RP Note 96

Calibration of the Tennelec LB5100 and APC Wipe Counting Systems

May 1992

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QA concerns prompted a review of the calibration data and methods used for the sample changer systems. Records of the methods and sources used to calibrate the original (Nuclear Chicago) and replacement (Tennelec) wipe counting sample changer systems have been lost. The sources available to provide specific isotope calibration references were either of undesirable geometry and configuration, or passed through many half-lives. For example, many of the isotopes referenced in the Radiation Safety Guide are available in the ES&H Sections inventory only in configurations which do not possess the geometry (shape and mounting) of a wipe sample. The questions of geometry, beta backscatter differences, and wipe absorption were, quite probably, not taken into account.

A calibration was performed in June 1990, of the gas flow proportional counter (LB5100) and the GM based counter (APC) systems, using the best available sources in geometry, configuration, and calibration. Backscatter calculations[1] were used to correct for beta backscatter from the various source mounts, as required. No corrections were attempted for wipe absorption, however. It was quite obvious that new sources with a more ideal geometry and configuration were necessary to achieve the best possible calibration for these systems.

Source manufacturers catalogs were researched, followed by contacts with the manufacturers of interest. Isotope Products was selected as the vendor of choice, as they could provide calibration sources in an ideal configuration[2]. Subsequently, 14 planchet standard sources were purchased from IPL.

With the exception of the open electro-deposited alpha standards, the newly acquired standard sources consist mainly of Fermilab supplied wipes, permanently attached to Fermilab supplied aluminum planchets, with a 0.25 mil (0.9mg/cm^2) window over the wipe to provide protection from damage and loss of activity. Isotope Products states that the source material is deposited on these standards

by "wiping of deposited radioactivity from a plastic surface..... The fraction transferred to the wipe was measured by assay of the plastic before and after transfer".[2] This method provides sources most closely representative of actual field wipes. The geometry and configuration are identical, thus corrections for area, distance, self-absorption, and backscatter are not required.

An area of concern is the absorption offered by the protective window/cover over the beta/gamma standards. Due to back-scattering and wipe self-absorption, determining the effects of the window/cover for a particular isotopic emission is quite complex. Thus the problem was addressed in an empirical manner. Repetitive counts were performed of each source, while adding an additional window for each count sequence. This was performed 5 times for each beta/gamma source, yielding count rate data for 5 different window/cover thicknesses. The counting rate for each source was plotted vs. the window thickness and the resulting curve extrapolated to zero thickness (see Figures 1 and 2 for Na-22 examples). The ratio of this zero cover thickness value vs. the single cover measured value is then used as a calibration correction factor for the absorption of the single window covered source (Table 1). The efficiencies for uncovered cloth beta/gamma wipe sources in aluminum planchets were subsequently determined (Tables 2 & 3).

Wipes containing alpha producing contaminants present a different problem. Contaminants buried in the fibers of a cloth wipe can be effectively shielded. Also the layer of contamination, if not microns thin, will present self-shielding to some of the alpha emissions. Thus determining the alpha efficiency for a wipe counter using only the electro-deposited alpha source standards will yield incorrectly high efficiencies. An attempt was made to characterize the alpha emission from an alpha/beta mixed wipe. A number of wipes were taken on depleted Uranium plates using different pressure on each wipe to assure a range of deposited material. The alpha/beta count ratios from each wipe were compared to the same ratio from the electro-deposited $^{238}U_{dep}$ alpha standards. This comparison revealed an average of 60% relative reduction in alpha counts from an open source to a wipe of the same isotopes. Thus the alpha efficiency of the LB5100 gas flow counter for open $^{238}U_{dep}$ sources was multiplied by 0.4 to yield a proper wipe alpha efficiency (Table 4). Two other alpha emitters of concern (^{230}Th and ^{241}Am) were also corrected using the 0.4 correction factor, as the

energy of the alpha emissions from these isotopes are in the same general range of 4-5 MeV as $^{238}U_{dep}$.

