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SPATIAL DISTRIBUTION FROM SMALL
BETA SOURCES AND THE EFFECTS OF
APERTURE SIZE

Technological Spinoff Report

Prepared by:
R. V. Heckman

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**Kansas City
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SPATIAL DISTRIBUTION FROM SMALL BETA SOURCES AND THE EFFECTS OF
APERTURE SIZE

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February 1974

Prepared by R. V. Heckman, D/144

Using a film technique, the forward and backward distribution of small beta sources were studied. In addition, the effect of the ratio of aperture size to source size was investigated for commercial coaxial-type beta-backscatter probes. Experiments indicated that the signal-to-noise ratio for such probes is intolerable when apertures smaller than 0.020 inch (0.5 mm) are used. Test configuration, probe, and detector design changes for measurements on areas 0.005 inch (0.13 mm) in diameter are discussed.

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THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

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SUMMARY

The beta forward and backscattered distribution and the effect of aperture size on the backscattered flux were studied to aid in the development of small area beta backscatter probes. The experiments indicated that the coaxial commercial beta probes were generally unsuitable for small area measurements because the geometry of the probes is such that the signal-to-noise ratio is intolerable when apertures smaller than 0.020 inch (0.5 mm) are used.

The experiments indicated that in order to improve the geometry, the sources should be moved closer to the surface of interest and preferably moved so as to not block the primary flux of electrons. The detector also should be enlarged and moved closer to the scattering surface so that it subtends as large a solid angle as possible.

An additional design requirement appears to be that the source-to-surface distance and the detector-to-surface distances be made variable so that the respective geometries can be optimized for the best signal-to-noise values.

On the basis of the report, it would appear that probes utilizing these general requirements could be capable of measurements on areas 0.005 inch (0.13 mm) in diameter.

DISCUSSION

SCOPE AND PURPOSE

Little if any published work can be found treating the subject of beta-backscatter except from a strict applications standpoint. A scattering of papers have been written on the relative backscatter produced by various materials and on a quasi-empirical method of calculating these percentages in terms of atomic weights and atomic numbers.¹ Other papers have been written dealing with the treatment of the statistics involved in beta-backscatter.² An explanation for this lack of literature is that by and large there has been very little interest in the interaction of betas with bulk material.

At Bendix Kansas City Division, development work has been underway for over two years to investigate techniques for making thickness measurements of thin coatings and films over extremely small areas. This work has been necessitated by the trend toward miniaturization and the increasing need for more precise in-process controls. A variety of methods have been investigated, and in recent months effort has been concentrated on the development of beta-backscatter technology. Of all methods tested to date, this technique has shown the best promise of meeting current thickness measurement needs. The principle limitation on the technique is that commercial equipment cannot be used with apertures less than 0.010 inch (0.25 mm) in diameter, and, for most applications, 0.020 inch (0.5 mm) is a realistic lower limit. The goal of the current development program is to build probes capable of operation with apertures 0.005 inch (0.13 mm) in diameter that can measure thickness variations to a precision of under 3 percent.

The absence of literature as well as the complexity of the beta interaction required that experiments be performed with existing probes to place on a quantitative basis the nature of the beta backscattered spectrum and the effect that variations in probe geometry have on this distribution. The following report presents the results of these studies and attempts to construct guidelines to be followed in building new probe systems.

ACTIVITY

Experiments were performed to measure the spatial distribution of backscattered electrons and to determine the effect of aperture size on the backscattered flux. The measurement of the spatial distribution of electrons was performed using a film technique, while the backscattered flux measurement was monitored using a geiger muller tube with a Hewlett-Packard Scaler.

Backscattered Distribution

The fixture used for measuring the beta-backscatter distribution is shown in Figure 1. As can be seen from that drawing, it consisted of a simple vacuum film holder constructed to hold the strip of film in a cylindrical geometry, the inner radius being machined to a 1/2-inch (12.7 mm) radius. The cap portion of the fixture was made interchangeable so that the source-to-scattering-surface distance could be changed by substituting caps of different lengths. The film holder was machined to fit tightly against the scattering surface so that as the source-to-surface distance was varied the surface-to-film distance remained constant. With the film cut to proper length the spatial distribution of electrons in the complete backward solid angle of 180° could be measured.

Kodak AA film was used in the fixture since this film provided the best combination of short exposure time versus resolution. Several radiographic and photographic films were evaluated, but these films either were too slow or too grainy for the purposes of this study. With the Type AA film, an exposure of 30 minutes was required with a 50 millicurie source. All film processing was done using a Pako automatic processor with Kodak chemicals. By using an automated processor, variations as the result of changes in development parameters were minimized.

