

# Radiation Physics Note 106

## AP0 Stack Monitor Calibration

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### I. INTRODUCTION

Tiger Team's findings and an apparent two-fold increase in the airborne radioactivity released, as normalized to the integrated beam intensity, over previous years, prompted us to independently check the calibration factor used to convert count-rate to released activity from the AP0 stack.

To determine the calibration factor, several different measurements were performed. These included measuring the AP0 stack flow rate using a velometer, taking a grab sample and using a Multi-Channel Scaler (MCS) to determine the isotopic composition of the sample, and performing gamma ray spectroscopy on filters placed in the AP0 exhaust stack sampling line. A gamma ray analysis of the emissions from a grab sample was conducted concomitantly with the MCS analysis.

### II. EXPERIMENTAL SETUP

A fraction of the exhaust air coming out of the AP0 stack (<0.05%) was diverted through a sampling line inserted in its center to our grab-sample container or a filter (see Figure 1.). In order to minimize the time required to collect a representative sample of the stack exhaust, a mechanical pump was connected to the output of the grab sample container through an air flow meter. This pump pulled the air through the container and flow meter to the pump exhaust. Air in the sampling line passed through a manifold which was constructed such that the sampled gas could either pass through a filter or be routed directly to a grab sample container. Two different containers were used to contain the grab sample. The first was an ordinary sealed paint can. It was constructed of tin with a 0.025 cm (0.01 inches) wall thickness, a 16.51 cm (6.5 inches) diameter and 19.05 cm (7.5 inches) height. Because of its thin wall, the paint can could be used for concurrent multi-channel scaling and high-purity germanium gamma-ray analysis of the air sample. The second container used for grab-sampling is called a lead-pig, that is a right-circular cylindrical container, inserted inside a 5.08 cm thick cylindrical lead shield. Each of the containers was fitted with inlet and outlet gas ports and a thin window 4.445 cm diameter GM tube<sup>1</sup>.

#### A. MCS Detector System

The signal out of the GM tube detector was sent to a Ludlum rate-meter<sup>2</sup>, which provided an analog display and a TTL MUX output signal. The rate-meter was modified to generate one positive TTL output pulse for every input pulse. The output signal was sent to the MCS module<sup>3</sup>, which is used with multi-channel analyzer (MCA) equipped with an external ADC interface and interfaced to a micro-computer data acquisition system<sup>4</sup> (S100). Dwell time per channel and the total number of channels are selectable on the MCS unit. To the S100 system the MCS module looks like an ADC. For each count input to the MCS unit the MCA performs an "add one to memory" cycle at a channel representing the current dwell address. At the end of the selected dwell time the unit will advance to the next channel automatically, until the end of the selected range is reached.

## B. HpGe detector system

An EG&G GEM series high purity Germanium (HpGe) detector (Serial # 28-TP30036B) was used to analyze the gamma ray emissions from the paper filter, the activated charcoal filter, and the paint can as it was being counted on the multi-channel scaler. The heart of this particular detector is an HpGe crystal having an active radius of 2.75 cm and an active depth of 4.29 cm. It is physically located 4.27 mm from the aluminum end cap of the detector assembly. Adding the inactive skin depth of 0.7 mm to the physical separation gives a total distance from the end cap to the active crystal face of 4.97 mm. An integral preamp is included in the detector assembly so that the output signal can be taken directly into a spectroscopy amplifier. For these measurements, an EG&G ORTEC Model 671 Spectroscopy Amplifier was used. The output of the spectroscopy amplifier was fed into the ADC input of an EG&G ORTEC Model 918A multi-channel buffer which was interfaced to a BSI-V Portable 486-33 ISA computer<sup>(5)</sup>. EG&G ORTEC's MAESTRO II<sup>(6)</sup> MCA emulation software was used for both the data acquisition and analysis.

## III. MEASUREMENTS

The production of radioactivity around the AP0 target depends on the beam parameters such as pulse rate and intensity. MCS and HpGe measurements were done during the stable anti-proton stacking operations, to reduce systematic errors and provide a more understandable background for the analysis of the data. To monitor the proton beam stability during the measurements and to obtain an average proton rate, the number of protons per pulse as obtained from a toroid beam-pickup coil was recorded using the accelerator division's Lumberjack data logger.

