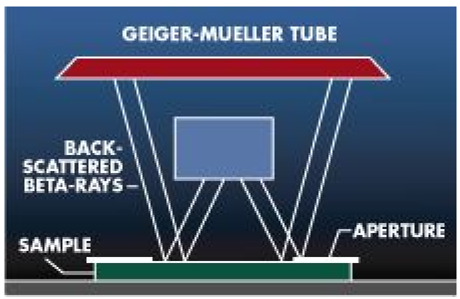
Testing a Pancake Style GM Probe for Beta Efficiency

by George Dowell

The task and apparatus available

**A friend works at a place where they use beta particles to test material's coating thickness.
The substrate is metal and it has a well-known "reflective" property to beta particles. We call this kind of reflecting "Backscatter".**

**At a known distance the metal will reflect a certain percentage of the beta rays 180 degrees back to a detector. Once this reading is established as a baseline, the same metal, this time with its paint coating applied, is measured. The beta backscatter will be reduced by the paint, and the thickness of the paint is what is being tested. Of course the beta energy must be known and maintained since both penetration and backscatter change with beta energy.
Once calibrated, very accurate measurement of quite thin coatings can be tested.**



Some industrial systems use this same technique on a paint or coating production line to keep tabs on the coating thickness in real time, actually adjusting the machinery to keep it within tolerance.

This machine is not that sophisticated, being basically a jig into which samples are periodically checked as part of their QC.

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The radioactive source is Pm-147, a beta emitter of 0.2447 MeV (244.7 keV) Peak/ 0.0619 (61.9 keV) keV average at 99.99% probability and a T/2 (Half-Life) of 2.623 years. For the rest of this discussion series we will use the convention of keV for energy and refer only to the average beta energy.

With such a relatively short half-life, the rad source must be replaced on a timed basis, every year or so.
One such old source has become temporarily available to test.

The known factors:
Original activity 75 = microCuries
Present activity = much less than 1/10th microCuries
The unknown factors:
Date of manufacture = unmarked or hidden for this test.

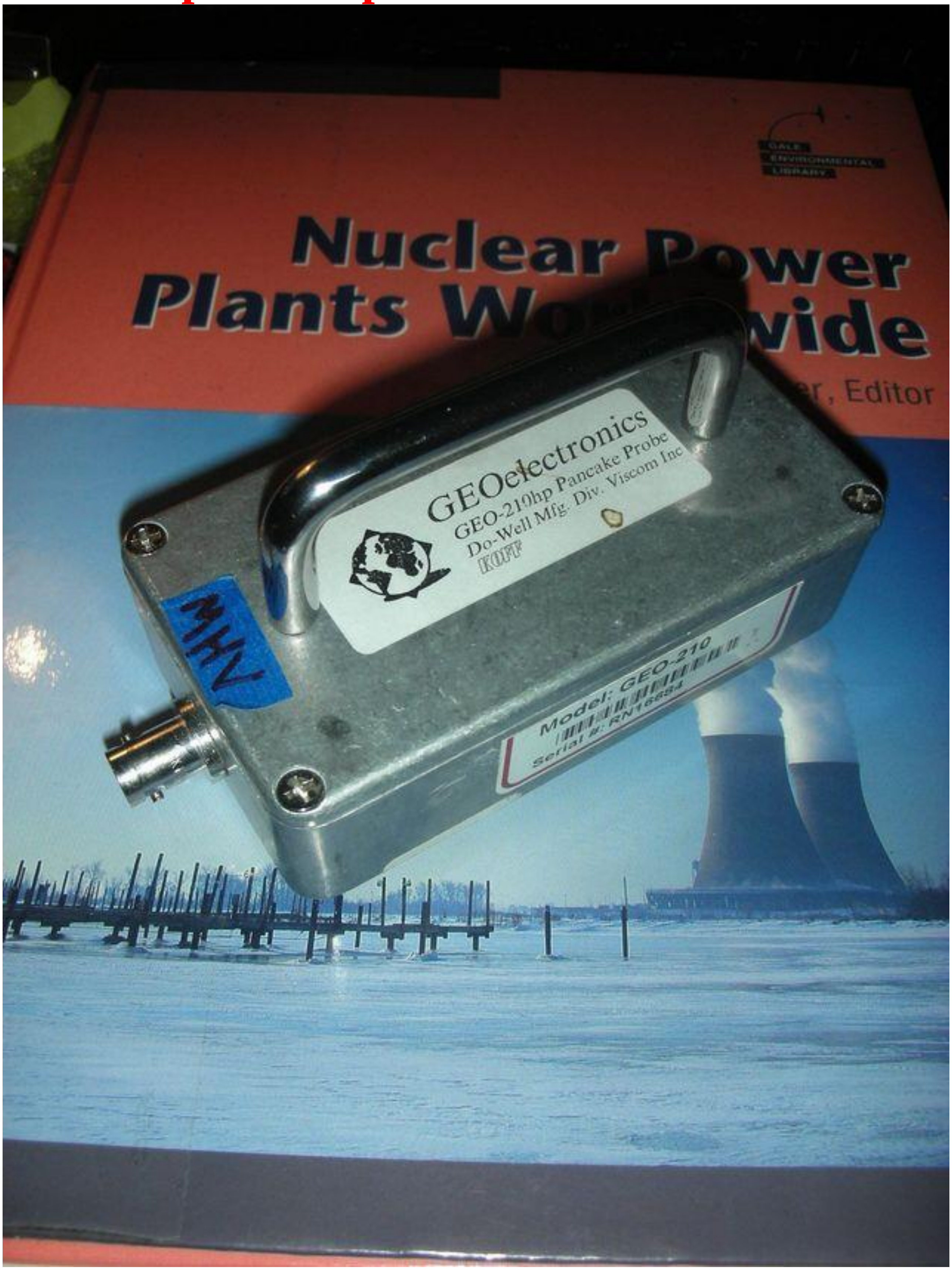
The goals of the testing:

1) Determine if the material is actually Pm-147 or some other isotope.
2) Determine the present activity level (in microCuries or nanoCuries)
3) Determine the age of the source.

Tools available for the experiments (not all will be used):
1) Pancake probe with analog + digital meter (scaler).
2) Calibrated absorber set (Spectrum Techniques)
3) Horseshoe magnet
4) Beta sources:
A) NIST calibrated Tc-99 @ 0.00353 uCi. (The Source)
B) Uncalibrated Tc-99 disc
C) C-14 discs (Spectrum Techniques)
D) Cl-36 disc (Spectrum Techniques)
E) Sr-90/Y-90 disc (Spectrum Techniques)
F) NIST calibrated Cs-137/Ba-137 disc (Spectrum Techniques)
G) Co-60 disc (Spectrum Techniques)
H) I-129 test tube
I) Kr-85 disc
J) Ni-63 disc
K) Tl-204 discs (Spectrum Techniques)

We'll go through the various steps in order, explaining everything along the way. Mistakes will be made but in the end we will have a sort of lab manual.

The pancake probe as a beta detector:



Pancake probe efficiency as beta detector is a variable depending on several parameters.

First and most important is the beta energy itself. Beta particles from nuclear decay are not monoenergetic like gammas and alphas tend to be, rather a beta stream will represent a RANGE of energies, from zero up to a particular maximum value for that isotope.

We often refer to beta energy by either its maximum energy, Emax or its average energy Eav. In most cases average comes in at about 1/3 max, but in all cases

both figures are well known and published.

Besides the beta energy, probe variations play a part in the absolute efficiency number for a particular isotope.

Window thickness, variations in the DAG coating, internal gas pressure all play a part:

Next we must consider the action of deadtime on any attempt at a true measurement. Gas filled detector tubes need a certain amount of time to regain their internal equilibrium (ionization status) between detection events. This so called dead time will affect final readings more and more as the count rate increases.

At some point, an increase in radiation actually fails to increase the count rate at all, and if even more radiation is encountered, the GM tube will fail to report at all, having reached saturation:

http://www.qsl.net/k/k0ff//Deadtime/

Lab Manual

Step 1: Evaluate available beta samples and chose the correct one for comparison:

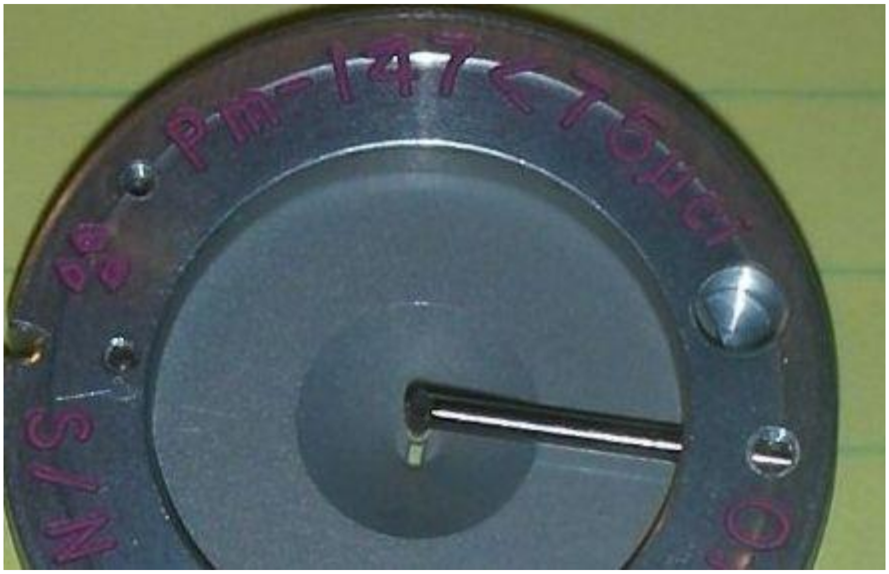
Comparative measuring has always proved to give the easiest and best results in the Home Rad Lab. If two samples are the same size, consistency, have the same geometry to the probe, and are of the same isotopes, they can be directly compared. If one of the samples is calibrated, the unknown sample can be quantified within a reasonable accuracy.

