it. Prior to performing this procedure, the Calibration Director, and DAQ Shift Leader should be notified of the intent to return the source to the axis.

11.9.2 Manpower

The CSOs are the only personnel required for the operation.

11.9.3 Rotating Hinge to Z Axis

As with several other operations, several images will be taken with the source LED illuminated. Prior to each such image, the DAQ Shift Leader should be notified of the impending illumination of the source LED.

- Take a reference image with the cameras
- Following the procedure on rotating the rod assembly (Section 11.8.4), rotate the rod assembly back to the initial insertion angle in 30 degree increments. *Do not rotate by more than 180 degrees in a given direction from the initial insertion angle*
- Take another reference image
- Release pressure on tube seal cap
- Insert 5 cm of tether
- Reapply pressure on the tube seal cap
- Take a picture with the cameras and ensure that the source has fallen. If not, NEVER continue to insert the tether if the source does not move as expected. This could cause the tube to become lax and/or kinked somewhere. If the hinge angle is less than 15 degrees, you may proceed on to section 11.10²⁹. Proceed to section 12.4 for instructions on what to do if the hinge does not begin to fall.
- Repeat this process until the hinge returns completely to the Z axis, or if the hinge angle is less than 15 degrees and the hinge ceases to lower³⁰
- Notify the Calibration Director that the source has returned to, or is within 15 degrees of the Z axis and that rod extraction may now proceed

11.10 Insertion Rod Removal

11.10.1 Goals

The purpose of this section of the procedure is to extract all, or some, of the insertion rods that are in the detector. This procedure should be used for removing all of

²⁸It may not be possible to lower the hinge completely to the Z axis without withdrawing some rods, this should be taken into account when deciding on placement locations for the source

²⁹Keep in mind that now there will be a slight discrepancy between the amount of rod removed and the amount of tube removed

³⁰Try to lower the source all the way to the Z axis, it will make later processes easier; in other words, don't just stop at 15 degrees if you don't have to

the rods that are in the detector (for instance, at end of a complete calibration), or to remove some of the rods for source repositioning purposes (i.e. if the next location that the source is to be positioned at lies above the current location). The Calibration Director should be notified that the extraction of insertion rods is ready to proceed.

11.10.2 Manpower

All operations will be performed by the Calibration System Operators in this part of the procedure. Again, the DAQ Shift Leader should be notified prior to taking any pictures.

11.10.3 Vertical Rod Extraction

- Begin by taking a reference image with the camera system
- Operator 1: Grasp the protruding insertion rod firmly
- Operator 2: Release compression on the rod seal cap, then check FM2 to ensure adequate flow rate
- Operator 2: Release compression on the tube seal cap
- Operator 1: Begin to extract the insertion rod, Operator 2: extract the tether tube at the same rate of extraction as the insertion rod, pause as necessary to coil excess tether in the tether drum
- When the coupling has passed through the rod seal, Operator 2 should apply compression to the tube seal cap and then to the rod seal cap
- Loosen the bolt on the slip lock and slide it down to the top of the rod seal (below the coupling that has just passed through the rod seal) and retighten it
- Rotate the collar until the holes line up with the two bolts, and loosen the bolts until they slip out of the male end of the coupling (do not take them all the way out)
- Remove rod from the coupling, lifting it up into the top hat and then back down into the glove box
- Place the rod into the weighing station in the rod holder. If the rod is heavier than prior to insertion, this indicates a leaking rod. Set it aside for further inspection after shutting down the system
- Take a reference image
- Repeat the extraction of each rod until the source nears the top of the IV

When the hinge (if present) enters the IV fill tube, there may be extra tension required as the fill tube forces the lower portion of the hinge into alignment (if you did not get it to 0 degrees previously). This is a very small lever arm, so be patient.

Extra caution should be exercised when the source nears the top of the IV because the tether tube is directed away from the rods. You can use the tube to *gently* pull the rods up past this difficult section. This may require even less compression on the rod and tube seals so that you can gain tactile feedback. However, monitor FM2 very closely when doing this to ensure adequate purging (you may have to open NV2 slightly more to gain extra flow).