### A. MCS Measurements

The MCS module was set to bin data in 4096 channels with a count time of 2 seconds per channel (a total of 2.276 hours). First the paint can was used to take a background for 30 minutes. Next after purging the paint can with the air coming from the stack for 10-15 minutes, a grab sample was taken by closing the outlet and then the inlet valves. This sample was counted with the MCS system for 2.276 hours. After looking at the gamma-ray background compared to the gamma-ray spectrum taken during the MCS counting, it was concluded that, as expected, there is a cloud with the same composition as the stack emissions nearby. The next step was to use the lead-pig which showed an extremely low and uniform background (2 counts per channel). Another 2.276 hours run with the MCS system was taken. The lead pig data, after subtracting the background, was used to determine the isotopic composition of AP0 stack emissions.

### B. HpGe Measurements

The initial series of measurements with the HpGe detector system were done on January 8 and 9, 1993. First the detector system was energy calibrated using an NIST traceable mixed gamma ray source from Amersham (QCD.1-8). When the energy calibration was complete, several 15 minute counts of the background were recorded to disc. These background spectra were essentially featureless with only the ubiquitous 511 keV annihilation peak and the naturally occurring <sup>40</sup>K peak at 1461 keV being observed. The stack exhaust was then passed through a Millipore cellulose filter for an hour at 9.5 liter/min flow rate. Approximately 40 minutes after the filter was removed from the sampling line to be counted, beam was lost to the AP0 target, thus suspending the measurements. Normal beam operations were resumed on the 15th of January, but the measurements could not be resumed until January 20 and 21, 1993. The gamma ray spectrum from the paper filter showed only an enhanced annihilation peak at 511 keV excitation energy.

When accelerator operations resumed gamma ray spectra were recorded for background, an activated charcoal filter, and for the paint can as it was being counted on the multi-channel scaler. Initially an energy calibration of the HpGe detector system was performed using the mixed gamma ray source cited in the first paragraph. Due to time constraints, the paint can grab sample and the activated charcoal filter respectively were counted immediately following the calibration before a background spectrum was taken. This background spectrum was counted for a full hour and revealed a number of features not discerned in previously measured background spectra. A number of different accelerator produced radionuclides were displayed at very low count rates. These new features may have been due to equilibrium levels of residual radioactivity around the APO service building and the APO exhaust stack which were absent during the initial series of measurements or they may have simply been an artifact of improved counting statistics or a combination of both. Radionuclides seen as background included  $^{48}\text{Sc}$ ,  $^{46}\text{Sc}$ ,  $^{56}\text{Co}$ ,  $^{60}\text{Co}$ ,  $^{24}\text{Na}$ ,  $^{137}\text{Cs}$ ,  $^{40}\text{K}$ ,  $^{41}\text{Ar}$ , and naturally occurring radionuclides from the uranium series. Only  $^{38}\text{Cl}$ ,  $^{39}\text{Cl}$ ,  $^{41}\text{Ar}$ ,  $^{54}\text{Mn}$ , and  $^{82}\text{Br}$  were observed to be statistically different from background on the activated charcoal filter. The count of the paint can grab sample yielded count rates for  $^{38}\text{Cl}$ ,  $^{39}\text{Cl}$ , and  $^{41}\text{Ar}$  which were statistically different from background.

### C. Flow Rate Measurements

The APO stack flow rate is needed to calculate its actual yearly release of radioactivity to the environment. The air flow rate out of the APO stack was measured using a Kurz velometer.<sup>7</sup> This measurement was performed in accordance with 40 CFR 61. This regulation requires at least an eight point sampling on two perpendicular diagonals in a horizontal plane be used. Two holes were drilled in the APO stack, and fitted with the proper connectors, that were capped when not in use.