An additional concern is the efficiency/sensitivity of the counting systems to a 'typical' wipe of accelerator produced isotopes. Many variables are present, eg. accelerator energy, cross-section of materials, half-lives of activation products, and decay times. The most common activated items consist of steel, aluminum, copper, or concrete. A typical wipe of accelerator produced contamination could conceivably contain activation products from any to all of the above abundant materials (copper least likely - most is contained inside magnet structures). Unless very specific information is available for specific wipes, a general purpose efficiency must be used to cover the high probability of mixed contaminant wipes.

An estimation of a 'typical' wipe efficiency makes several assumptions[3]:

1. Contamination from the 3 primary items (steel, aluminum, concrete) are present in equal amounts.
2. Steel activates primarily to ^{54}Mn and ^{60}Co in a ratio of 10:1.
3. Aluminum activates primarily to ^{22}Na.
4. Concrete activates primarily to ^{22}Na.

Using the values from table 2, the beta/gamma efficiency of the LB5100 proportional counter system for a 'typical' wipe is:

$$\text{Efficiency}_{\text{steel}} = \frac{\text{Eff}_{^{54}Mn} \times 10 + \text{Eff}_{^{60}Co} \times 1}{11} = \frac{2.4 \times 10 + 18.7 \times 1}{11} = 3.88, \text{ and}$$

$$\text{Efficiency}_{\text{aluminum}} = \text{Eff}_{^{22}Na} = 25.8, \text{ and}$$

$$\text{Efficiency}_{\text{concrete}} = \text{Eff}_{^{22}Na} = 25.8, \text{ thus}$$

$$\text{Efficiency}_{\text{mixed wipe}} = \frac{\text{Eff}_{\text{steel}} + \text{Eff}_{\text{aluminum}} + \text{Eff}_{\text{concrete}}}{3} = \frac{3.88 + 25.8 + 25.8}{3} = 18.49\%$$

$$\text{Thus, Sensitivity}_{\text{mixed wipe}} = \frac{\text{Eff}_{\text{mixed wipe}} \times 2200 \text{ dpm/nCi}}{100\%} = 406.8 \text{ cpm/nCi.}$$

The beta/gamma sensitivity for the gas flow proportional counter in present use is 400 CPM/nCi. The origin of this value is unknown. Comparison with the value determined above yields insight into the possible origin.

Substituting the efficiencies of the APC counter (see Table 3) in the above equation, yields 10.3% mixed wipe efficiency or 230 CPM/nCi sensitivity.

Further study of the sensitivity/calibration for accelerator produced contaminants was begun from 11/90 to 6/91. Wipes from the accelerator division (AD) and research division (RD) were obtained and counted in the ES&H Section's Activation Analysis Laboratory using gamma spectroscopy equipment[4]. The analysis of these wipes yielded a wide disparity in average beta/gamma counting efficiency (for the LB5100) from 7.3% to 36.4% due to the varying abundance of ^{7}Be. This isotope represents 45% of the total activity in one group of wipes (from AD). Due to only an 11% branching ratio to a 477 KeV photon, ^{7}Be is extremely difficult to detect with a gas flow proportional counter. This lowers the average detection efficiency of the LB5100 for the mixed wipe. Additionally, the relatively short half-life (53 days) of this isotope, creates extreme difficulties establishing a standard counting efficiency for a mixture of accelerator produced isotopes as the efficiency for the mixture increases rather rapidly.

Discussions with a number of Fermilab personnel (Butala, Carpenter, Cupps, Elwyn, Leveling, Vaziri) yielded some insight into the Accelerator Division ^{7}Be problem. The areas of contamination concern in Accelerator Division (AD) and Research Division (RD) have almost identical characteristics with a notable exception. The LCW pipes are aluminum in AD and primarily copper in RD. ^{7}Be production by spallation (from the interaction of accelerator beam particles) is much higher for aluminum. This most likely accounts for the AD dominance of ^{7}Be contamination.

Detailed studies of contaminated wipes from both areas will be performed, including gamma-ray spectral analysis of individual wipes. Data will include: time from beam-off; detailed wipe location; and wipe area photographs for reference. The present sensitivities of 400 CPM/nCi (LB5100) and 230 CPM/nCi (APC) will continue to be used until new counting efficiencies, based on these studies, are determined.

