LUDLUM MODEL 3101
TRITIUM IN AIR MONITOR

October 2020

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LUDLUM MEASUREMENTS, INC
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SAFETY SUMMARY

This manual describes operations and organizational-level maintenance of the Model 3101, including the potential associated risks. The user must become completely familiar with the information in this manual and adhere to the procedures, recommendations, warnings and cautions for the safe use, maintenance and storage of this instrument. The following are general safety precautions and instructions that users must understand and apply during use of the Model 3101 to ensure personnel and equipment safety. Portions of this may be repeated elsewhere in this publication for emphasis.

DO NOT SERVICE OR ADJUST ALONE!

Under no circumstance should any person reach into or enter the enclosure for the purpose of servicing or adjusting the equipment, except in the presence of someone who is capable of rendering aid.

RESUSCITATION

Personnel working with or near high voltages should be familiar with modern methods if resuscitation. Such information may be obtained from the Bureau of Medicine and Surgery.

WARNING, CAUTION AND NOTE STATEMENTS

WARNING, CAUTION and NOTE statements have been strategically placed throughout this text prior to operating or maintenance procedures, practices, or conditions considered essential to the protection of personnel (WARNING) or equipment and property (CAUTION). A WARNING or CAUTION will appear each time a related step is repeated. Prior to operating or conducting maintenance on the Model 3101 the WARNINGS or CAUTIONS included in the text for that task will be reviewed and understood.

WARNING

Users shall conduct all radiation surveys in accordance with Federal and organizational guidelines to prevent hazardous exposure to external radiation sources and/or contamination.

WARNING

High voltage (75 VDC chamber bias) is present in this equipment, which can cause injury to operating or maintenance personnel. Observe the following safety precautions during troubleshooting or maintenance.

- Never disconnect or unsolder cables or components while power is turned on.
- Always shut off power when connecting test instruments to the equipment.
- Use one hand only when necessary to move oscilloscope or multimeter probe when power is turned on.

- Do not use test instruments known to be in poor condition.

WARNING

The walls of the each ion chamber are at opposite 75-volt potentials. Do not contact either wall or its mounting hardware while equipment is operating.

CAUTION

Avoid immersing the Model 3101 in liquids or allowing spray or rainwater to collect around the instrument.

CHAPTER 1
GENERAL INFORMATION AND SAFETY PRECAUTIONS

1.1 SAFETY CONSIDERATIONS. There are certain things to consider in order to safely operate the Model 3101 and avoid damaging the instrument and/or causing personal injury. See Safety Summary before the Table of Contents for some general warnings and instructions.

1.1.1 Baseline Conditions.

a. Indoor or outdoor use.

b. Temperature range of 32°F to 122°F (0°C to 50°C).

c. Relative humidity (RH) of 40% to 90%.

d. Pollution Degree 3 (Defined by IEC 644. See Table 1-1.), typical of industrial and construction sites.

1.1.2 Avoid Contact With Hazardous Live Parts. Normal operation of the instrument should always be performed with the instrument front panel attached to the instrument can assembly. The operator is warned to take the following precautions to avoid contact with internal hazardous live parts, should it be determined that the chassis needs to be separated from the instrument case.

a. Turn the instrument power OFF and remove the batteries.

b. Allow the instrument to sit for one minute before accessing internal components.

1.1.3 Keep Out of Water. This instrument meets the standards as specified by MIL-STD-810G Method 506 procedures I & III for moisture exposure, but it is not waterproof and should never be immersed in or used in standing water. See Table 1-1 for specifics.

It is recommended that after operating in a wet or humid environment and the instrument has persistent readings above zero, the instrument can be run in PURGE mode to ensure the air in the system is dry.

1.2 INTRODUCTION. This Technical manual contains specifications, descriptions of instrument operation and use, and procedures for user maintenance.

Figure 1-1. Front View Model 3101.

1.2.1 Purpose. The purpose of this manual is to provide information that will assist in the operation and user maintenance of the Model 3101 in all its modes of use. Failure to follow the procedures described herein may result in unsatisfactory performance of the equipment.

1.2.2 Scope. This manual covers operations, technical specifications, and user-level maintenance information required to support the Model 3101. This manual applies to all users of the Model 3101. For more advanced technical information, see the Model 3101 Technical Repair Standard manual.

1.2.3 General Description. The Model 3101 shown in Figure 1-1 is an instrument with a maintenance-free, long-life pump that pulls air through the 250 cc ionization chamber to measure the ionization caused by tritium gas (HT) and to measure air flow internally with a mass air flow sensor. A second internal chamber provides gamma compensation, allowing operation in higher gamma fields. The auto-ranging digital display provides clear indication of the current tritium concentration. The measurement of tritium in air normally measures both tritium gas, designated as HT, and tritiated water vapor, designated HTO. The core of the tritium detection is the electrometer chamber, using a state-of-the-art, low-noise, temperature-compensated electrometer chip. This electrometer can reliably measure the femtoamperes of current resulting from ionization caused by tritium inside the chamber. The digital display provides feedback on the tritium concentration, as well as the status of several important conditions, such as temperature, pressure, power, airflow, chamber bias, and alarm or failure status.

1.3 EQUIPMENT INFORMATION.

1.3.1 Reference Data. Table 1-1 summarizes general information on the Model 3101.

Table 1-1. Reference Data.

DESCRIPTIVE INFORMATION			
Manufacturer (Mfr.)	Ludlum Measurements	**Mfr. Part Number**	48-4366
Mfr. Model	Model 3101	**Nomenclature**	Model 3101
SPECIFICATIONS			
Chamber	Aluminum with powder coat finish	**Power**	8 NIMH AA cell batteries; typical continuous battery life is 16 hours
Air Filter	External user-replaceable glass-fiber, 25 mm dia., GF/F grade	**DC Power Input**	+12 Vdc power supply included
Chamber Volume	approximately 250 cm^3	**Primary Battery Life**	Approximately 16 hours, with pump running continuously

Table 1-1. Reference Data, continued.			
Gamma Compensation	Allows for tritium monitoring in up to 5 mR/hr (0.05 mSv/h) gamma fields	**Display Range**	0-20,000 µCi/m^3 (0 to 740 MBq/m^3)
Battery Dependence	Calibration changes <5% within battery check limits	**Temperature**	32 to 122 ^{o}F (0 to 50 ^{o}C)
Humidity Range	40 - 90% RH maintaining response ±15% of reading at 40% RH and 71 °F (22 °C)	**Effective Range of Measurement**	From 1 to 20,000 µCi/m^3 (0 to 740 MBq/m^3
		Minimum Detectable Activity (MDA)	2 µCi/m^3 (0.074 MBq/m^3)
Mode Switch Positions	Off, Check, Measure, Sample (Pump On), and Purge	**Response Time**	Approximately 60 seconds
Construction	Rugged, gasketed, waterproof(1) aluminum enclosure with external user-replaceable glass fiber filter	**Linearity**	Reading within 20% of true value
LCD Display	2.7 in. (6.9 cm) diagonal transflective backlit LCD housed inside the electronics enclosure	**Pollution**	Degree 3 (As defined by IEC 644, "Occurs when conductive pollution or dry nonconductive pollution becomes conductive due to condensation.")
Audio	75 ±5 dB at 2ft, at a frequency of 2500 Hz on alarm or failure conditions, may be acknowledged and then reset by operator using ACK / RESET button	**Output**	internal 9-pin D connector provides potential-free relay contacts for pump active (pins 6 &7) and alarm active (pins 8 & 9), contacts rated for 60 V and 0.5 A. Also has communication lines to connect to computer for calibration on pins 1-4.
Dimensions	Instrument: 7.9 x 6.3 x 11.8 in. (20 x 16 x 30 cm) (H x W x L)	**Weight**	Instrument: 9 lb (4 kg) with attached cables and tubing

Notes:

(1) Lightly falling rain is defined as ¼ inch/hour for a period of 2 hours at 68 °F (20 °C). Grease may be added to gaskets to increase water resistance under conditions of wind-blown rain.

1.3.2 Equipment Supplied. Table 1-2 summarizes the equipment supplied with the Model 3101 and Table 1-3 describes equipment needed but not provided by the manufacturer.

Table 1-2. Equipment Supplied.

Quantity	Item Name	Part Number	Dimensions	Weight
1	Model 3101	48-4282-1	7.9 x 6.3 x 11.8 in. (20 x 16 x 30 cm) (H x W x L)	9 lb (4 kg) with attached cables and tubing
1	Technical Manual	Model 3101 Manual	8.5 x 11 in. (21.6 x 37.9 cm) (H x L)	0.5 lb (0.2 kg)

Table 1-3. Equipment Required but Not Supplied.

Category	Recommended Equipment	Application
Calibration	Tritium Gas Calibrator CL-1 or equivalent	Calibration
Battery	No. 1 Phillips Screwdriver	Battery door removal
Electrometer Desiccant	IP10 or T10 torx drive	Electrometer desiccant cover removal

1.4 RECYCLING. There are recyclable materials used in making the Model 3101.

1.4.1 Recycling Materials. These materials can be found in the Model 3101 and should be recycled separately.

a. Batteries-NiMH (nickel-metal hydride), Li-Ion (non-rechargeable coin cells), and/or alkaline

b. Circuit boards-fiberglass (FR-4)

c. Glass-LCD

d. Plastics

e. Aluminum and stainless steel

1.4.2 Labeling. The crossed-out wheelie bin lets the consumer know the product is not to be mixed with unsorted waste when discarding. Each material must be separated.

CHAPTER 2
OPERATION

2.1 INTRODUCTION. The Model 3101 is designed for use in applications where the presence or level of radioactive gas (tritium) must be determined. Radioactive gases, such as tritium, are low-energy beta emitters and must be brought inside the detector in order to obtain an accurate measurement of the level of radioactivity. The Model 3101 employs a flow-through type ionization (or ion) chamber and a small internal pump. Air from the surrounding atmosphere is drawn through the ion chamber, and the level of radioactivity is determined by a measurement of the ionization current occurring within the ion chamber. Another chamber, measuring the local gamma ionizations, is connected in parallel but with reverse voltage, in order to subtract out gamma background. The level of radioactivity in $\mu Ci/m^3$ (or MBq/m^3) of the air is displayed on a digital display. The digital display enables readings to be observed with scale levels of 10^2, 10^3, and 10^4 $\mu Ci/m^3$ of tritium in the air.

Whenever the indicated activity exceeds either of the two user defined levels (Alert/Alarm), a latching, “beeping” audible alarm accompanied by the text “Alrm” on the display is energized. The alarm audio can be silenced by pressing the ACK/RESET button once. If the radiation activity decreases below the preset level, a second press of the ACK/RESET button will clear the “Alrm” text from the display. The Model 3101 may be powered either by eight AA-sized rechargeable nickel-metal-hydride NIMH batteries, or eight AA-sized alkaline batteries, or be powered by wall-mount AC/DC adapter, connected at the front of the instrument.

The Model 3101 consists of the following sections: a tritium ion chamber, a gamma compensation chamber, an electrometer amplifier, range-dependent amplifier, microprocessor with A/D inputs, alarm, display, pump drive and pump, power supply, and battery charging circuits. The circuitry incorporates diagnostics enabling determination of the ability of the equipment to perform its intended function. Any failures are indicated by a latching steady audible alarm accompanied by a unique failure text on the display. The operator has access to the controls and indicators and is required to be familiar with their use and presentations during operation of the Model 3101 (See Figure 2-1).

2.2 CONTROLS AND INDICATORS. There are various controls and indicators users should make themselves familiar with prior to use.

