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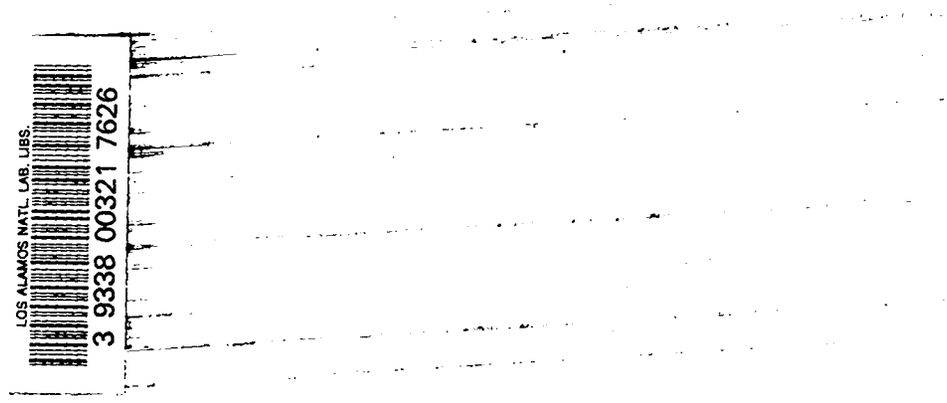

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A TRITIUM MONITOR FOR FUSION REACTORS

by

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ABSTRACT

This report describes the design, operation, and performance of a flow-through ion-chamber instrument designed to measure tritium concentrations in air containing ^{13}N, ^{16}N, and ^{41}Ar produced by neutrons generated by D-T fusion devices. The instrument employs a chamber assembly consisting of two coaxial ionization chambers. The inner chamber is the flow-through measuring chamber and the outer chamber is used for current subtraction. A thin wall common to both chambers is opaque to the tritium betas. Currents produced in the two chambers by higher energy radiation are automatically subtracted, leaving only the current due to tritium.

I. INTRODUCTION

At fusion reactors using deuterium and tritium as the fuel, monitoring for tritium releases into room air will be hampered by activation of local structures and especially by the presence of activated air, notably ^{13}N, ^{16}N, and ^{41}Ar. This report describes the design, operation, and performance of a flow-through ion-chamber instrument designed to measure tritium concentrations in activated air produced by neutrons generated by D-T fusion devices. Development of this type of instrument is important to the requirement to monitor for tritium releases within fusion reactor buildings. The near-term need for such an instrument is at the Tokamak Fusion Test Reactor (TFTR) presently under construction at Princeton University. The final development of the instrument, an early prototype of which was first described in 1975,[1] was funded by the Department of Energy, Office of Fusion Energy.

II. DESCRIPTION OF THE INSTRUMENT

The instrument consists of a double-chamber air-ionization detector, electrometer/amplifiers, power supplies, alarm circuits, recorder, and associated pumps and components for maintaining the sampled air at uniform pressure and temperature. The heart of the instrument is the detector, which consists of a cylindrical flow-through ion chamber coaxial with an outer cylindrical chamber used for subtraction of the current produced by contaminant gases in the sampled air. The common wall between the two chambers is constructed of square mesh (6.3-mm spacing) copper screen covered with 0.064-mm double-aluminized Mylar that stops the tritium betas but allows higher energy betas to penetrate to the outer chamber for current subtraction. The cylindrical walls and top and bottom plates of both chambers are maintained at a common high potential except for a grounded guard ring surrounding the central-chamber collecting electrode where it penetrates into the chamber. Collection of the signal current is made from the central electrode, whereas the subtraction current is obtained from four electrodes in the outer chamber. The currents from the two chambers feed separate electrometers with closely matched short time constants. At the low-impedance outputs of the electrometers, the signals are subtracted and a longer smoothing time constant is introduced. Signals from the outer (subtraction) chamber electrometer and the difference circuit may then be fed to separate four-decade log amplifiers. The amplifier circuit is shown schematically in Fig. 1. If more current range is required, a second range may be provided, but range changing must be done simultaneously for both amplifiers. The outputs of the two log amplifiers are then fed to separate panel meters with the final signal current, at least, also going to a strip chart recorder.

Photographs of the prototype chamber assembly, both assembled and with the outside walls removed, are shown in Figs. 2 and 3.

