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GAS TRANSPORT CALIBRATION SYSTEM FOR SNO: A PRELIMINARY DESIGN DOCUMENT

B. Sur, E.D. Earle,

ABSTRACT

The principles of operation of a proposed system for producing and delivering short-lived activities for calibration of the SNO detector are outlined. Experimental tests of the proposed sources are briefly described. A comprehensive listing of components required for the realization of this scheme in the SNO underground laboratory is undertaken, accompanied by a description of their functional requirements.

1. PRINCIPLES OF OPERATION

A system to produce and deliver short-lived radioactivities for calibrating the SNO detector has been developed. Radioactivities are to be produced utilizing a small 14 MeV neutron D-T generator, which is located about 50 m away from the detector. The activities are rapidly transported to a decay chamber inside the detector by a laminar gas stream flowing through a capillary tube. The following calibration sources have been tested.

(a) ^{16}N (t 1/2 = 7.13 s, 6.13 MeV γ-ray source) made by $^{16}O(n,p)$ and using naturally isotopic O_2 gas as both target and gas transport stream [Ref. 1].

(b) ^{8}Li (t 1/2 = 0.84 s, β's with a 13 MeV endpoint) made as recoils from $^{11}B(n,\alpha)$ and transported by aerosol particles in a He gas stream [Ref. 2].

(c) ^{17}N (t 1/2 = 4.4 s, β-delayed neutron source) made by $^{17}O(n,p)$ using $^{17}O_2$ gas in a recirculating loop [Ref. 3].

Schematic flow diagrams for implementing each of these sources in the SNO laboratory are shown in Figures 1, 2 and 3. Besides the commercially obtained DT generator, each of the above sources will require a gas source, a target chamber surrounding the neutron source for irradiation, a flexible capillary tube for transporting the activity from the target chamber to the universal interface on the acrylic vessel (AV) neck, a decay chamber where most of the activity will decay, and an exhaust for the transport gas and the negligible remaining activity it may carry. A device which will enable the decay chamber to be handled by the manipulator, as well as allow it to be connected by an umbilical cord carrying signal cables and gas transport capillary tubes is being developed separately at Queen's University. The ^{8}Li source will also require an aerosol generator consisting of a small 600°C oven with a Pyrex tube containing NaCl (common salt). Helium gas flowing through this tube will pick up salt aerosol particles. The ^{17}O source will use expensive separated $^{17}O_2$ gas which will necessitate a gas recirculation and recovery system.

2. EXPERIMENTS AND CALCULATIONS

The principles of operation of all three sources have been experimentally verified at the DT neutron generator facility of the Health Physics Department of Chalk River Laboratories. An additional test for ^{8}Li was also carried out at the TASCC facility at CRL. These experiments are described in References 1, 2 and 3. For ^{16}N, the measured yield in the decay chamber could be fully accounted for by a model using the known cross-section and the transit times deduced from the measured gas flow rates. For ^{8}Li, the calculation of the recoil yield from the target is uncertain, but the observed count rate was found to be consistent with calculations. In the case of ^{17}N, there was a discrepancy in the literature about the (n,p) cross-section, and we were able to resolve it by measuring this cross-section relative to that of $^{16}O(n,p)$. In all cases, after accounting for the radioactive decay of the nuclides due to the transit times, the gas transport efficiency was found to be close to 100%.

For the ^{16}N and ^{17}N sources, the gas flow velocity in the capillary will lie in the transition regime between laminar and turbulent flow. An ancillary experiment was performed to determine the parameters for a model of gas flow in long, coiled teflon capillary tubing [Ref. 4]. Experiments are now being carried out to develop active decay chambers for making tagged sources. A 4π plastic scintillator chamber to tag on the β's from ^{16}N and ^{17}N is being developed at LBL. A He wire chamber for tagging on the 2 α's following ^{8}Li decay to $^{8}Be^{*}$ is being developed at CRL.

Based on the experimentally determined yields and flow model, the operating parameters for the three proposed sources have been optimized. These calculations and their results are briefly described below. Calculations are also being performed to verify the configuration of the neutron pit for shielding. These will be described elsewhere.

2.1 ^{16}N

It is assumed that the target chamber is an annular cylinder. This is because the D-T generator neutron source (i.e., Tritium target) is 7.375" from one end of its $1\frac{1}{16}$" diameter cylindrical housing. The neutron flux at the end of the housing would be much lower than the flux available at the surface of the housing, radially away from the source. The inner radius of the gas volume is assumed to be 2.5 cm. The outer radius and length are parameters to be optimized. The total capillary tube length from target to decay chamber is assumed 70 m. This accounts for 45 m from neutron pit to the source box on the AV, ~ 20 m from the lowest point inside the AV to the source box, and the remaining 5 m for the least amount left on the spools of the block and tackle arrangement in the source box. This 70 m capillary tube run is assumed to have the same diameter throughout. The gas in the target and decay chambers are assumed to be fully mixed. A computer code maximizes the yield i.e., the decay rate per neutron in the decay chamber. The cross-section for the $^{16}O(n,p)$ ^{16}N reaction at 14 MeV neutron energy is taken to be 35 mb [Ref. 5].

It is found that four accessible regions of the parameter space, the optimized yield increases monotonically with the target chamber pressure (i.e., target density) and the decay chamber volume (i.e., residence time). Thus these two parameters need to be fixed *a-priori*. If a "safe" target chamber pressure of 5 atm. absolute or 60 psi Gauge, and a decay chamber volume of 524 cc (from an idealized 5 cm radius spherical chamber) are chosen, then the optimized parameters and yield are found to be:

Target Chamber Length	=	10.19 cm (4")
Target Chamber Outer Radius	=	6.29 cm (2.5")
Capillary Inner Diameter	=	3.62 mm (0.1425")
Decay Chamber Pressure	=	3.31 atm. (34.5 psiG)
Gas Flow Rate	=	422 std. cc s^{-1} (26.5 slm)
Optimized Yield (decay ch.)	=	1.8×10^{-6} ^{16}N decay per neutron

The capillary diameter in the above optimization is uncomfortably large (from the consideration of flexibility in the decay chamber umbilical), and the gas flow rate is high enough that a standard gas cylinder will on last ~ 2 hours of continual operation. An alternate optimization is found by limiting the capillary diameter to 2.4 mm. In this case the optimal parameters are:

Target Chamber Length	=	8.0 cm (3.15")
Target Chamber Outer Radius	=	5.19 cm (2.04")
Decay Chamber Pressure	=	2.61 atm. (24.1 psiG)
Gas Flow Rate	=	165 std. cc s^{-1} (9.9 slm)
Optimized Yield (decay ch)	=	1.61×10^{-6} ^{16}N decay per neutron i.e., 161 ^{16}N decays s^{-1} or ~ 100 6.1 MeV γ's s^{-1} for a DT generator at 108 neutron s^{-1}

The loss of yield of this configuration is only 11% compared with the previous. The rate can be increased by increasing the target chamber pressure, but at the expense of increased gas flow. The rate can also be increased with a larger decay chamber volume, at the expense of optical interference from the bigger chamber. In fact, both the calculation, and experimental experience show that the variation in optimized yield is small for a wide range of these parameters, especially when the system has mechanisms such as pressure or flow control, for compensating for some non-optimal conditions. In any case, the computer code will assist in fine tuning the mechanical design and operating parameters.