2.2.1 Description of Controls. The controls are shown in Figure 2-1 and are described following the figure.

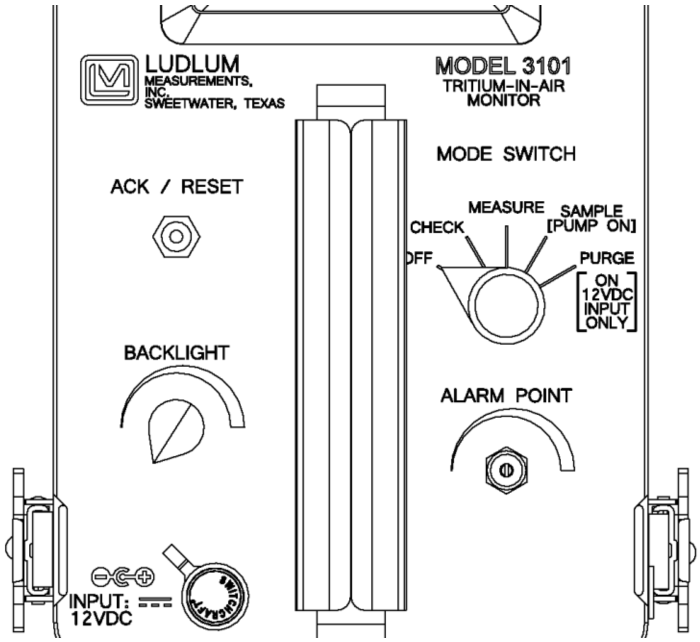

Figure 2-1. Identification of Controls.

2.2.1.1 <u>Backlight Switch.</u> This is a 295-degree rotary control that adjusts backlight intensity for minimum or maximum lighting contrast.

2.2.1.2 <u>ACK/RESET Switch.</u> Under alarm conditions, the first press of this button acknowledges (silences) the alarm audio, but maintains the “Alrm” text on the display. Once the radiation activity has decreased below the preset level, the second press resets the displayed alarm on the display. When in the CHECK mode, the ACK/RESET is used to toggle between the first check screen and the second check screen (see Section 2.2.1.4b).

2.2.1.4 <u>Mode Switch.</u> This is a five-position rotary switch marked OFF, CHECK, MEASURE, SAMPLE (PUMP ON), and PURGE.

a. OFF means the unit is turned off. Note that in this position the internal batteries are <u>not</u> being recharged, even if the AC/DC wall mount power supply is connected.

b. The CHECK mode displays the results of several automatic measurement diagnostics. Diagnostic results that are within tolerance are marked with a check mark, while out-of-tolerance measurements or conditions are marked with the letter “X.” By pressing the ACK/RESET button, the second CHECK mode screen labeled “Check Test” will be activated. This mode is meant to check the electrometer and amplifier and provides a preset bias to the tritium chamber, generating a repeatable reading if internal voltages and the amplifier are working correctly. This preset bias may be disabled during calibration, if desired, so that an external gamma check source may be used instead to perform the same check. If so, then a gamma source is placed on the instrument can at the tritium detector to obtain a repeatable and consistent reading.

c. The MEASURE mode allows the unit to measure already-sampled air inside the chamber, without the pump running. Note that the response time is approximately 60 seconds. This is the recommended mode to charge the internal batteries.

d. The SAMPLE mode turns on the internal air pump and allows the unit to pull air through the tritium chamber while displaying the current measured tritium concentration. Note that the response time is approximately 60 seconds. High levels of tritium may cause the “Alrm” message to appear on the display, and for a loud “beeping” audio signal to be sounded. Low airflow levels (possibly caused by pinched tubing or a dirty particulate filter) will result in a "Fail Air" text on the display.

e. The PURGE selection turns the air pump on and (when mains power is available) activates a heater in the tritium chamber to drive out tritium and/or moisture from the chamber. This mode is used whenever it is suspected that tritium has been adsorbed into the internal chamber walls, resulting in persistent high counts. This condition may occur especially when measuring high levels of tritium in a humid environment. Before starting the PURGE mode, the user should ensure that the air intake is sampling clean non-tritiated air. The PURGE mode will activate both the air pump and the internal heater, which has a thermostat set to limit the internal temperature to 149 °F (65 °C). The purge mode has a duration of 7200 seconds (2 hours) and countdown timer, shown on the display. The user should check after a purge cycle is complete and the instrument has returned to normal operation temperatures to see if the tritium level in the instrument has been reduced to normal levels. It may be necessary to repeat the purge cycle if the tritium level is still above normal.

2.2.1.5 Alarm Point Potentiometer. This flat screwdriver-adjustable 295-degree rotary potentiometer adjusts the tritium alarm threshold from 0 (OFF) to 20,000 $\mu Ci/m^3$or equivalent SI units (MBq/m^3). Whenever this control is adjusted, the display screen temporarily switches to displaying the adjusted alarm point value. The alarm point value may only be set while CHECK mode is selected. As the potentiometer is rotated and the units are set to $\mu Ci/m^3$, the amount of change varies by 5 while the value is less than 100, varies by 50 when the value is between 100 and 1000, and varies by 500 when the value is greater than 1000. The pop-up alarm point screen MUST be allowed to close (approximately three seconds with no change) and return to the check screen in order to save the new alarm point value. When the instrument is set to utilize MBq/m^3 units, the rate of change is equivalent to the same values in $\mu Ci/m^3$.

Note: The software allows the user to establish a second non-latching alarm point labeled "Alert," independent of the user-settable (screwdriver-adjustable) alarm point.

2.3 OPERATIONAL CHECK.

2.3.1 Purpose. To assure proper operation of the instrument between calibrations and periods of non-use, an instrument operational check should be performed daily or prior to each use. This check should include battery test and instrument test. Obtain a reference reading with a check source at the time of initial calibration for use in confirming proper instrument operation. In each case, ensure a proper reading on each scale. If the instrument fails to read within 20% of a reference reading, it should be sent to a calibration facility for recalibration.

2.3.2 Battery Test/Installation. The unit may be operated from the connected AC/DC wall mount power supply or from internal batteries. The batteries, if used, should be checked each time the instrument is turned on. See Section 5.2 for the correct procedure to replace the batteries.

2.3.3 Check Test. When the unit is deployed, the first check is to rotate the main rotary switch from OFF to CHECK. The unit powers up and temporarily shows the Ludlum logo. This screen also shows the firmware version number, the alert and alarm setpoints, and the number of hours that the pump has run. All internal relays become active for 3 seconds immediately after power-up, so connected devices should be able to see this test.

The screen then displays a diagnostics screen that shows several key parameters and status measurements. Any measurement outside of normal operating bounds will be marked with an "X" on the display. If battery power is too low for operation, the user may operate with the connected AC/DC power supply. Otherwise, the user should ensure that the AC/DC power supply is connected, and leave the unit on and charging for several hours prior to use. Note that charging happens in the SAMPLE, MEASURE, and PURGE modes only, and is indicated by the lightning bolt icon next to the battery icon.

Figure 2-2. First Check Display Screen.

2.3.4 **Instrument Test.** To assure proper operation of the instrument between calibrations and periods of non-use, the following instrument operational check should be performed daily or prior to use. This test takes less than 60 seconds to complete.

Rotate the main rotary knob to the CHECK position. When the first screen (Figure 2-4) is shown, after the pump has shut off (this takes about 8 seconds), press the ACK/RESET button. The second CHECK mode screen, labeled “Check Test,” will then be shown. Two possibilities exist for this test – internal electronic-only test or external source test. For more instructions on how to set up this function, please refer to the Model 9-4 and 3100 Series Calibration software manual.

Note: If the airflow has not reached the minimum accepted value before the ACK/RESET button is pressed, the “Fail Air” audible alarm will turn on without the status message being displayed. Pressing the ACK/RESET button to silence the audible alarm will exit the “Check Test” screen.

Note: If the “Check Test” value is greater than the alert or alarm values, the audible alarms will be activated without the accompanying text being displayed.

Note: At the end of the 60 seconds, the instrument will display one of two screens, depicted in either Figure 2-3 or 2-4.

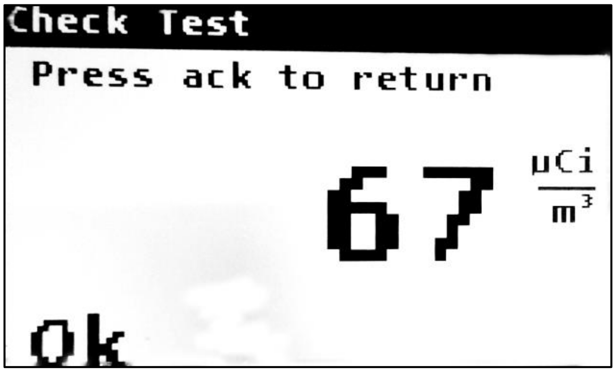

Figure 2-3. Check Test Screen Ok.

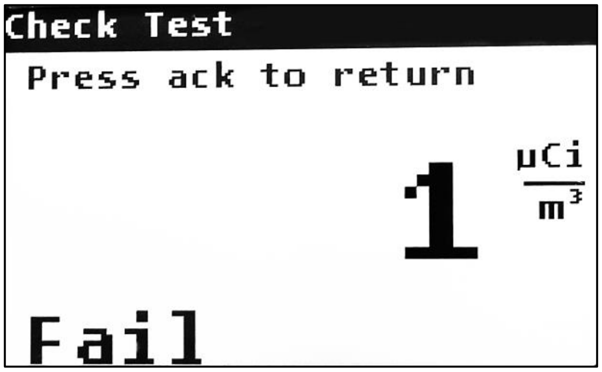

Figure 2-4. Check Test Screen Fail.

a. INTERNAL-A preset bias and the resulting reading may be defined at calibration in order to give a consistent reference reading during the CHECK operation. This reading tests the electronics and amplifier and will generate a repeatable reading if the circuits are functioning properly. If the instrument fails to read within 20% of a proper reading within 60 seconds, it should be sent to a calibration facility for recalibration. See Figure 2-5 for an example of an internal test screen.

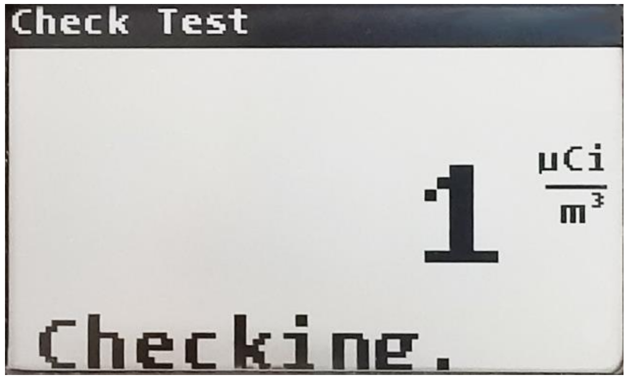

Figure 2-5. Internal Instrument Test Screen.

b. EXTERNAL-If desired, an external gamma source can be used during the operational check. In this case, a reference reading with a gamma check source should be obtained at the time of initial calibration or as soon as possible for use in confirming proper instrument operation. The user should place the gamma check source over the dimple on the side of the instrument enclosure marking the center of the tritium chamber. If the instrument fails to read within 20% of a proper reading within 30 seconds, it should be sent to a calibration facility for recalibration. See Figure 2-6 for an example of an external test screen.

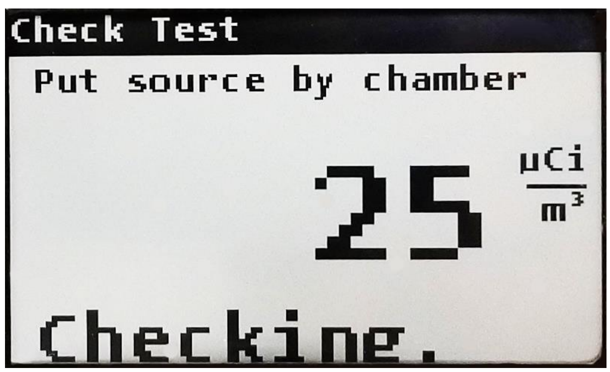

Figure 2-6. External Instrument Test Screen.

c. Rotate the rotary switch to the SAMPLE position, to display the following screen (see Figure 2-7), as an example. The following example screen shows the current tritium concentration in bold in the middle of the screen, the temperature, pressure, and power status on the top line, the current airflow in the lower right, and fail indications in the lower left. Ensure that the status of the airflow is NORMAL in the lower left of the screen. A "Fail Air" warning is given any time the airflow is too low, likely resulting from either a clogged particulate filter or kinked air hoses on the IN or OUT side of the instrument. Replace the particulate filter as described in Section 5.4, or troubleshoot as described in Section 6.