All of the distributions shown in this report were made using a promethium 147 beta source with an activity of approximately 50 millicuries. Distributions were also made with thallium and strontium sources but the results were essentially the same for all the sources. One problem encountered with the strontium source was that because of its high energy an appreciable contribution to the film blackening was caused by backscatter from the film holder itself. This problem was alleviated by using double film thickness.

Aluminum was used for the scattering surface since aluminum is one of the principle materials of interest and was readily available. The effect of using different scattering materials would be to increase or decrease the total backscattered flux but the relative flux magnitudes and distribution would remain unchanged.

Exposures were made to determine the forward and backward scattered distributions for source to surface distances of 0.015, 0.040, and 0.060 inch (0.38, 1.0, and 1.5 mm). The actual distributions obtained are shown in Figures 2, 3, and 4. As an aid to interpreting the backscattered distribution a schematic of the source film geometry is shown in Figure 5. As can be seen from this figure, the source and source holder were located in front of the film, with the film wrapped around them in a semicircle. Because of this geometry, the central portion of the backscattered electron spectrum was masked by the source and source holder.

Figure 1. Beta Backscatter Distribution Fixture

Forward Scatter

Backward Scatter

Figure 2. Beta Distribution at Source-to-Scattering-Surface Distance of 0.015 Inch (0.38 mm), 5X

Forward Scatter

Backward Scatter

Figure 3. Beta Distribution at Source-to-Scattering-Surface Distance of 0.040 Inch (1.0 mm), 5X

Forward Scatter

Backward Scatter

Figure 4. Beta Distribution at Source-to-Scattering-Surface Distance of 0.060 Inch (1.5 mm), 5X

Figure 5. Schematic of Film Source Geometry Showing Relative Position of Source to Film

The line shown down the center of the film shows the location of the spherical plane of interest. Lines drawn parallel to this line represent other spherical planes but are actually further away from the source than corresponding points on the centerline. This is of course caused by the cylindrical shape of the recording film.

As an aid in interpreting the distributions recorded on the films an Interpretation Systems VP-8 was used to color encode the film negatives. The VP-8 enables the user to assign different colors to various density or transmission ranges. In this manner, various shades of gray can be converted into distinct colors. As in this case, this type of image enhancement greatly aids interpretation of the films.

The quantitative information contained in Figures 2, 3, and 4 is given in Figure 6 which plots effective beam size as a function of source-to-surface distance. The value recorded for beam size is the diameter of the red portion of each distribution which corresponds with the central core of radiation produced by the source. For a typical source to aperture distance of 0.030 inch (0.76 mm), the 0.012-inch (0.30 mm) diameter source has an effective diameter of 0.104 inch (2.64 mm). From Figure 6, it can be calculated that the cone of radiation produced by the source spreads out with an effective angle of approximately 52° with respect to a line drawn parallel with the source. This spreading effect accounts for the extremely poor signal-to-noise ratios obtained for small diameter apertures.

As can be observed from Figures 2, 3, and 4, the forward distribution consists of a uniform center core surrounded by a flux of electrons of rapidly decreasing intensity (decreasing number). The elliptical shape exhibited by the distribution at closer source-to-surface distances is apparently an indication that the source used was not perfectly circular in shape. This same anomaly probably accounts for the skewed distribution observed in the backscattered distribution.

It should be mentioned that in both the forward and backscattered distributions, the same scale was used so that comparisons could be made of the forward versus the backscattered distributions and the effects of changing the source-to-surface distances. In analyzing the backward flux, the forward distribution is in a sense the effective source which produces the backscattered distribution. The general shape of the backscattered distribution as seen in these figures is essentially two broad peaks, the valley between being the result of shadowing by the source and source holder.

The relative intensities of these distributions are shown in graphical form in Figure 7. It can be extrapolated that, in the

Figure 6. Diameter of Central Core of Beta Radiation as a Function of Source-to-Scattering-Surface Distance

Figure 7. Relative Intensity of Backscattered Distribution as a Function of Source-to-Scattering-Surface Distance

absence of the source masking, the distribution would show a central maximum at an angle of 180° scattering with a minimum occurring at a scattering angle of 90° ; however, with the coaxial geometry used here as in all commercial probes and because of the masking effect of the source, the maximum flux, instead of occurring at 180° , occurs at some angle approximately 135° . If a spherical film surface had been used, the distribution would be essentially donut shaped with a minimum in the center and at the outer edge and with a maximum in between. Referring to Figure 7, it can be seen that as the source moved farther away from the surface and closer to the film the two peaks moved slightly closer together. This phenomenon is explained in Figure 8. As the source moves farther away from the surface, the solid angle represented by the source decreases; the source-to-film distance also decreases. The two effects result in allowing a greater percentage of the backscattered electrons to reach the film.

