A NEW SOLID STATE TRITIUM SURFACE MONITOR

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Traditionally the amount of tritium on a surface is determined by swiping the surface with a material such as filter paper and counting the removed tritium by scintillation. While effective, this method can be time consuming, can alter the surface, only measures removable tritium and produces radioactive waste. For a given application each of these considerations may or may not be a disadvantage. A solid state monitor, on the other hand, has the potential to provide rapid analysis, not alter the surface, measure all tritium on a surface and produce little or not radioactive waste. This allure has promoted open wall ion chamber and PIN diode-based tritium surface monitor development, and these techniques have enjoyed certain success. Recently the first tests were performed with an avalanche photodiode (APD) for surface tritium measurement. While quite similar in concept to PIN diode based measurements, side-by-side testing showed that the APD provided substantially better counting efficiency. Considerations included count rate, background, sensitivity, stability and effect of ambient light. Of particular importance in the US, the APD was able to measure concentrations down to the "free release" limit, i.e., the concentration below which items can be removed from radiological control areas.

I. INTRODUCTION

A key component of radiological control in tritium facilities is measurement of tritium surface concentrations. This is needed to prevent the spread of contamination, determine appropriate personnel protective equipment and to assess the effectiveness of decontamination activities. Measurements are particularly important at radiological boundaries to determine whether or not items can be cleared (released for use) outside of the facility. Currently this function is accomplished by swiping the item and measuring the removed tritium with scintillation. This method produces hazardous waste and can be time consuming, especially when centralized facilities are used for counting.

To clear material out of a tritium facility, the material's tritium surface concentration must be measured and shown to be below the free release limit. For many years the free release limit for US DOE (Dept. of Energy) tritium facilities was 1,000 disintegrations per minute per 100 cm^2 (dpm/100 cm^2). Not long ago, DOE increased the free release limit to 10,000 dpm/100 cm^2. However, to maintain an added level of safety, some DOE facilities maintain local free release limits at 1,000. A tritium surface characterization technique will be most useful for US DOE facilities if it is capable of accurate measurements at both levels.

Solid state tritium detectors have potential advantages over the standard swipe/scintillation method. Solid state instruments can be direct-reading, rapid, simple-to-use and waste-free. In earlier work Wampler and Doyle [1] showed that a PIN diode-based system could be used for tritium measurements. However, this method has not yet been shown to be sensitive down to free release concentrations. Avalanche Photodiodes (APDs), on the other hand, have the potential to accurately measure tritium surface concentrations at the free release limits. The first work on APDs was over thirty years ago by Johnston, et al. [2]. And they have been considered for use as various types of tritium detectors by McGann, et al. [3], Surette [4], and Shah, et al. [5]. These references give detailed physical descriptions of APDs.

The present work was dedicated to evaluating the suitability of an APD-based system as a practical technique for measuring tritium surface concentrations at or near the free release limits. This work also has broader implications such as scientific studies which need non-invasive methods for measuring tritium surface concentrations.

II. EXPERIMENTAL SETUP

A 77 mm^2, square-shaped prototype avalanche photodiode (APD) was manufactured by Radiation Monitoring Devices, Inc. (RMD) for testing. RMD also manufactured a prototype electronics package for the APD. This package supplied an adjustable bias voltage to the APD and collected its pulsed signal output. The package included the APD's post-amplification output. This signal was passed to a multi-channel analyzer (MCA) (Amptek MCA800A). The MCA integrated counts from the APD into 1024 channels. The APD gain was set so that the entire tritium beta spectrum (0 to ~18.6

keV) was captured by these channels. Information collected by the MCA was displayed and stored on a laptop computer running Pmca supplied by Amptek. These components are shown on fig. 1.