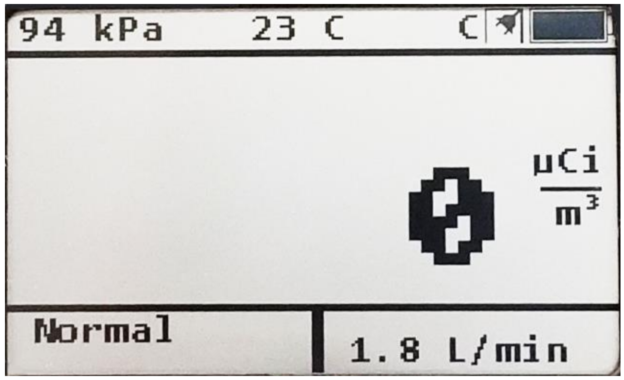

Figure 2-7. Sample Display Screen.

2.4 <u>MAINTENANCE ACTIONS.</u> There are several maintenance actions suggested below to help with the continued proper working of the Model 3101.

2.4.1 <u>Scheduled Maintenance.</u> Maintenance and verification activities will increase confidence and extend the usable life of the instrument, and are recommended at the intervals suggested below.

2.4.1.1 <u>Daily When In Use.</u> The operational tests described in Section 2.3 shall be conducted daily or prior to instrument use. The operational tests verify power, chamber bias, high voltage, temperature, pressure, airflow, and include either an electronic or radiological check on the tritium detector.

2.4.1.2 <u>Quarterly.</u> The Model 3101 shall be visually inspected, including electrometer desiccant condition checks, and cleaned when necessary and at least quarterly, per Section 5.1 and 5.3.

2.4.1.3 <u>Calibration.</u> Instrument response shall be calibrated yearly at a calibration facility. Users shall turn in the Model 3101 within a month of the labeled calibration due date to their servicing calibration facility. See Appendix A for the calibration procedure.

2.4.2 <u>Storage.</u> The instrument and accessories used with the instrument have certain storage requirements, as listed below.

2.4.2.1 <u>Remove Batteries.</u> The AA-size batteries may be removed any time the instrument is placed into storage. Battery leakage may cause corrosion on the battery contacts, which must be scraped off and/or washed using a solution made from lemon juice or diluted vinegar, and mixed 50% with water.

2.4.2.3 <u>Humidity.</u> If the instrument is stored in an area with high humidity, rapid changes in temperature should be avoided to reduce the chance of condensation. A storage cabinet with a light bulb inside is one means of keeping the instrument in a slightly warmer-than-ambient temperature environment in order to prevent problems from rapid changes in temperature and humidity.

In order to prevent moisture or humidity build-up inside the instrument, any time that the instrument is in storage or not in use, caps should be placed on the inlet and outlet ports. See Figure 2-8.

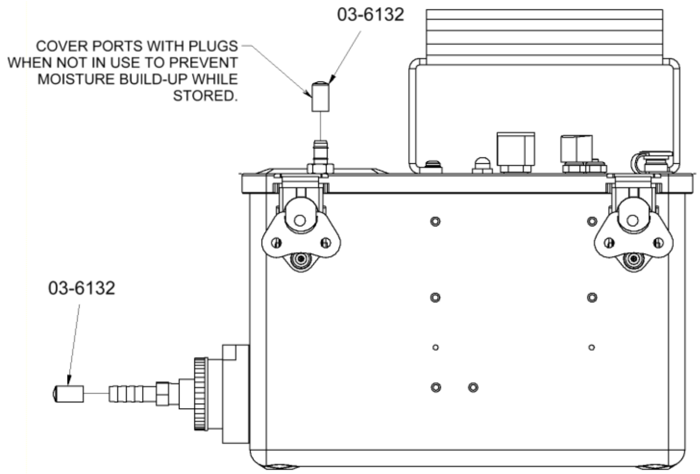

Figure 2-8. Prevent Moisture Build-up

CAUTION

Although this instrument will operate at very high ambient temperatures, battery seal failure may occur at temperatures as low as 100 °F (37 °C). Should battery seal failure occur, corrosion on the battery contacts may appear and battery chemicals may damage interior components.

2.4.3 Desiccant. An electrometer desiccant is used internally to ensure dryness of the electrometer board and gamma chamber. A small window is provided internally to view the desiccant.

If either desiccant remains blue, when visually checked, it can then absorb moisture from the airstream. If the desiccant becomes pink, it should be replaced. See Section 5.3 for the procedures to replace the desiccant.

WARNING

The silica used may cause irritation to the skin if handled directly. Please take necessary precautions to avoid long-term physical contact with the silica. Should handling of the product be required, avoid rubbing your eyes or placing your hands in or around your mouth, as the silica may also cause an irritation of the digestive tract. Wash hands with mild soap and water after handling.

2.4.4 Grease. In order for the instrument to remain watertight under wind-blown rain conditions, dielectric silicone grease must be applied to the front-panel gasket. Anytime the instrument front panel is opened, grease should be reapplied in the front-panel gasket slot.

CHAPTER 3
SHIPPING AND TRANSPORTATION

3.1 LITHIUM BATTERIES.

The Model 3101 contains two lithium metal (non-rechargeable) batteries.

WARNING

Although the lithium content is low, some precautions and labeling may be required to ship on commercial transportation.

The Ludlum part number for the lithium batteries is 2536-273. These batteries have been tested and passed per the UN Manual of Tests and Criteria, sixth revised edition, sub-section 38.3. This report is available upon request from Ludlum Measurements, Inc. Each battery is made of 25 “coin” cells (Panasonic CR1220), with a total of 0.25 g of lithium content in each battery. The two batteries are mounted securely inside the instrument and have a combined lithium content of 0.50 g.

CHAPTER 4
FUNCTIONAL DESCRIPTION

4.1 FUNCTIONAL DESCRIPTION.

The Model 3101 is intended for continuous measurement of tritium activity concentration in the ambient atmosphere. Tritium, which is a low-energy beta emitter, must be brought inside the detector in order to be detected. The instrument employs a pump and a flow-through pneumatic system to circulate ambient air through the otherwise sealed ion chamber detector. The level of activity is determined by measuring the ionization occurring within the chamber. The level of radioactivity in microcuries per cubic meter of air is shown on the digital display. Three ranges provide full-scale levels of 10^2, 10^3, and 10^4 µCi/m^3 of tritium in the air. An audible alarm can be preset so that the user is notified when the alarm level is exceeded, and must be manually reset whenever triggered.

The instrument is shown in block diagram in Figure 4-1. The unit consists of an inlet filter, tritium detector, gamma compensation ion chamber, an electrometer amplifier, a range-dependent amplifier, display, alarm circuit, pump drive and pump, power supply, and battery charging circuits. See overall description following the diagram.

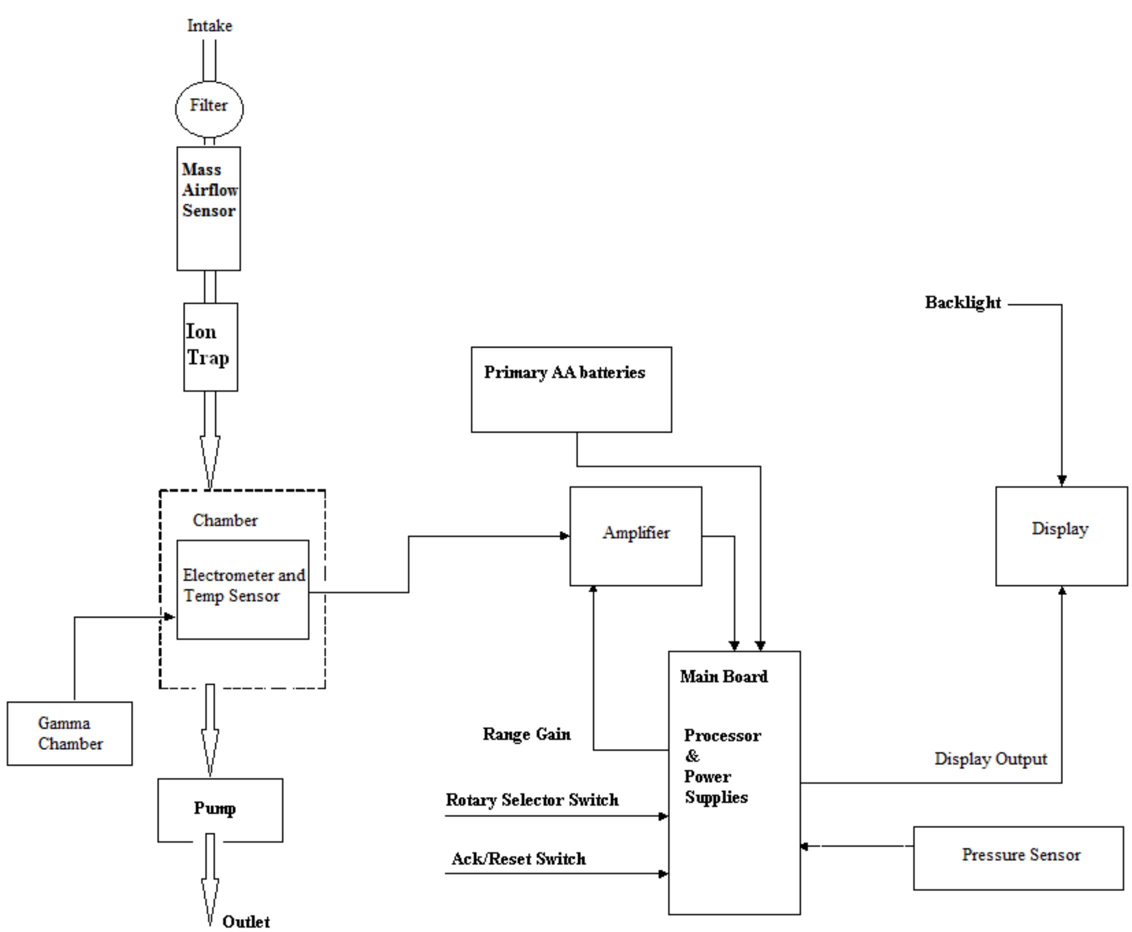

Figure 4-1. Functional Block Diagram.

4.2 <u>OVERALL FUNCTIONAL DESCRIPTION.</u> The following information describes the overall functions of the Model 3101.

4.2.1 <u>Filter.</u> The particulate filter's function is to filter incoming air (see Figure 4-2), capturing dust or other particles that might disturb the tritium measurement. The intake nozzle on the instrument is connected to the filter. The filter may become clogged over time, restricting the airflow, and need to be replaced. See Section 5.5 for replacement instructions.