2.2 ^{8}Li

Here, the dominant consideration is the short (0.84 s) half-life of ^{8}Li. Thus, the optimization is dominated by the largest time constant in the process: the transit time in the 70 m long capillary tubing. It has been experimentally verified [2] that (a) an aerosol is essential for transporting the ^{8}Li activity and (b) that gas flow in the turbulent regime, i.e., Reynold's No. > 1000, causes the transport to become very inefficient. Since the fastest transit time for a given length of capillary tubing occurs at the highest flow rate, the optimization code assumes a flow at the limiting value of Re = 1000 for the capillary. At present, the input for the code is the decay chamber pressure. The code then calculates the target chamber pressure, and the capillary transit time and flow rate for maximum flow. The ^{11}B solid target foil is assumed to be the inner surface of the 2.5 cm I.D., annular cylindrical target chamber. The outer radius of the target chamber is determined by the maximum range of the energetic ^{8}Li recoil reaction products in He gas at the target chamber pressure. Because of the short ^{8}Li half-life, a fully mixed target chamber gas is not a good approximation. The flow is approximated by a uniform gas velocity across the cross-sectional area of the chamber. A further approximation is that the total recoil yield from any position along the target foil length takes as much time to reach the outlet as the gas molecules at that point (i.e., a time given by dividing the distance to the outlet end of the chamber by the gas flow velocity). In this approximation, the position of the outlet end of the chamber is the dominant parameter, and the total yield in principle will increase as the length of the chamber is increased without limit. In practice a total target chamber length of 10 cm is assumed. Some sample calculations are shown below:

Capillary Diameter (cm.)	0.25	0.3	0.35	0.5	0.25
Decay Chamber Pressure (atm. abs.)	1.25	1.0	0.75	0.5	0.5
Target Chamber Pressure (atm. abs.)	2.6	2.1	1.653	0.997	2.5
Gas Flow Rate (std. cc s^{-1})	221	260	309	442	221
Outer Radius of Target Chamber (cm.)	4.037	4.5	5.05	6.73	4.19
Position of Target Chamber in Front of n-source (cm.)	1.5	1.6	1.7	1.8	1.4
% Yield in Decay Chamber	2.56	3.3	4.33	6.1	4.1

The total rate of ^{8}Li atoms produced is assumed to be at the measured rate of 3×10^{-7} per neutron intercepted by the solid angle covered by the target foil. The decay chamber yield percentage has this solid angle built into it. That is the rate at which ^8Li atoms are delivered is this percentage times 3×10^{-7} times the neutron output rate of the DT generator. So for system parameters as shown in the fourth column, the ^8Li delivery rate would be 1.23 per second for the DT generator running at 10^8 neutrons per second. The ^8Li decay rate in the decay chamber is further reduced to the fraction of atoms which decay during the gas residence time in the chamber. This residence time is given by the product of the chamber volume and pressure, divided by the gas flow rate. For intercepting the decay of ~ 90% of the delivered atoms, this residence time should be of order 3 half-lives, where the half-life is 0.84 s.

There are a few more tricks to be tried, such as making the 70 m capillary run in sections with different diameters.

2.3 ^{17}O

As mentioned previously, the principle of operation of this source, and the cross-section for the production reaction, $^{17}O(n,p)\,^{17}N$ have been verified at CRL. The only difference in the optimization procedure for this source is compared to the ^{16}N source is the half-life (4.4 s) and the cross-section (28 mb). Once again if the decay chamber is fixed at 524 cc volume and the maximum target chamber pressure at 5 atm. absolute, the optimum parameters are calculated to be:

Target Chamber Length	=	10.57 cm
Target Chamber Outer Radius	=	6.49 cm
Capillary Inner Diameter	=	0.454 cm
Decay Chamber Pressure	=	2.99 bar absolute
Gas Flow Rate	=	829 std. cc per second
Optimized Yield (decay ch.)	=	1.04×10^{-6} ^{17}N decay per neutron

However, if the same target chamber and transport capillary as the first case listed in the ^{16}N design above are used, then the yield is reduced to 9.07×10^{-7} ^{17}N decays per neutron. This is a loss of only 12%, and can easily be tolerated for the sake of the obvious convenience of being able to use the same target chamber and transport capillary for both sources. Further optimizations are under consideration.

3. DESIGN CRITERIA OF COMPONENTS

3.1 DT Generator

The DT generator which will produce the 14 MeV neutrons required for each of the three proposed sources will be commercially purchased. Sealed tube neutron generators are commercially made and used for assaying exploratory oil well boreholes. In recent years, they are also being increasingly used for baggage and cargo security assays at airports and other points of entry; and for on-line assays of the sulphur content of coal at coal burning power plants. The requirements for the generator to be used in the SNO calibration system are the following:

1) **Flux.** Tunable neutron output in the range of 10^7 to 10^8 per second into 4π steradians.

2) **Diameter.** As small a diameter as possible so that the neutron flux density in the target chamber can be maximized.

3) **Safety and Ease.** Safe, reliable and turn-key operation.

Three marketers of sealed tube generators in North America have been identified and quotes have been requested. Based on their replies, the generator from MF Physics Corp., model A-320L has been tentatively identified as being suitable for our needs. This choice is based on cost, small diameter, sealed tube life warranty and replacement cost, and ease and safety of installation and operation.

Since the design of the neutron generator housing, shielding, and attachments revolve around its physical dimensions, these are briefly described here (and illustrated in Figure 4, option 1). In the A-320L instrument, the sealed neutron generator tube is located at one end of a 1.688" diameter, 75.75" long Stainless Steel gas filled sealed tube. The rest of the tube contains a high voltage transformer, and control electronics for operation of the tube. The tritium target, hence the source of neutrons is located 7.375" from the end of the SS housing. A HV and control cable emerges from the end of the SS tube opposite to the sealed D-T tube. 7' of cable connect the generator housing tube to an electronics control box. This control box is sensitive to humidity. The minimum radius of bending the HV/control cable is recommended as 3. The control box is connected to a 19" wide, 5.25" high, rack-mounted control console by another 50' of cable. Operator access to the control console is required when the neutron generator is running, while access to the electronics control box is not required, and access to the neutron tube should be restricted.

3.2 The Neutron Pit

The DT generator, flux monitor, target chamber, and neutron shielding are housed in the "neutron pit" while associated gas flow control and electronic equipment are located in the area immediately adjacent to it. The neutron pit area lies immediately next to the wall of the utility corridor on the "Piccadilly Circus" side, and to the right of the utility room double doors when facing them from the Piccadilly Circus side. Originally, during excavation, a 6' 6" deep cavity was blasted in the floor of the drift here. This cavity was later mostly filled in with lean concrete, around two sections of concrete sewer pipe, 4' and 18" in diameter. The bottom of this cavity is the lowest excavated point on the level of the main drift, and thus a considerable portion of waste water in the laboratory ends up flowing into it. A sump pump is installed in the 18" diameter vertical pipe to pump out this waste water, and maintain the water level to ~ 20" above the bottom. The bottom of the two sewer pipe sections are bare rock at the time of this writing, but this situation may change in the near future. A schematic drawing showing components and shielding material and dimensions is given in Figure 4 (a) and (b). The requirements for the neutron pit are:

3.2.1 Contents of the Pit

1) **D-T Generator.** It will house the DT generator during operation. The preferred orientation is with the neutron source end at the bottom of the pit to maximize the neutron shielding between the DT tube and the laboratory drift. There should be a convenient mechanism provided to withdraw the DT generator probe from the pit for inspection and servicing. Either an A-frame hoist or an electrical or mechanical hoist attached to existing (Utility room balcony) or modified steel-work above the pit can be considered.

2) **Target Chambers.** There should be a mechanism to accommodate different target chambers surrounding the DT generator probe at the DT tube end. The individual target chambers are described in more detail in section 3.3. They are envisaged to be sealed, annular stainless steel pressure vessels, with outer diameter and length of order 10 cm. The recommended method is to withdraw the D-T probe, and replace the chamber. A 10″ diameter hole will be left in the shielding to accommodate different targets and their associated components.

