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# Environmental Physiology and Shelter Engineering

*With Special Reference to Domestic Animals*

## XL. Design and Testing of a Hair Measurement Beta-Gauge

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# Environmental Physiology and Shelter Engineering

## *With Special Reference to Domestic Animals*

## XL. Design and Testing of a Hair Measurement Beta-Gauge

CLIFTON BLINCOE*

## INTRODUCTION

The quantitative measurement of hair is an important factor in studies of heat exchange between animal and environment. Methods currently employed consist of counting the number of hairs per unit area, measuring the mean hair length, and determining the weight of hair per unit area. In measurements of hair number or hair weight per unit area, a major error arises from the difficulty of measuring precisely an area on the mobile, elastic, non-planer skin of an animal. Any method requiring the removal of the hair for measurement changes the heat transfer characteristics of the area and repeat measurements cannot be made on the same area.

For long range studies of the effect of climatic factors on hair coat one must be able to measure the hair density repeatedly at several locations on an animal. An absorption type beta gauge appears to offer a solution to this problem. The absorption of beta-particles by matter is dependent only on the weight per unit area of absorber and is independent of the physical state or chemical composition of the absorber so long as its average atomic number is low. A beta gauge makes use of this principle. By measuring the percent of beta particles which penetrate a given layer of material one can find the weight per unit area of the material.

Since beta gauging is a relatively recent outgrowth from nuclear physics, a definition of some of the terms may be helpful. Following is a list of the nuclear physics terms used in this bulletin:

Areal density: The density on an area basis. The weight per unit area.

Atomic number: The number of protons in the nucleus.. An integer

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that expresses the positive charge of the nucleus in multiples of the electronic charge.[1]

Backscattering: Deflection of particles (or radiation) by scattering through angles greater than 90°.[1]

Beta particle: A negatively or positively charged electron emitted from an atomic nucleus during a radioactive transformation.[1] One type of radioactive particle.

MEV: The symbol for one million electron volts. A unit of energy.

Millicurie (mc): A quantity of radioactive material which undergoes $37 \times 10^6$ disintegrations per second.

Nucleus: The positively charged core of an atom.[1]

Scattering: The change in direction of a particle (or radiation) due to a collision with another particle.[1]

## GENERAL CONSIDERATIONS

Almost immediately after large quantities of radioactive materials became available in 1946, beta gauges were studied as a means of measuring thickness without touching the material being measured. Since beta gauges measure directly the weight per unit area, they can be used to measure thickness if the density (weight per unit volume) is constant. One of the first widespread applications of beta gauges was in the measurement of the thickness of paper. They have also been used in measuring the thickness of rubber, plastics, photographic film, sheet metal paint, ink on printing press rollers, and many other materials. It has been estimated that the beta gauge saves American industry $10 million annually.[2]

The errors inherent in beta gauging have been discussed by Zumwalt[3] and by Bogachev, Verkhovsky, and Makorov.[4] Two types of errors are inherent—the statistical nature of radioactivity and the imperfections of the instruments used to measure the radiation. As in all measurements of radioactivity, a measurement cannot be both fast and accurate. A large number of beta particles must be detected to minimize random fluctuations of the measurement due to the statistical nature of radioactivity. The precision of a measurement depends on the number of beta particles detected and the precision of the electronic circuits that average the results to give a meter reading. The percentage error measurement decreases markedly as areal density increases until the thickness equals about half the absorption coefficient. The absolute error increases with areal density. The errors are minimum when the thickness is equal to the reciprocal of the absorption coefficient.[4] Increasing the strength of the beta particle source decreases the error of measurement but increases the hazard in using the gauge.

The beta gauges used in industry consist of a rather intense radiation source and a ionization chamber type of detector. For portable application, it is desirable to use as weak a radiation source as possible and a sensitive detector. A mica-window Geiger-Müller counter has the advantages of being a rugged, sensitive beta detector. Also, the associated electronic equipment for a Geiger counter is more rugged and less expensive than for an ionization chamber. The following were selected for this study: A mica-window Geiger counter as the detector, an integrating rate meter for displaying the results, and as weak a radiation source as practical.

## CONSTRUCTION

A transmission type beta-gauge for *in vivo* measurement of hair areal density must consist of a radiation source that may be placed on the skin of the animal with minimum disturbance to the hair, and a sensitive receptor. In the present design the beta emitting radioisotope was mounted on a thin rod attached to a Geiger-Müller tube by a light aluminum frame (Fig. 1).

Fig. 2 shows the details of the radioisotope mounting. The radioisotopes were mounted as components of fused enamels[5] (see Appendix) on the bottom of a hole drilled into the side of a thin stainless steel rod. This method of mounting allowed the maximum energy of the beta emitters to be utilized because no absorbing material was introduced between the radioisotope and the detector. The enameled radioisotopes are highly resistant to shock and abrasion and are further protected by being recessed into the stainless steel rod. The stainless steel below and around the radioisotope is sufficient to provide saturation backscattering for beta ray energies to greater than 2 MEV. For energies below 1 MEV it is in excess of the range of beta particles in stainless steel and thus completely shields the animal from the radiation.

Radioisotopes of promethium ($Pm^{147}$) and thallium ($Tl^{204}$) were used as beta particle sources. The properties of the beta particles from these sources are compared with other common isotopes in the following table:

| Nuclide | Half-Life Years | Energy MEV | Range mg/cm$^2$ |
|---|---|---|---|
| $C^{14}$ | 5720 | 0.155 | 0.9 |
| $Pm^{147}$ | 2.7 | 0.223 | 50 |
| $Tl^{204}$ | 2.7 | 0.783 | 290 |
| $Sr^{90}$-$Y^{90}$* | 25 | 2.18 | 1100 |

*Equilibrium parent-daughter mixture.