REFERENCES

1. Tabata, et al., An Empirical Equation for the Backscattering Coefficient of Electrons, Radiation Center of Osaka Prefecture, Sakai, Osaka, Japan, March 1971.

2. Isotope Products Laboratory, Catalog on 'Radiation Sources for Research Industry Environmental Applications', p.13.

3. Allen, R., memo to S. Baker, Boneyard Cave Walls and Doors, activation estimations from accelerator production, August 1986.

4. Fermilab ES&H Section, Activation Analysis Laboratory report, on sample #901206FK01 and #901206FK02, 6/18/91.

Figure 1

The Effect of .9 mg/sq.cm. Mylar Source Covers to the LB5100 Counter's Beta Channel Response to a Na-22 Source 22(-2.1)-3, 4/19/91, FK.

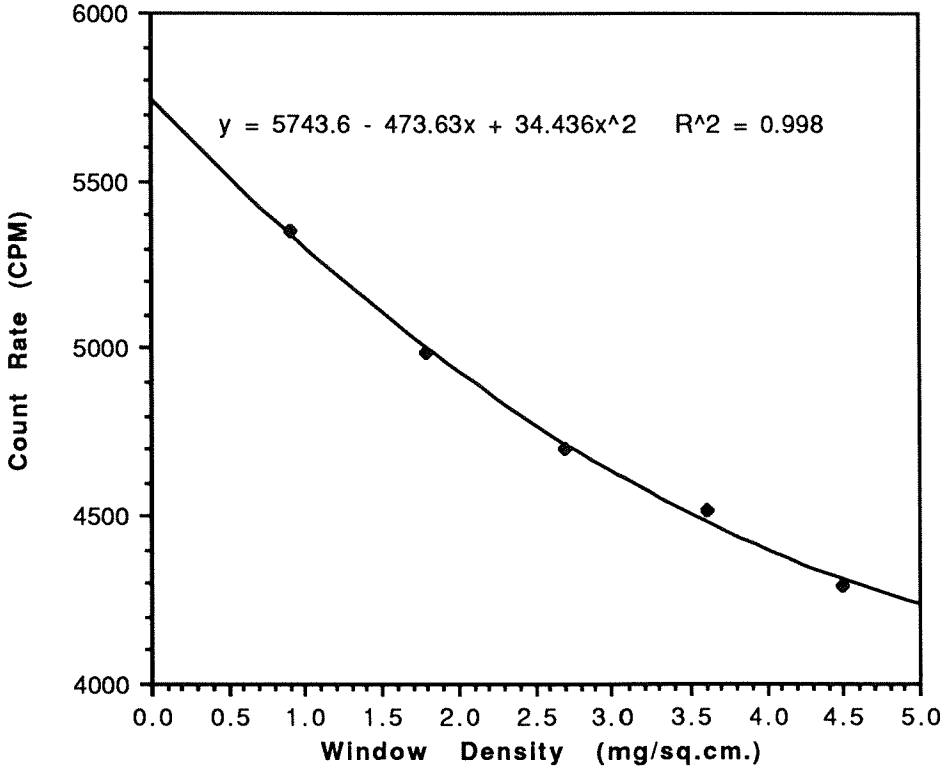

Figure 2

The Effect of .9 mg/sq.cm. Mylar Source Covers to the APC Counter's Response to a Na-22 Source 22(-2.1)-3, 5/21/91, FK.