3) **Positioning Mechanism.** There should be a mechanism to allow the adjustment of the relative position of the target chamber to within 1 mm along the length of the DT probe. The exact position of the gas outlet face of the cylindrical, annular target chamber will affect the yield, particularly in the case of the short-lived ^{8}Li activity. It is preferred though not essential that this adjustment be possible while the neutron generator is on.

4) **Gas Lines.** there should be provision for gas flow lines into and out of the target chamber. The gas in line will be a ¼″ polyflo tube. The gas out line will be a flexible capillary tube. Different capillary tubes will be used for each of the different sources. The gas lines may also need to be replaced at times. There should also be provisions for signal cables from the target chamber (such as from pressure or flow transducers), though at present, none are anticipated to be used.

5) **Other Activities.** Other devices will have a need for irradiations using the DT generator. For instance, the activated NaI source Ref. 6, if realized will need on-site neutron activation. Calibration of the fast neutron flux will probably require an Iron or Aluminum foil activation. Some flexibility in running with configurations other than the gas source target chambers must be built into the design of the neutron pit.

6) **Fast Neutron Flux Monitor.** There will be a fast neutron flux monitor located close to the DT tube. At present, this is envisaged to be a small plastic scintillator detector coupled to a small photo-multiplier tube (PMT). It has not been determined whether such a device will be obtained commercially or made in-house. In any case it is

anticipated to be physically smaller than a cylinder of 5 cm diameter and 20 cm length. There should be provisions for physically accommodating, mounting, and routing of HV and signal co-axial cables from the PMT.

3.2.2 Radiation Safety and Mechanical Integrity of the Pit:

1) **Concrete Shielding Blocks and Cap.** The DT tube when operational, must be adequately shielded, so that radiation fields outside the neutron pit are at acceptable levels. The shielding material must fill the volume of the neutron pit, and must satisfy mine materials requirements, particularly with respect to flammability and toxicity. At present, pre-cast, "donut" shaped concrete shielding blocks filling up the volume of the cavity appear to be adequate [Ref. 6, 7]. Care should be exercised in ensuring that there are no unshielded paths, such as along the length of the DT probe itself, for fast neutrons to egress the pit. At present, a removable concrete shielding cap is considered adequate for this purpose. Any other neutron streaming paths must however be minimized.

2) **Neutron and β-γ Radiation Monitors.** Radiation (and general) safety measures for personnel working in the neutron pit area must be ensured. There must be an alarmed thermal neutron radiation monitor mounted on the cap of the neutron pit. There must exist a β-γ radiation survey meter to be used in particular when the DT probe, or any other irradiated components are withdrawn from the pit. It is essential that there be an interlock system which will prevent the generator from being run outside the neutron shield, and will trip it if the external radiation field exceeds a pre-set limit. A procedure to ensure radiation safety will be written, and provisions will be made to adhere to it. Finally consideration must be given to fences or other means of access restriction for the vicinity of the pit including the balcony located above it when the D-T generator is running.

3) **Water Proofing.** There is direct evidence that water has entered the pit. Two possible sources have been identified: (a) "ground water" from mine and lab operations streaming through the rock blocks in the ground, and (b) "wash water" from the frequent lab clean-up operations flowing in through the present man-hole cover. Water leakage into the vicinity of the D-T generator must be prevented for both radiation safety and mechanical integrity reasons. Options that can be considered are: (a) a polyurethane, polyethylene, fibre-glass or carbon steel liner for the entire pit, (b) a liner for the inner 10″ diameter cavity of the shielding and (c) a lip or shielding raised above ground level to prevent wash water entry into the pit.

4) **Cleanliness.** The SNO laboratory is a < class 10000 clean room. All components and floors, walls, etc., inside the laboratory are spotlessly clean. It should be ensured that all surfaces, such as those of concrete shielding blocks etc., are painted with smooth epoxy paint to prevent flaking and assist in wiping and cleaning.

3.2.3 Components Surrounding the Pit

The area outside the neutron pit itself must be organized so that all subsystems can be operated in a safe and efficient fashion. Fences etc., must be considered to ensure safety of laboratory personnel. The design must define a layout for these components. A list of the equipment which must be located in the immediate vicinity of the neutron pit is given below. It is probably not comprehensive.

1) **DT Electronics Box.** DT generator electronics control box. Located on floor or low platform near the pit. Connected by 7′ cable to the top of the DT generator probe.

2) **DT Console.** Operator's console for DT generator. Mounted on standard 19″ wide electronics rack.

3) **NIM Bins.** At least 2 NIM Bins. These will accommodate NIM modules for miscellaneous electronics requirements, including control and readout of the plastic scintillator fast neutron flux monitor.

4) **Misc. Electronics.** Miscellaneous electronics boxes, including interlock system (if any), interface to main DAQ (if any), interface to the main Controls Monitors and Alarms (CMA) system, readouts for pressure and flow meters for the three source systems, High Voltage boxes for detectors etc. At the present time, at least two ventilated, 19″ × 6′ electronics racks should be anticipated for all of items 2, 3 and 4, with provision left for a third.

5) **Gas Cylinders.** Gas cylinders, regulators, particle filters and spares for the three sources. There will be oxygen and Helium gas required. There is the possibility of using boil-off oxygen from a small (~ 10 liter) LOX dewar for ultra-pure natural oxygen.

6) **$^{17}O_2$ Recirc. & Recovery System.** Separated $^{17}O_2$ gas source and recirculation, and recovery system for $^{17}O_2$. The recirculation system consists of a small to medium size (~ 1 cfm) metal-bellows sealed pump, and a system of about 10 valves, possibly mounted on a board for clarity. The recovery system is yet to be defined, and may consist either of a modest compressor, or a cryo-pump for a cryogenic recovery system. The LBL group is responsible for this system at present.

7) **Vacuum Pump.** A clean mechanical vacuum pump to evacuate gas systems and their components for cleanliness. It is possible that there may be needed an additional mechanical pump to lower the gas transport exhaust pressure for more efficient transport.

8) **Exhaust.** An exhaust with slight suction on it, connected to the mine or laboratory exhaust. This will be used for miscellaneous exhausts, including those of the mechanical vacuum pump(s).

9) **Set-up Area.** An area to load, evacuate, and test the glove boxes which initially contain the decay chamber, manipulator interface mechanism and umbilicals has not been specified. If there is space, it is certainly concise to have such an area in the vicinity of the neutron pit. A small work area to set up and store the other calibration devices would also be desirable.

10) **Oven.** A small oven with NaCl loaded Pyrex oven tube through which the He gas stream for the ^{8}Li source flows. This is the aerosol generator. Adequate ovens which can be run up to 1000 C can be found in the Cole-Parmer catalogue.

3.3 Target Chambers

There will initially be two target chambers manufactured: one common chamber for the ^{16}N and ^{17}N sources, and a different chamber for the ^{8}Li source. The required specifications are:

1) **Cylindrical Annular Shape.** The shape of the chambers is such as to fit as closely as possible around the neutron source region of the tubular DT generator probe. It is anticipated that this will result in a cylindrical, annular target chamber shape. The inner walls of the annulus should be as thin as possible to maximize the neutron flux.

2) **Leak Tight.** The chambers must be gas-tight. They will be He leak checked to the sensitivity limit of normally available leak detectors ($\sim 1 \times 10^{-9}$ torr-cc s^{-1}). The target chambers must be made from stainless steel, with viton or other durable elastomer or metal seals.