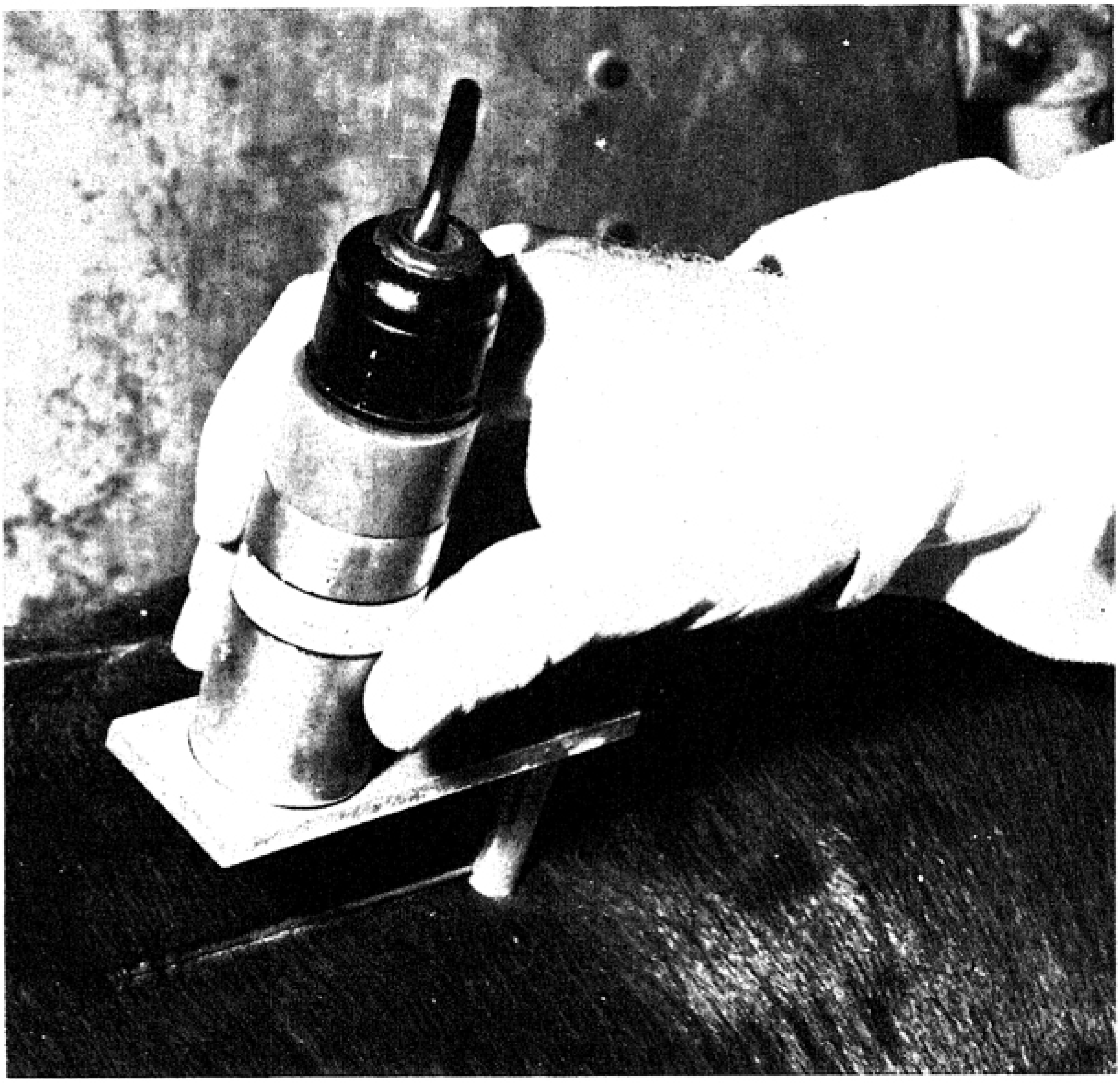

Fig. 1—Using the hair measurement beta gauge. The probe is slid along the skin, under the hair, and the decrease in count rate noted.

It was found that $Pm^{147}$ was useful to approximately 15 mg/ $cm^2$. and $Tl^{204}$ to approximately 80 mg/$cm^2$. These two isotopes provided a wide range in which measurements could be made to an equal number of significant figures. These isotopes are sufficiently long half-life (2.7 years) to provide a stable gauge that will be useable for one to two years before recharging.

The construction of the hair measurement beta gauge is shown in detail in Figs. 3 and 4. The particular Geiger tube used (Anton Electronic Co., No. 210-H) is threaded around the mica window and screws into the base plate, thus becoming an integral part of the structure of the gauge. Approximately 2 inches was chosen as the distance between the source

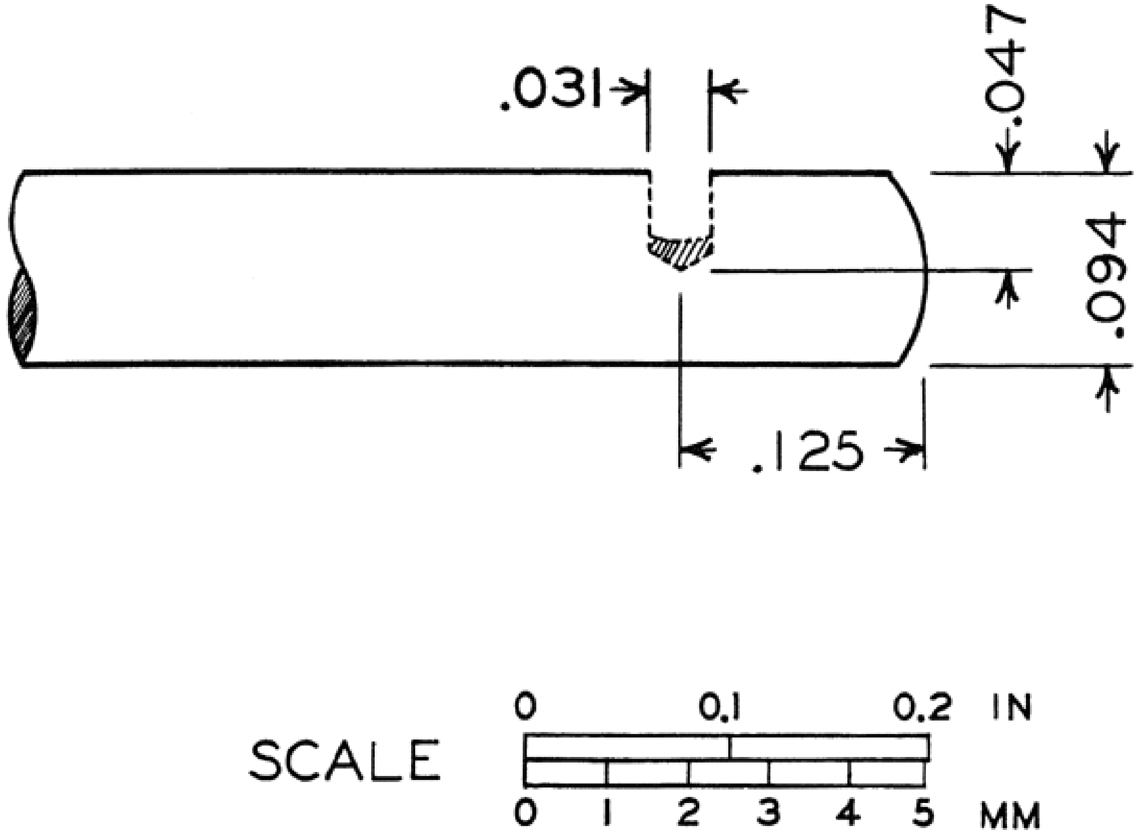

Fig. 2—Detail of radioisotope mounting.

and the detector. This distance is adequate for the hair of cattle and is also large enough that a small amount of bending of the source holder can be tolerated. For example, a deflection of 1 mm will change the count rate by only 4 percent. The other dimensions were selected for convenient construction.

A measurement of hair areal density is made by sliding the probe along the skin, under the hair, at right angles to the direction of hair growth (Fig. 1). The count rate is noted and expressed as a percent of the count rate with the gauge held in air. The hair areal density is found from a calibration curve (see Figs. 5 and 6). In all work on animals, an integrating rate meter with an independently variable time constant was used to average the count rate.