The air sampling arrangement is shown in Fig. 4. Air being sampled is directed through a particulate filter, local-air/sampled-air, copper-coil heat exchanger (temperature equalizer), ion precipitator, central ionization chamber, air pump, flowmeter/regulator, and is returned to the sampling point. The sampled air is introduced into, and removed from, the central chamber through small holes along the length of the hollow central electrode in order to minimize unbalanced transient currents at the time the concentration of the activated air is rapidly changing. A differential pressure gauge may be used to

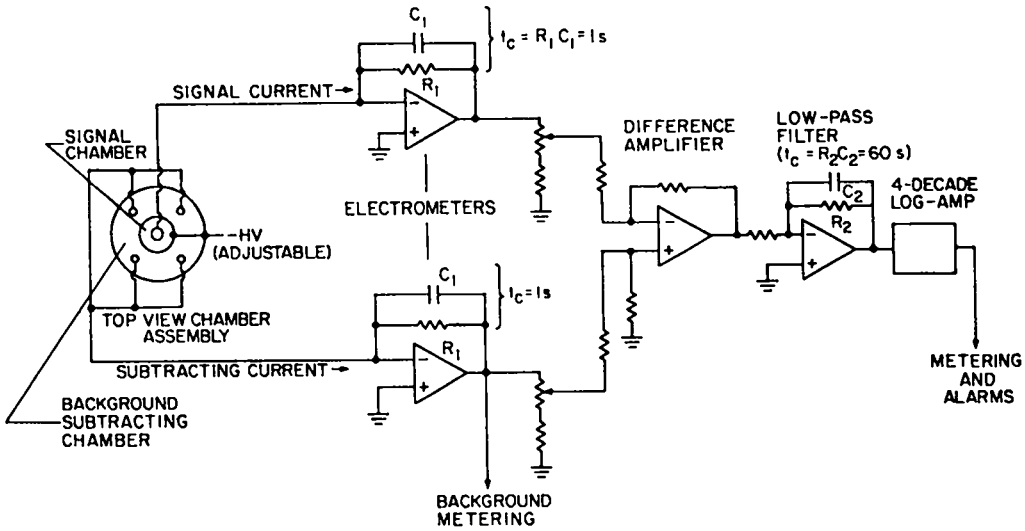

Fig. 1.
Simplified schematic of the amplifier. Background metering may also include a four-decade log-amplifier. The current range may be extended by switching in different feedback resistors.

monitor the pressure difference between the inner and outer chambers (Fig. 4). For maintaining the air in the outer chamber at a stable pressure and temperature, a second pump with a flowmeter/regulator directs clean air to the outer chamber through a filter and second heat exchanger. The air exits through cracks between the chamber wall sections. The two heat exchangers are wound together to maintain the temperatures in the two chambers as nearly identical as possible. Specifications of the mechanical components, except for the chamber assembly and ion precipitator, are given in Appendix A. Specifications for the electronic components (electrometers, power supplies, recorder) are given in Appendix B. Some of the operating parameters and assembly notes are listed in Appendix C.

III. PERFORMANCE

The theoretical limitation of such an instrument to detect tritium in the presence of a high-energy beta emitter has been shown to be[1]

$$C_T(\text{min}) = 9 \times 10^{-5} K_{HE}\, C_{HE}^{1/2} (Vt_c)^{-1/2} \ \mu Ci/m^3 \quad ,$$

