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BETA DOSIMETRY STUDIES AT LLNL*

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Abstract: This paper summarizes three beta-dosimetry studies made recently at the Lawrence Livermore National Laboratory. The first study was to determine the beta-gamma exposure rates at the Los Alamos Godiva IV Critical Assembly. The beta spectra from the assembly were evaluated using absorption curves and the beta-gamma dose-rate ratios were determined at various distances from the assembly. A comparison was made of the doses determined using two types of TLD personnel dosimeters and a film badge. The readings of an Eberline RO-7 instrument and the dose rates determined by TLDs were compared. Shielding provided by various metals, gloves, and clothing were measured. The second study was to determine the beta energy response of the Eberline RO-7 instrument based on measurements made with the PTB beta sources. This study required additional calibration points for the PTB sources which were made using extrapolation chamber measurements. The third study resulted in two techniques to determine the beta energy (E_{max}) from the readings of thin-window portable survey instruments. Both techniques are based on the readings obtained using aluminum filters. One technique is for field application, requires one filter, and provides a quick estimate of the beta energy in three energy groups: <0.5 MeV, 0.5 MeV to 1.5 MeV and >1.5 MeV. The second technique is more complex requiring measurements with two or three filters, but gives the beta energy and the approximate shape of the beta spectrum.

Introduction

We recently completed three related studies on beta dosimetry at the Lawrence Livermore National Laboratory. These studies originated from a request we received to aid in the reevaluation of an exposure that occurred in 1963 at a critical assembly. Of particular interest was the beta component of the dose and the corresponding beta spectra from a critical assembly. This study began shortly before the Beta Dosimetry Workshop was held in New York City in December 1981 and this meeting was attended to determine the present state of the art in beta dosimetry. At the meeting, it was learned that a simple technique to determine beta energies using survey instruments at field locations was needed. In this paper we discuss two techniques we have developed to meet this need. We also became aware of the beta measuring capability of the Eberline RO-7 survey instrument which appeared to be an ideal instrument for use in our critical assembly study. Unfortunately, the beta energy dependence was not adequately known so we performed a study of the beta energy dependence of this instrument.

Each of these studies has been prepared into separate reports (Ha 82a, Ha 82c, and Ha 82e) and this paper describes only a part of the results. Copies of the complete reports are available from the author or will be published later in a journal.

I. Beta- and Gamma-Dose Measurements of the Godiva IV Critical Assembly

The dose received by personnel while working around criti·.l assemblies is now and always has been measured using the regularly issued pe sonnel dosimeter. In the past, this was a film-badge dosimeter, and of particu r interest here is a simple film badge worn by the personnel at the Nevada Test Site (NTS) in 1963. The doses indicated by the film-badge for a person who worked at NTS on the Fran Critical Assembly has recently been reviewed (Ho 81). The badge consisted of a du Pont film with a strip of 0.028-in. lead wrapped around one end of the film. The film was worn by placing it in a clear plastic (0.004 in. thick) heat-sealed bag which was attached to the back of the security badge with a clip. The records of the individual exposed in 1963 did not indicate any beta, but it is known that some beta exposure occurred.

We were asked to perform measurements on a bare-metal critical assembly to determine the accuracy of the film badge for beta and gamma doses from an assembly similar to the Fran Assembly (which no longer exists). The beta/gamma ratio as a function of distance from the assembly and of time after a burst (beginning at four days and extending at least one week) was required to simulate an earlier exposure in 1963. An evaluation of the shielding afforded by various metals, gloves and clothing, which were used in 1963 on and around the Fran Assembly was also requested and we added to this request a study of the response of personnel TLD badges presently in use.