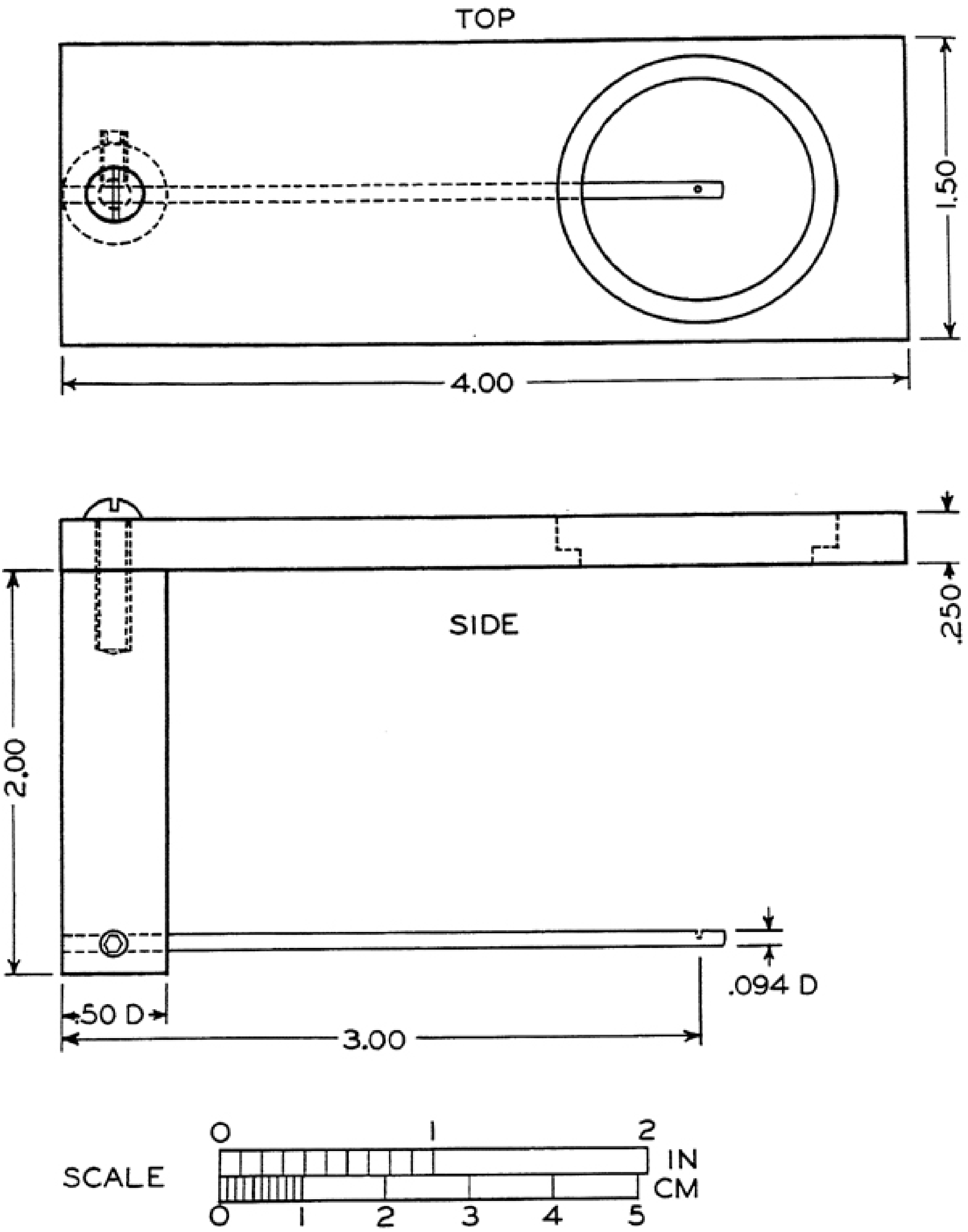

Fig. 3—Assembly of the hair measurement beta gauge. All dimensions are given in inches.

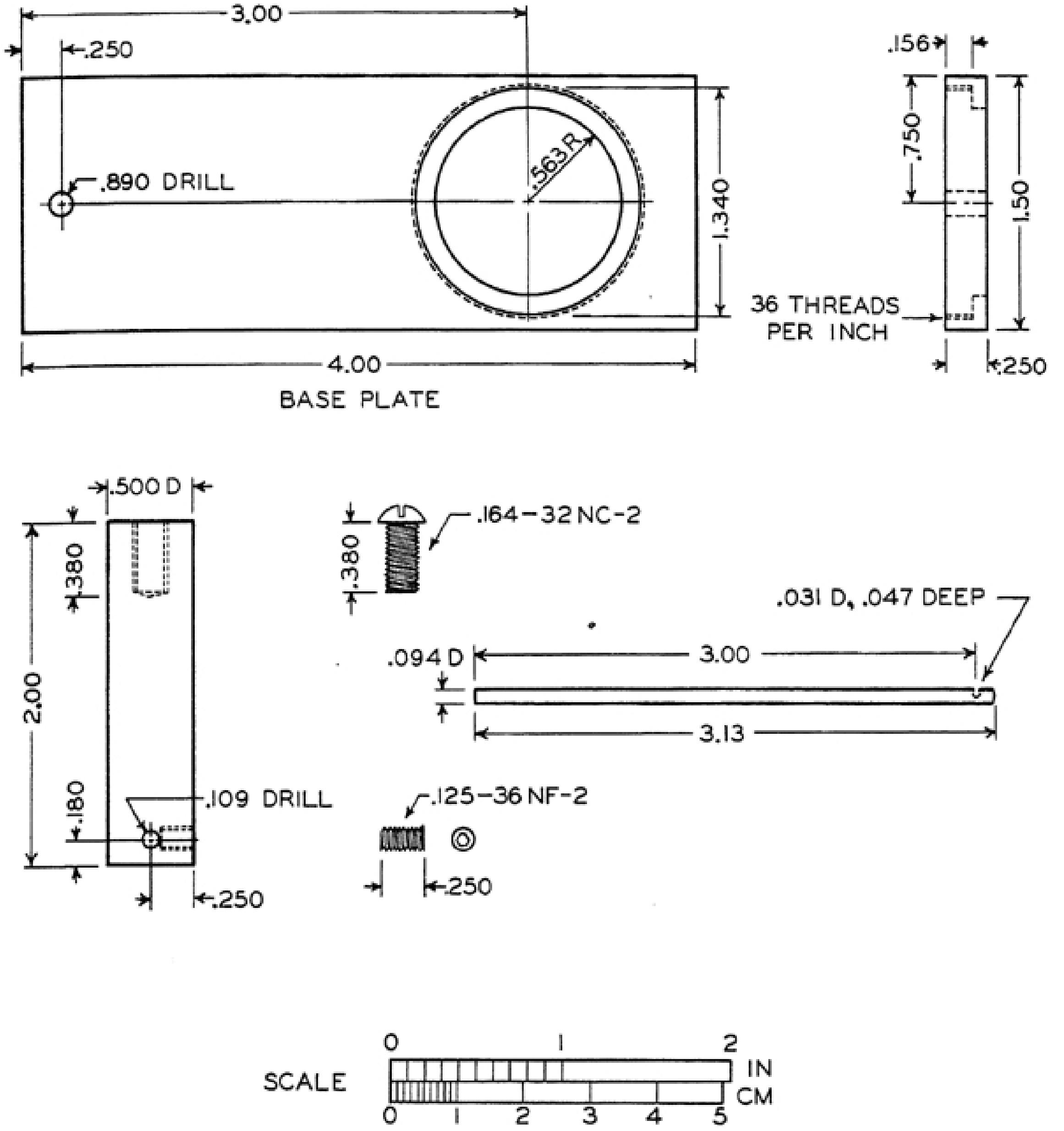

Fig. 4—Parts of the hair measurement beta gauge. All dimensions are given in inches.

