Radiation Physics Note 70

AP0 Stack Monitor Calibration

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The Antiproton Target Hall, AP0, is a release point for radioactive gas at the Fermilab site. This area is designed to irradiate a one interaction length target with 120 GeV protons at an intensity of 1E12 protons per pulse and a cycle time of one pulse every three seconds. Stack releases are continuously monitored by a GM based sampling system, identical to the one used at the N01 target hall for several years. These samplers pull air through a 2.25 liter cannister which is shielded by a 2 inch thick layer of lead. A thin window GM probe is mounted in the container and is input to an Eberline RM-14 Ratemeter. This in turn is input to the MUX data logger.

In order to convert the Stack Monitor count rate to a meaningful quantity, i.e. activity concentration, this device is calibrated against a Triton 955B ion chamber, manufactured by Johnston Laboratories. The procedure used is to draw air from the stack through the Stack Monitor, and then into the Triton from which it is then exhausted outdoors. The ratio of Triton response (activity concentration) to the Stack Monitor's background corrected count rate can then be established. A key factor to be understood is that the Triton must be set to the H-3 (tritium) scale. We then **divide by a factor of 5 to convert to C-11 response,** as has been done by Peetermans (Pe72).

A cross calibration was first done for the period 4-11 February 1987. The Triton was monitored by a chart recorder while the Stack Monitor was logged on MUX. As an example, during one period of steady running on February 4, the Triton had a response of about 320 pCi/ml **(H-3 scale)** while the Stack Monitor measured 290 counts in the same hour. The latter system's RM-14 ratemeter was set to divide by 100. Its background count rate was 12 counts/hour. The calibration factor, K, for this period is:

$$K = \frac{320 \text{ pCi/ml}}{5 \times (290 - 12) \text{ cts/hr}} = 0.23 \text{ pCi/ml/ct/hr}$$

A total of 14 representative, one hour periods were selected and the **average calibration factor** was determined to be **0.23 pCi/ml/ct/hr**. This calibration factor is in poor agreement with the value determined for the N01 Stack Monitor system. While sampling the N01 stack, the latter system was found to have a calibration factor of **0.024 pCi/ml/ct/hr** for an RM-14 on the divide by 100 scale (Bu88).

Further investigation could find no record of the actual Triton scale setting used in the initial AP0 Stack Monitor calibration. If the Triton had been set to the x10 scale, then the calibration factor is 0.023 pCi/ml/ct/hr, which is in excellent agreement with the value determined at N01. Since both air sampling systems use identical detectors and electronics, it is likely that the K factor determined originally is in error.

Measurements Using the N01 Stack Monitor at AP0

In order to verify the smaller value K factor, the N01 Stack Monitor system and Triton #4 were set up in the MERL to sample the AP0 stack on 25 February 1988. Initially, the N01 Stack Monitor and Triton were connected in series to a 1/4" I.D. by 40' long hose that was inserted into the AP0 stack from above (see Figure 1). Flow rate was set to 4 lpm; the Triton was set to the H-3 (tritium) x10 scale; and the RM-14 was internally set to a divide by 10 scale. MUX results from February 22, 1988 indicated an N01 Stack Monitor background count rate of 150 cts/hr. (The fixed target run period had ended on February 15, 1988). The first measurement indicated the following:

Triton Meter Face:	21 pCi/ml (H3)/ 5 = 4.2 pCi/ml (C-11)
Triton MUX Output:	61 cts/10 sec x (20pCi/ml / 30Hz) = 4.1 pCi/ml (C-11)
RM-14 Count Rate:	10 cts/30 sec x 3600 sec/hr = 1200 cts/hr
Calibration Factor:	4.15 pCi/ml/(1200-150)cts/hr = **4.0E-3** pCi/ml/ct/hr

Additional measurements were made about 90 minutes later with the following results:

Triton Meter Face:	17 pCi/ml (H3)/ 5 = 3.4 pCi/ml (C-11)
RM-14 Count Rate:	15 cts/36 sec x 3600 sec/hr = 1500 cts/hr
Calibration Factor:	3.4 pCi/ml/(1500-150)cts/hr = **2.5E-3** pCi/ml/ct/hr

Triton Meter Face:	16 pCi/ml (H3)/ 5 = 3.2 pCi/ml (C-11)
Triton MUX Output:	237 ct/60sec x (20pCi/ml / 30Hz) = 2.6 pCi/ml (C-11)
RM-14 Count Rate:	18 cts/60 sec x 3600 sec/hr = 1080 cts/hr
Calibration Factor:	3.2 pCi/ml/(1080-150)cts/hr = **3.4E-3** pCi/ml/ct/hr
Calibration Factor:	2.6 pCi/ml/(1080-150)cts/hr = **2.8E-3** pCi/ml/ct/hr

There is discrepancy of about 20% between the Triton's meter face and its MUX output for the later readings. The average calibration factor for the RM-14 on divide by 10 scale and including the conversion for C-11 is: **3.2E-3 pCi/ml/ct/hr.** If the RM-14 were on the divide by 100 scale, the factor would be **0.032 pCi/ml/ct/hr.** This value is in good agreement with the smaller calibration factor we believe to be correct for AP0. The existing discrepancy is likely due to the short counting periods (1 minute) used during the February 25 measurements. Averaging over a 1-8 hour period would give a better indication of the true calibration factor.