3) **Pressure Vessel.** The target chamber may be operated with gas pressure as high as 5 bar (75 psiA), and as low as 0 psiA (vacuum). The chamber must meet the relevant pressure vessel codes. It may be fitted with a pressure relief valve in the event of exceeding the design pressure. The venting of the relief valve, and any possible interlock with the DT generator operation must be consistent with safety requirements.

4) **Gas Fittings.** Gas inlet and outlet lines must be connected to the chambers. It is desirable to achieve laminar flow conditions along the length of the chambers, so generally, the inlet and outlet tubes will be located on opposite end-caps of the cylindrical, annular chambers, and distributed along the circumference. Inlet lines are expected to be ¼" (polyflo) tubing while outlet lines are small diameter capillary tubes, which are gathered up into a single flexible (Teflon) gas transport capillary tube in as short a distance as possible. The tube connections to the chamber, and tubing unions are expected to be locking type, detachable commercial units such as swagelock, polyflo or Cajon. Careful attention must be paid to the suitability of the connectors from a mechanical as well as radiation safety point of view. Especially in the ^{8}Li chamber, it is of the utmost importance to minimize turbulence, as this causes the

aerosol particles to plate out. Special care must be taken to achieve this at the chamber to tubing connections and at tubing unions.

5) **Dimensions.** Tentative inside dimensions for the $^{16,17}N$ target chamber are: inner diameter ≤ 5.0 cm; outer diameter = 5.19 cm; and length = 8.0 cm. For the ^{8}Li target chamber, inner diameter ≤ 5.0 cm; outer diameter = 4.2 cm; and length = 10 cm. Along the long dimension of the DT probe, the $^{16,17}N$ chamber is expected to perform optimally when approximately centered on the neutron source position, while the ^{8}Li chamber should be positioned with its outlet displaced by 1.4 cm (adjustable) from the assumed point neutron source position.

6) **^{11}B Target.** The $^{16,17}N$ target chambers are empty inside (filled with oxygen gas during operation), while the ^{8}Li target chamber has a solid ^{11}B target foil on its inner radius. In the experimental tests, an adequate target was fabricated (by P. Dmytrenko, the TASCC target maker) by using 97% enriched, ^{11}B powder with ~ 10% powdered polyethylene by weight as binder. The mixture was heated till the polyethylene melted, then cooled and rolled to an ~ 0.5 mm foil. This foil is fairly brittle, but it is hoped to employ basically the same technique to make a somewhat larger foil which will be rolled up tightly against the target chamber inner diameter.

7) **Modular Design.** It is desirable to have a modular design, so that they can be easily modified in the future.

3.4 TUBING AND CABLE RUNS

Other than the tubing and cable in the immediate vicinity of the neutron pit, required for operating the DT generator and the various source target chambers, there are two separate long cable and tubing runs. These are the ~ 45 m run between the neutron pit and the source box located on top of the AV, and the ~ 25 m run which forms the "umbilical" from the source box to the decay chamber. The requirements are listed below.

3.4.1 Neutron Pit to Source Box Run

1) **List of Flexible Tubes.** The following diameter tubing is required, each preferably in one contiguous length:
   - (a) 2.5 mm ID teflon tube for the ^{16}N and ^{17}N transport capillaries.
   - (b) 2.5 mm ID teflon capillary for the ^{8}Li transport.
   - (c) 0.25″ OD tube for the O_2 gas return (exhaust) for ^{17}N (^{16}N).
   - (d) 0.25″ OD tube for He gas return and exhaust for the ^{8}Li source.
   - (e) 0.375″ OD alternate exhaust line.
   - (f) Spares if required.

2) **List of Cables.** Signal cables are required for (i) System parameter measurements such as pressure and flow, and (ii) operation of the tagged sources. Since neither of these requirements has been entirely defined as yet, and in any case may change in the

future, it is proposed that a number of general purpose cables with corresponding labels on either end be layed between the neutron pit, source box area, and the control room. The specific cable types and manufacturers or sources need to be defined. Approximately 2 each of 50, 75 and 100 Ω coaxial cables with BNC connectors on each end will suffice. In addition, 2 suitable HV cables with SHV connectors for the tagged source biases and signals are anticipated. One each of HV, 50Ω and 100Ω coax, with appropriate connectors (SHV or BNC) may be required between the neutron pit and control room and source box.

3) **Paths for the Runs.** A suitable path for the tubing and cable runs needs to be identified. Tubing runs must be consistent with mine safety requirements. For example, it is much easier to justify tying a tube carrying oxygen gas to an existing water pipe (from the utility room to the AV) than to lay it in a cable tray with potentially inflammable plastic cable jackets.

4) **Kinks and Leaks.** The teflon capillaries kink easily. Thus the capillary runs must be amenable to visual inspection, and also to leak testing. It should be possible to replace the tubing in the run easily.

5) **Cleanliness.** Other cables (and in fact all materials) in the lab have been pre-cleaned, checked and bagged before underground transportation. A similar procedure must be defined and followed for the tubing and cables. This is mentioned here because the teflon tubing needs to be handled carefully to prevent kinking.

3.4.2 Source Box to Decay Chamber Run

This run will consist of a gas in and gas out capillaries and a small diameter coax cable to carry both bias voltage and signal for the tagged sources. All three components must run inside a 3/8" ID flexible silicone or Tygon tube. The fitting of these tubes and cables inside the umbilical must be verified. The umbilical will be wrapped around a "block and tackle" arrangement to take up the slack. It must be verified that the capillaries do not kink in the reeling in and out process. The capillaries will need to interface with the world outside the source box through ball or plug valves, mounted in a leak tight manner on the wall of the source box. Similarly, the HV/signal cable will interface via a leak tight BNC or SHV feed-through.

3.5 SOURCE BOXES

The source box is a large hermetically sealed container, made largely of Stainless Steel with acrylic viewports, which holds the decay chamber, its attachments, the umbilical for the decay chamber and the "block and tackle" arrangements for reeling in the slack in the umbilical when the decay chamber is employed. The bottom of the source box has a port to couple it to the gate valve which provides access to the manipulator box and thence the AV. The most important function of the source box, besides being a container and tether point for the decay chamber and umbilical, is to provide a hermetically sealed container in which to purge or pump the whole source system of Radon gas before insertion into the AV.

At present, it is anticipated that the source box and reel design of the Queen's group, for the laser diffuser ball, can be easily adapted to the needs of the gas transport sources. Hence this item will not be separately designed.

3.6 DECAY CHAMBERS

At least two decay chambers, one for ^{16,17}N and the other for ^{8}Li, will be build. Common features of both chambers are:

1) **Volume.** Each chamber will have adequate "free" volume for the radioactive species to have enough residence time to decay. At the present time, this is anticipated to be ~ 500 cc for both chambers.

2) **Pressure.** The external (compressive) pressure on the chambers may vary from ~ 18 psiA which is mine air pressure to a hydrostatic pressure of ~ 20 m water at the bottom of the AV. The internal pressure may vary from vacuum for purging to a maximum of 5 bar absolute for the ^{16,17}N chamber (equal to the target chamber pressure if flow is stopped).

3) **Flow.** The ^{16,17}N chamber should generally be designed to ensure that full mixing of the gas takes place. On the other hand, laminar flow should be encouraged in the ^{8}Li chamber so that minimum plate-out of the aerosol occurs.

4) **Size and Shape.** There are two considerations here. First, the decay chamber and all its accessories must be able to fit through the nominal 5 1/2" diameter opening of the gate valve on the universal interface. Note, however that there is a larger 2" gate valve opening that can also be used. Second, attention must be paid to making the profile of the decay chamber such as to minimize its shadowing of Cerenkov photons produced near it by the source activities.