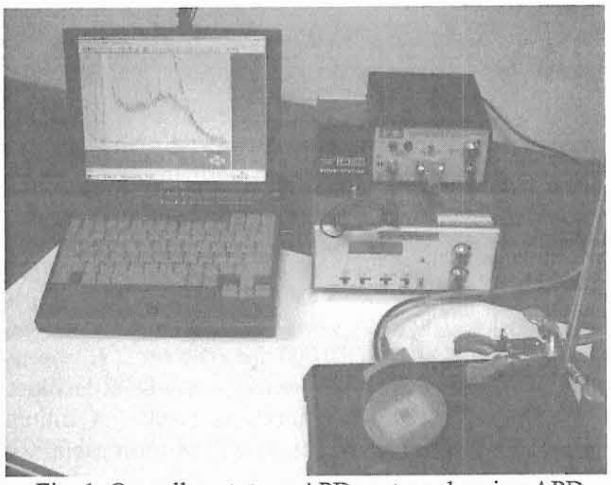

Fig. 1. Overall prototype APD system showing APD within light shroud (diode facing camera), APD electronics package, MCA and data collection laptop

To supply a known beta emission rate to the APD, three commercial tritium surface standards were used. The standards consisted of 100 cm^2 of porous aluminum with each standard containing a different quantity of tritium. The actual beta emission rate from the surface was characterized and certified by the manufacturer using NIST-traceable techniques. The three standards were selected to be nominally 100,000, 10,000 and 1,000 dpm/100 cm^2. The actual characteristics of the three plates used for this test are summarized in Table I.

TABLE I. Tritium Surface Standards Characteristics

Nominal Specific Activity (dpm/100 cm^2)	Specific Activity on Date of Test (dpm/100 cm^2)
100,000	85,440
10,000	11,700
1,000	1,000

All measurements were performed at room temperature. Ambient light can adversely affect measurements. However, this was quite easily controlled by surrounding the APD housing in black polyurethane foam. By lightly pressing the foam against the surface of interest, light was effectively excluded without further measures such as additional shrouding or turning room light off.

To prevent contamination or damage to the APD itself, it was recessed approximately 0.5 mm within its housing. To prevent contamination of the APD housing, 0.14 mm thick polyethylene plastic was placed between the APD housing and the surface of interest. A hole was cut in the plastic so that the surface of interest was directly visible to the APD. Using this setup, the distance from the APD to the surface of interest was maintained at 0.64 mm. It is important that this distance be has short as reasonable and repeatable since tritium beta particles have a limited range in air (1.82 mm for 5.68 keV beta in 1 atm air). All tests were run in air at 0.776 atm (78.6 kPa). Fig. 2 shows the prototype APD separated from the light exclusion shroud and protective plastic.

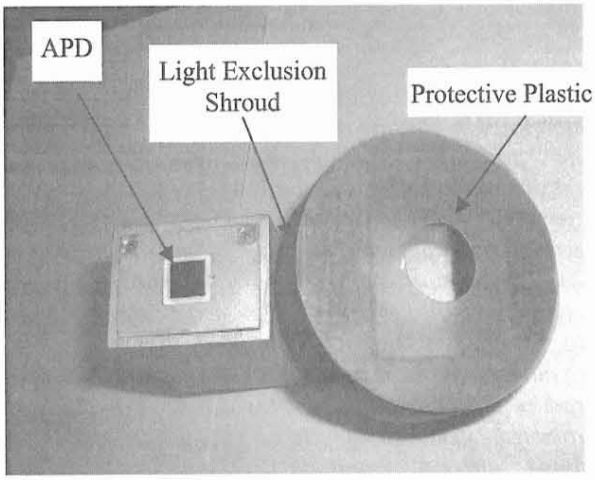

Fig. 2. Prototype APD in housing, light exclusion shroud and protective plastic

III. RESULTS

An example of data collected with the APD is shown on fig. 3. Shown are counts vs. channel (energy) spectrum for the 85,440 dpm/100 cm^2 tritium standard plate. The counts were integrated over 69.8 hours. Extended counting was performed to clearly show the shape of the collected spectrum. Four significant regions are visible in the spectrum. At the far left (channels 0-100) no counts are shown. Counts in this region are dominated by meaningless background, and they are electronically excluded. The next region is channel 100-200 which is the tail of the large background peak. The next region, roughly channel 300-900 is dominated by counts associated with tritium. The last region on fig. 3 is channel 900-1000 where there is no signal above background. These channels are believed to be above the tritium beta cut-off energy.

Long-term measurements were performed with all three tritium standard plates. Fig. 4 shows the collected spectra, expressed as count rate vs. channel. All spectra show similar features.