As a result, the flux increases slightly as the source-to-surface distance increases and the overall flux broadens. As has been mentioned previously, the asymmetry of the backscattered distribution was apparently the result of the elliptical cross-section of the source.

Effects of Aperture Size

All of the above distribution measurements were made without any aperture present between the source and the surface. In order to determine the effect of such an aperture, a 0.030-inch (0.76 mm) aperture was placed over the source previously used at a distance of 0.030 inch from the source. The backscattered distribution observed is shown in Figure 9. As can be seen, the aperture causes an overall broadening of the distribution as contrasted with the case where no aperture was present. The settings used on the VP-8 analyzing this film were the same as those used on the other films so that the colors represent the same degree of blackening or flux.

In addition to these distribution experiments, experiments were performed to determine the effect of aperture size on the relative flux backscattered and on the signal-to-noise ratio present. The signal-to-noise ratio was determined in these experiments in the following manner:

$$\text{Signal-to-Noise} = \frac{\text{Total \# Backscattered} - \text{Background.}}{\text{Total \# Backscattered}}$$

The background figure in this case is the number backscattered without any scattering surface other than air present.

Figure 8. Schematic of Backscatter Distribution Fixture Showing Effect of Changing Source-to-Surface Distance

Figure 9. Beta Backscatter Distribution With 0.030-Inch
(0.76 mm) Diameter Aperture and Source-to-Aperture
Distance of 0.030-Inch, 5X

The fixturing used was essentially the same as that used in the distribution measurements, except that a geiger/muller tube and a counter/scaler were used to determine the flux of electrons present instead of using film as a detector. To investigate the effect that source size has on the measurements, a promethium source 0.011 inch (0.28 mm) in diameter and a radium source 0.013 inch (0.33 mm) in diameter were used.

Apertures ranging from 0.010 to 0.093 inch (0.25 to 2.36 mm) were placed on these sources and the background flux and signal flux obtained from aluminum and steel surfaces were recorded for each aperture size. Table 1 contains the average values obtained for each of these measurements. Figures 10, 11, 12, and 13 show this same data in graphical form.

In both Figures 10 and 11, which plot signal in terms of count rate as a function of aperture size for the two sources, it can be seen that a definite inflection is present in both sets of data. If the slope of the upper portion of these two curves is extrapolated back to zero (dotted line), this curve intersects the aperture axis at 0.011 inch and 0.013 inch respectively, which corresponds to the diameters of the two respective sources. It would appear, therefore, that the beta flux for a coaxial detector could be expressed by two functional expressions: one for the case where aperture size is less than the source size, and the other for the case where the aperture size exceeds the source diameter.

The fact that the inflection point occurs at a point greater than the source is probably because of the spread exhibited by the sources in the distribution study.

Figures 12 and 13 are plots of the signal-to-noise ratio as a function of aperture size. From this data, it is clear why conventional probes are unable to function with apertures less than 0.020 inch (0.51 mm) in diameter. Combining the findings of the distribution study with these measurements, it is interesting to compare the signal-to-noise ratio observed with a value computed strictly as a function of geometry. As an example, consider the signal-to-noise ratio observed for an aperture 0.010 inch (0.25 mm) in diameter. From Figure 6 it can be seen that the effective beam diameter at a distance 0.030 inch (0.76 mm) from the source as used in these experiments is approximately 0.10 inch (2.5 mm). Therefore, the percentage of electrons which are backscattered from the sample to the total number backscattered from the aperture and sample would be proportioned as in the following formula.

$$\frac{(0.010)^2}{(0.1)^2} = 1 \times 10^{-2}$$

Table 1. Count Rate From Aluminum and Stainless Steel Surfaces as a Function of Aperture Size.