5) **Total Weight.** The wet weight of the chamber must be of order 2 Kgs in order to induce sufficient tension in the manipulator strings. This will probably necessitate the hanging of weights from the decay chamber. The dry weight must be adequately supported by the hanging mechanism in the source box.

6) **Attachments.** In addition to the possible external weight, the decay chamber will have an attachment point for a wire which will support its weight in the source box, and will be used to reel it back on withdrawal from the AV. The decay chamber will be suspended from a bar with two pulleys on it. The manipulator ropes will be threaded over these pulleys in the manipulator box which sits underneath the source box on the universal interface. There will be a water and gas tight connection to the

umbilical tube. Inside this, there will also be water and gas tight connections to inlet and outlet gas capillaries, and an HV/signal coaxial cable.

7) **Radiopurity and Cleanliness.** This is of utmost importance, since the decay chamber will be directly inside the most sensitive D_2O region of the detector. The cleanliness goal of the heavy water itself corresponds to 1 disintegration per day per tonne, which translates to 3×10^{-15} g/g equivalent Thorium and 1×10^{-14} g/g equivalent Uranium, or roughly 60 ^{222}Rn atoms per tonne. Since the "influence" of the source extends to roughly a tonne of water surrounding it (a radius of ~ 60 cm), ideally, the entire decay chamber and attachments should have a Th and U content of less than 3 and 10 nanograms respectively, and a radon emanation rate of less than 1 per day. This amounts to several kilos of the best acrylic material that has been tested ($\leq 0.4 \times 10^{-12}$ g/g) but only 3 to 10 g of typical Stainless Steel ($\approx 10^{-10}$ g/g). Failing these high ideals, the decay chamber should be made as clean as possible! It must also be made so that it is possible to rinse, wipe, blow or otherwise thoroughly clean all its surfaces.

3.6.1 ^{16,17}N Decay Chamber

It is possible to tag all the decays of ^{16}N and ^{17}N by detecting the β's which precede the 6 MeV γ's or neutrons respectively. A decay chamber whose walls are made of plastic scintillator to detect these β's is being developed at LBL. The signal from the scintillator will be detected by a small (1") PMT. The PMT will be operated by a single coax cable for both HV and signal. The present understanding is that this component will be built by the LBL group.

If, as originally planned [Ref. 8], the ^{16}N decay chamber is made so that it is semi-permanently left "parked" inside the AV, then it will probably have to be made separately, out of ultra-pure materials (acrylic), without a tagging mechanism, and with opaque, non-reflective outer walls.

3.6.2 ^{8}Li Decay Chamber

^{8}Li β-decays to the first excited state of ^{8}Be, which immediately breaks up into 2 α-particles, each with ~ 2 MeV kinetic energy. Detection of these α's in the decay chamber can thus be used to tag the ^{8}Li β-decay. The ^{8}Li source strength is relatively weak, so tagging is very useful for discriminating against other "background" activities. On such activity that we know is produced copiously is 14 s ^{11}Be via ^{11}B(n,p). The ^{11}Be recoils can be stopped by a ~ 1 mg cm^{-2} "dead layer" of, say, polyethylene on the ^{11}B target surface, but at the cost of losing a factor of 2 to 3 in the ^{8}Li source strength. Thus tagging provides a stronger, cleaner, and potentially more localized ^{8}Li source.

At CRL, we have tested a flow through cylindrical wire chamber of about 2.5" diameter at 3" length. It was equipped with a central 0.005" wire. A removable, 80 Bq, bare ^{241}Am α-source could be installed on the inside surface of this wire chamber. The chamber was operated with He gas flowing through it, with and without an aerosol, and with a variable mixture of CH_4 "quenching" gas. The chamber was found to perform quite adequately with pure He and a few hundred volts (typically ~ 400 V) on the wire. The α-peak was well separated from the noise, and its count rate matched the 2% strength calibration of the ^{241}Am source. There was negligible background under the α-peak. The wire chamber performance was quite adequate even in the presence of the aerosol for long time periods. Finally, it was observed that a few percent mixture of CH_4 gas reduced the gain, but allowed higher voltage without breakdown, an better resolution. The conclusion was that a quench gas is not required for the SNO decay chamber.

Meanwhile, Tom Radcliffe at Queen's has been simulating various possible configurations for this tagged source. The possibilities for the decay chamber are listed below:

1) **Transparent Wire Chamber.** We want to calibrate with the Cerenkov light from electrons in a medium with index of refraction equal to that of heavy water. Apparently such a solid medium is available, in the form of a transparent flourocarbon made by DuPont. The decay chamber could be made in the form of a (say, cylindrical) flow through wire chamber, with ~ 7 cm wall thickness to stop up to 13 MeV β's, out of this material. The cathode (the walls of the wire chamber) can be made by depositing a thin layer of Al or Au on the inner cylindrical surface, or by a wire mesh or grid. Advantages are a robust, very clean and transparent (no optical shadowing) chamber with effectively no wall thickness as far as the β's are concerned. The disadvantages are that (a) the Cerenkov radiator is not actually the detector material, (b) dE/dx and multiple scattering are slightly different in the transparent plastic than in water, (c) the plastic has a different UV absorption than water, and (d) the Cerenkov light has to traverse at least one, and as many as three interfaces before exiting the source.

2) **Thin-Walled SS Spherical Chamber.** The inspiration for such a design is the spherical wire chambers which the detector group at CRL builds for BTI. These have a 0.5μ wire, 0.020″ thick stainless steel wall, 2″ to 4″ diameter, and are filled with typically 10 bar hydrogen gas for use as fast neutron detectors. The detector body is manufactured in the form of two spun hemispheres, one of which has a filler tube built in. Two hemispheres with filler tubes can be used for a flow through chamber. However, high energy b's lose ~ 0.78 MeV energy in traversing 0.020″ thickness of SS. They also radiate Cerenkov light in the immediate vicinity of the source, thus aggravating the optical shadowing effect of the opaque source. Tom's simulations indicate that while a 0.020″ wall produces a noticeable distortion, the effect of a 0.10″ thick SS wall may be negligible. Obviously, the issue is whether such a thin walled chamber can be made, and whether or not it will meet the pressure requirements of the decay chamber.

3) **Thin-Walled SS Cylindrical Chamber.** Advantages: (a) thin walled (0.010″) SS tubes are commercially available; (b) optical shadowing is less for a thinner, longer cylindrical source than for a spherical source of the same volume, and (c) position

sensitivity along the wire will provide a more localized source position, potentially to within a few mm thick disc. The main disadvantage is that for a reasonable volume (~ few 100 cc's) and cross-sectional area (~ 1.5 cm^2), the chamber will be very long. Of course, the *ab initio* issue still is whether a 0.010" wall thickness meets the pressure requirements for the decay chamber.