The Godiva IV critical assembly located at the Los Alamos National Laboratory (Los Alamos) was selected for our study (Pa76). The assembly core is made of six plates, 1 in. thick of 93% enriched uranium. The core is a right cylinder 6.1 in. by 7.1 in. diameter and is held together by three steel "C" clamps spaced at 120^0 intervals around the core. The uranium has a thin coating of vapor plated aluminum to decrease contamination and oxidation problems. This aluminum coating is 1 to 2 μm thick and therefore does not provide any significant beta-particle shielding when compared to a bare-metal assembly. (Alpha particles can be detected through this plating.) Our results can be used with other assemblies having metal coating by applying the results from our studies of shielding by various metals.

Los Alamos agreed to have a special burst of the Godiva IV assembly four days before we began the study. They also volunteered to include their personnel dosimeter in the study which provided an independent check of our calibration and dosimetry procedures.

Considerable background work was required to evaluate the results obtained in this study. This included an energy-dependence evaluation of the RO-7 instrument (Ha 82a); a determination of the effective beta thickness of 0.036-in. LiF TLDs, compared to aluminum (Ha 82b); and a method to evaluate the beta energy (E_{max}) by using the RO-7 or other thin-window beta instruments (Ha 82c). We used ^{7}Li TLDs and an Eberline Instrument Corporation RO-7 survey instrument to determine the beta- and gamma-dose rates from the assembly.

Summary

The following conclusions were reached during this study.

Film Badges

The film dosimeter, consisting of a piece of film with a 28-mil lead foil wrapped around one end to serve as a beta shield, can measure the gamma-ray dose received from critical assemblies within the ±20% required for personnel dosimetry. This film dosimeter was normally worn behind a plastic security badge which does not affect its gamma-ray response. Although our results do not give an accurate measurement, the film dosimeter apparently is reasonably accurate when exposed to beta particles without the security badge; but, when located behind the security badge, the response is low by about a factor of 2.

TLD Badges

Personnel TLD badges of the type presently issued to LLNL personnel can measure the gamma-ray exposure from critical assemblies to within ±20%. The beta response of the badge to the beta spectra from this critical assembly is low by about a factor of 2. The Los Alamos badge records the gamma-ray dose correctly, but is low by a factor of 4 for the beta dose.

RO-7 Instrument

The RO-7 instrument, when properly calibrated and adjusted for elevation, can be used to accurately measure the gamma ray dose rate from a critical assembly. When the beta shield is removed a factor of 1.3 must be applied to the beta reading to correct for the under-response of the instrument. The gamma ray and beta doses measured with an RO-7 appear to be accurate to within ±20%.

Beta/Gamma Ratio

The beta/gamma ratio from the Godiva IV critical assembly is a function of the distance from the assembly and is about 1.3 at 0.5 in., about 1.2 between 4 to 18 in. and drops to about 0.63 at 36 in. where the beta is being appreciably attenuated by the air.

Shielding by Metal, Gloves and Clothing

Reductions in the total dose rates of 40% and 44% are obtained behind shielding of 10-mil Cd and 30-mil lead gloves indicating almost complete beta absorption. Surgeons gloves, household plastic gloves and 1-mil Cu provide a reduction in the total dose rates of 11%, 15% and 9%. Clothing consisting of one, two and four layers of lab coat reduced the total dose rate by less than 10% indicating that clothing provides essentially no protection against the radiations from the Godiva IV assembly.

Backscattering of Beta Particles

There was no indication in the TLD readings of any backscattering from the Lucite we used in the study. This means that backscattering materials are not required for TLD measurements of beta particles coming from critical assemblies. The lack of backscatter also indicates that the gamma ray spectrum does not have significant gammas with energies between 30 and 100 keV, where backscattering is significant.

Non-uniform Activation of the Core

The dose rates on the side of the core is higher near center line than at the top or bottom. The dose rates near the bottom are higher than near the top probably because of the safety block which is located just below the core. Surveys made close to the core of a critical assembly should consider these variations.

Beta Absorption in TLDs

A 35-mil thick TLD has an effective absorption thickness of 175 mg/cm^2 of aluminum compared to an actual thickness of 236 mg/cm^2. The correction factor for beta absorption in the TLD varies with distance from the assembly and decay time following the burst. In this study, the correction factors based on absorption curves obtained using aluminum varied from 0.604 to 0.712.