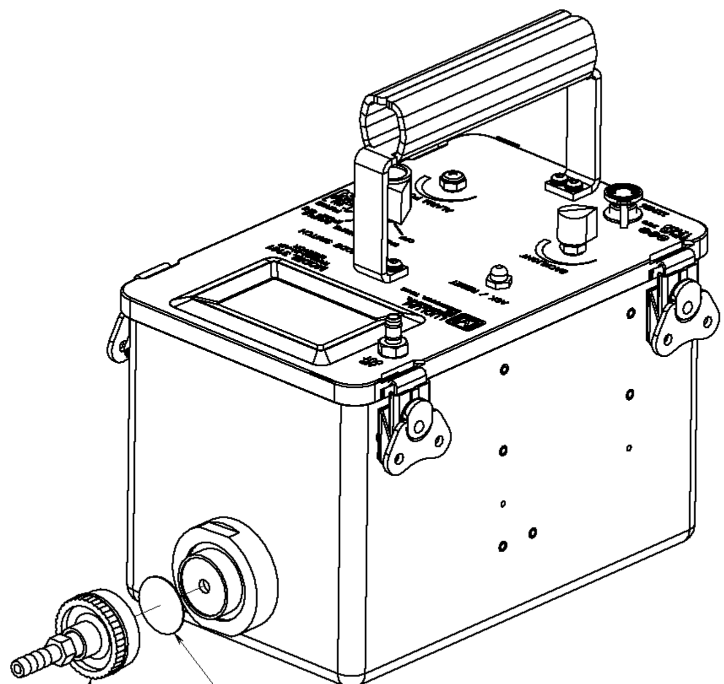

Figure 4-2. Particulate Filter.

4.2.2 <u>Intake.</u> The plastic intake nozzle is attached directly to the front of the filter on the front of the instrument, and is designed to fit 0.25-inch tubing.

4.2.3 <u>Mass Airflow Sensor.</u> The flow of air into the instrument is measured by a mass airflow sensor connected internally to the intake nozzle. The mass airflow sensor produces an analog voltage that the main board measures and converts to an airflow in L/min (liters of air per minute).

4.2.4 <u>Tritium Detector Ion Chamber.</u> Incoming air from the mass airflow sensor enters the tritium ionization chamber. The polarization voltage applied to the tritium chamber causes a low-level current to flow when ionization occurs in the ion chamber detector. The magnitude of this current is directly proportional to the level of tritium present in the air being monitored. The mark on the instrument can closest to the back of the instrument identifies the center of the tritium chamber. Note that ionization of the air being monitored can also be produced by either a radioactive contaminant in the air or by the action of a background gamma radiation incident to the tritium detector. Since it is the purpose of this unit to measure the concentration of tritium in the air, the contribution made by gamma background must be subtracted. This subtraction is accomplished by means of the gamma compensation ion chamber detector.

4.2.5 Gamma Compensation Ion Chamber Detector. The gamma compensation ion chamber detector is equal in size and shape to the tritium detector but is isolated from the air being monitored. It will only react to gamma radiation. The mark on the instrument can closest to the front of the instrument identifies the center of the gamma chamber. The current produced by this detector is electrically subtracted from the tritium chamber's current by the electrometer board, which provides an output voltage proportional to the tritium level only.

4.2.6 Electrometer Board and Temperature Sensor. The electrometer board is mounted to the gamma and tritium chambers and is connected to the electrodes of both chambers. The signal produced by the detector is an extremely low DC current in the order of femtoamperes that is applied to the electrometer, which converts the low-level DC current into a DC voltage to send to the amplifier on the main board. The electrometer board also has a temperature sensor that produces an analog voltage. This analog voltage is measured by the microprocessor on the main board. The electrometer board has a gasketed lid with a window to view the desiccant. To work effectively, the electrometer board must be kept clean and dry.

4.2.7 Pump. The pump draws incoming air through the instrument and through the tritium ion chamber detector. The air passes through the pump and is then exhausted from the equipment by the OUT nozzle back into the area being monitored or to a designated location. The pump used to draw air into the tritium chamber is a relay-driven positive displacement pump. It is powered by the pump drive circuit, consisting of a transistor switch and switching power supply.

4.2.8 Power Supply. The equipment is capable of operating from 85-250 VAC 50/60 Hz power (thru a supplied +12VDC AC/DC power supply) or from internal AA-sized batteries**.** While the instrument is operating with +12VDC power applied, the internal batteries, if low, may be recharged with a constant (approximately 100 mA) circuit. The +12 VDC regulated voltage provides input power to the main board, which produces 5 VDC and several other voltages. The power supply board also has a relay to activate the tritium chamber heater when in the PURGE mode, as well as signal relays that provide contacts for remote indication of alarm and sampling conditions.

4.2.9 Primary AA Batteries. The instrument may be operated from internal AA batteries, mounted in a battery compartment at the bottom of the instrument. See Section 5.2 for replacement of these batteries. Nickel-metal hydride (NIMH) or alkaline batteries may be used. Note that the battery compartment does also contain a self-resetting fuse (a positive temperature coefficient resistor) designed to protect the batteries from short circuits. The batteries can be either rechargeable or non-rechargeable. Ensure the selector switch is switched to the correct type.

4.2.10 Amplifier. The output of the electrometer is applied to the range-dependent amplifier on the main board for current amplification to input to the A/D converter of the microprocessor. This amplifier provides three levels of gain, adjusted by the microprocessor for the three ranges of measurement from 0-100 µCi/m^3, 100-1000 µCi/m^3, or 1000 to 10,000 µCi/m^3 (or Bq/m^3 equivalent). The microprocessor uses the serial communications lines SDI and SCL to communicate with the transflective LCD (liquid crystal display).

4.2.11 Processor. The processor is located on the main board and is responsible for handling all the inputs and outputs of the instrument. The instrument's firmware is stored in flash memory on the processor. The processor also has variables and parameters that may be adjusted via software. Inputs to the processor include analog voltages representing temperature, pressure, chamber bias, and the amplified electrometer signal. The outputs include a pulse-width-modulated (PWM) output for an electrometer offset, as well as digital outputs to turn on the internal heater and the airflow pump.

4.2.12 Pressure Sensor. The pressure sensor is located on the main board and produces an analog voltage related to the atmospheric pressure. This voltage is measured and utilized by the microprocessor to make compensations for the variation in air density.

4.2.13 Display. The display, located on the front panel, supplies status and measurement information to the user. The tritium concentration level, which can be displayed in µCi/m^3 or Bq/m^3, is displayed in a large font. Other information, like current temperature or pressure, is less prominent. The display has a backlight, controlled by a 295-degree rotary control on the front panel. The display is controlled by a serial interface by the microprocessor.

4.3 PUMP AND AIR FLOW SYSTEM.

The air flow system is shown in Figure 4-3. Air is drawn into the instrument through the input particulate filter. The air then moves to the mass airflow sensor, then the ion trap, then the tritium ion chamber. The tritium ion chamber detector is where the ionization, occurring while the air containing tritium is in the detector, is collected as ionization current. This current is proportional to the tritium level in the chamber. If the gamma background radiation is compensated for, this tritium chamber current is exactly proportional to the tritium (or other radioactive gas contamination present in the air stream). The air is then removed through the pump and then to the OUT outlet. The pump operates on a regulated direct current voltage provided by the power supply on the main board.

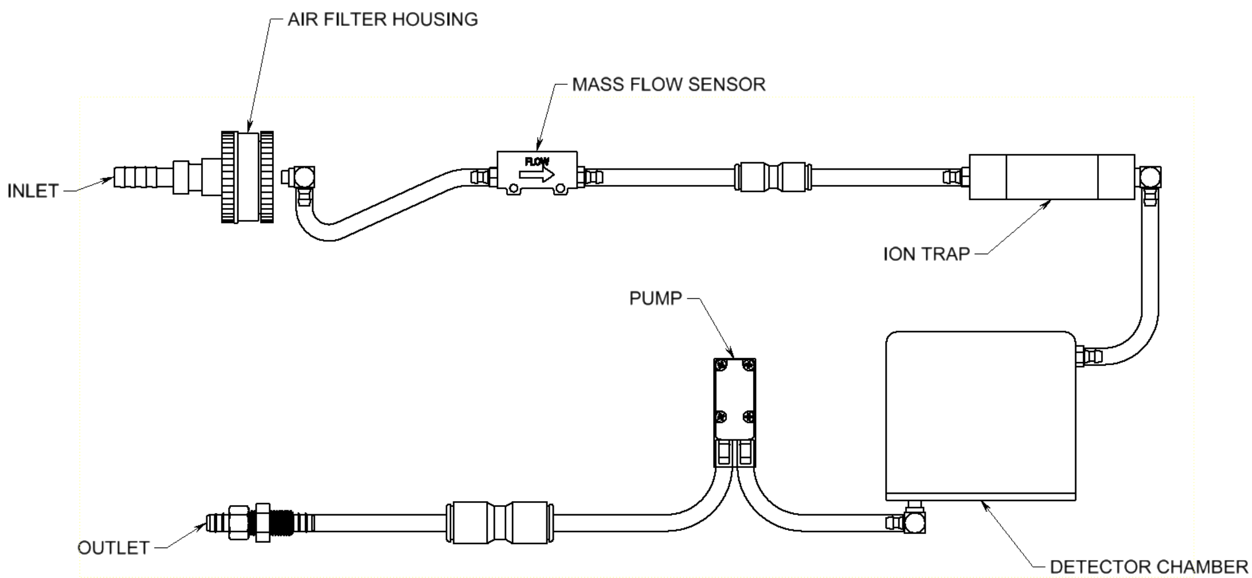

Figure 4-3. Air Flow Diagram.

4.4 RADIATION DETECTION.

The Model 3101 has two ionization chambers – one to measure tritium and the other to subtract out background interference from the tritium measurement. These two chambers are mounted into the bottom of the instrument can, which has marks on the outside to identify the center of each chamber. The mark on the instrument can closest to the front of the instrument identifies the center of the gamma chamber. The mark on the instrument can closest to the back of the instrument identifies the center of the tritium chamber. The chambers are mounted together on an aluminum plate, with the electrometer circuit board mounted on the top of the plate. These two chambers and the associated electrometer board (commonly called an electrometer) are the basis for the radiation detector of Model 3101.

4.4.1 Chambers. The cylindrical chamber housings, approximately 250 cc in volume, are constructed from drawn aluminum and are powder-coated black on the outside wall. Chamber wall thickness is 0.032 in. (0.081 cm). The wall of the tritium chamber, which is electrically isolated, is maintained at approximately -75 VDC, while the wall of the gamma chamber, which is also electrically isolated, is maintained at approximately +75 VDC. The center electrodes of both chambers are connected electrically together at the electrometer board. Since gamma background affects both chambers, this parallel subtracting arrangement provides the gamma compensation so that the resulting electrometer signal is due solely by the additional ionization within the tritium chamber.

The electrodes of both ionization chambers are connected to the electrometer board input and are maintained at guard potential by the electrometer.

For air (at standard temperature and pressure: 22 °C and sea level), the average energy W to ionize a single ion pair is 34 eV/ion pair. The expected ionization current per µCi (37,000 disintegrations per second) of tritium (identified as "I" in the following equation) in the chamber, given a W of 34 eV in air, the charge of an electron equaling 1.60207×10^{-19} C, and an average beta tritium energy of 5.65 keV (assuming negligible wall losses since the maximum range in air of tritium is approximately 5 mm) is:

$$I = (5.65\text{x}10^{3}\ \text{eV}) \times (37{,}000 \text{ disintegrations per second}) \times (1.60207 \times 10^{-19}\ \text{C}) \ / \ 34\ \text{eV}$$

$$I = 9.9 \times 10^{-13} \text{ coulombs/sec}$$

$$I = 0.99 \text{ pA (per µCi of tritium)}$$

4.4.2 <u>Electrometer.</u> The electrometer consists of summed electrodes providing a net signal to the input of a guarded trans-impedance amplifier with a feedback resistor that provides a short time constant. A short time constant means that the chamber reacts quickly. Large spikes in the output data are caused by radon or other alpha emitters, which have approximately 1000 times the energy of the tritium beta particle (5.5 MeV vs 5.65 keV). These spikes are filtered out in firmware, without affecting the tritium signal, using a proprietary algorithm.

Given a chamber volume is 250 cm^3, and that the current is measured with a feedback resistor of 500 Gohm (=$500\text{x}10^9$ ohms), then the resulting voltage output of the electrometer V, per microcurie/m^3 is:

$$V = (0.99 \times 10^{-12})\ (250 \times 10^{-6})(500 \times 10^{9}) = 0.124 \text{ mV per µCi/m}^3$$

The voltage output of the electrometer board is then connected to the main board for further processing.