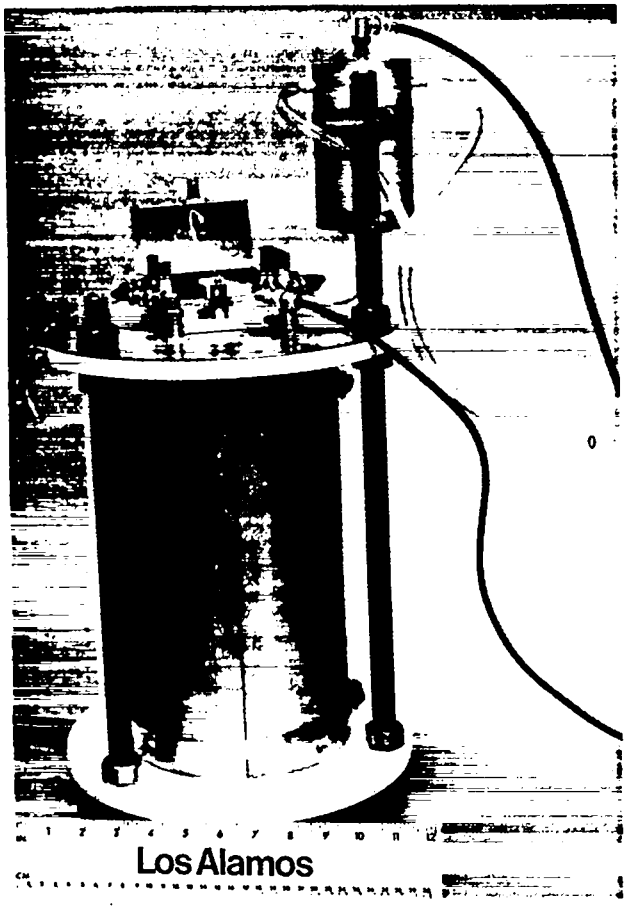

Fig. 2.
Chamber assembly showing the air hoses and some of the cable connections. loose fitting outer wall allows flushing air to exit from the outer chamber. The top cylinder is the ion trap.

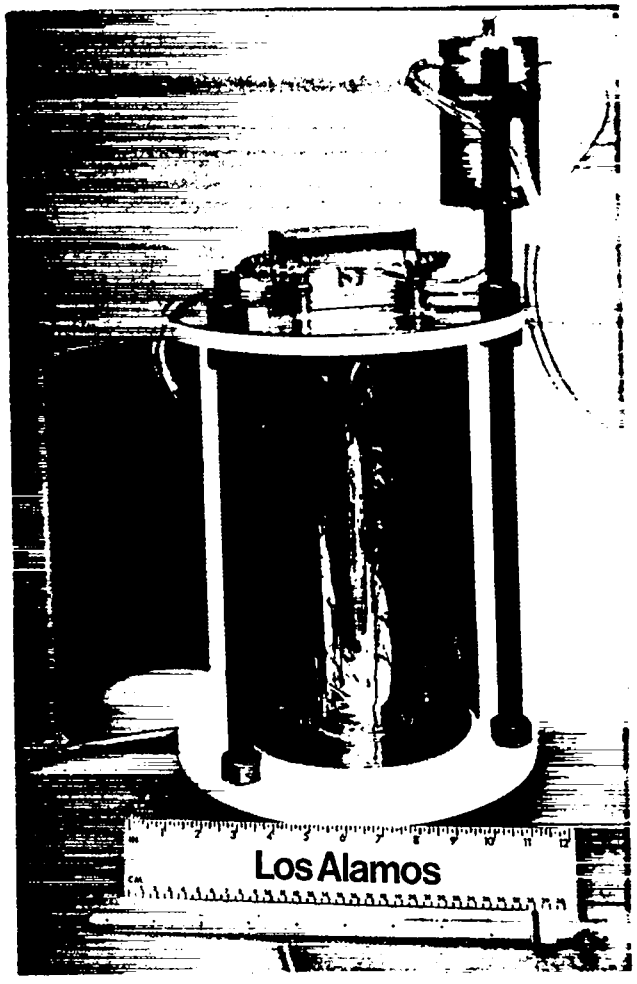

Fig. 3.
Chamber assembly with outer wall opened to show collecting electrodes and inner chamber. The Mylar wall is tightly drawn against the copper screen when the pumps are turned on.

where $C_T(min)$ = the minimum detectable concentration of tritium in $\mu Ci/m^3$ (defined here as that which, in the background current instabilities or "noise" generated by the high-energy gas, produces a current equal to three times the standard deviation of the noise).

K_{HE} = average energy deposited by the high-energy beta emitter in eV.

C_{HE} = concentration of the high-energy beta emitter in $\mu Ci/m^3$.