Since we are testing Pm-147 in this experiment, it's qualities must be charted.

We find from the literature that Pm-147 is a beta emitter with 99.99% probability with 224.7 keV max beta energy and 61.9 keV average beta energy.

Pm-147 has nil gamma rays.

75 uCi Pm-147 source of unknown age:



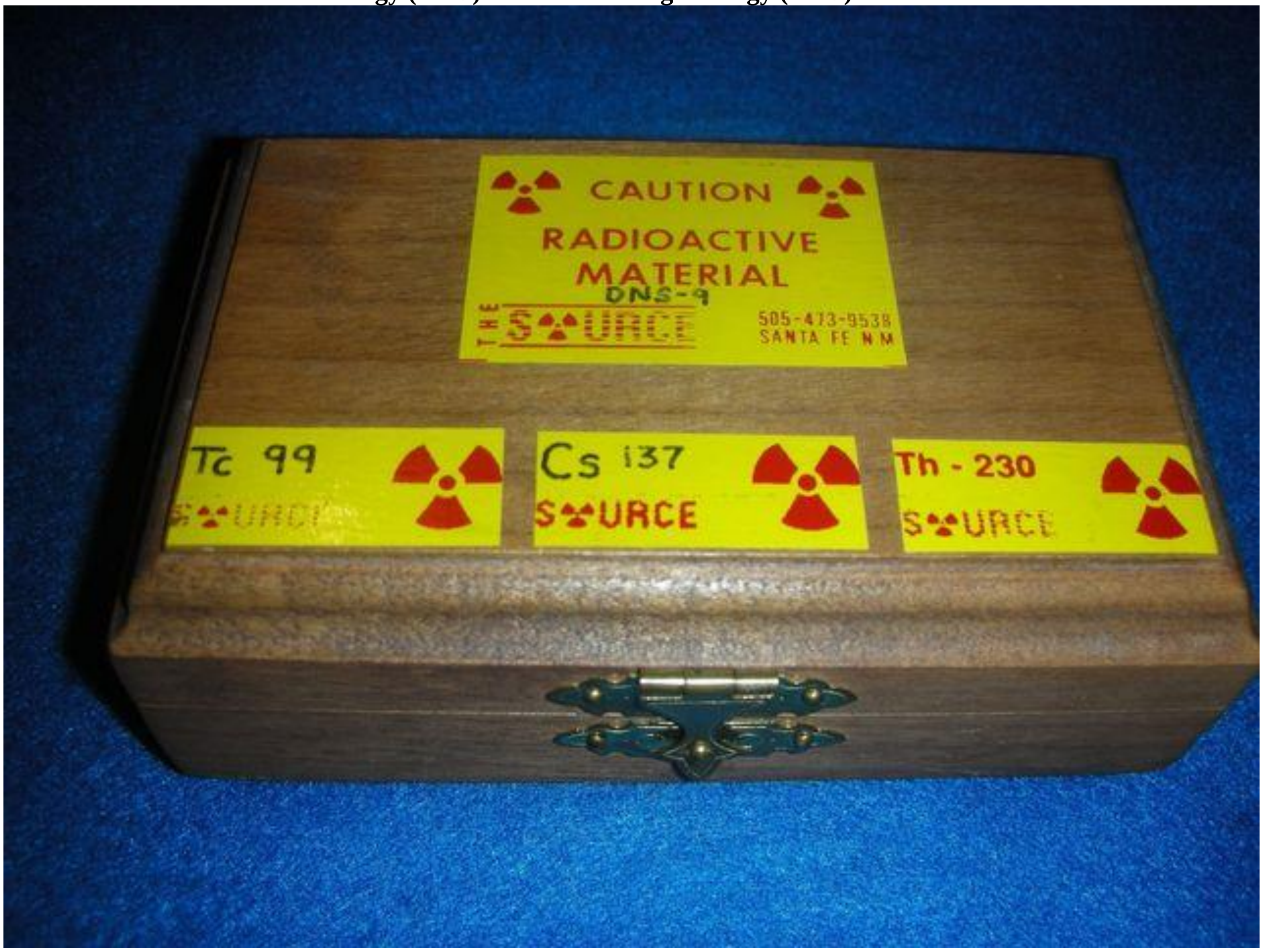
A chart was made of all the available lab isotopes, only a few of which are NIST traceable calibrated:

http://www.qsl.net/k/k0ff//Pancake%20Probe%20Beta%20Efficiency/Beta%20Sources%20Available.txt

Ideally a calibrated Pm-147 test disc would make the measurement easy, but we had no such disc. It was decided to compare to Tc-99, also a pure beta emitter, and we do have one calibrated disc.