Beta Spectra

The beta spectrum from the critical assembly varies as a function of time following the burst and of distance from the assembly. The spectrum at 4 days following the burst contains a lower energy component that is missing 12 days following the burst. The intensity of the betas drops markedly at 36 in. indicating considerable absorption by air. The beta spectrum at 36 in. is harder than the spectra closer to the assembly. The beta spectrum is complex consisting of a composite of betas and gives an approximate straight line absorption curve. The betas have an E_{max} of about 2.5 MeV.

Low Energy Betas

There was no indication of a significant low-energy beta component in the beta spectra from the critical assembly. To confirm this, measurements were made with thin and thick TLDs, we obtained absorption curves using aluminum and we compared the results of the RO-7 instrument and TLD measurements.

II. Beta/Energy Response of the Eberline RO-7 Survey Instrument

We obtained an RO-7 radiation survey instrument from the Eberline Instrument Corporation to use in a study of the beta dose rates from the Godiva IV Critical Assembly at Los Alamos National Laboratory. We have performed a limited evaluation of the instrument and have determined its energy dependence for beta particles.

Description of the RO-7 Instrument

The RO-7 instrument is a hand-held, cutie-pie style survey meter with a liquid crystal digital readout. The instrument is available with three interchangeable ion chamber probes, although we used only the midrange probe (RO-7-BM) in this study. The midrange probe has a full-scale range of 199.9 R/h and a resolution of 0.1 R/h. The ion-chamber has a 1-in.-diameter entry window 2 mils thick (~ 7 mg/cm^2) of aluminized mylar. The chamber is lined with phenolic nominally 1/8 in. thick. The housing is nominally 60 mil thick. The chamber's internal dimensions are 1-in. diameter x 0.6-in. length (2.5 cm x 1.5 cm) with a sensitive volume of 7 cm^3. The beta shield is a plastic cap (~1000 mg/cm^2) over the beta window and is held in place over the probe by an O-ring.

One disadvantage of the RO-7 instrument we found in this work was its low sensitivity. The lower detection limit is 0.1 R/h and the display is in units of tenths of R, so a source reading between ~0.06 and 0.14 will indicate 0.1 R/h. At the overlap region the instrument will flip back and forth between the two numbers and we found this to be an area where the dose rate could be determined with greater accuracy because the switching occurs over a small region; for example, ~0.14 to 0.16 R/h.

Gamma Evaluation

The first part of the evaluation was to determine the linearity and the instrument's relative response to ^{60}Co and ^{137}Cs gamma rays. The response of the instrument was found to be exceptionally linear over its three-decade range. There is no discernable difference between the ^{60}Co or ^{137}Cs calibrations.

The above results were obtained with the plastic beta shield on the probe. When it is removed, the instrument responds to electrons being ejected from the ^{60}Co and ^{137}Cs source encapsulation (the rabbit tubes) and from the air. Figure 1 shows the increased readings obtained with the beta shield removed from the probe. The increase in readings varies from about 6 to 14% depending on which source is used and the source-to-detector distance. These high readings are not reproducible under different scattering conditions; for example, we found that an aluminum plate (~3 ft dia., 1/4" thick) which previously had been located just under the source to place dosimeter on during irradiation, increased the instrument reading to ~19% for ^{60}Co and also resulted in a different shape curve beyond one meter. For a narrow beam geometry, the effect of these scattered electrons will be negligible and in addition, the reading of the instrument without the shield will probably be lower than the dose rate value because electron equilibrium has not been established in the RO-7 instrument. The RO-7 window is only 7 mg/cm^2 which is far short of the several hundred mg/cm^2 necessary to establish electron equilibrium for gamma rays from ^{137}Cs or ^{60}Co.