4.4.3 Main Board Radiation Signal Processing.

4.4.3.1 <u>Amplifier Range Change.</u> The microprocessor on the main board controls the amplification of the electrometer signal. The Model 3101 is auto-ranging so the user doesn't have to switch a range control as the radiation level changes, but internally, the microprocessor controls three ranges to properly adjust the amplifier gain. The microprocessor starts in the X1 range, which covers from 1 to 100 µCi/m^3 (0.037 to 3.7 MBq/m^3). When the chamber reaches 100 µCi/m^3 (3.7 MBq/m^3), the output of the electrometer is 12.4 mV relative to guard potential, and the gain on the main board is switched to the X10 range. When the chamber reaches 1000 µCi/m^3 (37 MBq/m^3), the output of the electrometer reaches 124 mV relative to guard potential, and the gain on the main board is switched to the X100 range. The top calibrated reading is 10,000 µCi/m^3 (370 MBq/m^3) when the output of the electrometer reaches 1240 mV relative to guard potential.

4.4.3.2 <u>Offset Adjustment.</u> The electrometer operational amplifier (op amp) will have some offset voltage. An internal calibration control on the main board marked OFF provides an offset voltage that can be adjusted during calibration to null out the electrometer offset voltage.

4.4.3.3 <u>Analog-To-Digital Input.</u> The voltage from the amplifier section of the main board then enters the analog-to-digital (A/D) input of the microprocessor. The microprocessor samples and measures this voltage input every 200 milliseconds. It compares this input to the 2.5 V reference voltage and digitizes the result. The microprocessor uses proprietary digital filters to average the results and then converts the readings into the calibrated displayed reading.

CHAPTER 5
SCHEDULED MAINTENANCE

5.1 <u>CLEANING.</u> Cleaning the Model 3101 is important in keeping it in working order and in helping the instrument last. The following is the procedure for cleaning the instrument.

5.1.1 <u>Preparation.</u> Shut the instrument down properly before cleaning.

a. Turn the MODE SWITCH to OFF.

b. Disconnect the AC/DC power supply if attached.

5.1.2 <u>Clean With Care.</u>

<u>CAUTION</u>

Do not immerse the instrument in any liquid.

Gently wipe all exposed surfaces with a damp cloth, using only water as a wetting agent. Allow instrument to dry thoroughly before reuse.

5.2 <u>BATTERY REPLACEMENT.</u> Turn the MODE switch to OFF, and disconnect the AC/DC power supply if attached before replacing the batteries.

5.2.1 <u>Remove Batteries.</u> Open the battery lid by removing the screws (Figure 5-1). Remove the 8 NIMH AA batteries from the compartment (see Figure 5-2).

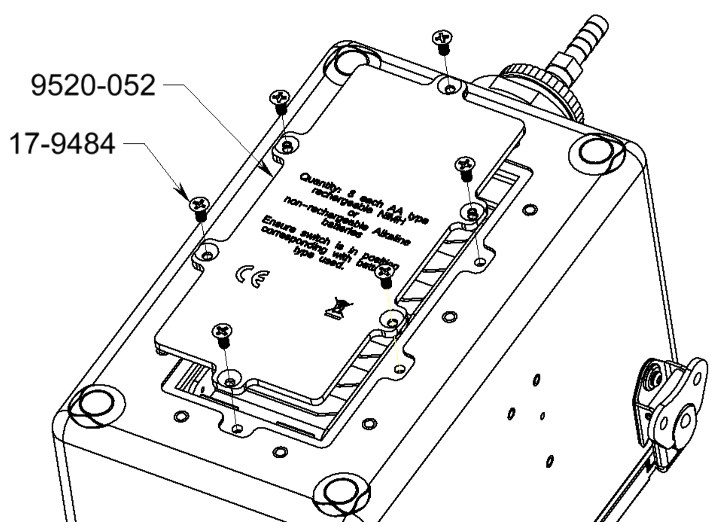

Figure 5-1. Battery Lid Removal

5.2.2 <u>Install Batteries Properly.</u> Install 8 NIMH AA batteries into the compartment (see Figure 5-2), taking care to orient all batteries correctly. Note the (+) and (-) marks inside the battery holder. Match the battery polarity to these marks.

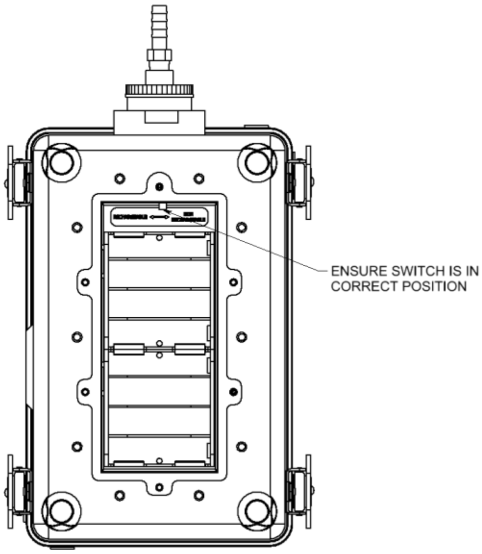

Figure 5-2. Battery Compartment.

Insert all batteries to match these marks. The center post of each battery is positive. Note that batteries are placed in the battery compartment in alternating directions.

Ensure the battery selection switch (Figure 5-3) is in the correct position for rechargeable or non-rechargeable batteries.

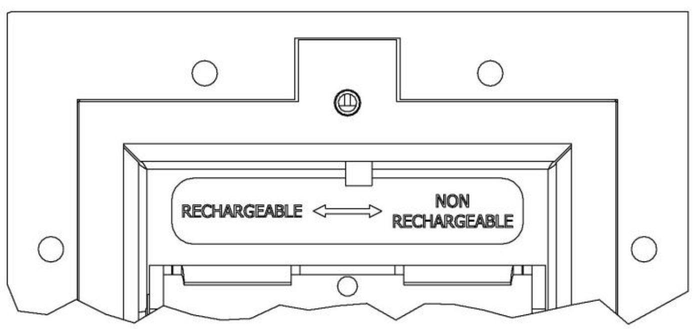

Figure 5-3. Battery Selection Switch

Reinstall the battery lid by tightening all the screws around the perimeter of the battery lid.

5.3 REPLACING ELECTROMETER DESICCANT. In the event the desiccant needs to be inspected and/or replaced, perform the following procedure.

5.3.1 Inspection and Removal. Turn the rotary Mode knob to OFF and remove the AC/DC power supply if applicable. Open the instrument using the four rotary draw latches on the sides of the instrument and carefully lay the front panel over so that the electrometer section is visible. Visually inspect the desiccant. A clear window in the electrometer lid is provided to view the desiccant.

a. If the desiccant is all blue, then it is in working order and will protect the sensitive electrometer electronics from moisture.

b. If the desiccant is pink, carefully remove the electrometer lid using the four screws and replace the desiccant packs with new or rejuvenated desiccant packs.

Note: It is recommended to remove HV bias batteries and discharge chamber wall voltages (using HV bias battery slug), and to disconnect the electrometer board ribbon cable before removing electrometer lid.

CAUTION

Be careful not to touch the electrometer board with your bare hand. Oils from your skin can cause electrical leakage, resulting in erratic readings.

5.3.2 Replacement/Rejuvenation. The pink (wet) desiccant may be replaced with fresh desiccant packs or rejuvenated as follows:

a. Rejuvenate the desiccant by:

(1) Placing the pink desiccant in an Erlenmeyer flask in a microwave oven on the high setting for a maximum of 20 seconds. Then allow to cool for a minimum of 60 seconds.

(2) If water vapor is apparent, wipe off the water and heat for 20 seconds. Repeat these steps until no water vapor is seen.

b. Once the desiccant is replaced or rejuvenated, replace the electrometer lid using the four screws. See Figure 5-4.

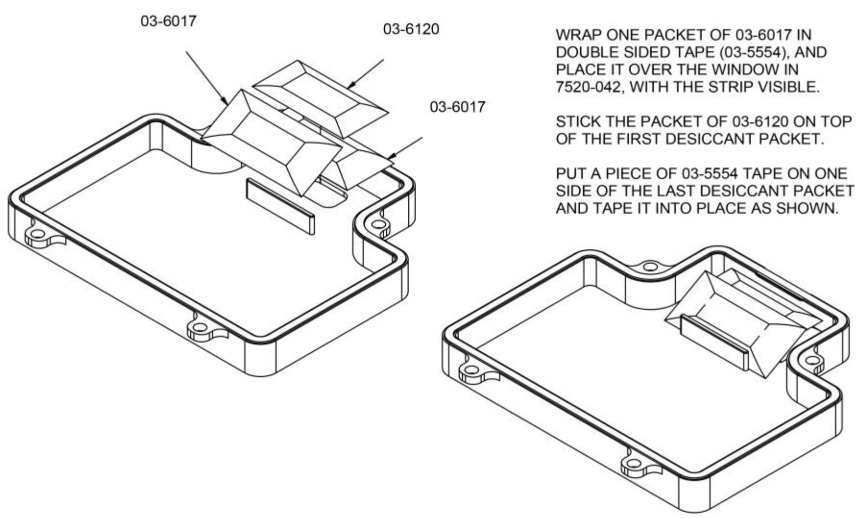

Figure 5-4. Electrometer Desiccant.

5.4 REPLACING PARTICULATE FILTER. The particulate filter is user-replaceable and is located at the front of the instrument. Under normal use, it will gradually become clogged with trapped particles and limit the airflow. In the event the particulate filter at the front of the instrument needs to be inspected and/or replaced, perform the following procedure. (See Figure 5-5.)

5.4.1 Particulate Filter Removal. Turn the rotary Mode knob to OFF and remove the AC/DC power supply if applicable. Unscrew the filter holder from the front of the instrument. The instrument is designed to hold the bottom half of the filter holder, this will allow access to the thin 25mm filter.

5.4.2 Particulate Filter Replacement. Place Whatman 25mm GF/F filter (or equivalent) in the filter housing base (connected to the instrument). Screw top half of housing onto bottom half until hand tight. See Figure 5-5.

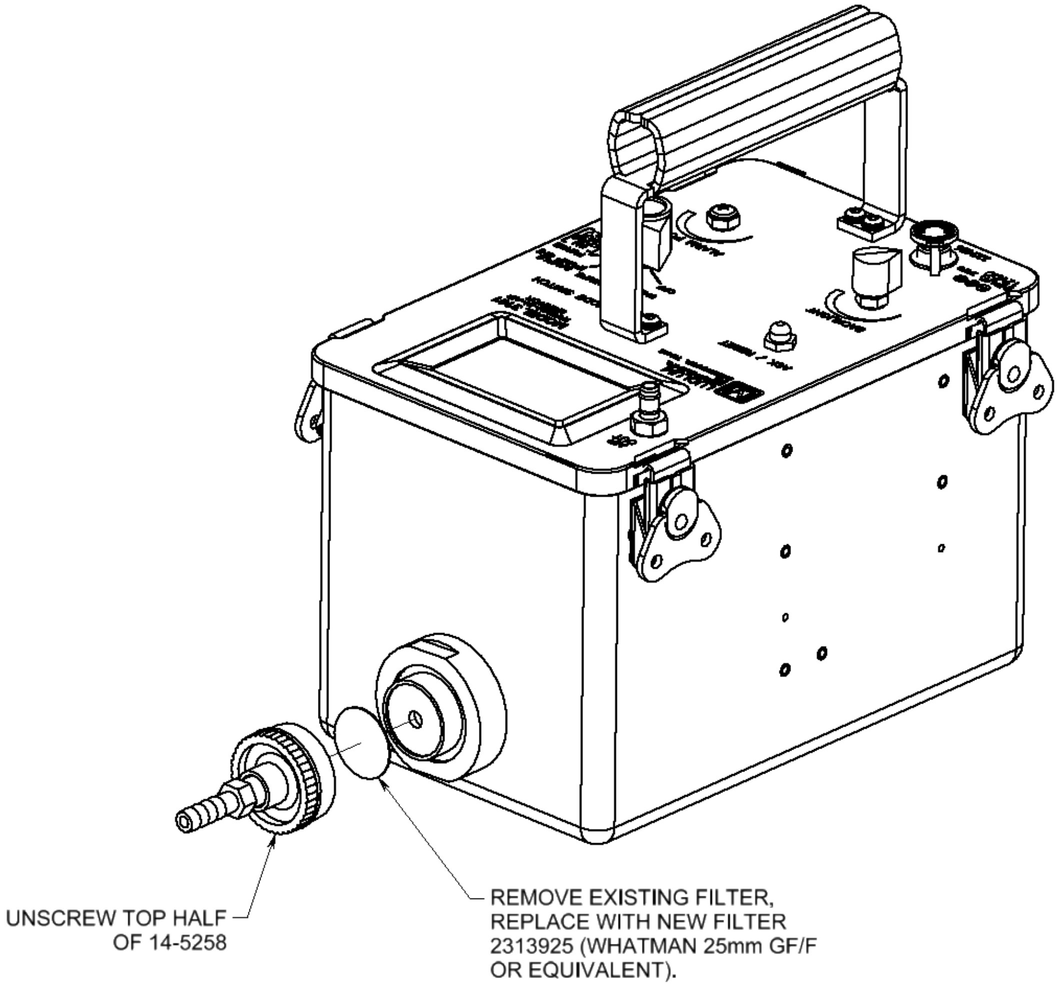

Figure 5-5. Particulate Filter Replacement.