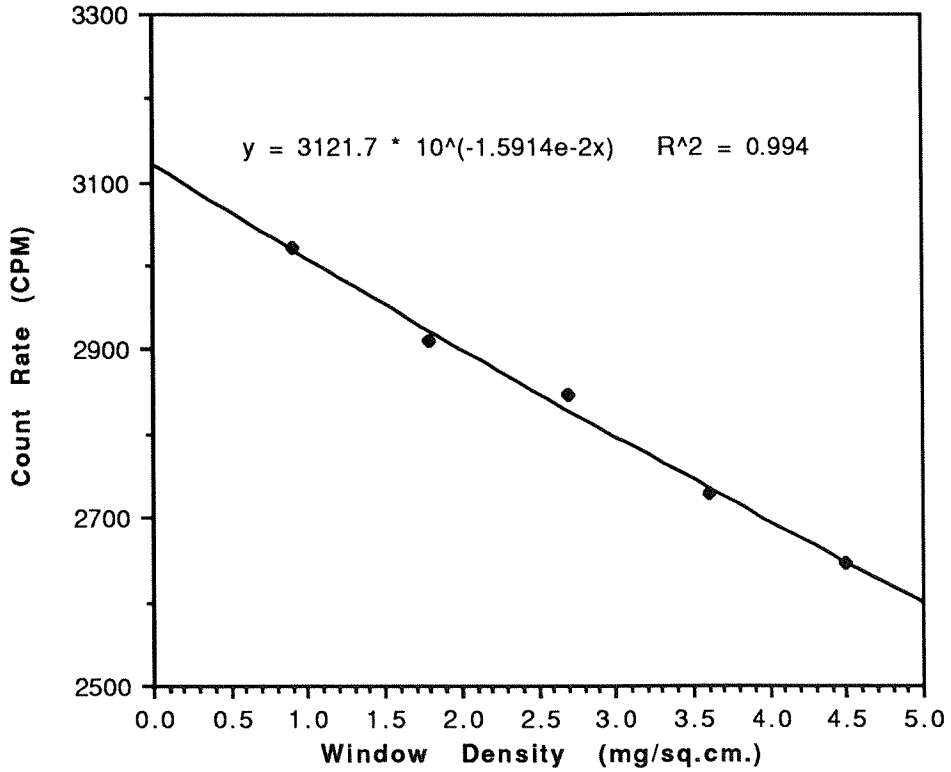

Table 1

0.9mg/cm2 Mylar Source Cover Attenuation for the Tennelec Sample Changer Systems

Isotope	APC Counter			LB5100 Counter Beta/Gamma Channel		
	1 cover	0 extrapolated	Correction	1 cover	0 extrapolated	Correction
C-14	702.84	889.27	1.27	1864.9	2392.1	1.28
Na-22	3021.34	3121.7	1.03	5353.3	5743.6	1.07
Cl-36	2224.94	2351.2	1.06	3825.00	4051.70	1.06
Mn-54	289.74	296.51	1.02	2354.50	2370.10	1.01
Fe-55	360.42	375.88	1.04	5192.10	5345.60	1.03
Co-57	1258.44	1413.7	1.12	8632.80	9046.80	1.05
Co-60	3799.14	4090.1	1.08	7401.50	8257.30	1.12
Sr-90	8695.64	8885.7	1.02	15015.00	15436.00	1.03
Tc-99	1807.04	1957.7	1.08	3507.80	3893.40	1.11
Ru-106	10176.34	10228	1.01	17842.10	17890.00	1.00
Cs-137	1594.64	1651.8	1.04	2767.50	2896.70	1.05
Pb-210	2558.94	2724.7	1.06	4595.50	4864.00	1.06
U-238	2589.44	2675.3	1.03	4530.90	4733.50	1.04

Table 2

Tennelec LB5100 Sample Changer Counting Efficiency for Various Isotopes (1)