## IV. ANALYSIS OF DATA

### A. Multi-Channel Scaler Decay Curve Fitting

It is generally assumed that the grab sample is composed of several radioactive gases, mainly produced by the secondary neutrons interactions with air as well as the proton beam going through air gaps, and any gaseous radioactivity produced from the target upon which beam impinges. The possible candidates from air and their half-lives are given in the table I.<sup>8</sup>

Isotope	$^{16}\text{N}$	$^{10}\text{C}$	$^{14}\text{O}$	$^{15}\text{O}$	$^{13}\text{N}$	$^{11}\text{C}$	$^{38}\text{Cl}$	$^{39}\text{Cl}$	$^{41}\text{Ar}$
Half-life	7 s	19 s	1.18m	2.04m	9.97m	20.39m	37.24m	56.60m	109.6m

Table I. Gaseous isotopes produced from beam-air interactions. Half-lives are given in seconds (s) and minutes (m).

The time it takes for air activated at the APO target to reach the APO exhaust stack can be estimated from first principles by dividing the volume of the APO target vault by the rated capacity of the ventilation fan. Performing this simple calculation yields a time of approximately 20 minutes for the air around the target to be transported to the exhaust stack. Since it takes 20 minutes for the air from APO-target vault to arrive at the APO stack, most of the very short lived isotopes have decayed. Therefore,  $^{16}\text{N}$ ,  $^{10}\text{C}$ ,  $^{14}\text{O}$  were dropped from the fit parameters.

Several methods are available for deconvoluting the MCS spectrum. Manual stripping, least square fit and Chi-squared fit are a few examples. However, in a multi-parameter space there usually exist several local minima that can produce a reasonable fit to the data, but not necessarily the best fit. For the present analysis, the Singular Value Decomposition method<sup>9</sup> in conjunction with the data and the functional form of the decay product was used. This method showed that the

data after background subtraction fit a sum of pure exponential decays (Equation E.1) and no other hidden components existed. To obtain the best fit a chi-squared fit with the steepest-gradient search was used.

Using the half lives of the six candidate isotopes given in Table I., the fit-function was assumed to have the following form:

$$F(t) = \sum_{i=1}^n A_i e^{-\lambda_i t} \quad (E.1)$$

$F(t)$  is the activity of the grab-sample at the time  $t$ . The activity of nuclide  $i$  at  $t=0$  is given by  $A_i$  and  $\lambda_i$  is its decay constant. Different nuclides are enumerated by the index  $i$ , and it is assumed there are  $n$  kinds. Two constraints were put on the chi-squared fit. First, large initial values for the parameters  $A_i$  were chosen and the radius of this hyper-sphere was reduced in small steps (0.01 step-size). A reduced  $\chi^2 < 2$  for the fit to the data was required as the second constraint. Fits to data indicated that omission of  $^{15}\text{O}$  will lower the chi-square of the fit. None of the other isotopes could be omitted from the parameter list without increasing the chi-square.

There are 4096 data points available from the MCS spectrum for fitting. Several reasonable fits with reduced chi-squares greater than 10 were found that translated into widely varying and unreasonable isotopic compositions (e.g., ~80% of the sample was chlorine isotopes and argon!). The final fit with a reduced chi-square of 1.17 (see figure 2.) was found to be stable. Other solutions found around this region (e.g., reduced chi-square=1.3) gave a composition very close to that obtained for the 1.17 solution. Five radio-isotopes were identified as the long lived constituents of the AP0 stack emissions (see Table II).

Isotope	$^{13}\text{N}$	$^{11}\text{C}$	$^{38}\text{Cl}$	$^{39}\text{Cl}$	$^{41}\text{Ar}$
$N_o$ (Bq)	27.0	33.8	1.1	1.1	1.1
$\%N_o$	42.1	52.7	1.7	1.7	1.7
$\epsilon_{GM}$	13.2%	10.7%	21.3%	18.3%	13.3%
$N_{true}$ (Bq)	204.5	315.9	5.2	6.0	8.3
$\%N_{true}$	37.9	58.5	1.0	1.1	1.5

Table II. Radionuclide composition of the AP0 grab-sample; activity  $N_o$ , composition as a percentage of the total,  $\%N_o$ , detector efficiency  $\epsilon_{GM}$ <sup>10</sup>, the true activity of isotopes present in the sample  $N_{true}$ , and the percentage of the true radioisotopes composition  $\%N_{true}$ .