CHAPTER 6
TROUBLESHOOTING

6.1 FAILURE DURING CHECK MODE. A FAIL or "X" on the display when the Mode switch is in the CHECK position can be caused by a number of different problems. Note that this section contains information for procedures for both user (organizational level) and repair (intermediate level) personnel.

6.1.1 Temperature. If the internal operating temperature goes outside the normal operating range of the instrument (from 32 to 122 ^{o}F {0 to 50 °C}), and this temperature is not obviously caused by environmental conditions, an adjustment of the instrument by a technician may be required.

6.1.2 Pressure. If the internal pressure goes outside the normal operating range of the instrument (from 76 to 120 kPa), and this pressure is not obviously caused by environmental conditions, an adjustment of the instrument by a technician may be required.

6.1.3 HV+. If the internal positive high voltage (used to bias the internal gamma chamber) goes outside the normal operating range of the instrument (from 50 to 100 VDC), a replacement of this internal battery by a technician may be required.

6.1.4 HV-. If the internal negative high voltage (used to bias the internal tritium chamber) goes outside the normal operating range of the instrument (from -50 to -100 VDC), a replacement of this internal battery by a technician may be required.

6.1.5 Operational Check. The operational check may be performed electronically or with an external gamma source. In either case, a failure to measure the correct value within 20% may result. If an external gamma source is being used, ensure that it is the correct source and that the placement of the source is correct per Section 2.3.4. If this action does not result in a correct reading, repair by a technician may be required.

6.1.6 Problem Still Exists. If after performing the operational check, and/or battery replacement (as appropriate) the instrument still exhibits an improper reading, the problem is most likely electrical in nature and service by a technician may be required

6.2 LOSS OF BIAS (CHAMBER) VOLTAGE. If during power on, or whenever the CHECK position of the Mode switch is chosen, the words "Fail HV Pos" (positive) or "Fail HV Neg" (negative) show on the display, then it is likely that one or both lithium coin cell batteries is old or weak. Replacement of these internal batteries by a technician may be required.

6.3 LOSS OF AIRFLOW. If a minimum airflow of 0.8 L/min is not maintained, a message on the display will warn of "Fail Air." Low airflow is most commonly the result of a clogged particulate filter. The particulate filter should be replaced immediately, or the instrument response time may be longer than desired. If replacing the particulate filter does not clear the "Fail Air" message, then some other airflow restriction may be present. Check the IN and OUT hose connections to see if the restriction can be pinpointed and corrected.

6.4 TEMPERATURE FAILURE. If the temperature reading on the display begins to flash, then the measured temperature is beyond the operating temperature range of the instrument. To restore proper operation, reduce or increase the temperature as necessary. If this message is seen in error, then it is possible that the temperature sensor, located on the electrometer board, has failed and should be replaced by a technician.

6.5 LOW POWER. If the message "Low Batt" is shown on the display, then it is likely that the primary batteries need to be replaced or recharged. Ensure that when replacing batteries (Section 5.2), the battery selection switch (Figure 5-3) is in the correct position for rechargeable or non-rechargeable batteries. Alternatively, operation is possible if the external AC/DC power supply is properly connected into a source of 85-250 VAC power.

6.6 LEAKS. Perform the can assembly and the air circuit leak tests if a leak is suspected. The leak test procedure for the Model 3101 ensures that the air circuit is functioning properly and water ingress will be limited to ensure compliance with MIL-STD-810G Method 506 Procedures I and III.

6.6.1 Can Assembly Leak Test.

a. Open the front panel of the Model 3101 by loosening the four latches.

b. Disconnect tubing from quick-disconnect in-line connector. See Figure 6-1.

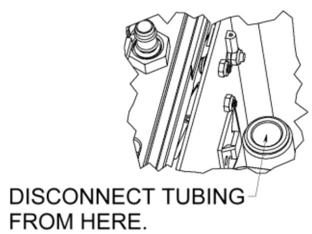

Figure 6-1. Loosening Air Hose.

c. Apply grease to the front-panel gasket as required.

d. Close the front panel by securing all four latches tightly.

e. Attach the handheld vacuum pump to the OUT port located under the air filter. See Figure 6-2.

f. Plug the IN port. See Figure 6-2.

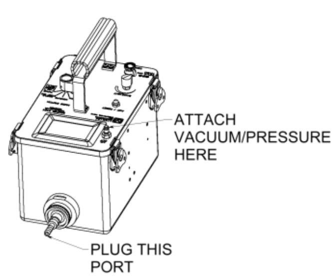

Figure 6-2. Vacuum.

g. Apply a vacuum of -5 inches Hg.

h. If the vacuum is held, proceed to Air Circuit Leak Test, Section 6.6.3.

i. If the vacuum is not held, identify and repair leaks.

6.6.2 Identifying Can Assembly Leaks.

a. Open the front panel of the Model 3101 by loosening the four latches.

b. Disconnect tubing from quick-disconnect in-line connector. See Figure 6-1.

c. Apply grease to the front-panel gasket as required.

d. Close the front panel by securing all four latches lightly.

e. Attach the handheld air pump (electronic pump such as the one in the Model 3101 may be used with caution) to the OUT port located under the air filter. See Figure 6-2.

f. Plug the IN port.

g. Apply air pressure.

h. Water test options:

(1) Dunk the unit under water while applying pressure in order to locate air bubbles.

(2) Spray the unit with soapy water/bubbles while applying pressure to identify leaks.

6.6.3 Air Circuit Leak Test.

a. Open the front panel of the Model 3101 by loosening the four latches.

b. Ensure all air hoses are properly connected.

c. While the front panel is open, attach the vacuum pump to the OUT port located under the air filter. See Figure 6-2.

d. Plug the IN port. See Figure 6-2.

e. Apply a vacuum of -5 inches Hg.

f. Verify that the vacuum is holding before proceeding.

g. If the vacuum will not hold, identify and repair the leak. Repeat the air circuit leak test before proceeding.

CHAPTER 7
PARTS LIST

Table 7-1. Parts Details for Model 3101.

Item	Part Number	Manufacturer	CAGE Code	Reference Number	Description
Model 3101	48-4366	Ludlum	23609	Figure 1-1	In-air tritium monitor, including accessories
AC/DC power supply	8303-1029	Ludlum	23609	Section 4.2.8	Wall-mount AC/DC +12V power supply

Table 7-2. Replaceable Parts for Model 3101.

Other replaceable parts referenced in this manual include:

Item	Part Number	Manufacturer	CAGE Code	Reference Number	Description
Batteries	21-8844	Duracell	90303	Section 5.2	NIMH AA batteries
Desiccant	03-6017, 03-6120	Multisorb Technologies	22627	Figure 5-4	1g, 1.5g desiccants in electrometer
Particulate Filter	2313925	Whatman Inc.	3S4C7	Figure 5-5	glass fiber filter 25mm diameter, grade GF/F
Clear Silicone Dielectric Grease	14-5359	W.W. Grainger, Inc.	25795	Section 2.4.4	3 oz, super lube, NLGI Grade 2

Table 7-3. List of Manufacturers.

CAGE Code	Name and Address
23609	Ludlum Measurements, Inc. 501 Oak Street Sweetwater, TX 79556
90303	Duracell Duracell Berkshire Corporate Park Bethel, CT 06801
22627	Multisorb Technologies 325 Harlem Rd. Buffalo, NY 14224
3S4C7	Whatman Inc. 800 Centennial Ave., Bldg. 1 Piscataway, NJ 08854
25795	W.W. Grainger, Inc. 100 Grainger Pkwy Lake Forest, IL 60045

APPENDIX A
CALIBRATION

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A.1 CALIBRATION PROCEDURES.

All instruments used in the calibration of the Model 3101 must be calibrated by standards traceable to the National Institute of Standards and Technology and must have a current calibration label attached. Calibration for the Model 3101 involves calibrating the pressure, the airflow, tritium calibration, and check source reading of the instrument.

A.1.1 Equipment Required.

LMI can provide the following items:

a. Model 3101 calibration software (part # 1370-090)

b. RS-232 9-pin D to phone plug adapter cable (part # 8303-1038)

c. Connector RJ12 inline coupler (part # 13-7676)

d. Model 9-4 pressure calibration kit (part # 4293-675)

e. Calibrated air flowmeter (part # 2313771)

f. Gamma +HV battery replacement "slug" (part # 7520-152)

The other required equipment items include:

g. A ^{137}Cs source capable of exposure rates of 0.25 mR/hr to 25 mR/hr, if using the gamma calibration method, OR a Model CL-1 Tritium Calibrator with traceable tritium gas cylinder attached

h. Weather station or barometer to measure current temperature and atmospheric pressure

i. Low background area (≤ 10 μR/hr)

A.1.2 Initial Checks.

If any calibration procedure cannot be completed satisfactorily, the instrument shall be tagged and removed for proper disposition.

a. Perform mechanical checks and visual inspections to ensure that the switches, buttons, seals, and other mechanical devices function properly and that no obvious defects are present.

b. Turn the instrument on, rotating the mode switch to the CHECK position. Verify the audio is activated briefly, and record the firmware number from the initial screen.

c. From the CHECK display, verify battery voltage and/or +12 VDC voltage from mains voltage. Ensure that power measures +12 VDC or above when the AC/DC power supply is plugged in. If using rechargeable batteries, ensure that they are above +10 VDC, or charge overnight and check again. If using non-rechargeable batteries, ensure that battery voltage is above +10 VDC.

d. Verify also, from the CHECK display, that both the HV+ and HV- (the two bias batteries) are reading at ±50 to ±100 V or above. Replace the HV bias batteries if necessary, waiting an hour after battery replacement to ensure stable operation before continuing.

e. Perform Air Circuit Leak Test. See Section 6.6.

f. Ensure that the airflow is OK (typically between 1.0 and 2.0 L/min). Low airflow is typically caused by either a kinked hose or a clogged particulate filter. Straighten or replace the hose or replace the filter as necessary to restore normal airflow.

g. While in CHECK Mode, rotate the alarm point potentiometer completely counter-clockwise to zero. When the alarm potentiometer is changed, a pop-up alarm point screen shows the setpoint value. The pop-up alarm point screen MUST be allowed to close (approximately three seconds with no change) and return to the check screen in order to save the new alarm point value.

h. If the check screen shows a failure condition, and then fix the condition highlighted on the screen before continuing. If the check screen shows OK, rotate the MODE switch to the MEASURE position.