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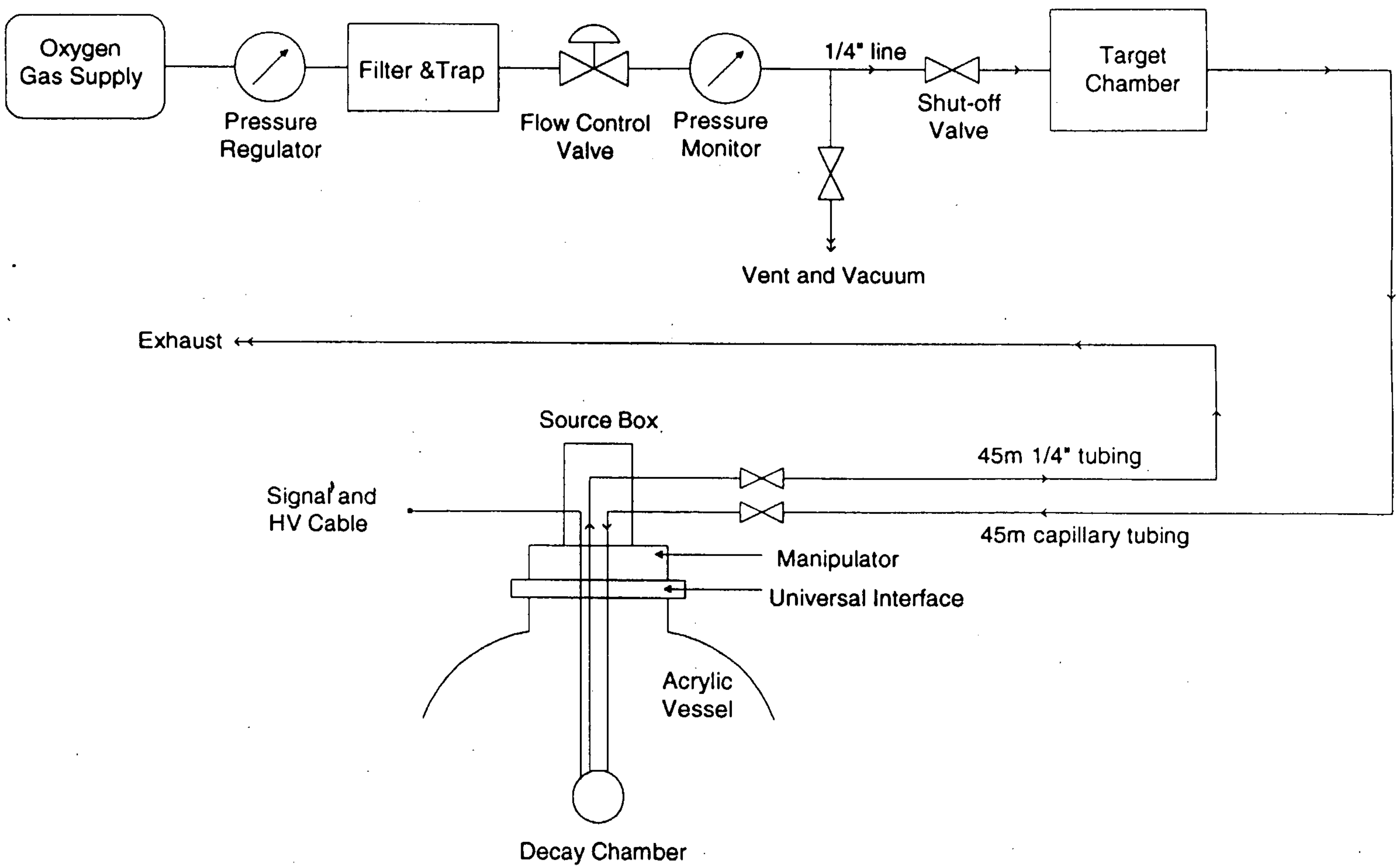
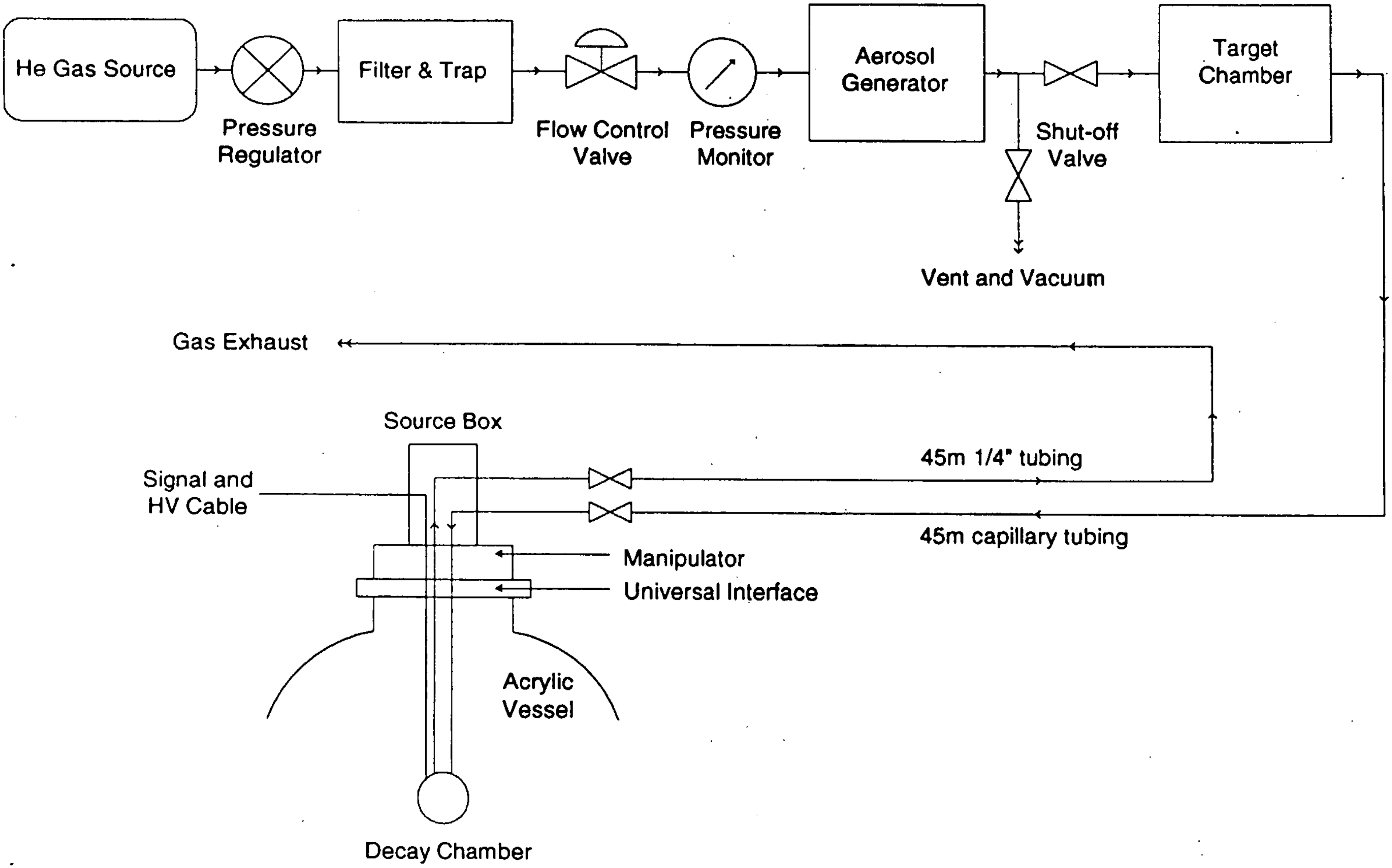
FIGURES