## B. HpGe Analysis of Filters

Analysis of the collected gamma ray spectra was performed on the BCI-V Portable 486-33 ISA computer using the MAESTRO II MCA emulation software marketed by EG&G ORTEC. The MAESTRO II software has a built in library guided Mariscotti peak search algorithm. This algorithm was initially used for each gamma ray spectrum to establish the Region of Interest (ROI) for each peak in the spectrum. For strong peaks, this method works quite well. However for peaks from radionuclides present in quantities near the instrument detection limit, this method must be supplemented by an operator search of the spectrum. All gamma ray spectra were initially searched using the algorithm and then visually searched by an operator. Peaks which were missed

by the algorithm were marked by hand. A background subtracted peak sum was then calculated for each identified peak.

The gamma ray spectrum from the Millipore cellulose filter yielded a count rate for the 511 keV peak that was approximately 2.5 times the average background count rate. No other radionuclides were observed on this filter.

A much different spectrum was observed from the activated charcoal filter. As previously mentioned  $^{38}\text{Cl}$ ,  $^{39}\text{Cl}$ ,  $^{41}\text{Ar}$ ,  $^{54}\text{Mn}$ , and  $^{82}\text{Br}$  were all identified in the spectrum from this medium. Although the counting geometry was not as well controlled as it would normally be in a laboratory, one can still estimate the activities of the various radionuclides on the filter since the intrinsic full peak efficiencies ( $\epsilon$ ) for the HpGe detector system are well known from laboratory calibrations with a NIST traceable mixed gamma ray source. The following equation was used to estimate the radionuclide specific activities for each excitation:

$$S_A = \frac{\Sigma}{L_t \cdot 0.037 \cdot \Omega_F \cdot V \cdot B_R \cdot \epsilon \cdot A_b} \quad (\text{E.2})$$

where  $L_t$  is the live time of the count in seconds,  $\Sigma$  is the number of counts in the peak of interest, 0.037 is the conversion factor from Bq to pCi,  $V$  is the volume of exhaust gas passed through the filter,  $B_R$  is the branching ratio for a particular gamma ray excitation,  $\Omega_F$  is the average solid angle subtended by the detector at the source,  $A_b$  is the absorption correction factor, and  $\epsilon$  is the intrinsic full peak efficiency of the detector. It can be seen from inspection that the first four terms in the denominator can be grouped together as a constant,  $K$ , which is the same for all gamma ray emissions during a given measurement. For the activated charcoal filter this constant was 12,463.5 liters/pCi. The average solid angle,  $\Omega_F$ , was estimated using the method of Gardner, et. al.<sup>11</sup>, for a coaxial circular disc detector and circular disc source. Multiplying the volume flow rate by the time the filter was in the sample line gave the total volume of gas which passed through the filter. The branching ratios were taken from reference (12) and the efficiencies were taken from the efficiency vs. energy curve in the HpGe calibration logbook. Results of these calculations are presented in Table III below:

Radionuclide	Gamma Excitation Energy (keV)	Estimated Specific Activity (pCi/l)(E-2)	Error in Specific Activity (pCi/l)(E-2)	Weighted Average (pCi/l)(E-2)	Weighted Error(pCi/l)(E-2)
$^{38}\text{Cl}$	1642.4	35.2	4.1	35	2
	2167.5	34.6	3.1		
$^{39}\text{Cl}$	250.3	35.9	4	35	2
	1267.2	32.7	3		
	1517.4	38	3.8		
$^{41}\text{Ar}$	1293.6	25.6	2	26	2
$^{82}\text{Br}$	554.3	3.6	1.2	3.8	0.8
	776.5	4	1.1		

Table III. Specific activities of radionuclides detected on the activated charcoal filter after 3 hours in the APO exhaust stack sampling line.

### C. HpGe Analysis of the paint can gamma-ray spectrum

During the first hour of the MCS decay curve data collection for the paint can grab sample, a gamma ray spectrum was taken using the HpGe detector system. Analysis of this spectrum was performed in an identical manner to that explained above for the activated charcoal filter. Since the paint can wall is very thin and the gamma ray energies for the radionuclides of interest were generally high, the absorption correction factor was set to 1. The average solid angle subtended by the detector at the paint can source was estimated using the method of Rizk, et. al.<sup>13</sup>, for a disc detector coaxial with a right circular cylinder source. Table IV presents the results of these analyses.