Beta Emission Products: Tc-99

Fraction .999990 Maximum Energy (MeV) 0.204200 Average Energy (MeV) 0.084600



A second disc is also available, labeled but not calibrated:

With an extremely long half life of 213 thousand years, no effort was made to calculate the present day activity of the calibrated Tc-99 disc.

It has been stored well and we have the documents on it, so basically it will be our standard:

The second Tc-99 disc has been well used:

Surface scratches led us to question the veracity of it's present activity. Sure enough, it only gave a 150 CPM reading on the pancake compared to a 400 CPM reading from the gently stored disc.

Careful measurements were taken, being sure that the deadtime of the tube was not an issue, and with those readings and some math we decided to remark the second Tc-99 disc as being 0.00132 uCi today.

Now the Pm-147 gives a reading of 500 CPM at close contact. One Tc-99 disc gives 400 CPM while the other gives 150 CPM.

Together the two Tc-99 discs give nearly the exact same reading as the Pm-147. So we can say the Pm-147 is equivalent to 0.0047 uCi Tc-99.

Observe the efficiency of a pancake probe to Tc-99 compared to Pm-147:

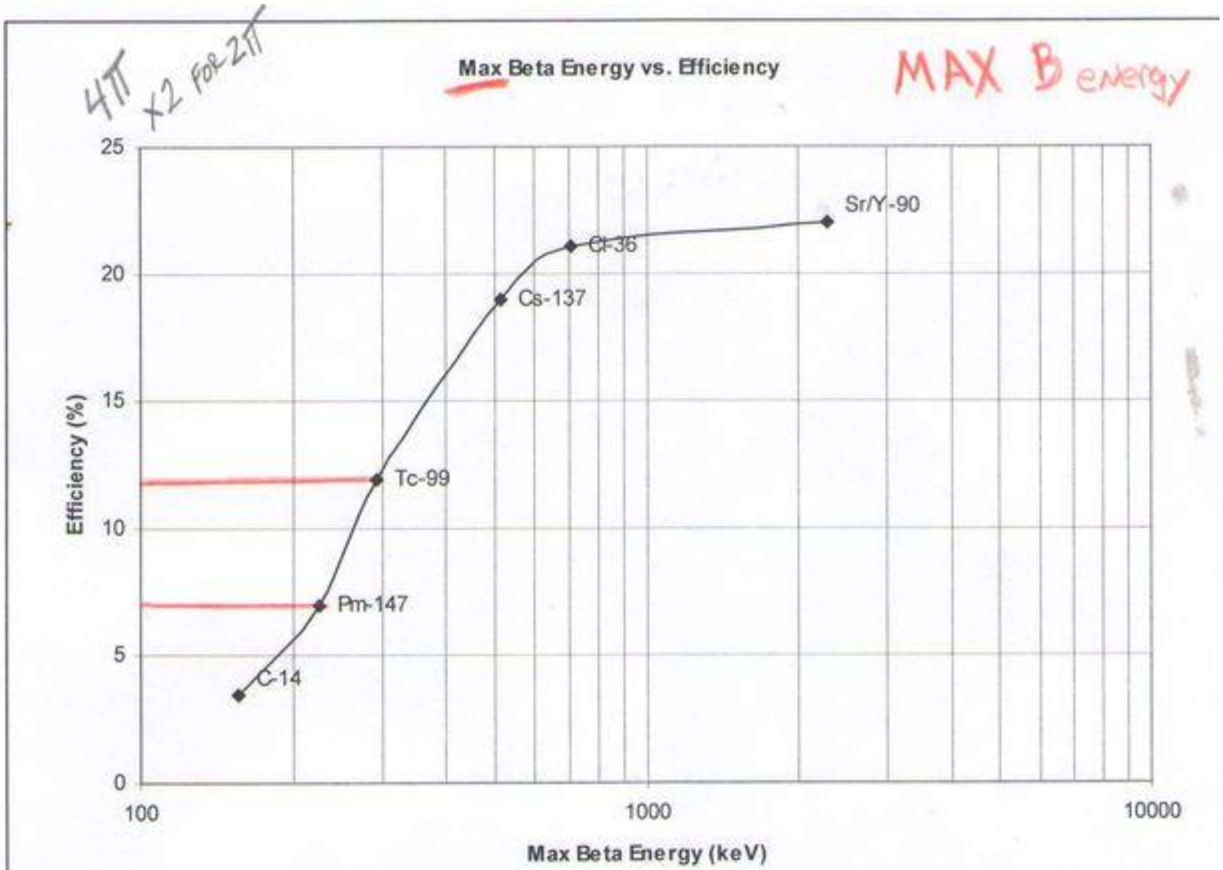


Figure 3. Beta particle energy vs. efficiency for a G-M pancake detector.