ATTACHMENTS

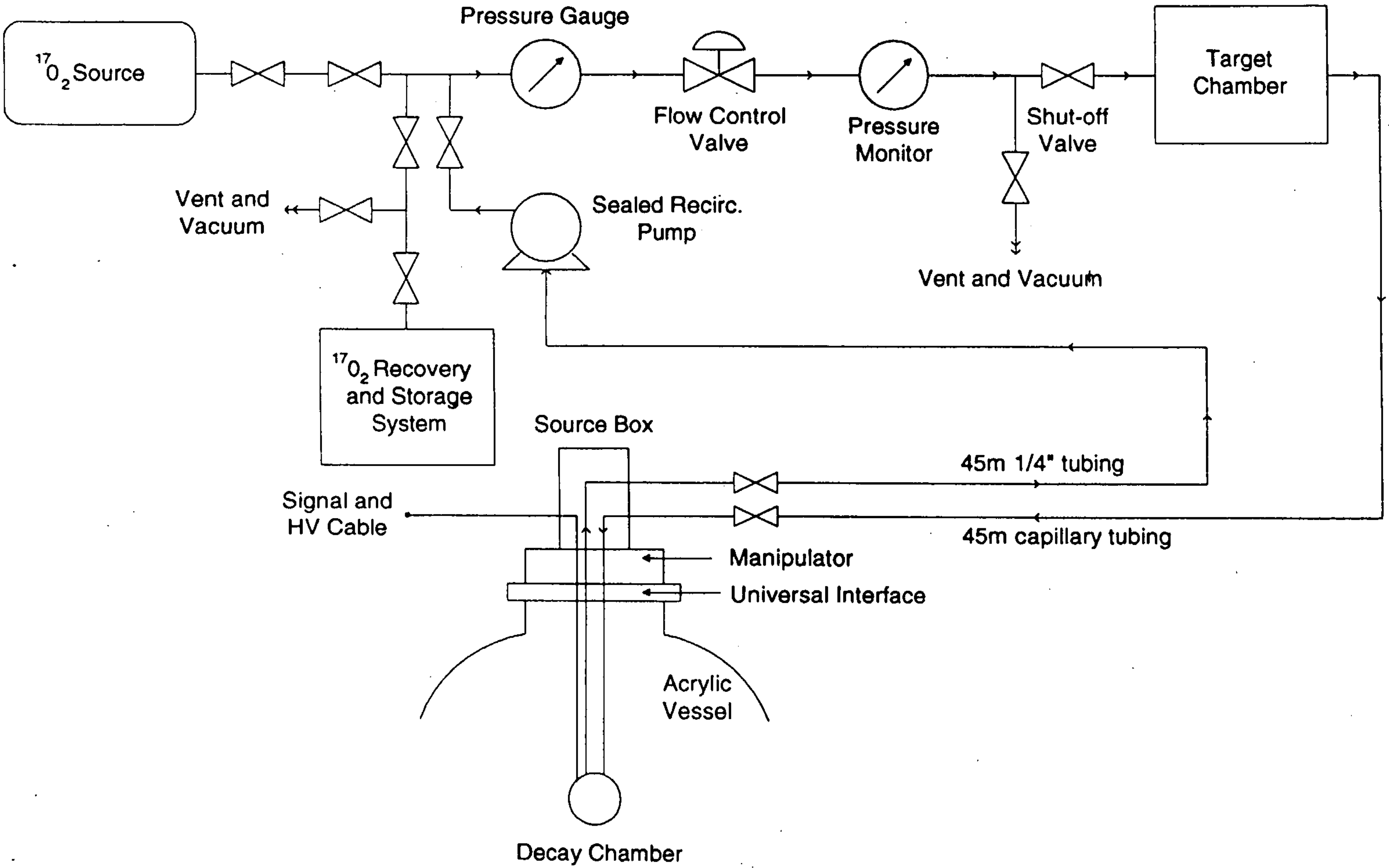
^{16}N Source: Schematic Flow Diagram



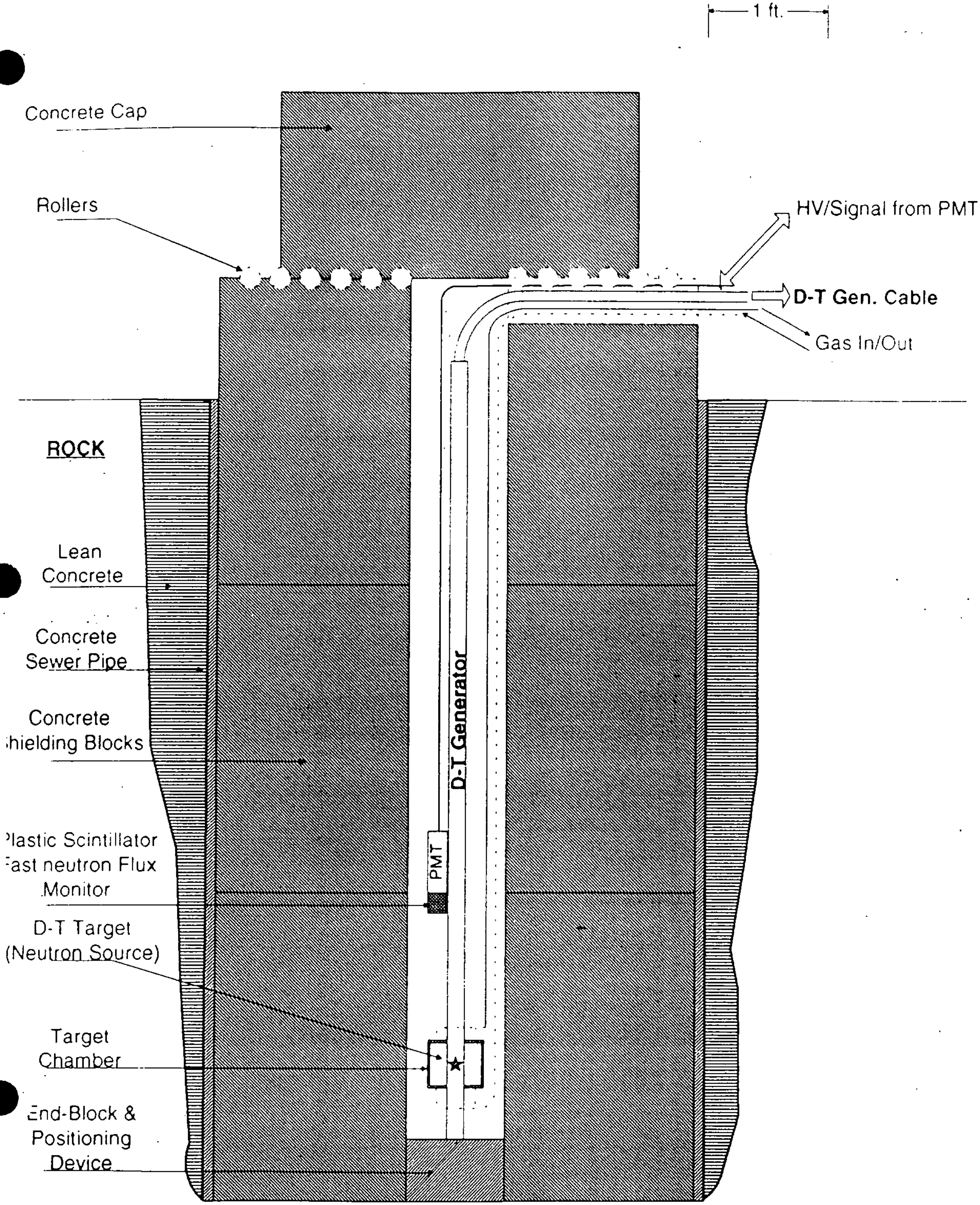
^{8}Li Source: Schematic Flow Diagram



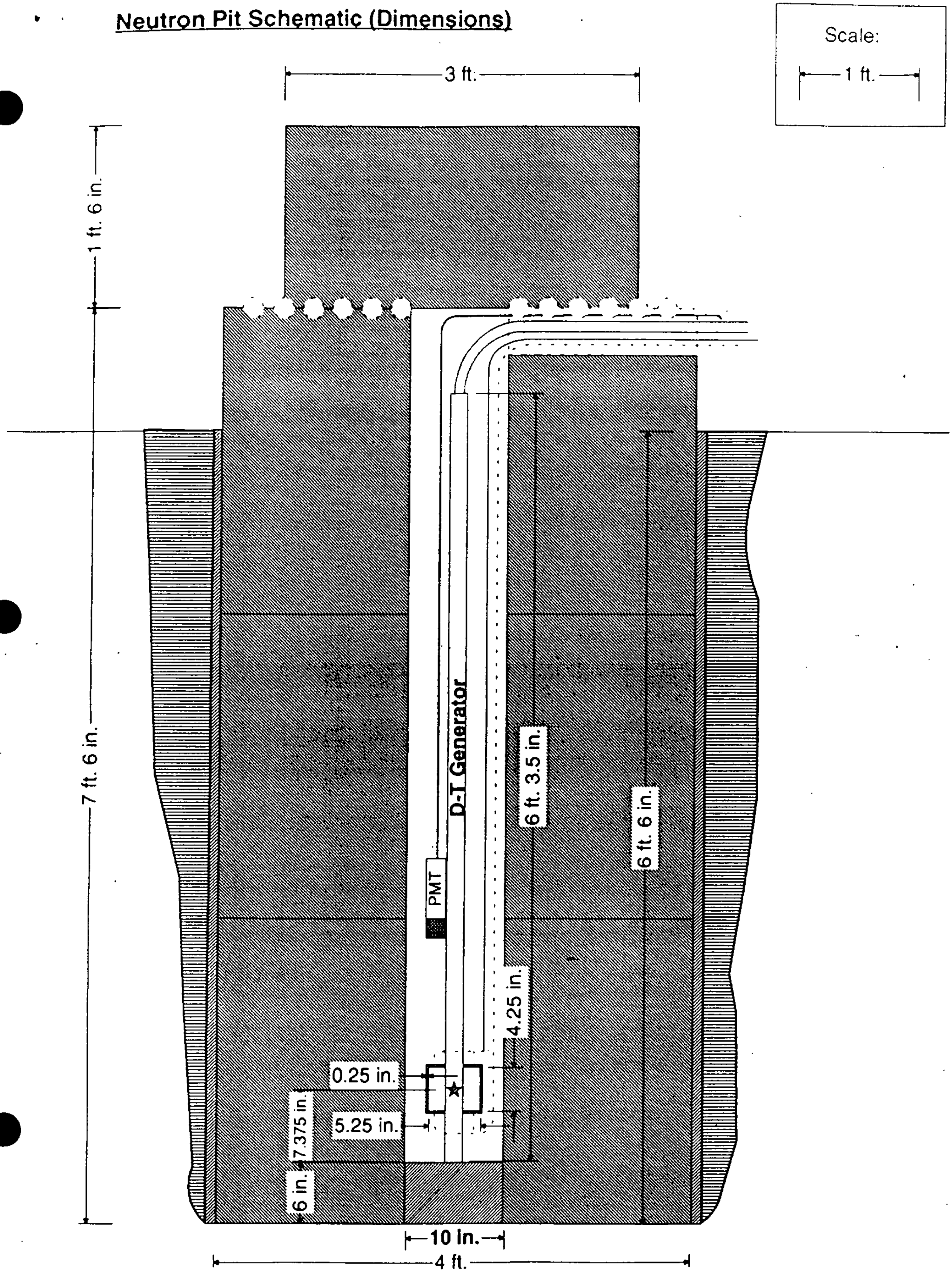
^{17}N Tagged Neutron Source: Schematic Flow Diagram



Neutron Pit Schematic



Neutron Pit Schematic (Dimensions)



Item	Action	Manpower (p-d	Cost(in K$)	Responsibility	Status
D-T Generator	ID/Quotes	5		Queen's, CRL	Done ✓
D-T Generator	Procurement	0	65	Penn	✓
D-T Generator	Training	2	2.5	???	
D-T Generator	Transfer to CRL	0	1	Penn, CRL	
D-T Generator	Licensing	???		Queens, Penn, SNO Sudbury, CRL	✓ ongoing
D-T Generator	Transfer to Sudbury	1	0.25	CRL	
n-pit: liner	design	0.5		SNO; CRL	✓
n-pit: liner	procure	0	0.5	SNO	
n-pit: liner	clean, crate, xport	0.5		SNO	
n-pit: liner	grout in (install)	0.5	0.25	SNO	done
shielding blocks	design	1		SNO, CRL	ongoing
shielding blocks	pour	2	1	SNO	
shielding blocks	paint	1	0.25	SNO	
shielding blocks	clean,crate,xport	1		SNO	
shielding blocks	install	2		SNO	
hoist for sh. blocks	procure	?	?	SNO	exists?
hoist for DT generator	design, procure	?		SNO/CRL	
	install	?		SNO	
n-pit:inner liner	design	0.5		CRL	
inner liner	procure, machine		0.5 ✓	CRL	
inner liner	clean,crate,xport	0.5		SNO	
inner liner	install	0.25		SNO	
DT positioning	design	0.5		CRL	
DT positioning	procure, machine	2	1 ✓	CRL	
target chambers	design	1		CRL	
target chambers	machine, assemble	4	0.5 ✓	CRL	
11B for target	procure		0.5 ✓	CRL	exists
11B target fabrication	fabricate	1.5		CRL	
Monitors:					
Plastic (fast n flux)	procure	0.5	1.5 ✓	CRL	