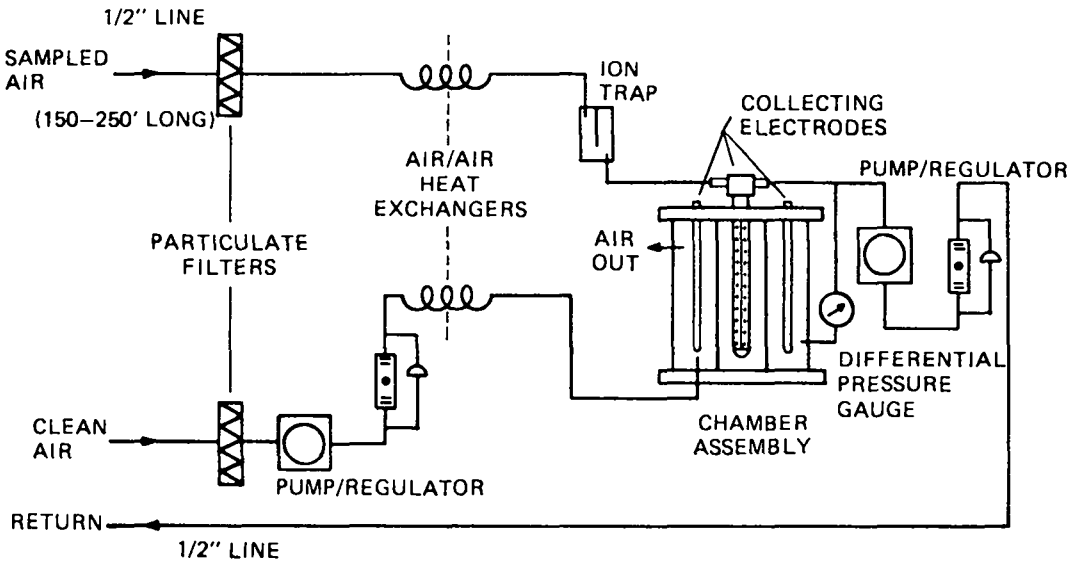

Fig. 4.
Monitor air flow paths.

V = volume of chamber in liters.

t_c = electronic time constant in seconds.

Thus, for $K_{HE} = 1.5 \times 10^4$ eV (approximate value for ^{85}Kr but should be close to that of ^{41}Ar or ^{13}N),

V = 1 liter (in this design), and

t_c = 60 s (the suggested time constant)

$$C_T \text{ (min)} = 0.17\ C_{HE}^{1/2}\ \mu Ci/m^3 \quad .$$

The derivation assumes infinitely long chambers and the same number of events in the inner and outer chambers produced by the high-energy gas. Since these assumptions are not met in a real instrument, the performance is somewhat inferior to that given above. However, a relationship of $C_T(\text{min}) = 0.5\ C_{HE}^{1/2}$ $\mu Ci/m^3$ appears to be readily achievable.

Sample records obtained with ^{85}Kr with the prototype instrument are shown in Figs. 5 and 6. Note that the records were obtained with a time constant of 18 s. The beneficial effect of the altitude at Los Alamos, NM, would tend to cancel partially the negative effect of using a time constant of 18 s instead of

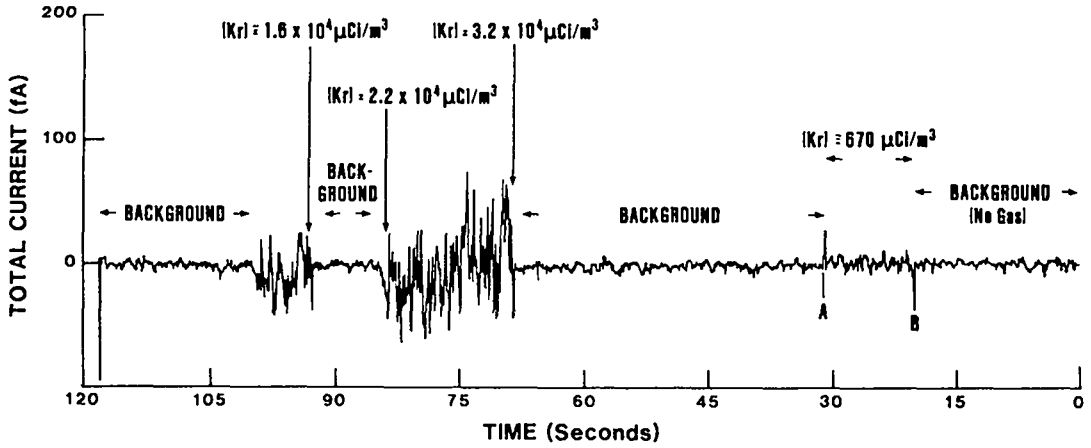

Fig. 5.
Recorder trace using different concentrations of ^{85}kr gas. Time constant of the electrometer was 18 s.