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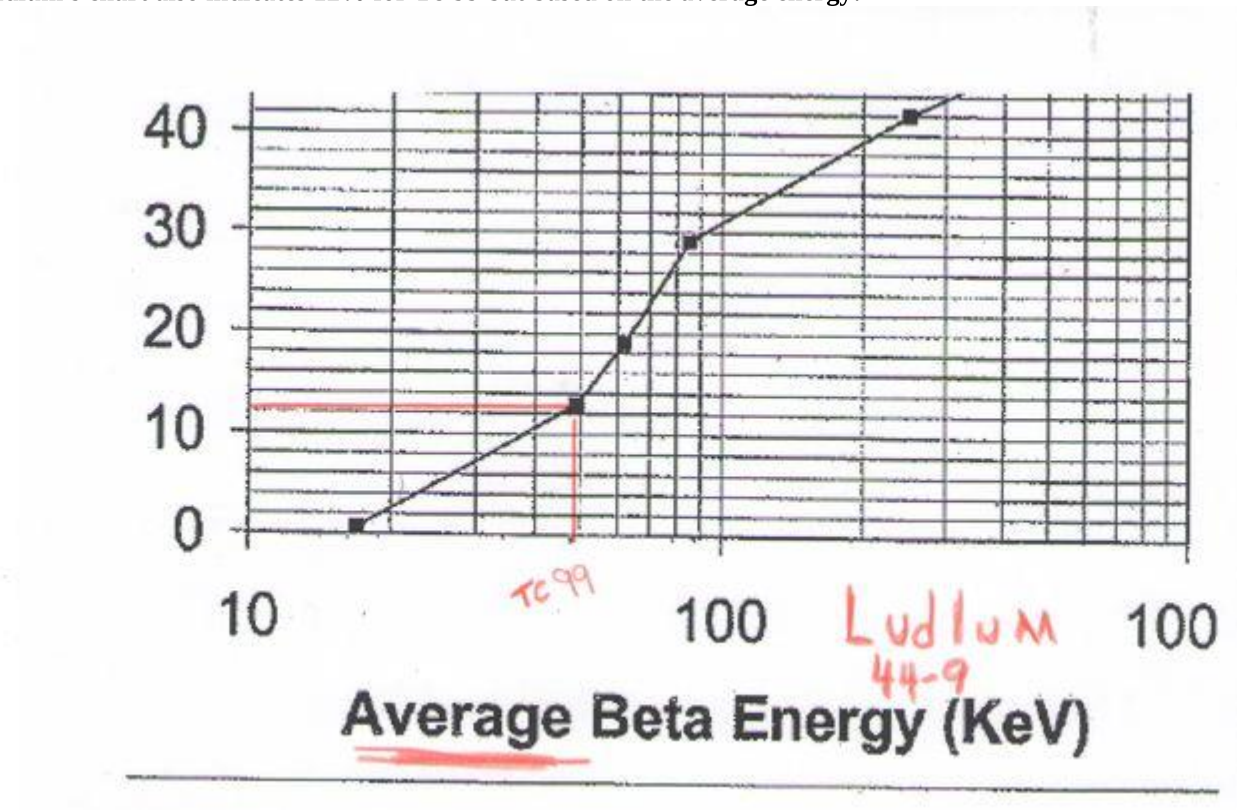
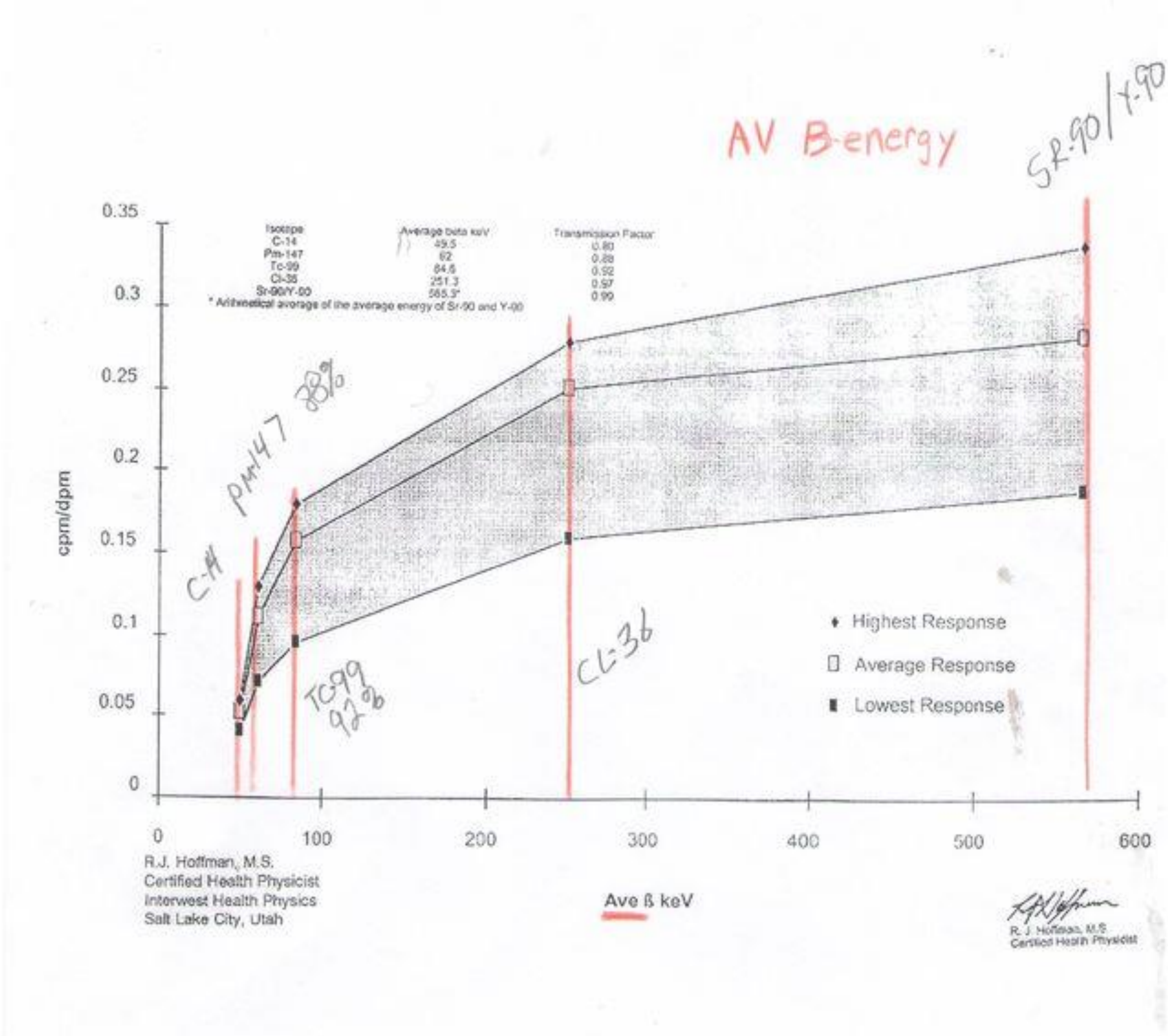
Paul's chart above indicates about 12% eff. for Tc-99 compared to about 7% for Pm-147 based on maximum energy.