A.1.3 Computer Connection.

a. Assuming the interface software has been previously loaded on your PC, connect the USB-to-serial adapter to the test the computer; next connect the other end of the calibration cable to the Model 3101 9-pin "D" connector, located inside the instrument. Refer to the software manual for further information.

b. Pull up the Model 3101 software program on the computer. The first thing you should see when the program loads will be a selector box. Choose the "Model 3101" as the instrument choice. The second screen will be a small dialogue box entitled, Select Device Serial Number, in front of the main program screen. This refers to the USB adapter, which is now plugged into the USB port of your computer.

c. Confirm that the serial number displayed in the software matches the instrument's serial number. If it does not, correct it. (If correcting the instrument serial number is not necessary, skip the remainder of this section and proceed to the Section A.1.4 Pressure Calibration to continue.)

d. Once the serial number is corrected, tab over to the next field to get to the Update button on the lower right-hand corner to turn pink. Press the Update button to save the correction just made.

e. Do a Ctrl + R (press the Ctrl key followed by the R key) to reload all data. This is to confirm that the correction just made to the serial number has been saved correctly.

A.1.4 Setting the Board ADC Offset and Pressure Calibration.

a. The following steps b. through m. may be skipped if the unit has been previously calibrated and no repairs have been made.

b. From the computer, enter the BOARD ADC VALUE into the Board ADC Offset box. This shall be **less than 0.050**. If the BOARD ADC VALUE is greater than 0.050, repeat step A.1.2.h.

c. Obtain the current atmospheric pressure reading. If the pressure reading is in "inHg" (inches of mercury), convert the pressure reading from inHg to kPa by multiplying the pressure reading by 3.3864. (Example: If the pressure reading on a weather station reads 27.67 inHg, multiply this by 3.3864 to get 93.701688. The number to use in this example is 93.70.)

d. The Pressure Calibration button must be selected. Before pressing it, open the Model 3101 can by turning the four latches. Locate a small black surface mount component at the top edge of the circuit board. This is called the "pressure sensor." Take the vacuum pump hose and attach it to this part.

Note: Take special care that you do not pull or cause the vacuum line to slip off of this component. If it comes off during the next set of steps, you will have to start your pressure calibration over again in order to do it correctly.

e. Squeeze the trigger slowly until you drive the needle on the vacuum pump gauge to -10 inches of mercury (10 inHg). If you do go past the -10 value, slightly pull on the release valve until you either settle back over -10 or slightly under where you can increase by pulling on the trigger.

f. Once the gauge is showing -10 inHg vacuum, click on the Pressure Calibration button. A dialogue box will appear to enter Low Pressure Value in kPa. This value is calculated by subtracting 33.86 from the current atmospheric pressure obtained in the first step of this section.

g. Once the Low Pressure Value has been entered, select the Take Voltage Readings button.

h. The Voltage readings will populate in the window (ensure that these values are fluctuating near the displayed average voltage reading.) Once the status bar has completed, press the ACCEPT button in lower right corner of the dialogue box. Two possible problems indicated by non-fluctuating values could be a loss of communication between the software and instrument or a loss of vacuum.

i. The next dialogue box will appear to enter High Pressure Value. Remove the vacuum pump from the pressure sensor before proceeding. Then select the Take Voltage Readings button.

j. The voltage readings will populate in the window (ensure that these values are moving around the average.) Once the status bar has completed, press the ACCEPT button in the lower right corner of the dialogue box.

k. The next dialogue box will appear as a reminder to update the new calculated pressure values. Press OK.

l. The UPDATE button on the main window must be selected to save the new Pressure Calibration Slope and Offset.

A.1.5 Airflow Calibration. This step in calibration is optional and is recommended for new instruments or whenever airflow miscalibration is suspected.

a. Connect a calibrated airflow meter to the input (the port labeled IN) of the Model 3101.

b. Operate the instrument in SAMPLE mode, and compare readings from the external flowmeter to the Model 3101 displayed value.

c. If there is a significant difference between the two readings, adjust the Airflow Cal Constant value on the Pressure/AirFlow tab of the software until the two readings match.

Note: Since this instrument utilizes a diaphragm pump, airflow readings taken from the outlet (port labeled OUT) of the Model 3101 may be incorrect.

A.1.6 Zeroing: Electrometer Offset.

a. Adjust the Electrometer Offset value in software in order to change the background display value to 0 µCi/m^3. This value shall be between 1.8 and 2.1.

b. If using the Electrometer Calibration Wizard, target a filtered ADC average between -10.0 and 0.

Note: It is recommended to confirm that the instrument is zeroed correctly by enabling streaming. Streaming through the software is recommended since the data shown has better resolution. The instrument readings should be less than 1.000 µCi/m^3, but occasionally greater than 0.000 µCi/m^3.

A.1.7 Tritium Calibration. The Model 3101 calibration software is used to adjust the calibration constants for each of the three tritium ranges – from 1to 100 µCi/m^3, from 100 to 1000 µCi/m^3, and from 1000 to 10,000 µCi/m^3. These three Calibration Constants are found on the ^{3}H Calibration tab of the software.

a. There are four calibration methods for calibration of the tritium readout on the Model 3101.

    1. **Three point tritium calibration** is recommended by ANSI 42.30 (2002), and for the Model 3101, requires three tritium gas concentration levels of approximately 25 µCi/m^3, 500 µCi/m^3, and 7500 µCi/m^3. Using this method, the calibration constant is adjusted to correct the displayed tritium concentration value of the Model 3101 at each of the three ranges. See Section A.2 Use of the CL-1 Tritium Gas Calibrator.

2. **Single point calibration** is easier, requiring a single tritium gas concentration value. A calibration constant is adjusted at this one concentration point to correct the displayed tritium concentration value of the Model 3101. Using this method, all three ranges are set to the same calibration constant. See Section A.2 Use of the CL-1 Tritium Gas Calibrator.

3. **Three point gamma calibration** uses an open-air ^{137}Cs calibration range. This calibration method uses a manufacturer-determined gamma equivalence value to determine gamma fields to establish known readings in the middle of each range. Using this method, a calibration constant is adjusted to correct the displayed tritium concentration value of the Model 3101 at each of the three ranges. In this mode, the gamma compensation chamber is disabled by substituting the calibration kit's gamma +HV replacement "slug" in place of the gamma +HV battery. See Section A.3 Use of a Cs-137 Gamma Calibration Range.

4. **Single point gamma calibration** uses an open-air ^{137}Cs calibration range. This calibration uses a manufacturer-determined gamma equivalence value to determine a gamma field to establish a known reading. A calibration constant is adjusted at this one concentration point to correct the displayed tritium concentration value of the Model 3101. In this mode, the gamma compensation chamber is disabled by substituting the calibration kit's gamma +HV replacement "slug" in place of the gamma +HV battery. Using this method, all three ranges are set to the same calibration constant. See Section A.3 Use of a Cs-137 Gamma Calibration Range.

A.2 USE OF THE CL-1 TRITIUM GAS CALIBRATOR.

A.2.1 Equipment Required.

a. Becton Dickinson Cl-1 Tritium Calibrator or equivalent traceable tritium gas injection device.

A.2.2 Unpacking.

a. The calibrator is shipped disassembled (in accordance with government regulations) into three main parts.

   1. Gas cylinder containing approximately 60 liters of tritiated methane at approximately 1600 PSIG.

   2. Lecture bottle regulator and adaptor fittings.

   3. Calibrator base plate.

b. Unpack each part and inspect them for damage.

A.2.3 Assemble Calibrator.

a. Remove the cap plugs from the regulator connector and outlet valve connector of the regulator. Inspect and clean the regulator connector, if necessary, to ensure that the sealing O-ring is in place. Inspect and clean the outlet valve connector also, if necessary.

b. Remove the threaded dust plug from the gas cylinder and inspect and clean the sealing surface, if necessary.

c. Adjust pressure by slowly turning the outlet pressure adjust knob clockwise to approximately 15 PSIG on the outlet pressure gauge.

d. Carefully slide the gas cylinder and regulator into the gas cylinder holder on the calibrator base plate. It may be necessary to loosen the cylinder-locking screw. Line up the outlet valve connector with its mating fitting on the calibrator base plate. Remove and discard the three caps on the base plate tubing.

e. Hand-tighten the outlet valve connector. Tighten the cylinder-locking screw and finish tightening the outlet valve connecter with a wrench.

f. Connect the two lengths of plastic tubing supplied to the inlet and outlet of the calibrator.

A.2.4 Leak Check.

a. Close metering outlet valve and open both metering inlet valve and regulator outlet valve.

b. Apply pressure to regulator by opening lecture bottle valve.

c. Adjust pressure by slowly turning the outlet pressure adjust knob clockwise to approximately 15 PSIG on the outlet pressure gauge.

d. Close the lecture bottle valve to isolate tubing from the gas supply. If the system is leaking, the cylinder pressure gauge will slowly drop.

e. A tight system should lose less than 50 psi on the cylinder pressure gauge in one hour.

f. If tubing is leaking, determine whether the leak is in the regulator part or in the metering volume and associated valves.

g. Having determined the portion which is leaking, tighten appropriate connections and retest.

Note: The calibrator is a precision instrument capable of accurate, reproducible results. Operation is simple, but erroneous results can be obtained if an incorrect technique is used. Before proceeding further, note that the bellows-sealed valves on either side of the metering volume have Teflon seals, which close with a small amount of pressure.

CAUTION

The valves may be damaged by the use of excess pressure when closing them.

Note: Before injecting tritium gas into the instrument's chamber, air must be flushed from the calibrator.

A.2.5 Initial Procedure. The procedure need only be done the first time the cylinder is connecting to the regulator.

a. Open the lecture bottle valve momentarily, reclosing tightly.

b. Open the metering outlet and inlet valves, as well as the regulator outlet valve. Turn the regulator outlet pressure adjust knob clockwise until the cylinder pressure gauge drops to 0.

c. Close the metering inlet and outlet valves and back off the outlet pressure adjust knob.

A.2.6 Flushing. The metering volume should always be flushed before performing a calibration.

a. Check to see if the metering inlet and outlet valves are closed, the regulator outlet valve is open, and the outlet pressure adjust knob is backed off counterclockwise until it is loose.

b. Momentarily open and reclose the lecture bottle valve, admitting as to the regulator and causing the cylinder pressure gauge to indicate.

c. Turn the outlet pressure adjust knob clockwise until the outlet pressure gauge reads about 20 psi.
d. Momentarily open and reclose metering inlet valve.

e. Momentarily open and reclose metering outlet valve, flushing the metering volume.

f. Repeat steps "d" and "e" if required. The calibrator is now ready for use.

A.2.7 Closed Loop Calibration.

a. Connect the calibrator outlet hose to the outlet of the instrument and turn on its air pump.

b. If the cylinder pressure gauge shows any pressure reading, there is enough gas contained in the regulator to proceed with the next step. If not, momentarily open and close the lecture bottle valve so that this gauge reads upscale.

c. Open metering inlet valve. Metering outlet valve should be closed.

d. Turn the outlet pressure adjust knob slowly clockwise, watching the reading on the outlet pressure gauge.

e. When the outlet pressure gauge reads the desired injection pressure (typically 20 or 30 psi), close the metering inlet valve.

f. Connect the inlet hose to the inlet connector on the instrument.

g. Open the metering outlet valve for between two and four seconds, and then reclose it firmly. Longer or shorter times will lead to incorrect results.

h. In the above step, a known aliquot of gas was injected into the chamber. To inject a second aliquot, repeat Steps “c” to “f” above. Any number of aliquots may be injected with the instrument reading increasing proportionately.

In closed-loop calibration, the activity enters the chamber rapidly but is then redistributed throughout the volume of the instrument and calibrator gas system. Since the bulk of the volume is in the tritium ion chamber, the scale reading will rise (spike), then drop, and then level off to a constant value independent of time constants or pumping speeds. The indicated scale reading depends solely upon the system volume and the pressure in the aliquot as described in the next section.