Thermal n	procure	0.5	???	CRL/ SNO	exists?
beta-gamma	procure	???	???	CRL/SNO	exists?
Gas equipment:	mine safety	0.5		SNO	
cylinders, tiedowns,	define layout	0.5		CRL	
regulators,pressure	procure	0.5	1 ✓	CRL	some exists?
gauges, filters etc.					
He flow monitor	procure	0.25	1 ✓	CRL	

N2 flow monitor	procure	0.25	1	CRL	exists
pressure monitors	procure 5(?)	0.25	1 ✓	CRL	some may exis
oven	procure	0.1	1 ✓	CRL	
oven tube	procure	1		CRL	glass-blowing
tubing: 1/4", 3/8",	define layout	1		CRL	
capillaries, fittings,	list, procure	1	1 ✓	CRL	
valves ...	assemble (UG ?)	2		CRL/SNO	
mechanical vac pump	procure	0.25	2	CRL/SNO	exists?
"	procure fittings	0.5	0.5	CRL/SNO	exists?
"	plumb in	0.5		SNO	
17O source and recirc	design, procure	???	???	LBL	
NIM bins (2)	procure	0.25	4	SNO	exist?
NIM modules:	list,				
amps, HV supplies,	procure	0.25	10	SNO/CRL	some exist?
scalers, gate,delay etc	install				
Electronics racks (2)	procure,clean,xport	0.5	???	SNO	exist?
Misc. electr. equip	procure etc.	0.5	1	SNO	exist?
Interfaces to DAQ,	define,	1		?	
CMA, safety interlocks	implement	5	5	?	
Source boxes	design	?		Queen's, CRL	
Source boxes	machine, assemble	10	5	ueen's, contract?	
Capillary runs	define	1		CRL/SNO	
Capillary runs	string	1	0.25	SNO	
Umbilical	develop	1	0.25	CRL/ Queen's	
Umbilical	procure, assemble	1.5	0.5	CRL/ Queen's	
Dec chamber 16,17N	design, test	???	???	LBL/ CRL	
Dec chamber 8Li	design, test	1	0.5	CRL	
Dec chamber 8Li	machine, assemble	5	2	CRL	
Misc. cleaning, crating,		5	1	SNO	
transporting, assembly					
TOTAL		69.35	112.75		