6/13/91 rev. 1, May-92 F.P. Krueger

Isotope	Reference Source Calibrated by:	Stated Uncertainty (%)	Total Efficiency (%)			Count Rate Conversion (CPM/nCi)		
			Gas Flow Proportional Counter		NaI Counter	Gas Flow Proportional Counter		NaI Counter
			Alpha (2)	Beta/Gamma	Gamma	Alpha	Beta/Gamma	Gamma
C-14	Isotope Prod.	3.4	-	10.5	-	-	230	-
Na-22	Isotope Prod.	3.3	-	25.8	11.6	-	567	256
Cl-36	Isotope Prod.	2.6	-	34.4	-	-	757	-
Mn-54	Isotope Prod.	4.6	-	2.4	4.2	-	54	92
Fe-55	Isotope Prod.	5	-	12.6	0.0	-	277	0
Co-57	Isotope Prod.	2.1	-	4.4	5.1	-	97	112
Co-60	Isotope Prod.	2	-	18.7	8.2	-	412	181
Sr-90	Isotope Prod.	2.4	-	69.2	-	-	1523	-
Tc-99	Isotope Prod.	3.2	-	18.0	-	-	396	-
Ru-106	Isotope Prod.	4.3	-	40.0	2.2	-	879	-
Cs-137	Isotope Prod.	3.3	-	26.4	3.4	-	582	75
Pb-210	Isotope Prod.	8.9	-	45.4	-	-	999	-
Th-230	Eberline	UNK	9.8	8.6	-	216	188	-
U-238 (dep)(3)	Isotope Prod.	1.1	-	44.7	0.8	-	983	17
U-238 (dep)(3)	Eberline	10	9.2	-	-	203	-	-
Am-241	Isotope Prod.	1.9	12.8	8.1	0.9	283	178	20
Accel Wipe	N/A	UNK	10.6	18.2	-	234	400	-

NOTE (1): The efficiencies for the Isotope Products supplied Beta/Gamma sources are determined for the indicated isotope deposited on a typical Fermilab cloth wipe and attached to a typical Fermilab aluminum planchet. These materials were supplied to the source vendor, who deposited each isotope via a wipe transfer method (see Isotope Products 1991 catalog for the FP method). The efficiencies are corrected empirically for the effects of the 0.9 mg/cm2 cover protecting each beta/gamma source.

NOTE (2): The alpha counting efficiency includes correction for wipe self absorption. This correction factor (.04), used for all alpha wipes, was determined from a group of depleted Uranium wipes.

NOTE (3): Two U-238 sources were used to obtain the counting efficiencies. The Eberline standard is a Ni backed open source, thus is used only for alpha efficiency, as beta backscatter and bremstrahlung influence the beta and NaI gamma numbers. The Isotope Products source, used for U-238 beta efficiency, is a covered wipe source.

NOTE (4): Accelerator Wipe efficiency is determined by an estimated distribution of Na-22, Mn-54, and Co-60 in a mixed wipe (see R.P. Note 96).

Table 3

Tennelec APC System Counting Efficiency for Various Isotopes (1)

6/13/91 rev. 1, May-92 F.Krueger

Isotope	Reference Source Calibrated by:	Stated Uncertainty (%)	Total Efficiency (%)	Calibration (CPM/nCi)
C-14	IPL	3.4	3.8	84
Na-22	IPL	3.3	14.9	327
Cl-36	IPL	2.6	20.2	444
Mn-54	IPL	4.6	0.3	6.8
Fe-55	IPL	6.6	0.16	3.5
Co-57	IPL	2.1	0.7	16
Co-60	IPL	2	9.5	209
Sr-90	IPL	2.4	40.5	891
Tc-99	IPL	3.2	9.2	203
Ru-106	IPL	4.3	24.3	534
Cs-137	IPL	3.3	15.2	334
Pb-210	IPL	8.9	25.9	571
Th-230	Eberline	UNK		
U-238 (2)	IPL	1.1	23.6	520
Am-241 (3)	IPL	1.9	6.7	148
Accel Wipe (4)	N/A	UNK	10.3	230

NOTES (1): The efficiencies for the Isotope Products supplied Beta/Gamma sources are determined for the indicated isotope deposited on a typical Fermilab cloth wipe and attached to a typical Fermilab aluminum planchet. These materials were supplied to the source vendor, who deposited each isotope via a wipe transfer method (see Isotope Products 1991 catalog for FP method). The efficiencies are corrected empirically for the effects of the 0.9 mg/cm2 cover protecting each beta/gamma source.

NOTE (2): The APC counting efficiency for U-238 wipes was determined by cross-calibration with the Tennelec LB5100 gas flow proportional counting system on 7/9/90. The activity on the U-238 wipes was referenced to the IPL U-238 source.

NOTE (3): The APC counting efficiency for Am-241 was determined by filtering out the alpha particles to determine the photon component response, then adding 40% of the alpha response (for wipe absorption) to the photon component.