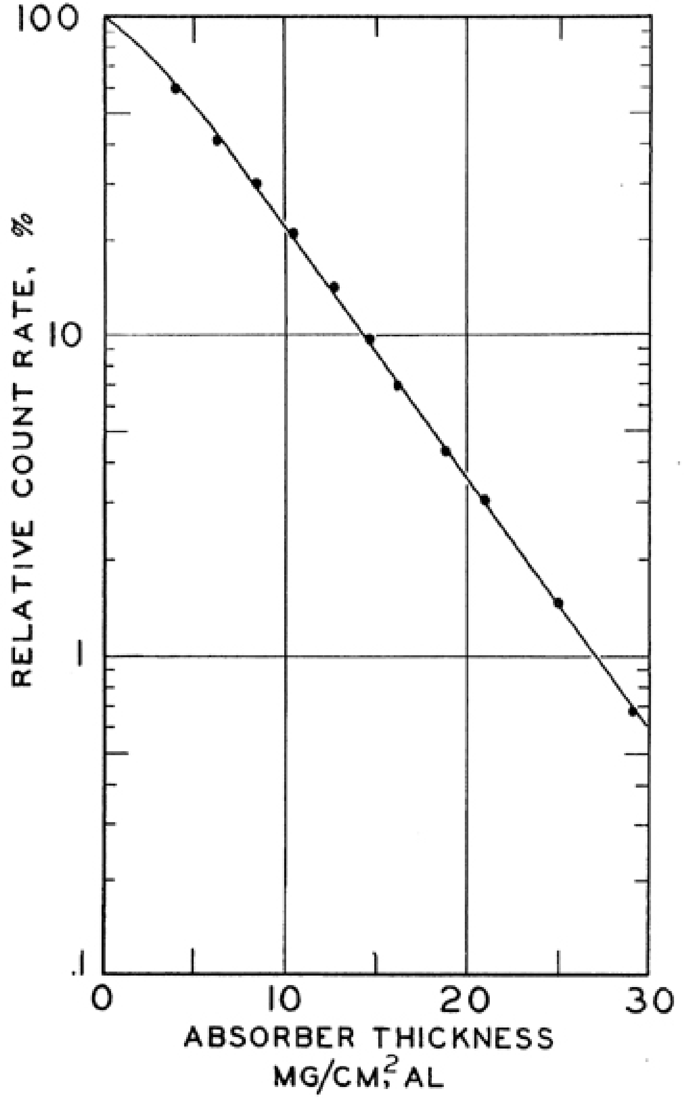

Fig. 5—Aluminum calibration curve for hair measurement beta gauge using $Pm^{147}$.

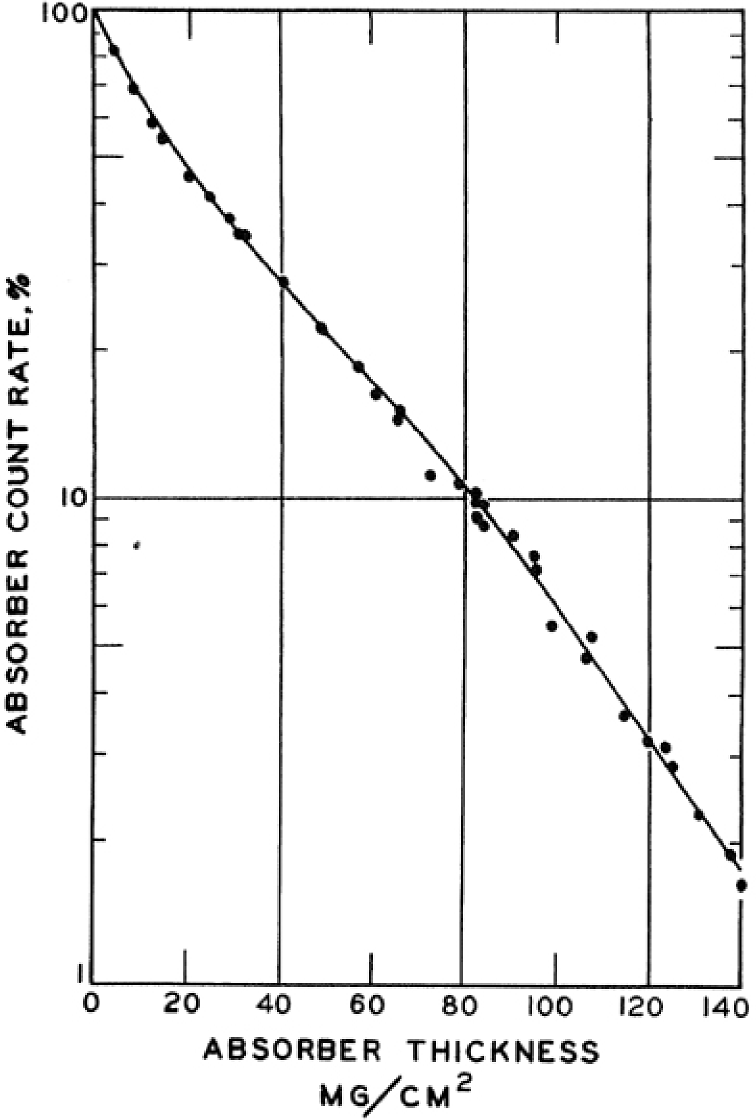

Fig. 6—Aluminum calibration curve for hair measurement beta gauge using $Tl^{204}$.

# TESTING

The hair measurement beta gauge was calibrated with aluminum absorbers of measured weight per unit area. These calibrated curves are shown in Figs. 5 and 6. All points were determined with a standard error of measurement of ±2 percent or less. To verify this curve for hair, weighed samples of hair were distributed in a cup of known area and areal density and the average decrease in count rate noted. These data are shown in Figs. 7 and 8. They indicate the validity of using an aluminum calibration curve with hair measurements.

Measurements of hair areal density made with the hair measurement beta gauge were compared with measurements made by weighing the hair clipped from a measured area. Twelve measurements with the beta gauge were made in the area to be clipped and were averaged. An area of about 30 square centimeters was clipped, yielding 0.2 to 0.5 grams of hair. These data are shown in Figs. 9 and 10. As can be seen, especially in Fig. 9, the error of measurement increases, as predicted, with decreased areal density. Also, at very low areal-densities the hair measurement beta gauge gives values slightly less than the clipped measurement. This is probably due to the finite size of the probe and a proportionately greater disturbance of short hair by the probe. If a sufficiently rigid material can be found, it would be advisable to reduce the diameter of the probe.

The hair measurement beta gauge was designed to provide saturation backscattering. If this were not the case, measured hair areal densities would be less if bone were near the point of measurement because of the backscattering of beta particles by the bone. To test this, counts were made with the probe resting in air, and on aluminum, wood, iron, and lead. In no case was the count rate affected; hence the measurements are independent of the surface on which the gauge is resting or the proximity of bone to the point of hair measurement.

The precision of measurements obtained with the hair measurement beta gauge was determined by repeated measurements on 12 cows. Two hundred and ninety comparisons indicated a probable error of ±4.4 percent when the gauge was used with an integrating rate meter whose time constant was equivalent to a standard error of ±2 percent.

Individual measurements required approximately one-half minute and calculation of the results required an additional one-half minute. The procedure is well tolerated by cattle.