Ludlum's chart also indicates 12% for Tc-99 but based on the average energy:



Hoffman's chart is probably more realistic, indicated the spread between actual tests made with different pancake probes and based on average energy:

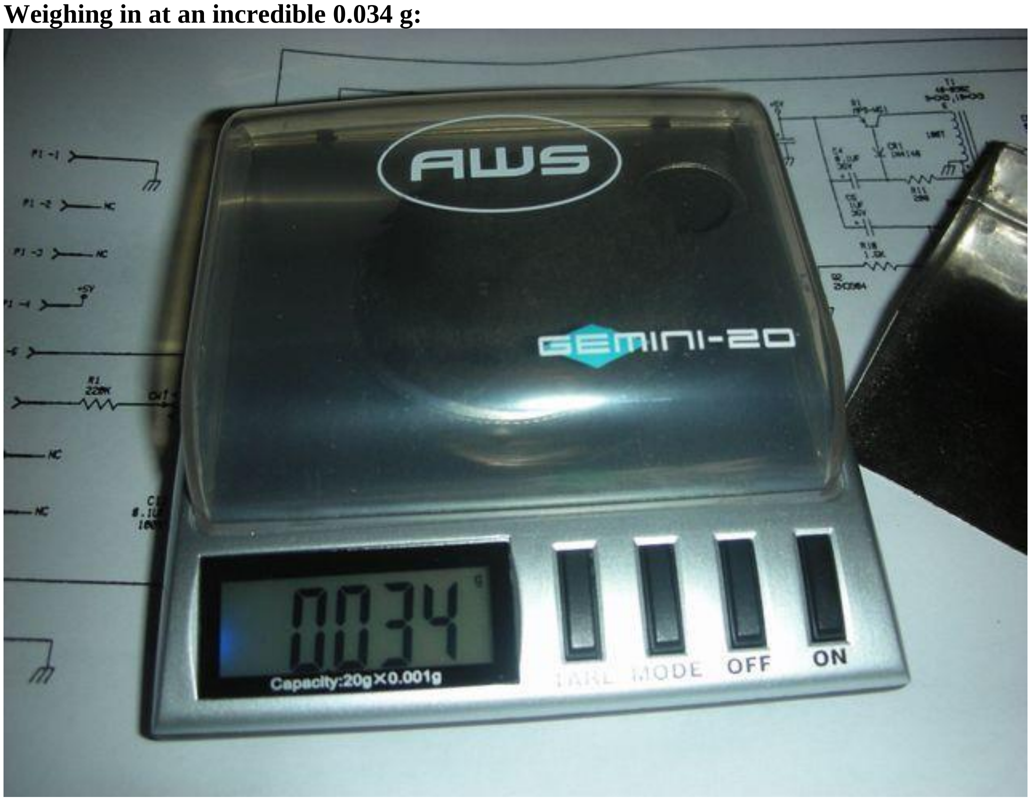


Without a calibrated source to compare against, any reading of a known energy beta emitter can only be accurate to a certain extent because of probe inconsistencies.