NOTE (4): Accelerator Wipe efficiency is determined by an estimated distribution of Na-22, Mn-54, and Co-60 in a mixed wipe (R.P. Note 96).

Table 4

U-238 Counting Efficiencies

LB5100 Response to U-238 Calibration Sources

Source No.	Alpha Eff. (1) (%)	Beta Eff. (%)	Alpha Calibr. (CPM/nCi)	Beta Calibr. (CPM/nCi)	Beta/Alpha Ratio	Wipe Counting Efficiency (%)		Wipe Calibration (CPM/nCi)	
						Alpha	Beta	Alpha	Beta
238(-4.3)-1	23.2		510						
238(-3.5)-1		44.7		983					
combined	23.2	44.7	510	983	1.93	9.2	44.7	203	983

Note 1: The ALPHA efficiency and sensitivity stated are for the open U-238 alpha source corrected for 1.5% source backscatter (Eberline).
The ALPHA wipe calibration stated on the LB5100 Counting Efficiency Table is corrected for wipe self absorption (40% of open source).

Depleted Uranium Wipe Study

From 7/9/90 data

TENNELEC LB5100A							APC SYSTEM		
Sample Description	Alpha CPM Gross	Beta CPM Gross	Alpha CPM Net	Beta CPM Net	Rel. Absorb. Beta/Alpha	Activity from Beta Net (nCi) note 2	CPM Gross	CPM Net	Response CPM/nCi
BACKGROUND	0.0	2.8	0	0	-	0.00	24.1	0	-
1-1st batch	695.6	3869.4	695.6	3866.6	5.56	3.93	1978	1953.9	496.9
2-1st batch	867.4	4941.2	867.4	4938.4	5.69	5.02	2747.5	2723.4	542.3
3-1st batch	901.8	4944.2	901.8	4941.4	5.48	5.02	2677.5	2653.4	528.1
4-1st batch	1206.6	7202.0	1206.6	7199.2	5.97	7.32	4008.5	3984.4	544.3
5-1st batch	1459.6	10129.6	1459.6	10126.8	6.94	10.30	5524	5499.9	534.1
6-1st batch	759.6	4740.0	759.6	4737.2	6.24	4.82	2416.5	2392.4	496.6
1S-2nd batch	247.4	1021.2	247.4	1018.4	4.12	1.04	499.5	475.4	459.1
2S-2nd batch	325.0	1370.4	325	1367.6	4.21	1.39	701.5	677.4	487.1
3S-2nd batch	120.0	468.6	120	465.8	3.88	0.47	279.5	255.4	539.2
4M-2nd batch	402.4	1756.8	402.4	1754	4.36	1.78	898	873.9	490.0
5M-2nd batch	152.0	583.6	152	580.8	3.82	0.59	336	311.9	528.1
6M-2nd batch	368.4	1505.8	368.4	1503	4.08	1.53	794.5	770.4	504.1
7H-2nd batch	244.2	1087.8	244.2	1085	4.44	1.10	606	581.9	527.4
8H-2nd batch	448.0	1743.6	448	1740.8	3.89	1.77	966.5	942.4	532.4
9H-2nd batch	610.4	2951.2	610.4	2948.4	4.83	3.00	1686.5	1662.4	554.5
10VH-2nd	249.4	1026.8	249.4	1024	4.11	1.04	574	549.9	528.1
				Average ratio =	4.85			Average Resp.	518.3
								Variation (%)	5.0

Note 2: Calculated from U-238 Beta calibration of LB5100.

APC Uranium wipe calibration = approx. 520 CPM/nCi.

Efficiency = 23.6 %

$$\frac{\text{Open source (Beta/Alpha)}}{\text{wipe source Beta/Alpha)}} = \text{correction factor for Alpha wipe} = 0.40$$

4/24/96

From: F. Krueger

To: File

Subject: Recalibration of the Tennelec APC Counter

During annual maintenance operations Scott Hawke discovered the plateau characteristics of the APC GM detector had changed dramatically. As this is the original detector assembly, we decided to replace it. We ordered two detector assemblies, one for a spare. Subsequent tests of the new detectors revealed that they appear consistent and have an approximately 10% change in calibration for some of the isotopes.