The hair measurement beta gauge measures the total weight per unit area of the interposed material. This would include, in addition to the "solid" structure of the hair, such added areal density as that due to absorbed and free water, oils, dirt, etc. Whether these should or should not

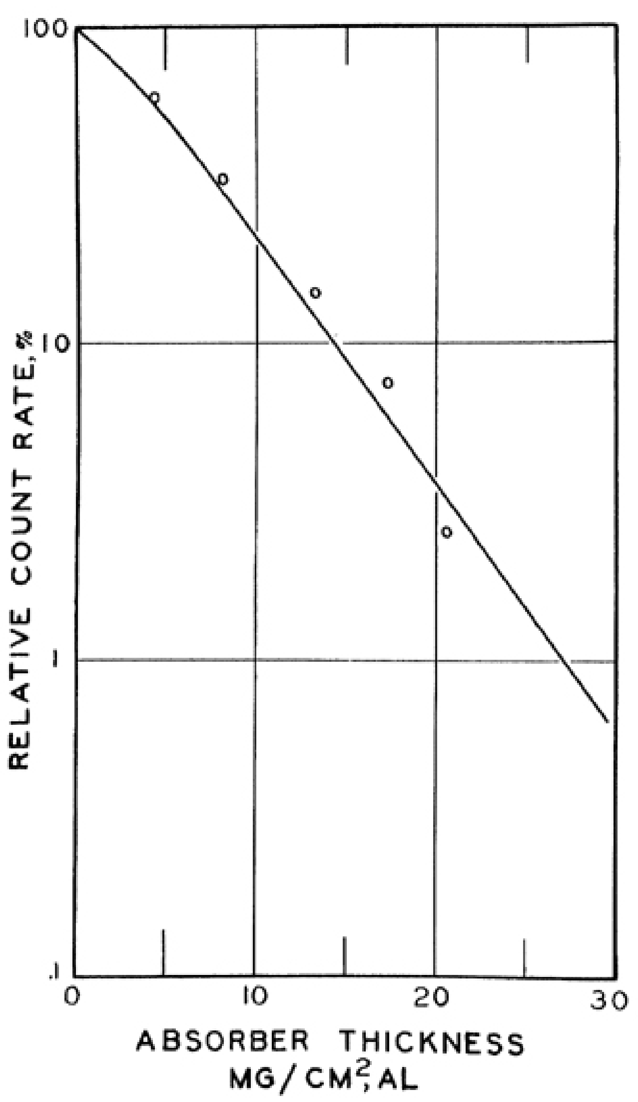

Fig. 7—Comparison of hair measurements with calibration curve for $Pm^{147}$.

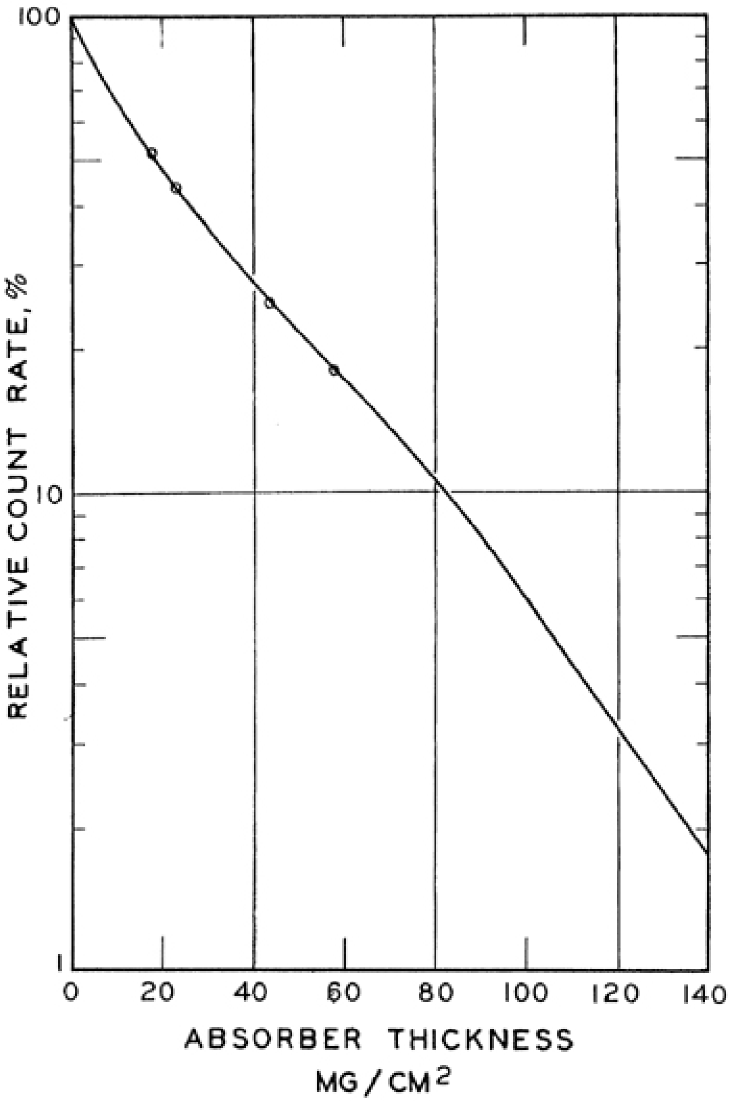

Fig. 8—Comparison of hair measurements with calibration curve for $Tl^{204}$.

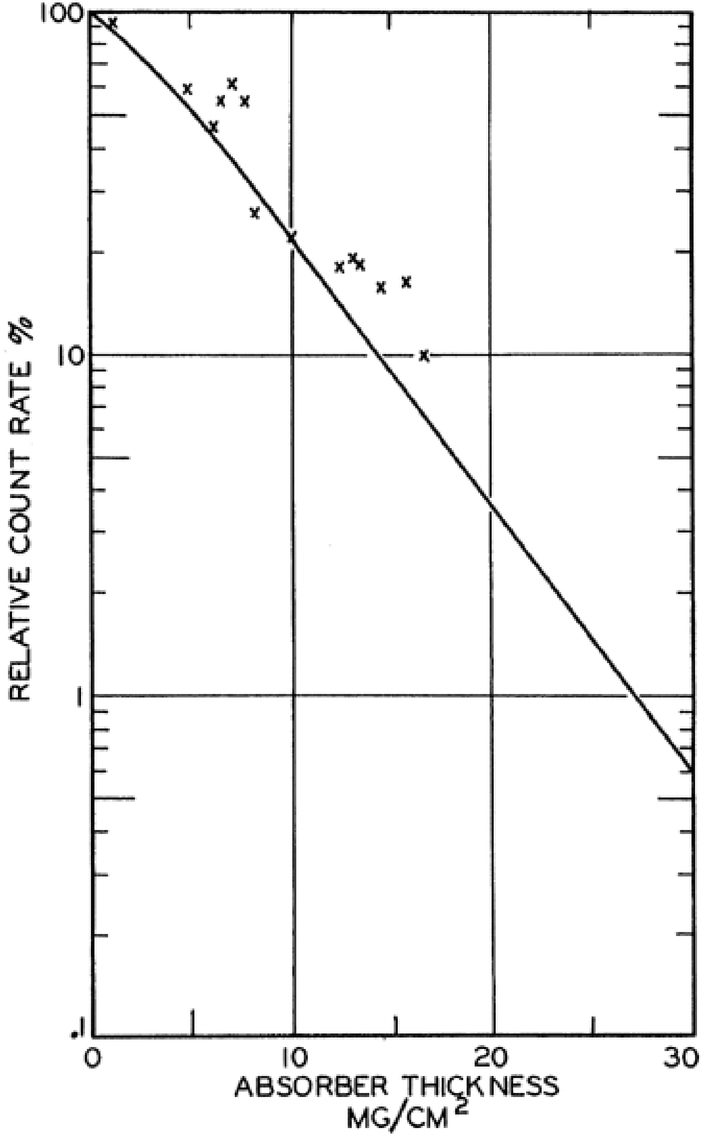

Fig. 9—Comparison of hair measurements by weighing the hair from a clipped area with the calibration curve for $Pm^{147}$.