We took apart a pancake probe that had a broken glass seal. Otherwise the mica itself was undamaged. Careful measurements of the thickness of the mica with and without the DAG coating are shown.

Intact 0.01 mm:

Weighing in at an incredible 0.034 g:



With DAG coating removed (clear as glass and beyond the capability of the digital caliper- reads 0.000 mm):

We suspect the real reason the Hoffman chart shows such variability at a given beta energy is the DAG coating. Here shown to have many voids and variances:

At sea level the mica is slightly bowed inwards due to the reduced pressure of the neon + chlorine gas inside. At higher altitudes, the mica flexes, and at about 8000 feet of altitude or equivalent air pressure, the bow reverses from concave to convex (Passenger airplanes are pressurized to 8000 ft equiv).

Our GEO-210 probe recognizes that issue and provides a 1/16th inch gap between the tube and the screen. This gap has saved many a probe going over the Continental Divide @ 7245 ft.

One time while transporting a dozen or more instruments across the Divide, only a brand new Ludlum popped (Grrr...)

That incident prompted the invention of the GEO-310 also known as the Pike's Peak Prospector:

This normal flexing happens to some extent everyday, even due to air pressure changes due to weather fronts.

In time the DAG coating will flake off to some extent, changing the relative window density:

OK - back to the beta efficiency charts. Here's an excerpt from an Eberline pancake probe's paperwork:

SHIELDING RATIO, HP-210T, DT-304 and HP-210L (Front to Back ^{60}CO): Approximately 4:1

*BETA EFFICIENCY (1 inch dia. source):

^{90}Sr-^{90}Y (E_{max} 0.54 - 2.2 MeV); Approximately 45 percent of 2π emission rate

^{99}Tc (E_{max} 0.29 MeV); Approximately 30 percent of 2π emission rate

.^{14}. (E_{max} 0.15 MeV); Approximately 10 percent of 2π emission rate

That one says: Tc-99- (eMax 0.29 MeV) approximately 30% of 2 Pi emission rate.

Let's address the Pi factor for a moment, it is very important and often misunderstood or misused. Consider the spec of radioactive material that makes up our test discs, it a tiny spec of contamination on a surface. The radioactive isotope decays at a certain rate, that radiation leaving the spec equally in all possible directions, think of it a as a sphere or hollow ball with the spec in the center. Radioactive "activity" is measured using the units Curie.

We use microCuries, abbreviated uCi for our small sources, one one-millionth of a Curie. Any source will have a disintegration rate of 2.22 million DPM (Disintegrations per Minute).

This radiation goes off in all directions, forming a sphere The whole surface of this sphere represents the radiation flux at that distance.

Naturally the only way we can intercept all locations on the surface of the sphere at the same time, the source must be INSIDE the detector, or several detectors can be placed to surround the source. Our method is far simpler than that, using a single pancake probe, we can at best see 1/2 of that sphere, a mathematical quantity referred tom as 2 Pi Radians, or 2 Pi. Relative placement of a probe to a source is called its ?geometry".

It should be apparent that changing the geometry, that is, the distance, angle of view and so on will change the final reading. Especially when considering the "inverse squared law" which allows a X 2 change in distance to equal a X4 change in radiation reading.

The perfect geometry would be a source placed far enough away to illuminate the entire sensitive volume of the probe equally. This distance is usually considered to be 10X the major dimension of the probe.

For a 2" pancake, that would be 20 inches.

Betas are attenuated in air at a rate that would give them a range of only 10 to 12 feet per MeV of energy. A perfect setup would use a strong source in a vacuum along weight the probe, not practical for this experiment. We use a single pancake at close range to reduce air attenuation.

Our measurements would correspond to a 2 Pi geometry.

Be careful when reading beta efficiency specifications given by manufacturers. Some are 4 Pi, some are 2 Pi, some are charted as maximum energy (Emax) some as average energy (Eav). As long as we recognize these facts, we can compare different charts intelligently.

Step 2- Determine if the source is actually Pm-147:

Method: testing half value layer with absorbers, compare to a known similar sample.

Careful measurements were taken of the Tc-99 source. Results in CPM were recorded. Absorbers from the Spectrum Techniques were placed between the source and detector until one was found that reduced the CPM reading by 50% This is the half-value-layer

for this particular beta energy. The absorber selected by experiment was the B sample, 1 mil of aluminum sheet, 5.6 mg/cm^2.