The measured dose rates from isotopes or combinations of isotopes containing high-energy gamma rays would indicate that beta radiation is present and a skin dose is being received, even though no beta decay is occurring. In field work, however, if the beta dose rate is as small as the above contribution by electrons, it is usually not considered to be significant (when compared to the

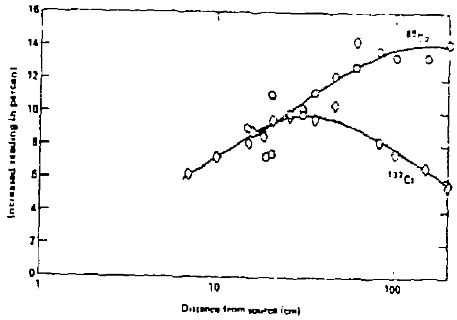

Fig. 1 *Response of the RO-7 instrument, with the beta shield removed, to* ^{137}Cs and ^{60}Co gamma rays as a function of distance from the source.

gamma exposures). This effect is not unique to the RO-7 and applies to all instruments with thin windows. The magnitude of the effect may be slightly different for other instruments depending on the window thickness and geometry factors of the probes.

Beta Evaluation

To determine the beta response of the RO-7 instrument, it was placed at various distances from the PTB beta sources used with and without their filters or flatteners. All distances were measured from the face of the source to the center of the probe. The PTB filters consist of disks made of thin plastic positioned at 10 cm from the source. These filters flatten the beta beam to permit larger probes to be exposed uniformly (see Ha 82d).

To help establish the response of the RO-7 instrument at low dose rates we obtained data with a pancake GM instrument. The window size was reduced by taping an aluminum disk with a 1.0 in. diameter hole (probe size of RO-7) on the pancake probe. When compared, the response of the RO-7 instrument and pancake probe agree very well even though the instruments have slightly different window thickness and are different types of instruments; i.e., a G.M. vs an ion chamber. This procedure may not be entirely accurate but is believed to give much better results than would be obtained by using an extrapolation or guess work.

Energy Response to Beta

To determine the energy response of the RO-7 to betas we compared the PTB calibration values and our extrapolation chamber results with the dose rates indicated by the RO-7 instrument. These data are shown in Table I. We have shown three dose rates for the PTB sources: (1) the measured dose in air, and (2 and 3) the calculated doses (using the factors provided by the PTB) in tissue (at 0 depth) and at 7 mg/cm^2 depth in tissue. In the last two columns we have determined the percent deviation of the RO-7 instrument from the tissue and 7 mg/cm^2 depth dose.

If the RO-7 instrument were an ideal Bragg-Gray air ionization chamber, the RO-7 should read ~1.15R when exposed to 1 rad of ^{90}Sr-^{90}Y betas. The lower-than-expected readings of the RO-7 to betas shown in Table 1 can be explained by the failure of the RO-7 instrument to meet the requirements for a Bragg-Gray air ionization chamber. This is not surprising since few, if any, instruments meet all the requirements for a Bragg-Gray air ionization chamber. With the RO-7 the number of ergs/g of air in the chamber caused by 1 R of gamma rays is most likely not the theoretical value of 86.9 (it is probably higher). By adjusting the instrument response, the meter can be made to read 1 R for any value of ergs/g. When this instrument is calibrated to indicate 1 R when exposed to 1 R of gamma rays the meter should, in theory, read 1.15 R when exposed to 1 rad of beta (100/86.9 ergs/g). The failure of the RO-7 to do so is caused by several factors; among them are (1) the change in the probe caused by removing the beta shield, and (2) the probe is not exposed to 1 rad because some betas are absorbed in the probe window. It would be difficult to quantitatively evaluate all the factors contributing to this problem and wouldn't be worth the effort. Consequently, the RO-7 instrument, when used to evaluate beta doses, requires a "beta factor" greater than one for all beta energies.

The "air dose" from betas is not normally of interest in health physics work where we are interested in dose to people. What is required is tissue doses either at the surface (0 depth), at 7 mg/cm^2 or some other selected depth in tissue. The beta factor curve for the RO-7 instrument for tissue at 0 depth is shown as the solid line in Fig. 2. This figure shows a large beta factor at low beta energies for tissue at 0 depth but for health physics application the tissue at 7 mg/cm^2 depth is the appropriate curve.