Radionuclide	Gamma Excitation Energy (keV)	Estimated Specific Activity (pCi/l)	Error in Specific Activity (pCi/l)	Weighted Average (pCi/l)	Weighted Error (pCi/l)
38Cl	1642.4	162.9	68.6	190	29
	2167.5	195.6	32.6		
39Cl	250.3	155.9	100.8	167	37
	1267.2	170.3	55.5		
	1517.4	167.3	57.9		
41Ar	1293.6	1809.5	79.7	1810	80

Table IV. Specific activities for radionuclides observed during MCS count of paint can grab sample.

### D. Flow Rate of AP0 Stack

The AP0 stack flow rate was measured at two perpendicular sample ports at nine distances from the inside wall of AP0 stack along the diagonal. The inner diameter of AP0 stack is 25.4 cm (10 inches). The connector on the AP0 stack and the adapter on the Kurz velometer necessitated that a 4.4 cm (1.75 inches) offset be added to the measured distances given in the first row of Table V. Weather conditions for these measurements were an ambient temperature of ~28 °F with gusting winds of ~25-30 mph.

Distance (cm)	0.81	2.67	4.93	8.20	17.20	20.47	22.73	24.59	12.70
Port 1(FPM)	1500	1200	1350	1400	1500	1900	1900	1600	1500
port 2(FPM)	1600	1300	1350	1400	1500	1500	1500	1500	1500
Average(FPM)	1550	1250	1350	1475	1500	1700	1700	1550	1500

Table V. Measurements of the AP0 stack flow rate. Distances are in centimeters and air speeds for ports 1 and 2 are in feet per minute (FPM) units.

The average velocity from all the above measurements is  $=1508 \pm 146$  FPM. The average volume flow rate in cubic feet per minute (CFPM) is

$$\text{Volume flow rate (CFPM)} = \text{Area} \times \text{Speed} = \pi(0.4167)^2 \times 1508 = 822 \text{ CFPM} . \quad (\text{E.3})$$

Independent measurements by a Facilities Engineering Services Section (FESS) engineer,<sup>14</sup> showed that the above measurement was consistent with the total expected flow rate of 1100 CFPM. Those independent measurements showed a 300 CFPM leakage from under the doors and louvers upstream of the stack and at the service building and verified the 800 CFPM

released from the stack. This amounts to a total flow rate of 1100 CFPM, which is consistent with the air exchange rate from the vault upstream of the release points.

## V. AP0 STACK MONITOR CALIBRATION FACTOR

Using the average number of protons per minutes obtained from the data-logger (PPM) and the stack flow rate (SFR in cubic feet per minute) the number of protons on the target is related to the amount of air released from the AP0,

$$PPCF(\text{protons per cubic foot}) = PPM / SFR . \quad (\text{E.4})$$

The activity due to each radioisotope found in the grab sample is calculated using

$$APCF(\mu\text{Ci per cubic foot}) = \left( \frac{N_0}{3.7 \times 10^4} \right) / V_p , \quad (\text{E.5})$$

where  $N_0$  is the initial activity of a given type of radioisotope that is given in the fifth row of Table II.  $V_p$  is the grab sample volume in cubic feet and  $3.7 \times 10^4$  is the conversion factor from number of disintegrations to  $\mu\text{Ci}$ . Then the actual number of  $\mu\text{Ci}$  per proton is obtained from

$$APP(\text{actual } \mu\text{Ci per proton}) = APCF / PPCF . \quad (\text{E.6})$$

As a conservative estimate, it was assumed that all 300 CFPM of the leakage activity is released 20 minutes "upstream" of AP0 stack. This is the time required for the air around the AP0 target to reach the AP0 stack release point. To obtain the activity in the air around the target,  $N_0$  was corrected for the decay of each individual isotope using,

$$N_{-20\text{min}} = N_0 \exp\left( \frac{20\text{min} \times \ln 2}{t_{1/2}(\text{min})} \right) . \quad (\text{E.7})$$

where  $t_{1/2}$  is the half life of the isotope in minutes.  $N_{-20\text{min}}$  was used instead of  $N_0$  to calculate the actual  $\mu\text{Ci}$  per proton of released activity due to leakage.