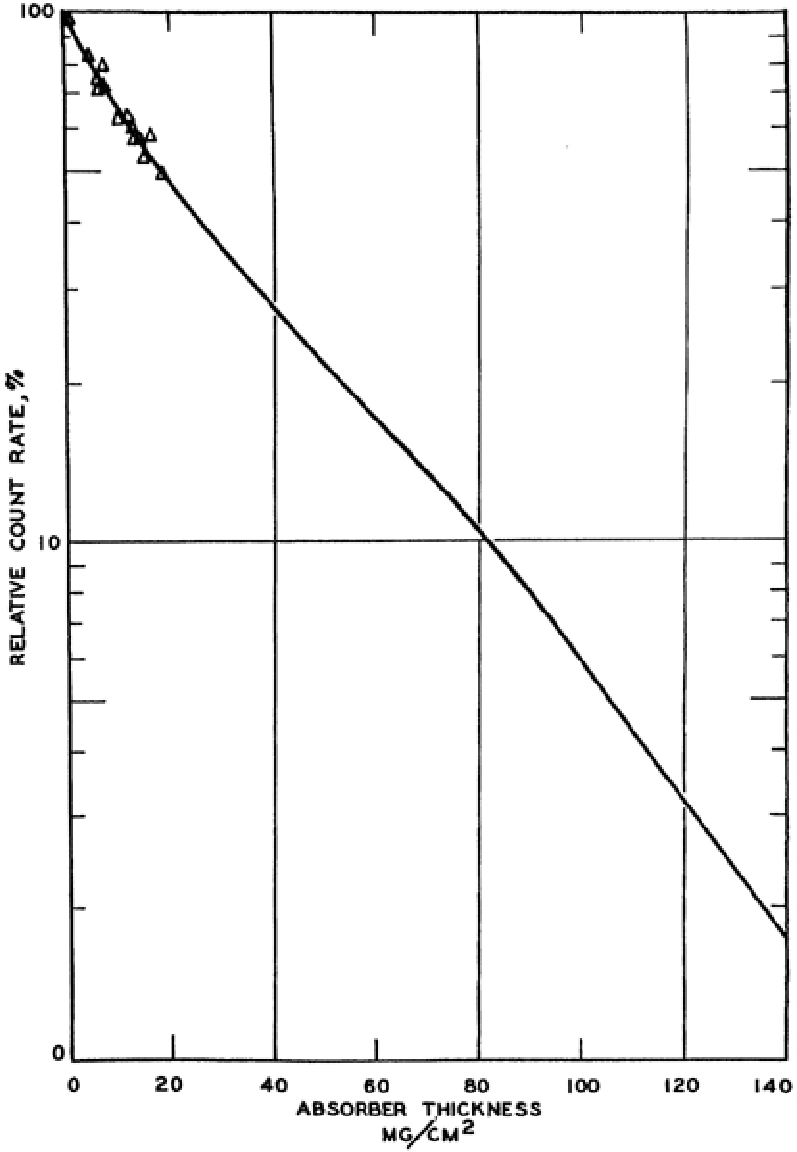

Fig. 10—Comparison of hair measurements by weighing the hair from a clipped area with the calibration curve for $Tl^{204}$.

be removed by appropriate treatment depends on the purpose for which the data are intended. In the data reported here the hair was untreated.

## EFFECT OF AMBIENT TEMPERATURE AND OTHER FACTORS ON THE AREAL DENSITY OF HAIR

The hair areal density was measured on heifers that were approximately 18 months old. The measurements were made in the Psychroenergetic Laboratory at several constant temperatures. These preliminary data were obtained while testing the hair measurement beta gauge. Detailed vital statistics concerning the heifers and a detailed temperature schedule will be published in a future bulletin. One group of heifers had been raised at a constant 50° F (10° C) and the other group at a constant 80° F (27° C). Four locations were selected for measurement of hair density. These points were on a circumference about midway along the body of the heifers. Measurements were made over the spine, on each side, and on the belly near the mammary vein. These points were chosen because they had been used for measuring hair and skin temperature.

The preliminary data are given in Table 1. As ambient temperature increased the hair areal density tended to decrease. Two-thirds of the measurements at 80° F were less than those at 50° or 65° F and all but two measurements at 110° F were markedly less than those at 80° F. The time

TABLE 1 -- EFFECT OF TEMPERATURE ON HAIR COAT

| Breed | Heifer No. | Hair Density, mg/cm$^2$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Side | | | Back | | | Belly | | |
| | | Heifers Raised at 50°F. | | | | | | | | |
| | | 50° | 80° | 110° | 50° | 80° | 110° | 50° | 80° | 110° |
| Shorthorn | 332 | 11.0 | 12.0 | --- | 8.5 | 14.0 | --- | 17.5 | 16.5 | --- |
| | 342 | 16.0 | 13.8 | --- | 7.0 | 14.0 | --- | 18.5 | 17.0 | --- |
| | 349 | 15.0 | 13.3 | --- | 7.0 | 14.0 | --- | 14.5 | 23.0 | --- |
| Santa Gertrudis | 366 | 7.3 | 5.9 | 3.0 | 9.4 | 6.6 | 3.2 | 6.2 | 6.9 | 5.0 |
| | 368 | 8.2 | 7.4 | 3.3 | 7.9 | 4.7 | 2.9 | 8.2 | 7.8 | 5.3 |
| | 387 | 7.1 | 5.5 | --- | 7.6 | 8.8 | --- | 5.0 | 8.8 | --- |
| Zebu | 301 | 5.1 | 4.6 | 1.5 | 7.0 | 7.8 | 3.3 | 4.4 | 5.2 | 2.1 |
| | 309 | 5.3 | 3.4 | --- | 8.7 | 4.7 | --- | 4.6 | 1.9 | --- |
| | 319 | 2.2 | 1.5 | 1.2 | 9.4 | 1.9 | 2.4 | 3.9 | 1.3 | 1.5 |

| Breed | Heifer No. | Heifers Raised at 80°F.* | | | | | |
|---|---|---|---|---|---|---|---|
| | | Side | | Back | | Belly | |
| | | 65° | 80° | 65° | 80° | 65° | 80° |
| Santa Gertrudis | 384 | 4.5 | 3.6 | 4.5 | 3.0 | 4.5 | 1.3 |
| | 393 | 4.9 | 4.4 | 6.6 | 2.4 | 5.1 | 5.5 |
| | 396 | 4.8 | 2.4 | 3.6 | 4.3 | 4.5 | 4.3 |
| Zebu | 301 | 2.1 | 1.6 | 2.6 | 2.6 | 2.0 | 1.2 |
| | 302 | 1.8 | 1.2 | 1.9 | 2.6 | --- | 0.8 |
| | 315 | 1.0 | 1.4 | 1.6 | 3.1 | 0.9 | 0.8 |

*Shorthorn heifers not measured because they were previously clipped.

between the measurements at 80° and 110° F was 33 days. During this time the temperature was 80° F or above, being two weeks at 90° and five days at 100° F. Since the ratio of day to night in the chambers was constant and had been constant for over a year, these data suggest that the reduction observed in hair coat was due to ambient temperature.

Measurements were made of the hair coats of three sets of identical twins. They were made in the same arbitrary location on the back of each twin. The data are given in Table 2. It will be observed that the hair areal density in identical twins kept under the same conditions was essentially identical.