- Continue rod extraction until approximately one meter remains below the gate valve
- Alert the DAQ Shift Leader that you will be removing the light blocking covers, and to watch for any increase in PMT rate
- Turn on the low level red lighting
- Turn off the CR4 fluorescent lighting
- Remove view port covers, and mark them as removed in the gas control software
- Operator 2: Check the state of the visible portion of the rod to ensure that the tether tube is not wrapped around the rod, or is very slack, etc.
- Operator 2: Continue to monitor the rod and tether as Operator 1 continues extraction, giving special instructions as required³¹
- Operator 1: Continue the extraction until the mechanical stop (thick collar on source coupler) stops further extraction
- Operator 2: Reapply compression on rod and tube seal caps
- Operator 2: Reposition rod slip lock just above rod seal
- Operator 1: Rotate the sweeper arm, located on the liquid level monitor, to ensure unimpeded rotation between the indicating marks
- If the sweeper goes fully from side to side, and visual inspection verifies that nothing is left in the path of the gate valve, inform the Shift Leader in the Control Room that the gate valve can be closed now
- When the Shift Leader in the Control Room authorizes the closing of the gate valve, proceed with closing it.
- Turn on CR4 fluorescent lighting
- Turn off low-level lighting
- Disable Local and OB Makeup Pump alarms in the gas control software
- Alert the Calibration Director, Operations Manager, DAQ Shift Leader, and Shift Leader in the Control Room that the gate valve has been closed
- Inform the Shift Leader in the Control Room that you will be opening v1421 and v1321
- Slowly open v1421, the IB valve to the IB header tank
- Slowly open v1321, the IV valve to the IV header tank³²
- Ensure that the OB header tank system is still functioning
- Let the system sit for 30 minutes, with gas still flowing, to allow components to dry; any PPO precipitate will be removed by the next acid wash

11.11 Source Removal

11.11.1 Goals

In this step of the procedure, the pressure in the cross will be bled off, the source will be removed from the coupler, and the coupler removed from the cross.

³¹ This will require that Operator 2 loosens, and reapplies, compression on the rod and tube seal caps since Operator 1 will have his/her hands full

³² There may be a bubble of LAKN released into the IV header tank if the PC level had been forced below the tee-off point for line 2"-PP-1120

11.11.2 Manpower

All remaining steps will be completed by the Calibration System Operators.

11.11.3 Cross Pressure Bleed Off and Flange Removal

- Ensure that the alarms have been disabled and that the system has had time to dry
- Slowly turn R3 until fully closed (counterclockwise)
- Wait for the pressure to bleed off (monitor FM2 and FM3)
- Close V3, and V5
- Remove bolts on the two cross flanges with viewports, keeping copper gaskets
- Remove flanges and place safely out of the way
- Examine the bottom of the cross for any PC that may have risen into the cross during the operation (if present, clean up, and determine its source at a later time)
- Insert catch cup into bottom of cross

11.11.4 Source Removal

- Retrieve the allen key required to remove the coupler bolts on the source coupler, and the allen key needed to remove the face plate bolts on the source coupler
- If using radioactive source, unthread it from the spring and store safely
- Rotate rod such that access to the two bolts on the source coupler faceplate are accessible
- While holding any items protruding from the source coupler (the extension spring in the case of the radioactive source, and the quartz ampoule in the case of the fiber optic source) remove the two bolts that secure the faceplate to the coupler
- Now that the tether is free from the coupler, one of the Operators should pull the tether tube up to its mechanical stop (the other operator can give visual feedback) so that it is safely out of the way
- Rotate the collar until its holes line up with the bolts on the coupler³³
- Loosen the two bolts until they are free from the male end of the coupler (do not remove them completely from the female coupler), reattach faceplate and store
- Do a visual check of the cross for any tools, bolts, washers, or any items left in the cross
- Using the same copper gaskets that were removed with the flanges³⁴, put the flanges back onto the cross and tighten bolts slightly (this is just to keep debris out)

11.12 Shutdown of System

11.12.1 Goals

In this final part of the procedure, the system will be put into its idle state; with at least a LAKN atmosphere left in each component; the glovebox will have a continuous, albeit small, flow of LAKN initiated.