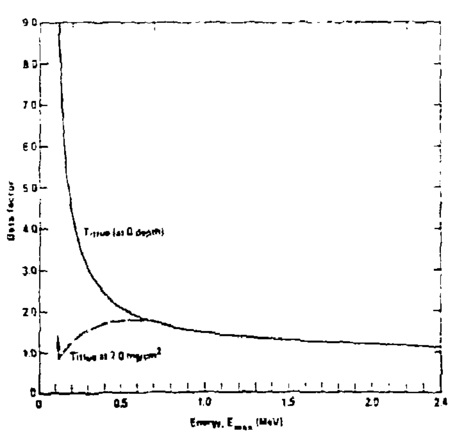

Fig. 2 Beta factor for the RO-7 instrument as a function of beta energy. See text for a discussion of the shape of the curves at low energy.

TABLE I Response of the RO-7 instrument compared to the beta dose rates in air.

Source	Distance	Extrapolation Chamber Dose Rates[a] (rad/h) air	Calculated Dose Rates (rad/h) Tissue	Calculated Dose Rates (rad/h) 7 mg/depth	RO-7 Dose Rate (R/h)	Relative reading of RO-7/ Air	Relative reading of RO-7/ Tissue	Relative reading of RO-7/ 7 mg depth
^{90}Sr large no flattener	11 cm	176	196	209	210	1.19	1.07	1.00
	30 cm	24.0	26.7	28.5	24	1.00	0.90	0.84
	50 cm	8.59	9.54	10.1	8.0	0.93	0.84	0.79
	1.0 cm	2.04	2.27	2.39	1.7	0.83	0.75	0.71
^{90}Sr small Flattener	30 cm	0.594	0.659	0.686	0.59	0.99	0.90	0.86
no flattener	11 cm	6.73	7.48	8.00	8.0	1.19	1.07	1.00
	30 cm	0.952	1.06	1.13	0.95	1.00	0.90	0.84
	50 cm	0.335	0.37	0.39	$\sim$0.31[b]	0.93	0.84	0.79
	1 m	0.0768	0.085	0.091	$\sim$0.07[b]	0.91	0.82	0.77
^{204}Tl Flattener	30 cm	0.0745	0.0849	0.0810	$\sim$0.04[b]	0.54	0.47	0.49
no flattener	11 cm	1.001	1.140	1.09	0.74	0.74	0.65	0.68
	30 cm	0.117	0.133	0.127	$\sim$0.075[b]	0.64	0.56	0.59
	50 cm	0.032	0.036	0.035	$\sim$0.017[b]	0.53	0.47	0.49
^{147}Pm flattener	20 cm	0.0659	0.0758	0.0152	$\sim$0.016[b]	0.23	0.20	0.99
no flattener	11 cm	3.41	3.92	0.784	0.73	0.21	0.19	0.93
	20 cm	0.302	0.347	0.0695	$\sim$0.065[b]	0.22	0.19	0.94

[a] Values shown are those obtained from the PTB calibrations where applicable or from our extrapolation chamber measurements.

[b] Dose rates determined using extrapolated values based on the response of a pancake probe (see text).

Beta readings of the RO-7 instrument (unshielded minus shielded readings) must be multiplied by the beta factor which varies depending on the beta energy. Unfortunately, the beta energy (E_{max}) is not often known. If an average beta factor of 1.5 is used for tissue in air, the corrected values would be between ±20%, for beta energies of 0.6 MeV to 2.0 MeV. For beta energies of <0.6 MeV the corrected reading would be low, significantly if very-low-energy betas are being measured. I explain how to determine the beta energy using the RO-7 instrument elsewhere in this paper.