TABLE 2 -- COMPARISON OF THE HAIR COATS OF IDENTICAL TWINS

| Heifer No. | Hair Density $mg/cm^2$ |
|---|---|
| 41 | 9.0 |
| 42 | 9.8 |
| 158 | 11.6 |
| 159 | 11.6 |
| 24 | 11.6 |
| 76 | 11.8 |
| 41 | 9.7 |
| 42 | 10.7 |

## SUMMARY

The construction and testing of a hair measurement beta gauge has been described. This gauge offers a quick, non-destructive, and accurate method of measuring the areal density of hair. Preliminary measurements indicated that increased environmental temperature, at constant "day" length, caused a reduced hair coat.

## APPENDIX

### Mounting of Radioisotopes in Fused Enamels**

For use in a hair measurement beta gauge, the radiation source must be mounted so as to be chemically stable and also resistant to abrasion and shock. The source must also provide beta particles of the desired energy. Fused enamels are among the most chemically stable surface coatings known. Being essentially glasses, they are highly resistant to abrasion and reasonably resistant to mechanical shock. Many radioisotopes are isotopes of elements normally used in fused enamels or are closely related

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to them. The incorporation of such radioisotopes into an enamel seems to offer a very satisfactory method of mounting.

Radioisotopes have previously been incorporated into glass and glass-like materials. Kisieleski, Svihla, and Brues[6] reported a method of incorporating $Y^{91}$, $Sr^{90}$, and $Ce^{144}$ into microscopic glass beads. They fused the hydroxide or carbonate of the isotope with powdered glass.

Most methods of mounting radioisotopes do not render them a part of the surface coating but rather cover them. This introduces an absorber between the isotope and the usable radiation, thus reducing their energy and penetrating power. Examples of such methods are the covering of a deposited radioactive salt with plastic or containing it in a metal capsule. Among those radioactive isotopes that can be electroplated, it is often necessary to cover the plated surface to make it more resistant to abrasion.

The mounting of the radioisotopes as components of a fused enamel was accomplished in a manner similar to that used for the application of decorative enamels to small jewelry.[7] The metal was first cleaned and rinsed in distilled water. A thick layer of crushed enamel was then applied. A small amount of alkali was placed on the enamel to neutralize the acidity of the radioisotope solution and the desired amount of an acid

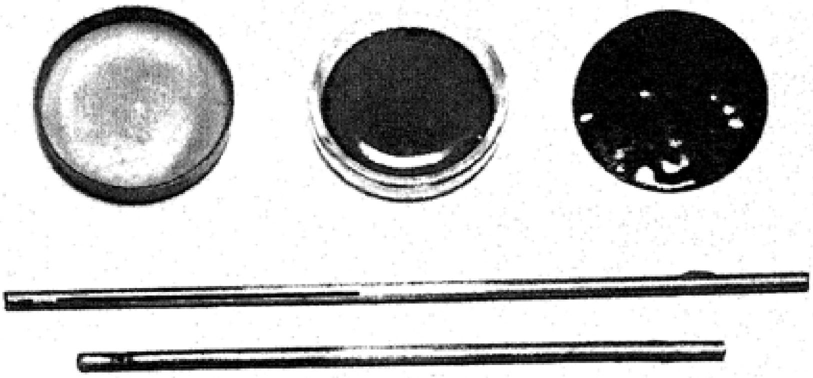

Fig. 11—Examples of enameled radiation sources. Top row, left to right, on stainless steel, glass, and copper. Bottom, mounted in a 1 mm slot and a 0.8 mm diameter hole (left end).

solution of the radioisotope was placed on the crushed enamel with sufficient water to thoroughly wet the powder. The mixture was dried by mild heat. After drying, the mixture was fused either in a gas flame or a muffle furnace. After the enamel had fused and the surface became glossy, the temperature was reduced slowly to effect a gradual cooling of the enamel. The sources were cleaned in appropriate decontaminating agents to remove any radioactivity not incorporated into the enamel. If enamel is fused in a gas flame, care must be taken not to permit the flame to touch the surface of the melt. In the case of $Sr^{90}Y^{90}$ it was necessary to fuse a thin layer of non-radioactive enamel over the finished source to prevent leaching of activity.

This technique has been used to make sources of $Pm^{147}$, $Tl^{204}$, $Sr^{90}$ $Y^{90}$, and $Cr^{51}$ on stainless steel, copper, and glass ranging in size from 0.8 mm to 25 mm in their major dimension. Examples of these sources are shown in Fig. 11.

For mounting radioisotopes in the needle-shaped source holder of the hair measurement beta gauge, it was necessary to work under a low power, long focus, microscope. Fig. 12 shows the apparatus used. The melt was fused in a depression in the source holder (see Fig. 2) with a gas flame. The sides of the depression were sufficient to prevent the flame from touching the surface of the melt. A sheet metal shield with a glass window protected the operator and the microscope from the heat, beta radiation, and any radioactivity that might be vaporized during fusion. In addition, the glass window and the microscope objective were cooled with an air jet. The radioisotope solutions were introduced into the depression with a square-tip hypodermic needle and syringe.

To provide sufficient illumination of the melt, one side of the binocular microscope was used as an illumination objective. A focusing microscope illuminator was placed so that its focal point coincided with the focal point of the eyepiece. This provided adequate illumination at the bottom of the depression in which the enamel was fused.

Tests of the chemical stability of the sources were made by the standard scrub test, soak test, and wipe test.[8] The scrub test consisted of immersing the source in a decontaminating solution and scrubbing vigorously with a brush—in this case a stiff, motor driven, nylon brush. The radioactivity of the solution was then determined. The soak test consisted of immersing the source for 8 hours in a decontaminating solution at 50° C and determining the radioactivity of the solution. The wipe test consisted of wiping the source with an absorbent material wet with a decontaminating solution and determining the radioactivity on the swab. In all tests the decontaminating solutions used were 10 percent sodium carbonate,