Proper quantification of surface tritium activity requires measurement of the APD system background. To accomplish this, a sample of non-tritiated aluminum was read. The resulting background spectrum is shown

on fig. 5. The background is not uniform across the region of interest; rather, it peaks at about channel 700.

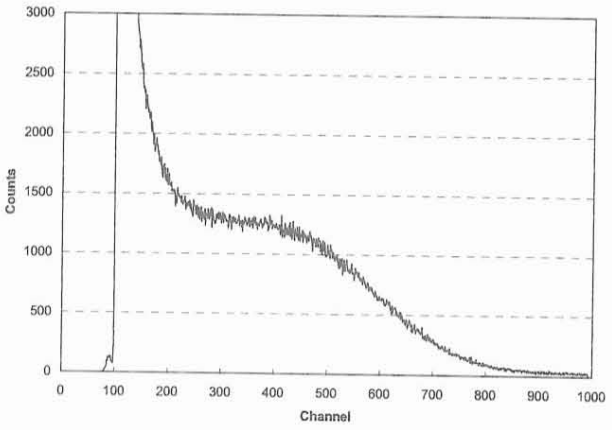

Fig. 3. Counts vs. channel (energy) spectrum collected with prototype APD for 85,440 dpm/100 cm^2 plate over 69.8 hours

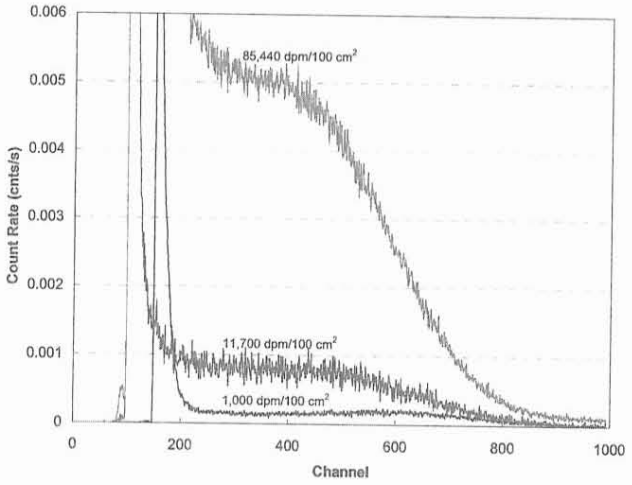

Fig. 4. Spectra for all three tritium standard plates expressed as counting rate

The integrated background count rate over channels 300-1000 was 0.041 cnts/s. The comparable results for the three standards are summarized in Table II. As shown, the integrated count rates for the two highest surface standards are much larger than the background. For the lowest standard (1000 dpm/100 cm^2), the integrated count rate was 0.080 cnts/s—about twice the background. This is sufficient signal over background for reliable measurements, though measurement much below this would not be meaningful.

Calculation of tritium surface concentration should be based on integrated count rate minus background count rate, so this quantity is also given in Table II. These values were plotted versus the actual, total beta emission rate under the 77 mm^2 APD, and the results are shown on fig. 6. The three experimental points fall nicely along a straight line which passes through the origin and has a slope of 0.141.