The 7 mg/cm^2 window causes the curve to go to zero at ~70 keV where complete absorption of betas <70 keV occurs in the window material. But the dead layer or air also stops all betas with energies <70 keV, so this drop in response is correct for health physics purposes. The beta factor curve for the RO-7 instrument is shown as the dashed line in Fig. 2. This curve indicates that for beta energies of >140 keV a single value for the beta factor of 1.5 could be used and the evaluted dose would be very close to the ±20% usually required of field survey results. Low readings would be obtained at beta energies of less than 140 keV and would require a beta energy determination to evaluate them properly.

III. Evaluation of Beta Energy (E_{max}) and Spectral Type Using Survey Instruments

The use of simple survey instruments for beta-energy analysis is complicated by large differences that exist in the beta spectra shapes. These spectral shapes are often complex and change continuously as the betas are absorbed in air. Changes are also caused by absorbing material between the source and the detector. One may frequently encounter a combination of beta energies, either from multiple emissions from a single isotope or from several isotopes in the sample being evaluated. There may also be monoenergetic conversion electrons present in the sample or low-energy X rays which are absorbed in a similar fashion to betas.

Obviously, a complete analysis of complex beta spectra cannot be performed using only survey instruments. We present two methods which will give the approximate E_{max} of the beta energy responsible for the most significant portion of the beta dose. Either technique should give adequate information about the beta spectra to provide necessary guidance for the health physics evaluation of the exposure. We discuss first the more complex beta-energy analysis technique since the simple method is based on approximations of the complex technique. The complex technique can also determine the average energy (E_{avg}), estimate the shape of the beta spectrum and determine if multiple betas are present. In many cases, the energy of the higher-energy betas can also be determined. Beta spectra information can be obtained from sources, swipes, or pieces of contaminated equipment, and the technique is simple enough to be used at many field locations.

Theory

If simple survey instruments are going to be used to determine the beta energy, the most reasonable approach would be to make absorption studies, but limit them to as few absorbers as possible. When an absorber is placed over the probe of the instrument, the reading is reduced, and this lower reading, for a specific absorber thickness, is a function of the beta energy. A single absorber does not adequately cover the entire energy region of interest (normally considered from ~100 keV to 4.0 MeV). In this study, we required that the change in the instrument reading be easily detectable and yet remain high enough to allow reasonable counting times or readings. We established these limits to be between 10 and 90% of the original instrument reading to beta. No single absorber thickness can meet this requirement because thin filters that would reduce the count rate of low-energy betas by about 90% would have less than a 10% effect for beta energies of 0.7 MeV and above. A thick absorber that would reduce the instrument response of 3.0 MeV betas by 10% would have greater than a 90% reduction for betas <0.4 MeV. Therefore, to cover the entire beta-energy range, at least two thicknesses of absorbers would be required and, for better resolution of the beta energies, three absorber thicknesses are desired and were used in this study.

Bleuler and Zünti have published absorption curves for the determination of beta energies (Bl46). Our first approach was to use their results and develop a curve from them that would apply to each of the three absorber thicknesses. When these curves were used to determine E_{max} from a number of beta sources, we found sometimes that the results were completely different than the known beta energy. The poor results were found to be associated with the shape of the beta spectra. The curves of Bleuler and Zünti were based on measurements made from beta sources which had typical beta spectrum (see the Type 1 source curve later in this report) and many of the sources we were using had different spectra shapes.

Mantel published the calculated beta spectra shape for 59 beta emitters (Ma72). The absorption curve obtained from each spectrum depends upon its shape. We calculated the absorption curve for many of the spectra given by Mantel. When the shapes of the absorption curves were compared, significant differences were apparent.

If analysis of E_{max} is to be based on absorption measurements (using the three filter thicknesses we chose earlier), the absorption curves have to be similar. Based on the shapes of the absorption curves obtained above, we divided the beta spectra given by Mantel into four spectra types. These spectra types are shown in Fig. 3.