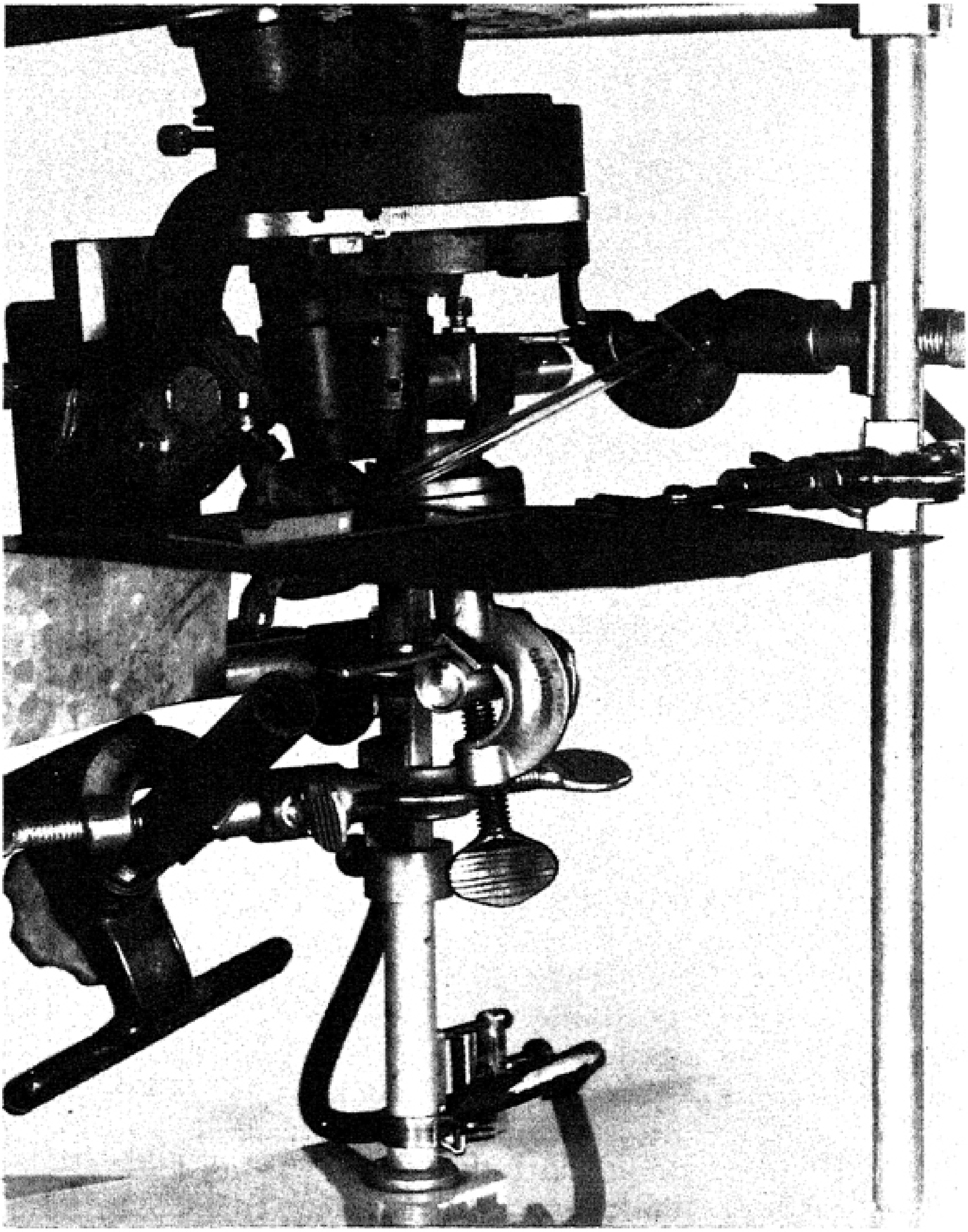

Fig. 12—Micro-fusion apparatus. The binocular microscope is used to observe the melt in a small hole in the thin rod.

10 percent nitric acid, and 10 percent citric acid. These were chosen to ascertain the effects of alkaline, acid, and chelating reagents.

In all cases the wipe tests were negative—i.e., no measurable radioactivity was found on the swab. Scrub tests and soak tests on the sources indicated that less than 0.0005 microcurie of activity was removed by these procedures. This is approximately one hundredth of the currently permissable amount for *sealed* sources.[8] The sources were least stable to nitric acid.

The range of the beta particles emitted by the weakest beta-emitter prepared ($Pm^{147}$) was compared with that of a weightless film of the isotope placed in a similar container. The ranges, as well as the aluminum absorption curves, were identical within the precision of the measurement (±1-5 percent). These data indicate that the radioisotope was present very close to the surface of the enamel (see Fig. 13). Although self-absorption was present, especially with low energy emitters, the maximum energy of the emitter was readily available from these sources.

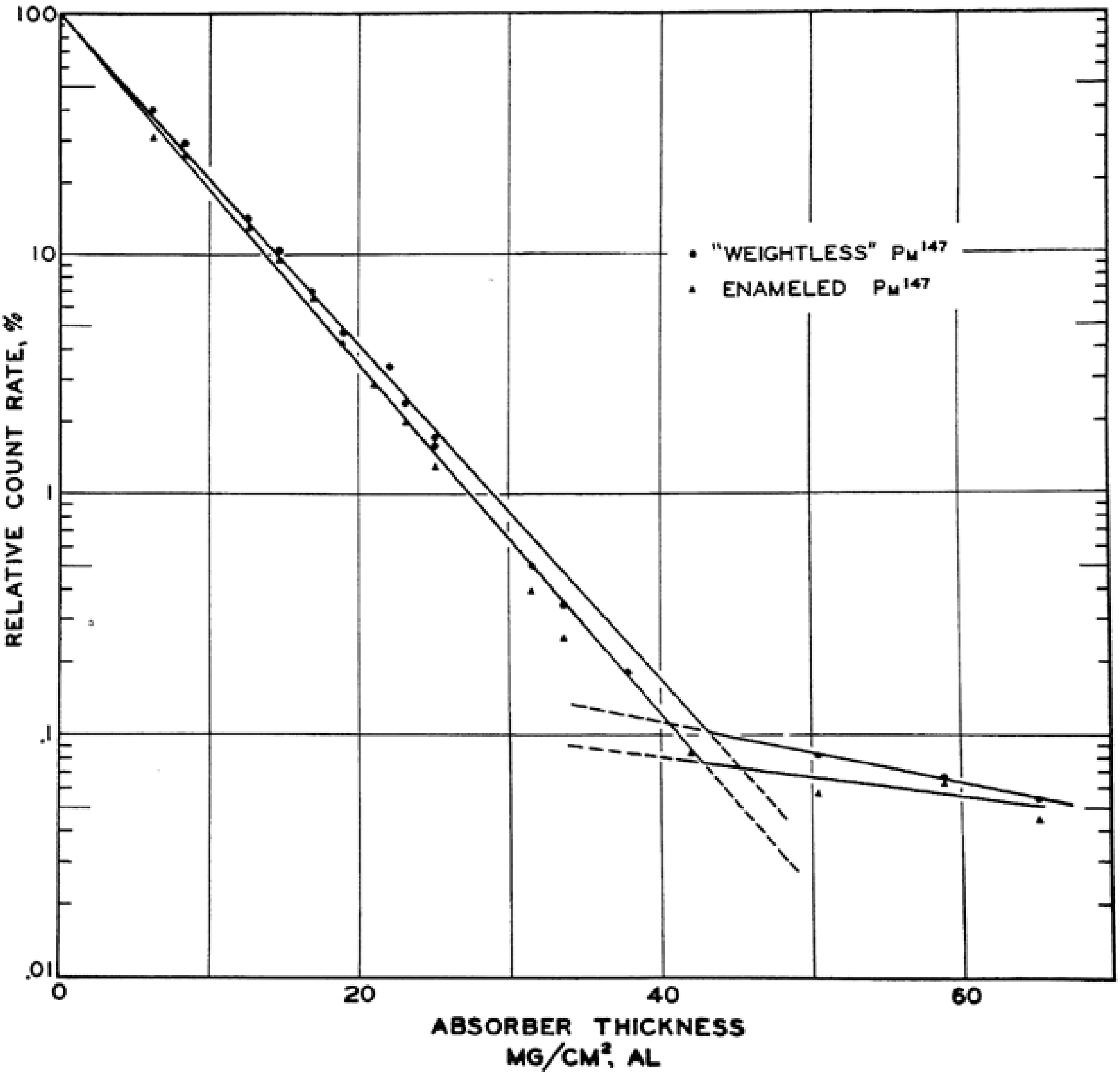

Fig. 13—Range of enameled and carrier free $Pm^{147}$. The ranges in aluminum are identical indicating that the maximum energy of the $Pm^{147}$ beta radiation is available from the enameled sources.

The mounting of radioisotopes in a fused enamel permitted the preparation of durable radiation sources without the interposition of absorbing materials. $Pm^{147}$, $Tl^{204}$, $Sr^{90}Y^{90}$, and $Cr^{51}$ were mounted in this manner on stainless steel, copper, and glass ranging in size from 0.8 to 25 mm in their major dimension. These sources possessed the chemical and abrasion resistance of fused enamels. The range of beta particles emitted from such sources was identical with the range from the carrier free isotope. The use of jewelers enamel permits the incorporation of color coding directly into the active source material.

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