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A WIDE RANGE TRITIUM MONITOR

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Abstract

An ionization chamber consisting of two active volumes in a single enclosure and an auto range changing electrometer covering a dynamic range of 10^8 are discussed. The tritium monitor is designed to have a reduced sensitivity to tritium contamination, to have a fast response, and to be useful for tritium concentrations of a few $\mu\text{Ci}/\text{m}^3$ to $10^8 \mu\text{Ci}/\text{m}^3$.

Introduction

There is a need for a wide dynamic range tritium monitor that has the sensitivity required for routine room or stack monitoring that can also react to unexpectedly large concentrations that may result from an accident. As a stack monitor, such an instrument should have a fast response time so that the total release can be determined. It is also desirable that the instrument have a reduced sensitivity to tritium contamination. Such an instrument, consisting of an ionization chamber having two active volumes in a single enclosure, combined with an auto ranging electrometer covering two 4-decade ranges, is described below.

Ionization Chamber Design

A schematic view of the wide range tritium monitor is shown in Fig. 1. The active region consists of 13 grids forming two active volumes, labeled low range monitor and high range monitor. The low range section has a geometric volume of 1.0 l with 15 mm grid spacing. The high range section has a geometric volume of 0.1 l with 7.4 mm grid spacing. The grids consist of stainless steel rings 9.5 cm in diameter, supporting stainless steel mesh with a 0.01 mm wire width and a pitch of 2 lines per cm. The grids are supported by 6 ceramic rods, 3 supporting the high voltage grids and 3 supporting the alternate collector grids. The collector grids are operated at ground potential and the high

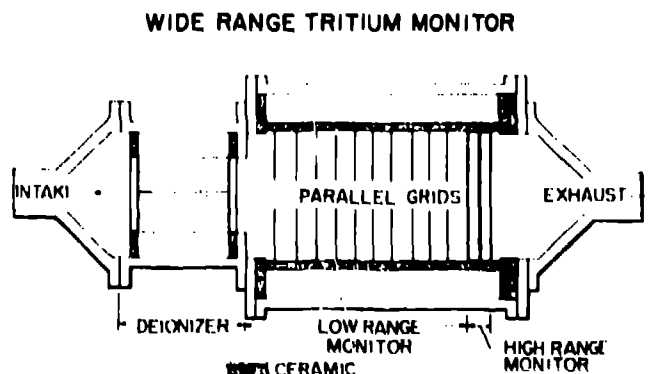


Fig. 1. Schematic view of the wide range tritium monitor

voltage grids are operated at +150V. This voltage produces an electric field of 100V/cm in the low range section and 200V/cm in the high range section. The short distance and high electric field in the high range section are to reduce recombination at high concentrations. Figure 2 is a photograph of two ionization chambers, one assembled and the second one partially disassembled.

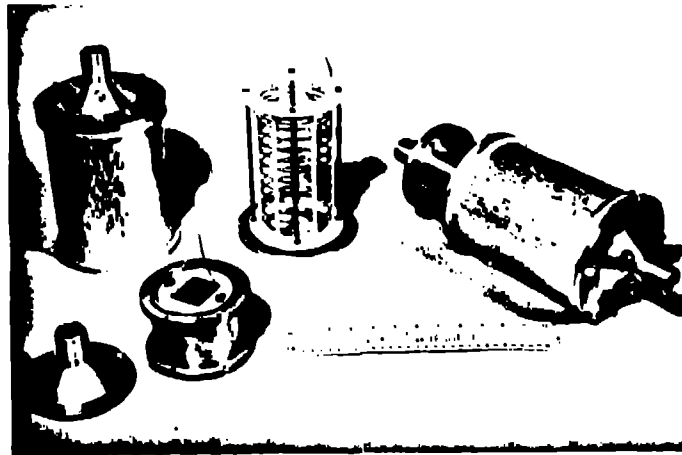


Fig. 2. Photograph of two ionization chambers, one assembled and the second partially disassembled

To reduce the problem of contamination due to tritiated oil or condensation of tritium water vapor, the inner wall of the chamber is 10 mm from the active volume. The maximum range of the tritium betas in air under standard conditions is 7 mm. Even at Los Alamos, New Mexico, where the pressure is only about 70% of an atmosphere, the maximum range is only 10 mm. Thus, with the chamber walls at the same potential as the collection grids, tritium-contaminated walls will not contribute to the signal. The contribution due to contamination is further reduced by making the electrodes out of fine grids to reduce the surface area.

A deionizer is provided to remove ions from the air before entering the chamber. The deionizer is made of parallel stainless steel plates spaced 4 mm, with alternate potentials of +150V and ground. The deionizer plates are supported by a ceramic frame and use the same +150V power supply as the tritium monitor.

It should be noted that although our first chamber used ceramic as the insulator, we have found that permall works as well, is less expensive, and much easier to fabricate.

Electronics Design

Figure 3 is a block diagram for the current- and charge-measuring electronics used with the wide range detector. The two electrometer amplifiers receive current signals, SIG 1 and SIG 2, from the large-volume (low range) and small-volume (high range) sections of the detector.