Source (Isotope)	Aperture Diameter (Inch) (mm)	Mask Background (Counts/Sec)	Aluminum (Counts/Sec)	Stainless Steel (Counts/Sec)
Radium	0.010 (0.25)	4072	4394	4907
Radium	0.014 (0.36)	3230	3814	4734
Radium	0.016 (0.41)	2568	3298	4392
Radium	0.020 (0.51)	2959	5027	7423
Radium	0.031 (0.79)	2355	6114	10494
Radium	0.047 (1.19)	1531	7485	12878
Radium	0.062 (1.57)	1038	8605	14163
Radium	0.093 (2.36)	697	9405	14722
Promethium	0.010 (0.25)	8560	8751	9491
Promethium	0.014 (0.36)	7203	7865	9467
Promethium	0.016 (0.41)	5949	7216	9749
Promethium	0.020 (0.51)	6713	9012	14699
Promethium	0.031 (0.79)	5224	10931	18043
Promethium	0.047 (1.19)	2213	11102	20032
Promethium	0.062 (1.57)	1333	12127	21298
Promethium	0.093 (2.36)	856	12913	21534

Figure 10. Background Corrected Count Rate From a Radium Source as a Function of Aperture Size

Figure 11. Background Corrected Count Rate From a Promethium Source as a Function of Aperture Size

Figure 12. Signal-to-Noise Ratio Versus Aperture Size for a Radium Source

Figure 13. Signal-to-Noise Ratio Versus Aperture Size for a Promethium Source

This value is approximately 1/2 the value observed for aluminum and 1/10 the value observed for stainless steel. The higher observed values are an indication of the effectiveness of the aperture design in backscattering the electrons from the aperture at such an angle that they would not strike the detector. In this case, the apertures had a conical inner geometry which caused the backscattered electrons to be scattered at angles exceeding the solid angle of the detector. Apparently the higher the backscattered flux, the more effective the aperture design is in improving the signal-to-noise ratio.

ACCOMPLISHMENTS

Several design criteria can be derived from the results of these experiments. First, on the basis of the signal-to-noise experiments and the character of the beta distribution it would appear that, in order to design probes capable of working on extremely small apertures, an alternative to the typical coaxial system such as used in this experiment should be sought. On the basis of these studies, it appears that a design which, in a sense, interchanges the positions of the detector and source might be fruitful. A conceptual probe of this type might use an annular source surrounding a well-collimated detector.

From the distribution experiments, it appears that moving the source closer to the scattering surface produces a better collimated beam and results in a broader distribution of betas. In terms of probe design, this suggests that the source should be located as close to the scattering surface as possible and, to enable centering on the maximum of the backscattered distribution, the effective detector-to-surface distance as well as source-to-surface distance should be made adjustable.

Since it is physically impossible to shrink the source size and still maintain an acceptable flux rate, the only way to improve the signal-to-noise ratio is to develop designs which avoid placing the source in front of the detector.

The fact that a significant number of betas are backscattered at extremely large scattering angles indicates that the detector should be designed to include as large a solid angle as possible. The experiments and geometrical considerations indicate that this can be accomplished by increasing the physical size of the detector, by moving the detector closer to the surface, or by a combination of both of these effects. Plastic scintillators appear to be good prospects for fulfilling these requirements since they can be machined to almost any geometry desired.

To summarize these experiments, it would appear that commercial probes are inadequate for use with apertures of 0.020 inch (0.5 mm) in diameter or less. But it would also appear that a probe with similar geometry but with the position of the source and detector interchanged might be able to operate with smaller diameter apertures. In designing probes, provisions should be made to make the source-to-surface and surface-to-detector distances variable. The optimum design would enable placing both the source and detector as close to the surface under investigation as possible. It is further indicated that the detector be designed to incorporate as large a solid angle as possible. If these design requirements are followed, the overall flux and signal-to-noise ratios may be improved sufficiently as to allow apertures 0.005 inch (0.13 mm) in diameter to be used.

FUTURE WORK

The results of this report are currently being incorporated into the design of first generation development probes. These probes will incorporate a technology which has been developed at Los Alamos Scientific Laboratory. This approach involves the use of plastic scintillators and photomultiplier tubes as detectors. Not only does this approach afford greater design flexibility than available with geiger tubes but it also has intrinsically better detection characteristics. It is felt that using this type of detector, along with applying the design criteria developed in this report, will make small area beta-backscatter measurements feasible.

REFERENCES

¹Ralph H. Muller, "Interaction of Beta Particles With Matter," *Analytical Chemistry*, Volume 29, Number 6, June, 1957.

²Jerry D. Fox and Grover M. Taylor, *A Statistical Theory of Design for Plating Thickness Measurements by Radiation Backscatter Methods*. Livermore: Lawrence Livermore Laboratory, Report UCRL-71605
Revision 1, July, 1969.