Measurements Using the AP0 Stack Monitor System

The next step was to have the Triton sample the AP0 stack via the tube used by the AP0 stack monitor. Air is drawn through a 1" diameter PVC pipe which has a volume of 8 liters. The Triton had a flow rate of 4 lpm when connected to its own sample tube. This dropped to 3.7 lpm upon connection to the short 1/4" diameter hose which connects to the PVC pipe. After several minutes the Triton meter read 6/5 = 1.2 pCi/ml (C-11 scale). This is a **factor of 3.5 lower** than the concentration measured via the sample hose inserted at the top of the stack. It should also be recognized that during February, the peak count rate for the AP0 Stack Monitor was about 80 cts/hr versus about 300 cts/hr during the previous Collider run period. Assuming that the target intensity was the same, this indicates a decrease by a factor of: (300-12)/(80-12) = **4.2.** Based upon the lower flow rate and reduced activity concentration, **we conclude that the AP0 air line was substantially blocked.**

Next, we connected the AP0 Stack Monitor to the sample hose that was inserted into the stack. The exhaust hose from this system was then input to the N01 Stack Monitor and Triton. After allowing time for the air to be drawn through this whole system, the N01 Stack Monitor measured 3 cts/60 sec = 180 cts/hr. This is a negligible increase above the background count rate of 150 cts/hr. It is concluded that **a second part of the air line was blocked.** This was confirmed a few days later by an Accelerator Safety Group Technician who discovered that two of the sampler air hoses were crimped. Thus, we were unable to directly calibrate the AP0 Stack Monitor.

Isotopic Gas Mixture Determination

The Triton and-N01 Stack Monitor were set up to draw air via the hose inserted into the AP0 stack. Once the activity concentration reached a stable plateau at 2.7 pCi/ml, the Triton pump was turned off and the inlet and outlet hoses connected to make a closed loop. The MUX output of the Triton was connected to a scaler and 60 second counts were recorded. The decay curve that was measured is seen in Figure 2. This agrees very well with the curve generated by a mixture of **42% C-11, 18% N-13 and 40% A-41.** This latter curve had been found to give the best fit for a similar decay measurement made at the NM2 target hall on 8 January 1988. The NM2 target pile in the Research Division fixed target area is similar to the AP0 pile in that both have very large steel shields; i.e. >1 meter radial and >5 meter longitudinal shield dimensions.

The isotopic gas mixture released at the N01 target hall stack has a different composition. Seperate measurements made on December 2 and 14, 1987 both found a mixture of **70% C-11 and 30% N-13, but no A-41.** It is interesting to note that at all three locations, the ratio of C-11/N-13 is about 2.3.

Both of these radionuclides are produced by interactions of particles (minimum energy threshold 5-10 MeV) with atmospheric oxygen and nitrogen. Air contains approximately 78% nitrogen, 21% oxygen and 1% argon. We believe that production of C-11 and N-13 occurs predominantly in the air spaces within the target pile by high energy particles (E > 20 MeV). These particles would include the incident proton beam, pions and kaons produced via targeting of the proton beam, and neutrons ejected from the hadronic cascade. The published activation cross sections are relatively flat above the 20 MeV energy level and are about 10-15 mb for C-11 and 5 mb for N-13 (Ba69). We would therefore expect the production ratio for C-11/N-13 to fall in the range of 2-3. Thus, our measured value of this ratio, 2.3, is consistent with the published data.

Gollon predicted that the neutron energy spectrum external to a large iron shield would peak at an energy below several hundred keV (Go76). A study done at the Meson East beamline in 1985 confirmed this prediction. It determined that neutrons emanating from the > 1 meter radially thick steel dump shield were in the energy range of 1 keV - 1 MeV (El86). The neutron spectrum external to the AP0 and NM2 target piles and beam dumps should have a similar appearance. Subsequent elastic collisions with the enclosures' concrete walls would cause many of the neutrons to thermalize and scatter back into the enclosure, allowing the capture reaction with A-40 to produce A-41. A significant fraction of the air activation measured at AP0 and NM2 is in fact due to A-41.

The lack of A-41 production at the N01 target area is apparently due to the dissimilar target geometry. The Triplet train which operated there during the 1987-88 run utilized a beam dump located at enclosure NW4. The 800 GeV proton beam traversed a 10 meter long air column, wherein C-11 and N-13 were produced. The target was followed by a beam collimator which had a 0.4 meter radially thick steel shield around it. This thinner shield near the target and lack of a beam dump apparently precluded any significant production of thermal neutrons at N01.