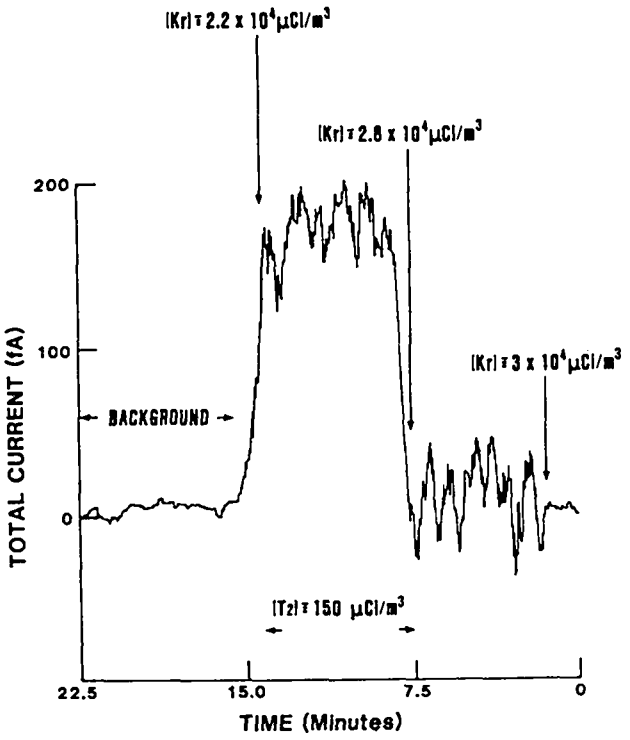

Fig. 6.
Recorder trace sharing the response of the instrument to tritium gas following the introduction of ^{85}Kr.

the 60 s recommended in the electronic specifications (Appendix B). Thus, records at sea level with a time constant of 60 s should be at least as good as those shown.

IV. DISCUSSION

Because the instrument is an ion-chamber instrument, it is subject to the same limitations of sensitivity as any other monitor operating on that principle. Its lowest detectable level, in the absence of contaminant gases, is about 1-3 µCi/m^3, depending on the stability of the electrometer, electronic noise, size of chamber, etc. Detection or measurement below that range (e.g., < 1 µCi/m^3) is best done with a proportional counter instrument or by passive monitoring (e.g., a bubbler system). Reference 2 contains a review of various methods that have been developed to monitor tritium in the presence of contaminant gases. The conclusion of that survey is that for

low-level active monitoring of tritium at fusion reactors, proportional counters probably should be considered. However, for monitoring high concentrations of tritium ($>10^3$ $\mu Ci/m^3$) or in high concentrations of contaminant gases, proportional counters are unsuitable because of saturation problems. Passive monitoring should also be given serious consideration especially for reporting the total tritium released to the environment. For monitoring close to the source of a potential release (e.g., within the primary shield of a fusion reactor), the instrument described here should prove quite satisfactory.

When sampling air with high concentrations of ^{13}N and much higher concentrations of ^{16}N, it is advisable to delay the intake of the sampled air into the flow-through chamber long enough for the concentration of ^{16}N to decay to a level below that of ^{13}N. In the case of sampling the igloo air at the Princeton TFTR following multiple pulses with no ventilation, this takes only about 1 min and has the advantage of much lower statistical fluctuations by a factor of about 10. A correspondingly lower concentration of tritium may be detected more quickly. For this reason, the size of the sampling line is chosen to provide this delay while providing an acceptable negative pressure in the inner chamber (8 to 15 cm of water) with the desired air flow ($\sim$10 ℓ/min). Depending on the size and length of the sampling line, it may be necessary to insert a throttling valve in the inlet sampling line to provide the necessary negative pressure. However, it has been found that a 60-m-long 1.3-cm-diam line provides the necessary pressure with a 10-ℓ/min air flow.