The AP0 stack monitor calibration factor calculation takes into account the activity released due to leakage upstream of the stack. The following data were used in the calibration factor calculations

$$\begin{aligned} V_p &= 0.2301 \text{ CF}, & \text{SFC} &= 1100 \text{ CFPM} = 1.8689 \times 10^9 \text{ ml/hr}, \\ \text{PPM} &= 31.37 \times 10^{12}, & \text{PPCF} &= 2.85 \times 10^{10}, \\ \text{ACPP (average counts per proton)} &= 0.5533 \times 10^{-12}, \end{aligned}$$

Isotope	$\mu\text{Ci}/\text{proton}$ for 800 CFPM	$\mu\text{Ci}/\text{proton}$ for 300 CFPM
$^{13}\text{N}$	$6.1272 \times 10^{-13}$	$9.2293 \times 10^{-13}$
$^{11}\text{C}$	$9.4624 \times 10^{-13}$	$7.0033 \times 10^{-13}$
$^{38}\text{Cl}$	$1.5457 \times 10^{-14}$	$8.4135 \times 10^{-15}$
$^{39}\text{Cl}$	$1.8003 \times 10^{-14}$	$8.6606 \times 10^{-15}$
$^{41}\text{Ar}$	$2.4773 \times 10^{-14}$	$1.0537 \times 10^{-14}$
Sums (Ci/proton)	$1.6509 \times 10^{-18}$	$1.6172 \times 10^{-18}$
Total Activity released = $3.2681 \times 10^{-18}$ Ci/proton		

Table VI. Activity per proton at each of the release points due to different radioisotopes. The total activity in the last row is given in Ci/proton.

The calibration factor is then calculated using

$$APC(\text{activity per count}) = \frac{APP(\text{total activity per proton})}{ACPP(\text{average counts per proton})}, \quad (\text{E.8})$$

$$APC = \frac{3.2681 \times 10^{-18} \text{ Ci / proton}}{0.5533 \times 10^{-12} \text{ counts / proton}} = 5.9065 \times 10^{-6} \text{ Ci / count}, \quad (\text{E.9})$$

$$CF(\text{calibration factor}) = \frac{APC(\text{Ci / count})}{SFC(\text{ml / hr})}, \quad (\text{E.10})$$

$$CF = \frac{5.9065 \times 10^{-6} (\text{Ci / count})}{1.8689 \times 10^9 (\text{ml / hr})} = 0.00316 \text{ pCi/count / ml/hr}. \quad (\text{E.11})$$

This calibration factor is seven times smaller than the previous<sup>15,16</sup> work mostly because of the smaller concentration measured for long lived  $^{41}\text{Ar}$ , but also because the previous work used an arbitrary absolute calibration factor of 5 for a flow-through ionization chamber.<sup>17</sup>

## VI. SUMMARY

The main purpose of the AP0 measurements was to provide critical information necessary to make a reasonable estimate of the dose equivalent rate at the laboratory's site boundary due to the emission of airborne radionuclides. The HpGe analysis showed that the relative abundance of the chlorine isotopes was about an order of magnitude less than the argon isotope. It also showed that the  $^{82}\text{Br}$  isotope was present in the emissions, but at extremely low levels; levels approximately an order of magnitude below those of the chlorine isotopes. However, since the argon concentration was only about 1% , determination of the exact percentages of chlorine isotopes and  $^{82}\text{Br}$  (that would be  $\sim 0.1\%$  and  $\sim 0.01\%$  respectively ) was not possible using the MCS data due to very low statistical precision of the large elapsed time data points. For this reason and because the CAP88-PC model doesn't recognize the two chlorine isotopes, the percentage of the emitted radionuclides represented by the chlorine isotopes were modeled as the longer lived argon isotope. This then provides a conservative estimate of the dominant immersion dose equivalent rate calculated by CAP88-PC.

Identification of specific radionuclide activities using the HpGe detector system was performed whenever possible to provide supplemental information for characterization of the airborne radionuclides. The activated charcoal filter, the Millipore cellulose filter and the paint can grab sample were all analyzed for gamma emitting airborne radionuclides with the HpGe detector system. Due to attenuation of the already low intensity gamma rays in the thick lead-pig walls no attempt was made to detect them in this particular grab sample. Results of the HpGe analysis were qualitatively incorporated into the calibration factor calculations. Quantitative determinations were impossible for the two filters because the collection efficiencies were unknown. Only estimates of relative concentrations for chemically similar isotopes were feasible from measurements made with the filters. Measurements made on the paint grab sample provided the most reliable quantitative information concerning the concentrations of  $^{41}\text{Ar}$ ,  $^{38}\text{Cl}$ , and  $^{39}\text{Cl}$  in air released from the stack.