Final Conclusions

A calibration factor of 0.023 pCi/ml/ct/hr will be used for the AP0 Stack Monitor until a direct cross calibration against a Triton can be made. The gas mixture will be assumed to contain 42% C-11, 18% N-13 and 40% A-41 at the release point.

References

Ba69 M. Barbier, Induced Radioactivity, North-Holland Publishing, 1969, Figures IV.21 & IV.22 on page 188.

Bu88 S. Butala and S. Baker, Calibration of the N01 Stack Monitor, Radiation Physics Note 68, Fermilab Safety Section, March 1988.

El86 A. J. Elwyn and J. D. Cossairt, A Study of Neutron Leakage Through an Fe Shield at an Accelerator, Health Physics, Vol. 51, No. 6, December 1986, pp. 723-735.

Go76 P. J. Gollon, Dosimetry and Shielding Factors Relevant to the Design of Iron Beam Dumps, TM-664, Fermilab, 1976.

Pe72 A. Peetermans, CERN Report 72-12, Geneva, Switzerland, 1972.

Figure 1 - Triton/RM14 Stack Monitor Cross Calibration at APO

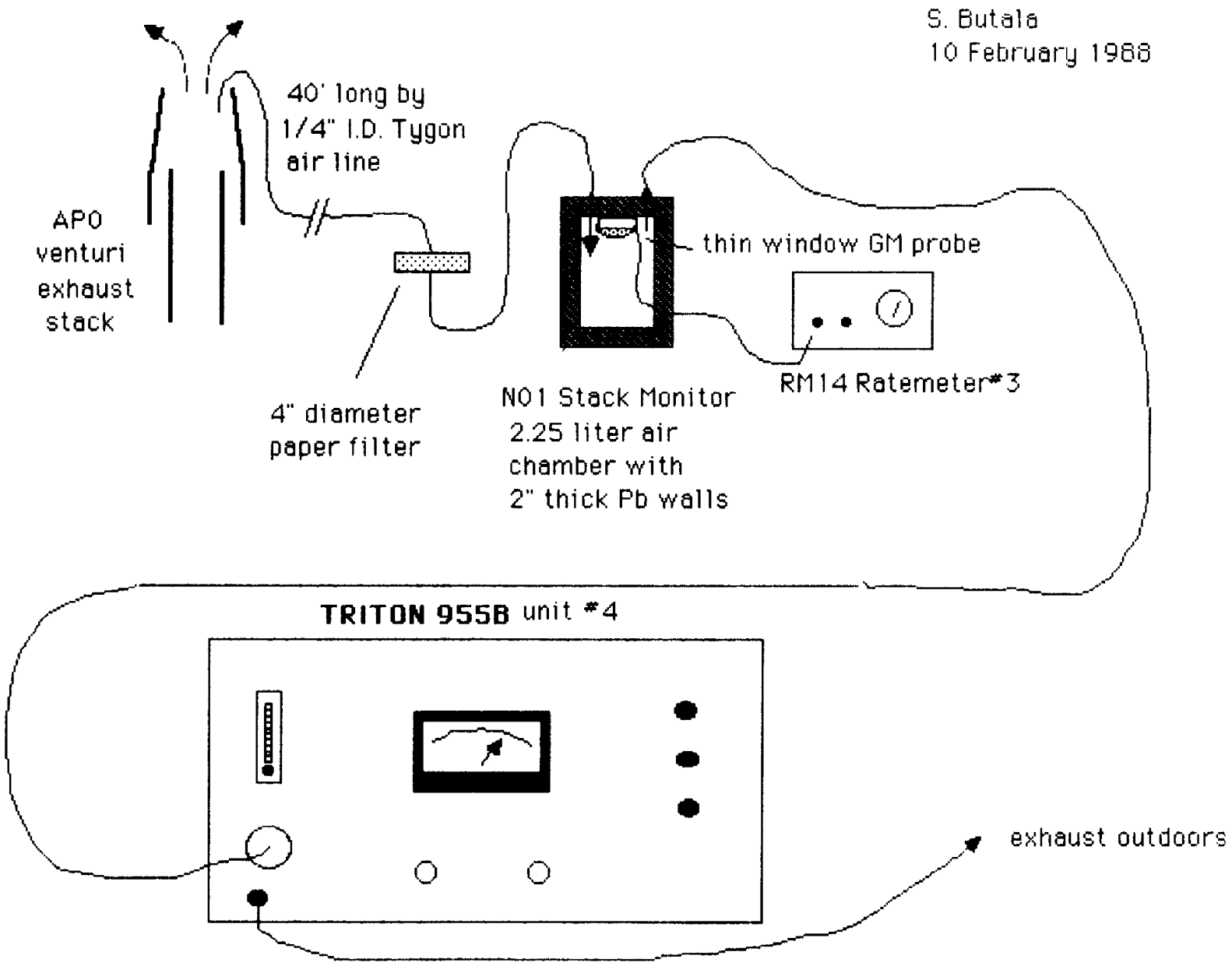

FIGURE 2

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