Following a daily series of spaced, planned pulses at TFTR, the maximum concentration of ^{13}N in the igloo with no ventilation has been calculated to be about 4×10^4 $\mu Ci/m^3$, whereas the concentration of ^{16}N is about a hundred times higher. Thus, after a minute's delay, a tritium concentration of 100 $\mu Ci/m^3$ is detectable--corresponding to a release of $\sim$30 mCi into the igloo or 0.008% of the tritium needed to produce the required neutron fluence to activate the air to this level (400 Ci). Note that this value (100 $\mu Ci/m^3$) also corresponds to a change in the temperature difference of the air in the inner and outer chambers of $\sim 0.25^{\circ}C$ or a change of the pressure difference of $\sim$8 mm of water. This emphasizes the need to maintain the pressures and temperatures of the air flowing through each chamber as nearly constant as possible, especially in the case of an instrument used for high concentrations (e.g., for sampling the igloo air). When monitoring lower concentrations, the requirement is not so rigid by virtue of the square root dependence of the electronic noise on the concentra-

tion of the activated air and the linear relationship of the temperature and pressure effects.

APPENDIX A

MECHANICAL COMPONENTS

Listed below are the mechanical components that we used.

Particulate Filters

Filter Housing: MSA Filter DZ78001 [Mine Safety Appliance Co., 600 Penn. Center Blvd., Pittsburgh, PA 15235]
Filter Cartridge: MSA Ultra Fine, Type H, No. 95302

Transfer Pumps

Central Chamber

Dia-Pump Model G-3 with steel mounting frame and power cord [Air Control, Inc., 1448 County Line Road, Huntington Valley, PA 19008]

Compensating Chamber

Thomas Pump Model 107CA11 [Thomas Industries, Inc., Power Air Division, Sheboygan, WI 53081]

Flowmeter/Flow Regulator

Devco Flowmeter Model L-125 with differential pressure regulator, Range 5-45 SCFH. Devco, Inc., P. O. Box Drawer D, Patton, MO 63662. (Dwyer also makes one which may be as suitable.)

Differential Pressure Gauge

Dwyer Magnehelic Differential Pressure Gauge Series 2000. Range 0-8 inches of water. Dwyer Instruments, Inc., P. O. Box 373, Michigan City, IN 46360.

Hardware Fittings

Swagelok fittings used for copper-tube/copper-tube and for copper-tube/pipe-thread connections.

APPENDIX B

SPECIFICATIONS FOR ELECTROMETERS AND POWER SUPPLIES FOR ACTIVATED-AIR-INSENSITIVE TRITIUM MONITOR

Current Measurement Range: from 10^{-15}A to $\sim 10^{-10}$A; range to have 4-5 decade span.

Primary Display: four-to-five decade logarithmic display on an analog meter, indicating "positive" readings only. Readings result of summing circuit. Positive means the direction of indication when tritium is detected.

Auxiliary Display: similar to primary display but represents output of central chamber electrometer.

Electrometer Stability: drift is not to exceed 1 mV for ambient temperature range from 18 to 28°C, for electrometer sensitivity of 1 V/pA. Mounting the electrometers in oven-controlled remote heads is therefore recommended. This has the added capability to minimize the distance from electrometers to chamber electrodes.

Recorder Output: normally -1.000 V → 0 → +1.000 V indication. Switch-selected option should give 0 to +1.000 V output from the logarithmic converter.

Electrometer Time Constants: 1 s, remaining the same for either sensitivity range. Overall instrument time constant ~1 min--introduced electronically after the current summing circuit.

Electrometer Accuracy: ±10% of reading, for input currents greater than 0.01 pA.

Alarms: continuously adjustable threshold level setting from 0 to 100% of full scale of primary display. Local alarms to be flashing red light and pulsating audio, with mute switch. Alarm action is to be latching, with local reset switch. Relay contacts (SPDT) are to be furnished for remote alarms.

Chamber High-Voltage Power Supply: negative voltages are to be furnished, one fixed for supplying voltage to the ion trap, and one variable voltage for supplying the chamber assembly proper. Fixed voltage of -200 V. The variable voltage is -200 to -500 V with a front panel meter to monitor the level. It should be set initially at -300 V and adjusted for the minimum value consistent with maintaining cancellation of the two chamber currents as the concentration of ^{13}N varies. Voltages to have ±1% accuracy, instability of less than 2 mV/s, and temperature coefficient of 100 ppm/^{o}C or better. Current requirements from these supplies are negligible, except for that needed for metering.