³³It may be necessary to lower the insertion rod slightly to make this easier to access

³⁴These will be replaced the next time the system is used

11.12.2 Manpower

The only personnel needed are the Calibration System Operators

11.12.3 LAKN Atmosphere in Cross

- Ensure that the two cross flanges have been applied and that the bolts are slightly more than finger tight
- Place rod seal plug into the rod seal.
- Check that V3 and V5 are closed
- Slowly open R3 until G2 reads approximately 10 mbar
- Open V5 and V6
- Open V3 and V2
- Adjust NV2 so that a 1 lpm flow rate is observed in FM2
- Wait for several minutes
- Close V2 and V6
- Close V3 and V5
- Fully close R3
- Fully close NV2 and NV3

The cross now has a LAKN atmosphere at a pressure of 10 mbar, and all flow has been stopped to the cross.

11.12.4 Establishing Idle Purge Flow in Glovebox

- Turn off P1 and close V1
- Adjust NV5 until FM4 indicates a 0.5 lpm flow rate
- Ensure adequate compression of rod and tube seal caps

11.12.5 Final Processes

- Clean up all tools used in the process, and return them to their proper location
- Ensure that all components (light blocking covers, glove port covers, etc.) are placed back into their correct locations
- Remove the radioactive source, if used, from CR4 and see to it that it gets disposed of properly
- Make any final notes in log about problems encountered, or any odd behavior of components
- Contact the Operations Manager, DAQ Shift Leader, and the Shift Leader in the Control Room and inform them of the completion of the calibration operation.
- Inform the firemen that the gate valve is closed, and there were no problems
- Contact the Calibration Director and debrief him/her on the process, paying special attention to any problems encountered

12 Emergency Procedures

The following subsections detail the procedures should any of the following instances arise: loss of pressure in cross, tangling of tether around rod or source, tether breakage, failure of source to return to within 15 degrees of Z axis, operators lose track of rod orientation / rotation, excessive force required for any of the normal procedures, a

discrepancy of more than 50 cm between the images taken and where the source is expected to be, source appears to be damaged after removal, source LED or camera system failure while source is in the IV. It is very important that the operators have these procedures committed to memory, and must be able to execute them immediately upon recognizing a problem.

12.1 Pressure Loss in Cross

In the event that the pressure in the cross falls below the acceptable limits, PC will begin to rise into the cross (if the pressure is low enough), an alarm will be tripped by the low pressure in G5 or G6, and/or the closure of the reed switch in the liquid level monitor as the float rises. The alarms are interlocked to the OB makeup pump, and will shut it off when tripped. Once the OB makeup pump turns off, the volume of the OB header tank can flow into the cross, and possibly up into the glovebox, and then will drain into the catch basin in CR4. Once the alarms are tripped, the Operators should execute the following procedures as quickly, and safely, as possible:

- Confirm with the Control Room that the OB makeup pump has turned off
- Verify that the PC is draining to the appropriate location
- Notify the guards and GLIMOS if someone in the Control Room has not done this already
- Notify the Calibration Director and Operations Manager

12.2 Tether Tangled

In the event that the tether tube becomes tangled around the insertion rods or source, execute the following procedure:

- Alert the Calibration Director of the problem
- Pictures will need to be taken with the lights on, have DAQ shift leader turn off HV, obtain key, and take image with cameras
- Use the information from the picture to decide how to proceed, taking more pictures as necessary
- It is highly likely that the hinge can just be lowered and normal rod extraction can take place with appropriate rotation of rod assembly