The low range electrometer is a varactor bridge type, housed in a temperature-controlled enclosure to assure long term zero stability.¹ The enclosure maintains its cavity temperature at $40^\circ \pm 0.5^\circ\text{C}$ for ambient temperature from 20° to 35°C . The electrometer drift is $2 \times 10^{-15}\text{A}$ (2 fA) or less after the oven and its contents have had several hours to stabilize. The electrometer (Teledyne Philbrick Model 1702) was chosen for excellent low frequency noise characteristics, low long term drift, good resistance to input overload transients, and low cost. The high range electrometer is a low cost FEI type, with its transimpedance resistor scaled appropriately for the range desired and for the smaller chamber volume.

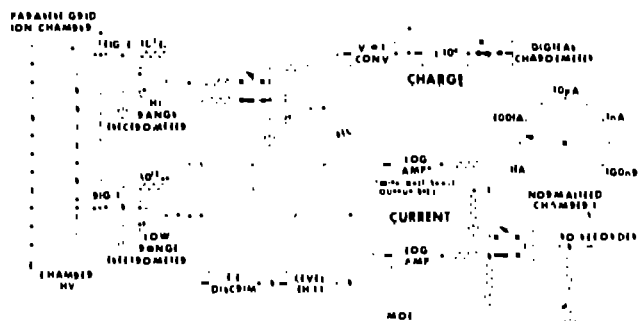


Fig. 3. Block diagram of the current and charge-measuring electronics

Each electrometer amplifier feeds its own 4-decade logarithmic amplifier. A solid state switching arrangement, figuratively shown with dashed joining lines in Fig. 3, connects only one input signal at a time to the current- and charge-measuring circuits. The crossover sensing between the two sets of circuits is done with a discriminator that triggers at the full scale level on the low range electrometer. If the time constants of the electrometer circuits are nearly matched, this crossover switching at low impedance levels can be done with minimal transient effect at the wide range output.

The final 8-decade analog current output indication is derived by mixing the two logarithmic amplifier outputs. The low range readings, spanning 1 fA to 10 pA, are fed directly to the output indicators if the crossover discriminator has not been triggered. The high range readings spanning 10 pA to 100 nA are superimposed upon a half scale dc bias voltage, giving continuity of readings over the full 8 decades.

Charge measurement is made with a low drift voltage-to-frequency converter fed from the switched linear outputs of the electrometer amplifiers. The pulse train from the converter is counted to provide digital signal integration, which is a measure of charge. Chargemeter readout is a digital display that covers 10 decades from 10^{-12} C/digit to 10^{-2} C full scale. There is a 3 digit readout with exponent multipliers. The counting scale factor is changed by 10^4 at the transition point between high and low current ranges. Readout of charge is auto ranging whereby the 3 most significant digits with non-zero information are displayed along with the correct exponent multiplier. If more than 3 significant digits are desired, the entire chargemeter memory contents can be read out manually, using a thumbwheel switch to select the exponent multipliers.

If background levels from the ionizer chamber are constant, a "reverse" current of as much as 100 fA can be injected to the input of the low range electrometer with the "Background Suppress" control. This reduced the undesired accumulation of charge from background over long integration periods.

Remote readout from the instrument is achieved with optional peripheral devices. A strip chart recorder may be used at the current meter output, or the analog level can be sent to a data acquisition system. The charge meter output consists of an analog level corresponding to the magnitude of the contents of the 3 decades of digital indicators, along with a 3-line BCD code for the associated exponent multiplier.

Several peripheral system requirements and features should be noted. The parallel electrode arrangement in the ionization chamber results in a high inter-electrode capacitance. Therefore, the chamber high voltage supply must have very low noise to avoid capacitively coupled noise into the electrometer. Batteries, or a highly filtered, regulated power supply, should be used. The capacitance of the chamber must also be stable, and the detector needs to be protected from microphonic sources to minimize mechanical noise. As is true of any sensitive electrometer system, signal cables between the detector and the electrometer must be short and rigid. The system described here allows the electrometer head to be close to the ionization chamber, but the control and readout chassis may be as far as 50 to 100 m from the point of measurement. A photograph of the chassis and low range electrometer preamplifier and the ionization chamber are shown in Fig. 4.

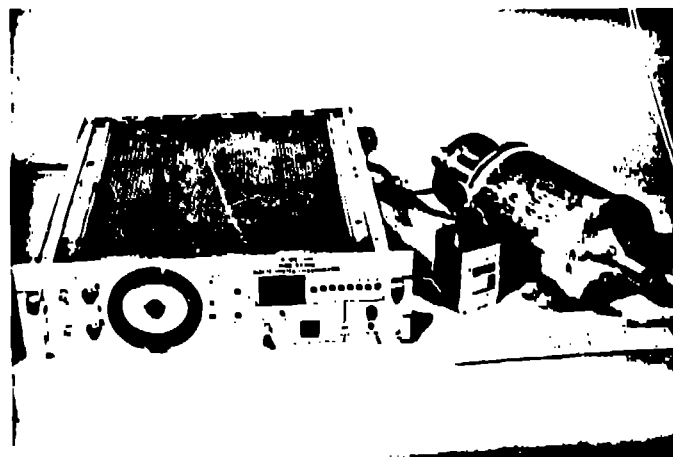


Fig. 4. Photograph of the chassis and low range electrometer preamplifier and the ionization chamber