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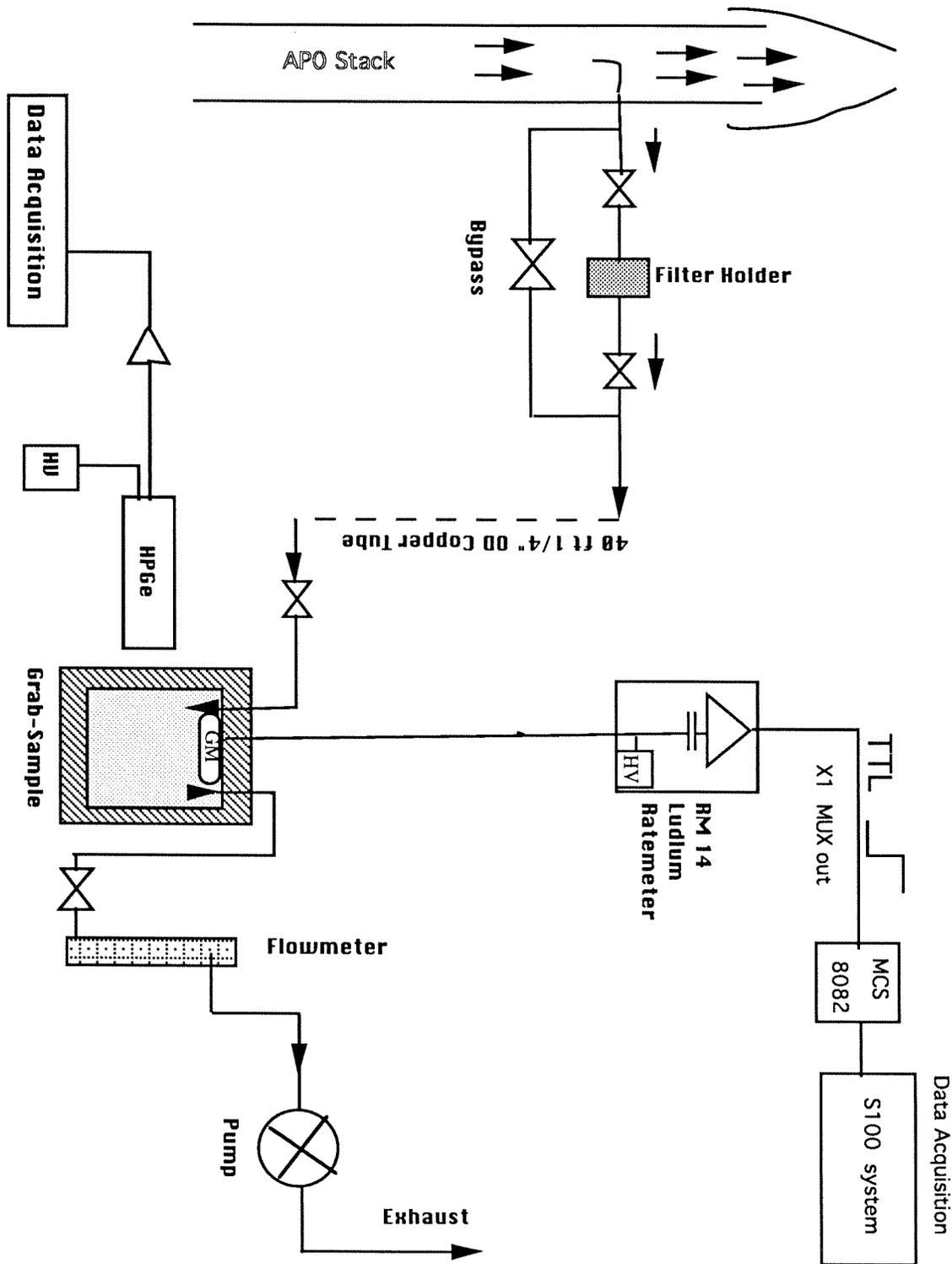


Figure 1. Setup for APO stack emissions measurements.