Next careful CPM readings were taken of the bare Pm-147 source and recorded. Then the B

Absorber was placed between the source and detector and the new CPM reading recorded.

Comparing the to values of CPM confirms that the beta energy of the source marked Pm-147 is indeed of the expected range.

Step 3 - The experiment:

For our test, we will use Paul's chart as published in the RSO magazine because it lists all the isotopes we are using:

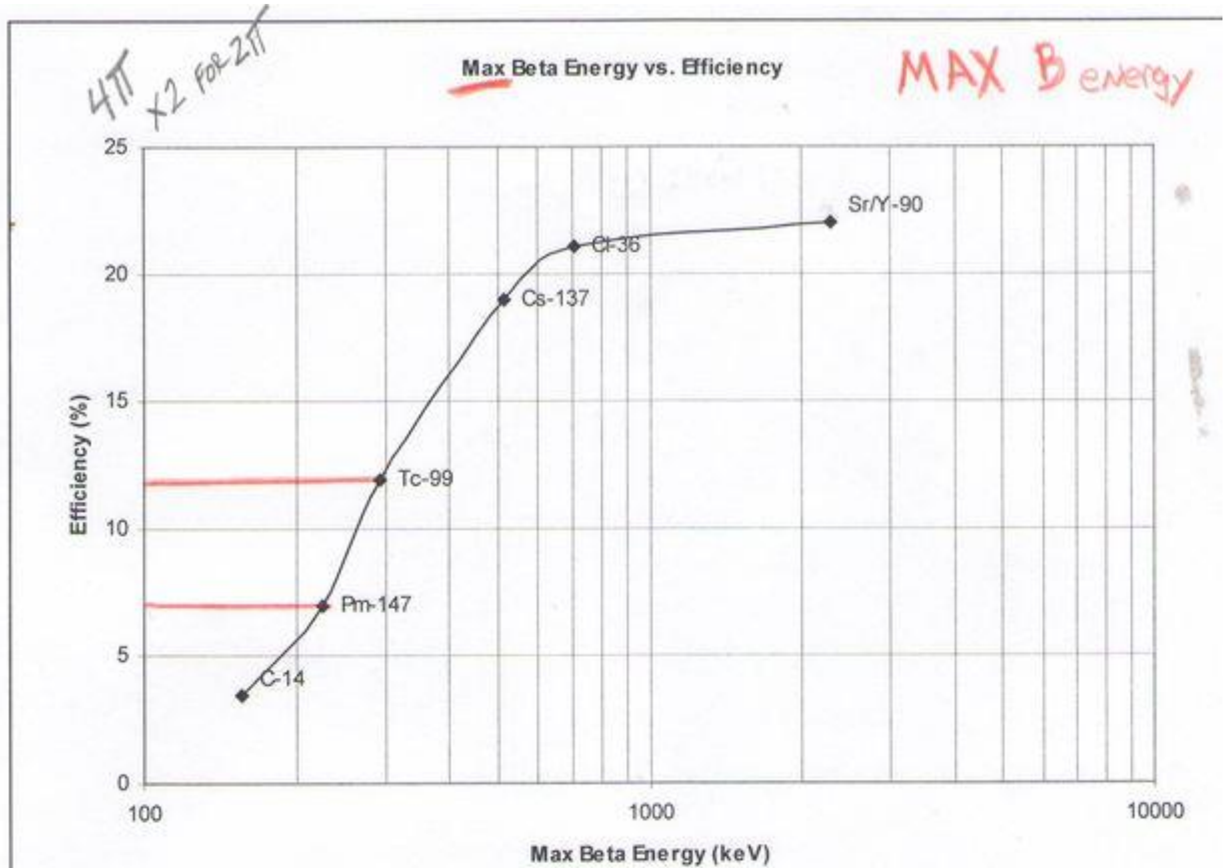


Figure 3. Beta particle energy vs. efficiency for a G-M pancake detector.

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Fortunately we are not concerned about absolute efficiency numbers, rather the DIFFERENCE in efficiency of Tc-99 compared to Pm-147.

This brings us back to 12% and 7% respectively. Doing the simple math results in a measured activity of 0.008342 uCi of Pm-147 left.

So how old is a 75 uCi Pm-147 that is now .008342 uCi?

The formula for decay= **t = -(T1/2/0.693) * ln(A/Ao)**
where -

A= final activity

Ao= initial activity

t= decay time

0.693 = Lambda, the decay constant

Pm-147 = 2.62Y

Solving for t = 34.41 Y ago = Date of manufacture 5 Feb 1975

Believe me, using an online calculator to do the math or at least to check the math is recommended:

http://www.radprocalculator.com/Decay.aspx

Have fun,

Geo

George Dowell

Comments, criticism and questions will be appreciated and may be directed to

the author by email to **GEOelectronics@netscape.com**