12.3 Tether Breakage

If the tether tube breaks at some point, PC will enter the tube and will become visible in any portion of the tether below the level of the PC in the IV header tank³⁶. Should this happen, execute the following procedure:

- Alert the Calibration Director of the problem
- Pictures will need to be taken with the lights on, have DAQ shift leader turn off HV, obtain key, and take image with cameras

³⁶ For this reason, the tether tubes rise above the level of the header tanks in CR4 before being connected anywhere

- Since the HV is off, you may remove the viewport covers on the cross
- Begin extracting the rods and tether at the same rate
- It may be necessary to pull very lightly on the wires / fiber in order to keep the tether tube sections approximately together
- Continue to take pictures and analyze the situation and make any adjustments necessary
- You will not be able to pull the other end of the broken section through the tube seal, you will have to pull the wires and/or fiber optic cable directly, and the tether will begin to nest inside of the cross
- When the source is above the gate valve, ensure that nothing is in the way of the gate valve before closing it.
- If you are unable to pull the tether into the cross (i.e. if using the scintillator collection tether, or if the length of tether below the break is too long to fit in the cross), stop and consult a vessel expert about the possibility of closing v1521 (OB to OB header tank) and removing the tube seal from the top flange and retrieving the tether tube.

Please note that the shearing of a Teflon tube is an extremely unlikely situation; recall that the Operators are constantly inspecting the tether tube for any damage as they insert it. In the event that the tether tube were to break and slip through the tube seal, there is a plug for the tube seal that can be inserted into the tube seal to prevent any loss of pressure in the cross while the Operators discuss with a vessel expert the possibility of closing v1521 (see the last item in the above list).

12.4 Source Fails to Return to Z Axis

Since the insertion rods are neutrally buoyant, only the small additional weight where the source is mounted is available to pull the hinge back down when one tries to return the source to the vertical axis. Should this not prove enough, one can actually use the vessel itself to provide a downward force by allowing the source to touch the vessel. Since the lever arm of this contact greatly exceeds that available from the central 4in pipe, and because the source is spring mounted, this should not pose undue danger to the vessel (during the CTF operations, the source was also brought into contact with the vessel in this fashion). Should this be necessary, consult a vessel expert prior to proceeding with the following steps.

- Alert the Calibration Director of the problem
- Pictures will need to be taken with the lights on, have DAQ shift leader turn off HV, obtain key, and take image with cameras
- Proceed with normal rod extraction as explained in section 11.10 until you are close to the vessel
- Take a reference image and discuss with the vessel expert any modifications to the status of the filling stations that might need to be made
- Once any modifications to the filling station status have been made, raise the rod assembly until the source is just touching the vessel

- Take another reference image
- Release compression on the tube seal cap, insert 5 cm of the tether, and reapply compression to the tube seal
- Slowly raise the insertion rod a few cm and then take another reference image to ensure that the hinge is lowering
- Continue as necessary until the angle is 15 degrees or less and then proceed with the rest of the extraction as outlined in section 11.10

12.5 Operators Lose Track of Rod Orientation or Rotation

In the event that the Operators fail to keep a sufficient record of the steps that brought them to a particular point, they need only take a picture with the lights on to resolve the situation.

- Alert the Calibration Director of the problem
- Pictures will need to be taken with the lights on, have DAQ shift leader turn off HV, obtain key, and take image with cameras
- Examine this image and determine the current orientation
- Go back through each prior reference image to piece together the steps that brought them to their current location
- Proceed as normal once resolved

12.6 Excessive Force Required

If any of the steps in the procedure require an excessive amount of force to complete, follow these procedures to diagnose problem:

- Check expected position of hinge. If it should be entering the IV fill tube, this is normal. If the hinge did not return to exactly 0 degrees, it is likely that the IV fill tube is forcing the hinge rod back down into place (this is a very small lever arm). If this is the case, just be patient, the hinge will eventually straighten, and you can proceed with the rest of the extraction
- Check the expected position of the source coupler. If it is expected to be entering the IV fill tube, the tether will need to be pulled taut for the source coupler to enter the IV fill tube. Since the tether exits the source coupler pointing away from the rods, it is likely that the tether tube is catching on the edge of the IV fill tube. Loosen compression on the tube seal cap a bit more than usual so that you can gain tactile feedback, and pull it taut while the other operator pulls upwards on the rod assembly. When it enters the fill tube, proceed with normal extraction
- If a rod is being inserted or retracted and the collar is making a transition into, or out of, an O-ring seal, the coupler may be biting into the O-ring, if this is suspected, release compression on the rod seal cap slightly (while monitoring FM2 for adequate flow), this will lessen the squeeze on the O-ring and make it easier for the coupler to pass.
- If you are trying to flex the hinge to move the source off axis by pulling on the tether, it will require more force than normal, again due to a very short lever arm.

Be very patient and continue to pull, but be cautious, when the source does begin to move, it will likely accelerate.

12.7 Large Discrepancy Between Expected and Reconstructed Positions

If a large discrepancy is noticed, the Operators should begin to look back through the reference images taken by the cameras and determine where the discrepancy first appeared. Check to make sure that there is no slack in the tether tube that may have caused the hinge to lower. If the problem still is not resolved, proceed with taking a picture with the quartz bulbs illuminated:

- Alert the Calibration Director of the problem
- Pictures will need to be taken with the lights on, have DAQ shift leader turn off HV, obtain key, and take image with cameras
- This image, when compared with all of the previous images, should determine the problem.
- If the source of the error can not be determined, proceed with rod extraction as per section 11.10

12.8 Evidence of Damage to Source

In the event that the source appears damaged after being withdrawn from the cross, document the damage completely in the log. If the damage is to the radioactive source, and the contents appear to have leaked into the IV, notify the Calibration Director, DAQ Shift Leader, and Operations Manager that you believe the IV has been contaminated with the contents of the source, and give a full description of the contents of the source (isotope, production date, last known activity and date, any other chemicals used to disperse the isotope in PC, etc.). Set the damaged source to the side, until all final operations can be completed. When the system is safely shut down, begin looking through reference images and trying to determine when the damage to the source occurred. Unfortunately, nothing can be done at this stage to remedy the state of the source; the focus should be on determining why it was damaged. Report your findings to the Calibration Director and Operations Manager.

12.9 Source Location System Failure

This section will describe what to do in the event that the source LED fails or the camera system fails.

12.9.1 LED Failure

- Check that the power and return lines are connected to the camera control box, and that the camera control box has power
- Check the setting of the potentiometer, located on the front panel of the camera control box that controls the brightness of the source LED. Try increasing it

- Check inventory again and ensure that the source is not in the IV fill tube. If expected to be just entering the IV, insert a few additional cm and try to image again.
- If the problem persists, you must take images with the quartz bulbs on and begin extraction.
- Alert the Calibration Director of the problem
- Pictures will need to be taken with the lights on, have DAQ shift leader turn off HV, obtain key, and take image with cameras
- Using this image as a reference, begin the extraction of the source, following the procedures outlined in sections 11.9, 11.10
- The problem can be further diagnosed once the source is out of the cross and can be inspected. Replace LED if necessary.

12.9.2 Camera System Failure

- Check the power to the control box, and ensure that output is enabled (check status of light on front of box)
- Notify the Calibration Director of the problem
- The Operators should analyze the log book and determine where the source is currently located, and should check the last reference image taken and ensure that its current theoretical location could be reached by the steps performed since its last known position.
- Proceed with the extraction procedures outlined in sections 11.9, 11.10. You may use less compression on the rod and tube seals to gain tactile feedback, but monitor FM2, G5, and G6 very closely while doing this.
- If careful logs have been maintained, there is no reason why the source cannot be safely extracted without the location system. The Operators should work slowly and carefully, always discussing each step, and mutually agreeing upon it, before proceeding with the execution.