APPENDIX C

CONSTRUCTION NOTES AND OPERATING PARAMETERS

I. HEAT EXCHANGERS

These may be made of 6.4-mm soft copper tubing in coils about 20 cm in diameter. The two exchangers should be wound together or placed one inside the other. Length of each coil is about 8 m.

II. AIR LINES

These may be of copper or plastic tubing except for the first few inches of the inlet and exhaust lines of the hollow central electrode. The first 2 cm should be of Tygon tubing (for electrical insulation), the next 5 to 7 cm (at least) should be metallic and grounded. The line from the area being sampled to the instrument should have a minimum diameter to give a delay time of over 1 min to allow the concentration of ^{16}N to decay to less than 0.1 of that of ^{13}N. This can be readily calculated on the basis of the actual pumping rate of the pump (8-12 ℓ/min is recommended) and the distance between the instrument and sampled area. The resultant negative pressure in the central chamber should be approximately 13 cm of water. A throttling valve may be needed in the intake line to achieve this desired pressure.

III. PUMPS

The pumping speed of both pumps should be about 10 ℓ/min. Regulators are included because the pumping speeds should be fairly constant to maintain the chamber pressures reasonably constant (within $\pm$3 mm of water).

IV. MOUNTING OF COMPONENTS

Most of the components can be mounted in any convenient fashion depending on the space available. Lines from the heat exchangers to the chambers should be kept reasonably short, however.

V. CHAMBER ASSEMBLY

In building the inner chamber screen wall, care must be taken to ensure a smooth outer surface so as not to damage the Mylar cover. When applying the Mylar sheet, the Mylar is cemented only to the end rings of the chamber wall and to itself along its length. This is done by rolling the cylindrical chamber, whose brass end rings are first coated with quick-drying epoxy cement, on a precut Mylar sheet. After allowing the epoxy to set, the precut Mylar is epoxied at the seam. If the seam is cemented at each edge, care must be taken not to produce a space between the overlapping sheets that is accessible from the inside of the chamber.

Before epoxying the Mylar to the inner chamber wall, the wall should be gold plated $(4\pm1)\times10^{-3}$ cm thick to minimize the contamination of the inner chamber by $^{13}NO_x$ formed by D-T neutrons. In addition, the central electrode and end plates of the inner chamber and their mounting screws should be similarly plated with gold. It is probably advisable to gold plate the pieces of the central electrode before assembly and then gold plate the electrode (on the outside) after assembly, making certain that all the holes are plugged before immersion in the plating solution.

The location of the small holes along the hollow central electrode may not be critical, but two rows of 1.6-mm holes along each half of the electrode and spaced about 25 mm apart are known to produce insignificant current imbalance caused by rapidly changing concentrations of background gases in the sampled air.

Because the outer walls are maintained at $\sim$300 V, some protection should be provided to prevent electrical shocks. As a minimum, the outside of the cylindrical wall sections should be covered with electrical tape. In addition, a grounded wire screen can be installed around the assembly if desired. Holes can be provided in one of the cylindrical segments of the outermost wall to permit visual inspection of the Mylar wall after the walls are in place and the pumps are operating.

The top and bottom rings of the cylindrical wall of the inner chamber should slip snugly into the grooves in the base and upper plates. Air-tightness is provided by O-rings.

Inasmuch as the temperature difference between the two chambers must be maintained as nearly constant as possible (hence the need for the heat exchang-

ers), it may be necessary to provide a thermal shield for the chamber assembly. This will be necessary if there is a thermal source close to chamber (e.g., a radiator or hot or cold air source). Twenty-cm-thick styrofoam blocks make a simple effective shield. Because the electrometers are sensitive to thermal changes, it is recommended that the electrometer preamplifiers be placed in temperature-controlled ovens or that they be placed with the chamber assembly in a thermally stable environment. Because the lengths of the shielded cables connecting the chamber-collecting electrodes to the electrometer should be as short as possible, it is preferable that the preamplifiers be placed on top of the chamber assembly.

Current balance must be re-established each time the chamber is reassembled since the volume of the outer chamber is mechanically altered by removal and replacement of the outer walls.

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