Scott performed a series of calibration baseline counts, using our traceable sample changer sources. Also, several sources (^{14}C, ^{60}Co, and ^{90}Sr) representing a wide range of beta energies were tested for cover attenuation effects. The correction factor for the single cover protecting the sources was virtually identical to the values found during the calibration of the original detector assembly (RP Note 96). From this information we decided to use the cover attenuation factors for the remaining sources from the original characterization.

The ^{238}U and ^{241}Am sources are special cases. The alpha efficiency of the APC counter cannot be determined directly as it is a GM counter. The APC counting efficiency for ^{241}Am was determined by filtering out the alpha particles to determine the photon component response, then adding 40% of the alpha response (60% loss due to wipe absorption, RP Note 96) to the photon component. The APC counting efficiency for ^{238}U was originally determined by intercomparison with the LB5100 (using wipes of depleted uranium) after calibrating the LB5100 with a ^{238}U calibration source. The depleted Uranium wipes are gone. Thus, the APC alpha counting efficiency for ^{238}U wipes was determined using the ^{238}U alpha wipe transmission factor (40% from RP Note 96) and the bare ^{238}U source alpha counting efficiency. This alpha counting efficiency was determined by filtration and subtraction of the estimated beta component. The APC beta counting efficiency for ^{238}U wipes was determined using the U-238 beta source. The total ^{238}U counting efficiency is the sum of the alpha and beta efficiencies.

The counting efficiency table has been updated and will be sent to wipe generators with other sample changer updates required by audit findings.

cc. J. Larson
S. Hawke
B. Arnold
RP Note 96 file

Table 3

Tennelec APC System Counting Efficiency for Various Isotopes (1)

Revised 4/23/96 F. Krueger

Isotope	Reference Source Calibrated by:	Stated Uncertainty (%)	Total Efficiency (%)	Calibration (CPM/nCi)
C-14	IPL	3.4	3.3	74
Na-22	IPL	2.6	11.6	257
Cl-36	IPL	2.6	17.4	386
Mn-54	IPL	3.1	0.3	7.7
Fe-55	IPL	5.4	0.2	4.4
Co-57	IPL	3.2	1.2	26
Co-60	IPL	2	9.1	202
Sr-90	IPL	2.4	36.7	816
Tc-99	IPL	3.2	8.3	185
Ru-106	IPL	4.3	23.2	516
Cs-137	IPL	3.3	13.1	292
Pb-210	IPL	8.9	22.9	508
Th-230	Eberline	UNK	-	-
U-238 (2)	IPL	1.1	23.9	530
Am-241 (3)	IPL	1.9	5.7	127
Accel Wipe (4)	N/A	UNK	12	265

NOTES (1): The efficiencies for the Isotope Products supplied Beta/Gamma sources are determined for the indicated isotope deposited on a typical Fermilab cloth wipe and attached to a typical Fermilab aluminum planchet. These materials were supplied to the source vendor, who deposited each isotope via a wipe transfer method (see Isotope Products 1991 catalog for FP method). The efficiencies are corrected empirically for the effects of the 0.9 mg/cm2 cover protecting each beta/gamma source.

NOTE (2): The APC **alpha** counting efficiency for U-238 wipes was determined using the U-238 alpha wipe transmision factor (RP Note 96) and the bare U-238 source alpha efficiency. (The APC alpha bare source efficiency was obtained by filtration methods.) The APC **beta** counting efficiency for U-238 wipes was determined using the U-238 beta wipe source.
The **total** efficiency is the sum of the alpha and beta efficiencies.

NOTE (3): The APC counting efficiency for Am-241 was determined by filtering out the alpha particles to determine the photon component response, then adding 40% of the alpha response (wipe absorption, RP Note 96) to the photon component.

NOTE (4): Accelerator Wipe efficiency is determined by an estimated distribution of Na-22, Mn-54, and Co-60 in a mixed wipe (R.P. Note 96).