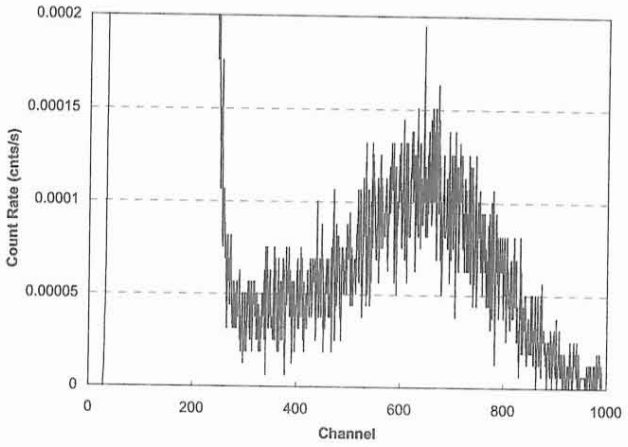

Fig. 5. Background spectrum for aluminum plate

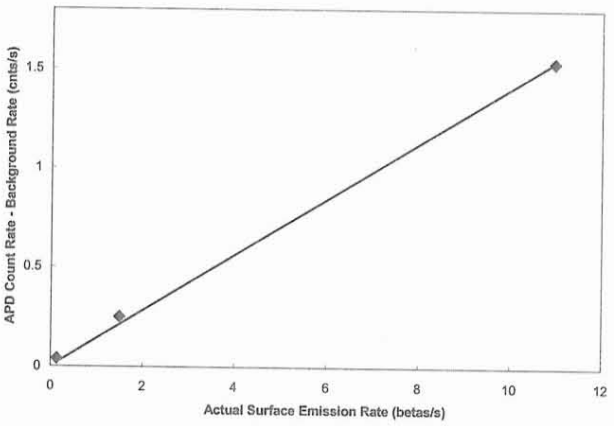

Fig. 6. Comparison of (APD count rate - background rate) to actual beta emission rate

TABLE II. Summary of integrated count rate for three surface standards

Surface Standard (dpm/100 cm^2)	Count Time (hours)	Integrated Count Rate, CN 300-1000, (cnt/s)	Integrated Count Rate minus Backround, CN 300-1000 (cnt/s)	Detection Efficiency (%)
85,440	69.8	1.577	1.536	14.0
11,700	19.4	0.291	0.250	16.7
1,000	96.4	0.080	0.039	29.3

Also shown in Table II is a detection efficiency, i.e., the percent of betas emitted that are detected by the APD. The values shown, 14% to 29% are reasonable considering that significant signal was lost due to air attenuation and that the largest part of the tritium spectrum was not usable due to the large, low-energy background.

Background measurements were performed on a plastic and paper as well as aluminum. These measurements are summarized with Table III. There was no significant difference between materials.

TABLE III. Results of background measurements over various materials

Material Measured	Count Time (hours)	Integrated Count Rate, CN 300-100 (cnt/s)
Aluminum	44.2	0.041
Aluminum	3.3	0.044
Plastic	73.4	0.052
Paper	4.7	0.041

IV. DISCUSSION

Based on these measurements the APD system appears to be a very promising technique for determining tritium surface concentration. The instrument has sufficient sensitivity for practical tritium facility radiation control measures. Such measurement can be obtained with convenient count times of about two minutes.

Traditional swipe/scintillation measures only removable tritium while the APD measures all surface tritium (removable and non-removable). Both types of tritium are of interest. Which type is of most interest depends on the type of control being performed.

The APD can directly measure tritium on flat surfaces. For other surfaces the APD can characterize the surface by swiping the surface and then using the APD to measure tritium on the swipe. Demonstration of this technique is planned for future work.

An APD system has the potential to significantly reduce the amount of waste associated with tritiated surface characterizations. Each swipe/scintillation sample requires a swipe, a vial and cocktail. The APD system would eliminate all of these except possibly the swipe.

For appropriately shaped surfaces, an APD can be used to map surface tritium by rastering the detector across the surface. This method could be particularly useful for contamination/decontamination studies since the APD does not affect the measured surface.

V. CONCLUSIONS

A 77 mm^2 prototype APD system was tested with a view to directly characterizing surface tritium concentrations down to the US free release limits. It was found that:

- The APD can accurately characterize tritium surface concentration at the lowest of the US free release limits, i.e., 1,000 dpm/100 cm^2. Such measurements are attainable with minute-scale count times.
- The APD was stable at room temperature, operated in normal room air, required no surface preparation and, when shrouded, was unaffected by ambient light.
- Excluding the low energy portion of the detection spectrum, the APD background was found to be very low.
- Across three orders of magnitude of surface tritium concentration, the APD response was found to be essentially linear and a calibration curve for the prototype APD was determined.
- As used in these tests, the only waste from APD operations was plastic placed between the APD and the measured surface.
- The APD was found to be stable with backgrounds and tritiated surface measurements remaining the same from day to day.
- Various scenarios were identified for APD use for tritiated surface characterization
- The efficiency (comparison of betas emitted to betas detected) of the APD system ranged from 14% to 29%.

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