A.2.8 Calculation of Response. Using the technique described in the previous section, the 11 mL metering volume is always kept filled with tritiated methane. When the outlet pressure gauge reads 20 psi and the metering inlet valve is open, the actual methane pressure in the metering volume is 35 psia. With the metering inlet valve closed and metering outlet valve opened momentarily, the methane pressure in the metering volume is now 15 psia. This means the mass of methane injected can be calculated from the pressure differential (35-15 psia), which is equal to the scale reading of the outlet pressure gauge.

It is very important to open the metering outlet valve for only 2 to 4 seconds. A longer opening time allows the residual 15 psia of pure methane in the metering volume to mix with the air stream flowing into the calibrator tubing, eventually distributing this extra gas throughout the system volume. The instrument scale reading will then correspond to injection of 35 psi of gas using the formula below. Although this technique can be used, we do not recommend it since it is slower and somewhat less reproducible.

A.2.8.1 Formula.

The response can be calculated using:
v = metering volume (11.0 mL in the CL-l)
V = total volume of instrument plus calibrator (in mL)
P = gauge pressure of gas in metering volume (psig) (i.e., reading of outlet pressure gauge)
A = original specific activity of gas in lecture bottle (µCi/liter at 25 °C and 14.7 psia)
n = number of aliquots injected
d = tritium decay since cylinder calibration (see below)
T = ambient temperature (°C)

The volume of gas injected =

$$nv \cdot \frac{P}{14.7} \cdot \frac{298}{273+T} \text{ ml}$$

Hence, activity injected =
$nv \cdot \frac{P}{14.7} \cdot \frac{298}{273+T} \cdot dA \times 10^{-3}$ µCi

So tritium concentration =
$nv \cdot \frac{P}{14.7} \cdot \frac{298}{273+T} \cdot \frac{dA}{V}$ µCi /m3

For the case where v = 11.0 mL and T = 25 °C, this becomes:
Tritium concentration = $0.75 \frac{nPdA}{V}$ µCi/m^3

The value of V is the sum of:

a. the inside gas volume of the Model 3101 (254 mL);
b. plus the volume of connecting tubing between the calibrator and the Model 3101 (48 inches of ¼ inch ID tubing is 39 mL);
c. plus the volume of tubing in the CL-1 calibrator (37 mL).

Thus, the total value of V, assuming a total of 48 inches of ¼ inch ID tubing is used to connect the gas calibrator to the Model 3101, is 330 mL.

Since tritium decays with a 12.26 year half-life, the specific activity of the cylinder gradually decreases. Be sure to get a current specific activity of the cylinder using the following formula:

Given that:
d = decay factor
HL = half-life (12.26 years for tritium)
T = years elapsed since original specific activity
$d = e^{-(0.693 \times T / HL)}$

A.2.8.2 Example of Decay Calculation.

What is the decay factor of a tritium gas cylinder calibrated a year ago?
$d = e^{(-0.693 \times 1 / 12.26)}$
d = 0.945

A.2 8.3 Example of Tritium Concentration Calculation.

Given that a tritium gas cylinder with a concentration of 45 x 10^3 µCi/m^3, calibrated a year ago, with a gauge pressure of 60 psi, what is the concentration of tritium gas with a single injection into a total volume of 330 mL at 25 °C and sea level?
d = 0.945 (as calculated above)
V = 330 mL
v = 11 mL

Tritium concentration
= 11mL/14.7psi*60 psi*0.945*45 x 10^3 µCi/m^3 /330mL,
= 5786 µCi/m^3

Note: If using a dilution method to obtain lower reading after final aliquot, the Model 3101 shall be placed in MEASURE Mode during valve manipulation.

A.3 USE OF A ^{137}CS GAMMA CALIBRATION RANGE. A ^{137}Cs gamma range can be used to calibrate the tritium readings of the Model 3101. The use of a gamma range can simplify the calibration, avoiding the complications of using tritium gas.

A.3.1 Equipment Required

a. ^{137}Cs gamma calibration range, NIST-traceable capable of producing a uniform gamma field from 0.15 to 60 mR/hr (if doing the three-point calibration), or a single point within this range if doing the single-point calibration method.

Note: The gamma equivalence value for the Model 3101 was determined by calibrating multiple instruments using NIST-traceable tritium gas concentrations. Once calibrated, the gamma compensation chambers were disabled by replacing the +75 V HV gamma bias battery with an aluminum slug of the same size. The units were then exposed to a uniform field from a NIST-traceable ^{137}Cs gamma source, and an equivalence established:
1 mR/hr ^{137}Cs = 177.6 µCi/m^3.

So, for a three-point calibration, the following gamma fields could be used:

0.25 mR/hr = 44 µCi/m^3
2.5 mR/hr = 444 µCi/m^3
25 mR/hr = 4440 µCi/m^3

A.3.2 Disabling the Gamma Compensation Chamber. Before starting on the gamma range, the following procedure should be used to disable the gamma compensation chamber.

a. Turn the Model 3101 instrument to OFF, rotate the four quarter-turn latches, and open the instrument.

b. Using a flat-blade screwdriver, remove the battery marked "+HV Gamma" from its holder. Be careful not to short both ends of the battery together. It is good practice to put the battery into a small plastic bag.

c. Replace the battery with the aluminum substitute "slug" (LMI # 7520-152). This action disables the gamma compensation on the instrument, making the instrument sensitive to gamma fields once the voltage from the bias battery has been completely discharged. This could take several hours.

d. Wait a minimum of 1 hour for settling time before continuing. Ensure the gamma wall voltage is fully discharged by shorting one of the two vinyl-covered screws near the HV bias batteries to the detector plate as pictured below.

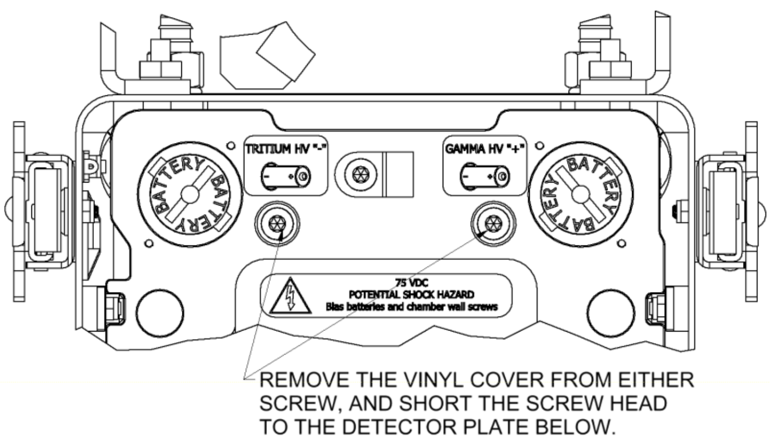

Figure A-1. Discharging Gamma Wall Voltage.

e. Turn the instrument back ON and verify proper operation. Note that you will get a warning about the lack of +HV, but this can be ignored during this procedure.

A.3.3 Placement of Model 3101 on the Gamma Range. Place the instrument on the gamma range with the front of the Model 3101 facing the gamma source (see Figure A-2). The dimple on the side of the can closest to the back end of the instrument marks the center of the tritium chamber for alignment purposes. To ensure a uniform gamma field, the instrument shall be at least 28 inches away from the radiation source.

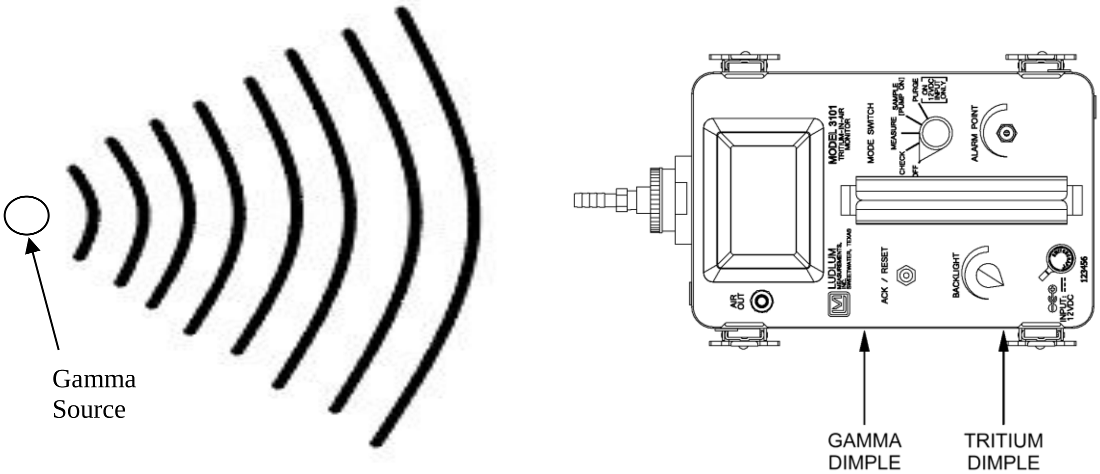

Figure A-2. Calibration Setup.

a. Record the background reading (which may be elevated since gamma compensation is disabled).

b. Expose the Model 3101 to the desired uniform gamma field using the dimple marks on the "can" to center the chamber. Note that the response time of the instrument is approximately one minute. If the instrument does not read the correct value after one minute has elapsed, increase or decrease the calibration constant for the appropriate range as needed until the correct value is reached. See Table A-1 for recommended calibration fields. "Cal" indicates the recommended point for adjusting the calibration constant, while "Ref" indicates where the reference reading is taken to confirm linearity.

Table A-1. Recommended Calibration Fields.

^{137}Cs µSv/h (mR/hr)	Tritium µCi/m^3 Equivalence	Range/Test
600 (56.4)	9967	During effective range of measurement
450 (42.3)	7475	X 100 Cal
150 (14.1)	2492	X 100 Ref
45 (4.23)	748	X 10 Cal
30 (2.28)	498	X 10 Ref
4.5 (0.42)	75	X 1 Cal
1.5 (0.14)	25	X 1 Ref

Note: Be sure to account for background reading when performing calibration. To calculate calibration constants: (Expected Reading/ Net Reading) * Existing Calibration Constant = New Calibration Constant.

c. The calibration software contains a calibration wizard to ease calibration. See the Model 3101 calibration software manual for more detailed instructions.

d. Repeat calibration steps for the remaining range multipliers, or if doing a single point calibration, copy the calibration constant found to the other two ranges.

A.4 FINAL CALIBRATION STEPS. If the ^{137}Cs range calibration method was used to calibrate the tritium reading, turn off the instrument and replace the +HV gamma bias battery, making sure to insert it into the holder correctly. Close the instrument and turn it back ON. Verify that the +HV measurement in the check screen has a check-mark beside it. Wait a minimum of four hours settling time to continue.

a. Review the parameters and settings and make sure that they are saved inside the instrument. There are two parameters that should be reviewed at this point:

   1. **Alert:** this parameter establishes a fixed alarm point, independent of the user-settable alarm point. If not desired, a set point of 0 disables this feature.

   2. **Check Source Mode and Target Reading:** The check source test is typically used on a daily or as-used basis, and can be either internal, or one can use an external check source. Choose either external or internal, and then enter the target reading you expect the source to cause. When the test is performed, the check should cause a reading within 20% of the target reading, or else the word FAIL will be displayed. See Section 2.3.4 for more detailed instructions.

b. Print your parameters by one of two methods:

   1. Go to Parameters at the top of the program screen and click there to get the drop-down menu to locate and select Print Parameters.

   2. Simply press the Ctrl and P keys to print.

c. Before closing the software program, take note of the firmware number located immediately to the left of the Update key at the bottom right corner of the program screen. This number should be documented in the comments section of the certificate of calibration.

d. Document all readings on an appropriate calibration form. Include a printout of parameters along with the calibration certificate.