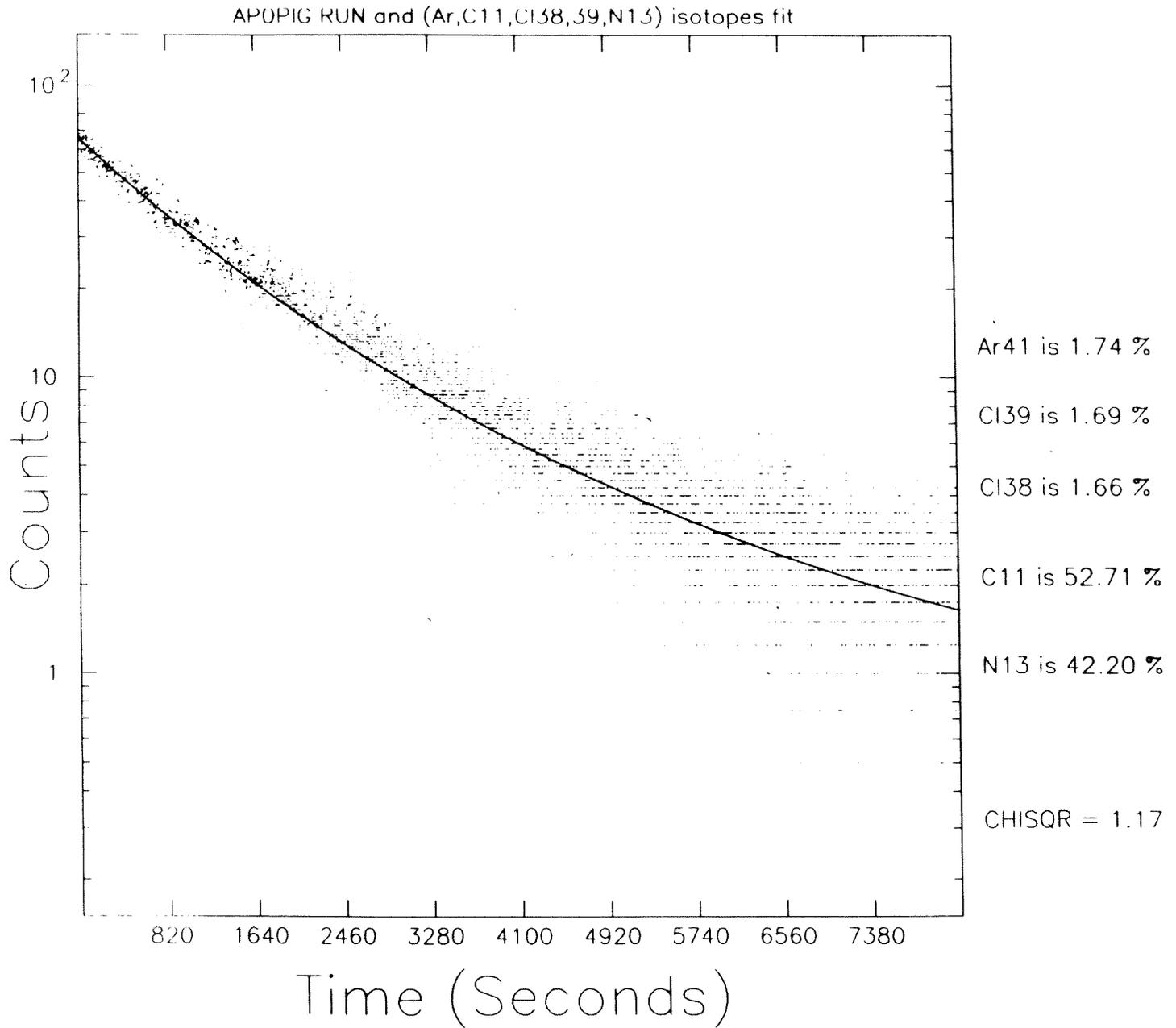


Figure 2.  $\chi^2$ -fit to the background subtracted MCS data taken with the lead-pig.