Performance

The wide range tritium monitor was first calibrated at the Los Alamos Gamma Calibration range. Radiation fields of 1.9×10^{-3} to 1.2×10^3 R/h were used. The output current, automatically normalized to the 1 cc chamber, was recorded. The results of the gamma calibration are shown in Fig. 5. At the range change, marked on the figure, there was slight deviation from a straight line. This corresponds to a reading about 5% too high at the range change caused by a submillivolt offset in the zero of the high range electronics. The results of the gamma calibration showed the monitor to be linear over almost 8 decades, with the limitation in the dynamic range due to the electronics and not the ionization chamber.

The wide range tritium monitor was then calibrated with four concentrations of tritium. These concentrations were 27, 81, 215, and 430 $\mu\text{Ci}/\text{m}^3$ shown as points A through D on Fig. 5. Points B, C, and D fall on a straight line. The large uncertainty in the 27 $\mu\text{Ci}/\text{m}^3$ measurement was due to the short measurement time used (100 sec.). The best fit to the tritium calibration was

$$C = 1.03 \times 10^{15} i,$$

where C is the tritium concentration in $\mu\text{Ci}/\text{m}^3$ and i is normalized current in amps. From these data it can be seen that in a low background environment and with a current integration time of a few minutes to average out signal fluctuations, tritium concentrations of a few $\mu\text{Ci}/\text{m}^3$ should be easily measured. A concentration of $10^8 \mu\text{Ci}/\text{m}^3$ is trivially measurable.

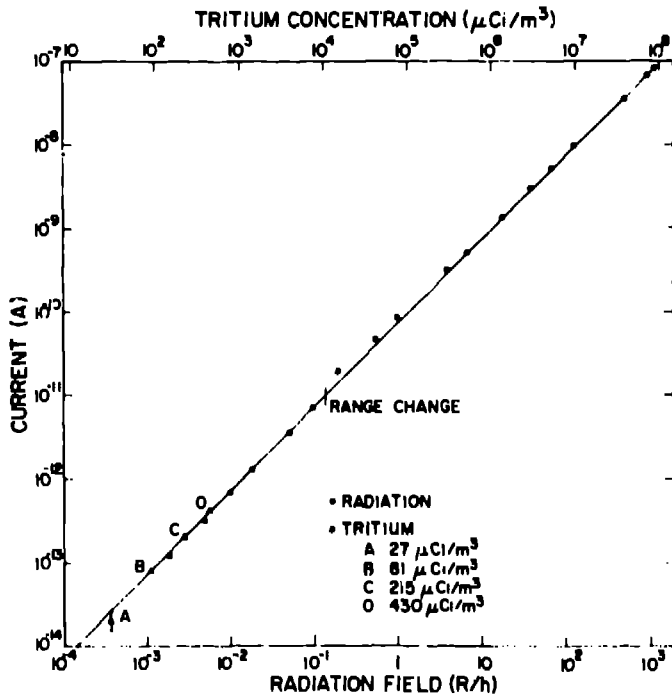


Fig. 5. Current normalized to the 1 s chamber, as a function of the gamma field and tritium concentration

The time constant of the current meter is one second, to allow faithful tracking of high concentrations of tritium. This fast response time results in large fluctuations from noise and signal statistical considerations at the most sensitive end of the scale. Therefore, as indicated above, signal averaging from charge readings is necessary for accuracy at low tritium concentrations.

The wide range tritium monitor was found to have a long hysteresis when dropping from the high range to the low range. The response time of the high range, and of the low range (without having been in the high range first), is just the time constant of the electronics. However, shortly after the monitor has shifted to the high range, the low range electrometer amplifier saturates and the virtual ground operation at the input is lost, causing a voltage buildup on the collector grids of the low range chamber. This voltage buildup on the insulators of the system results in dielectric absorption of charge in the insulators. When the radiation is reduced and the amplifier comes out of saturation, the charge slowly comes out of the insulators, giving a long recovery time. The low range chamber recovers to about 2×10^{-13} A in 2 minutes but takes half an hour to return to zero.

In hopes of reducing this charge injection problem, ceramic, permali, and polystyrene have been used as insulators, with similar results for all three. A solution to the problem would be to physically ground the input of the low range preamp at the range change. This would prevent the voltage buildup. In a complete operating system, this electrical hysteresis will not be a practical problem because the system would likely have hysteresis characteristics that dominate.

Conclusion

We have demonstrated a tritium monitor with a dynamic range of 10^8 for measuring tritium concentrations of a few $\mu\text{Ci}/\text{m}^3$ to $10^8 \mu\text{Ci}/\text{m}^3$. This instrument should be very useful for routine monitoring in applications where unexpectedly large concentrations of radioactive gases may be experienced, as at nuclear power plants. Its reduced sensitivity to contamination also makes it a useful instrument for monitoring the output of the vacuum pumps at fusion power plants and at particle accelerators.

References

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