Type 1 is the spectral shape usually associated with betas. However, many isotopes have spectra shapes shown as Types 2, 3 and 4. The Type 3 spectra are from isotopes which emit several betas with different E_{max} and these composite spectra frequently have an exponential shape. (The branching ratio is also important in determining spectra shape.) Type 4 spectra are from isotopes having two (or possibly more) major beta energies that are greatly different. The curve shown as Type 4 in Fig. 3 is a composite of two well-defined spectra of Type 1. The Type 4 spectra and isotopes with intense line spectra from internal conversion electrons are the most difficult to evaluate accurately.

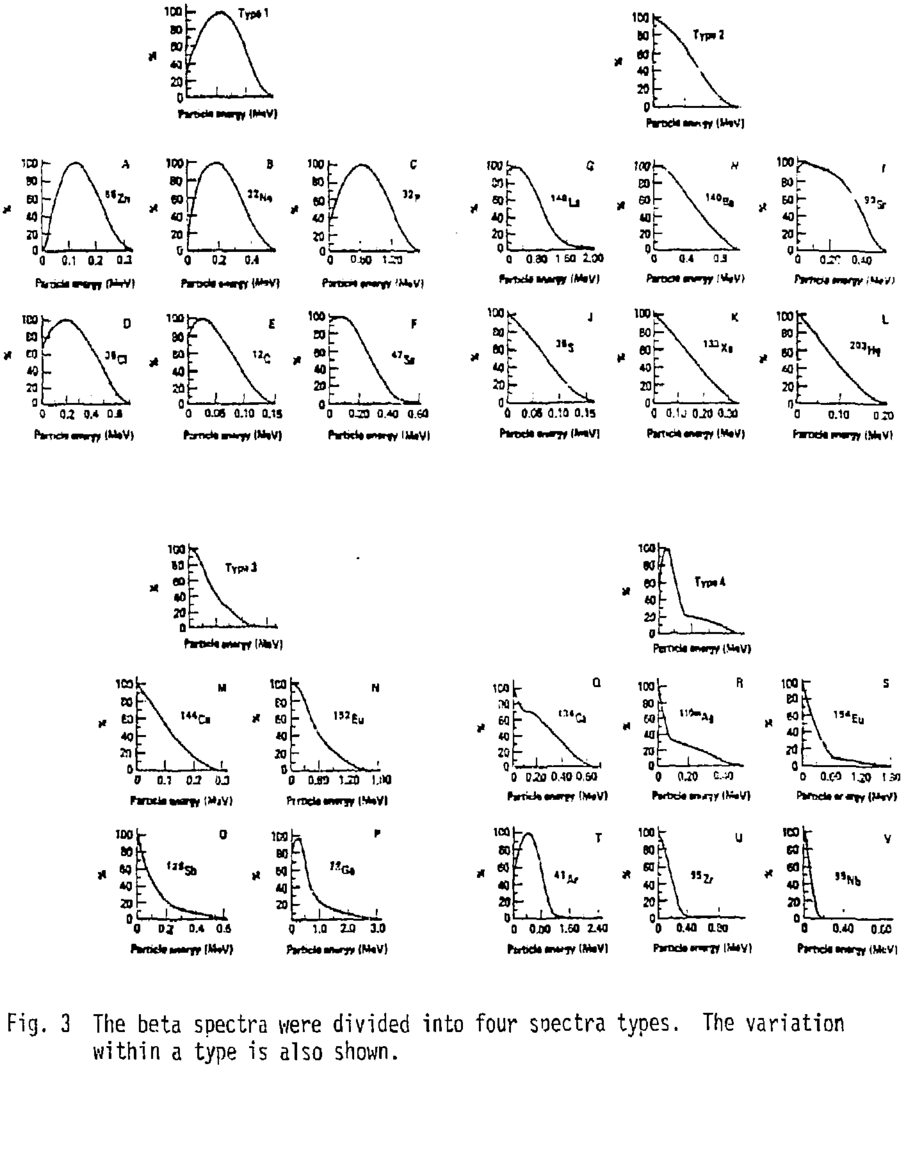

Fig. 3 The beta spectra were divided into four spectra types. The variation within a type is also shown.

Few beta spectra look exactly like the ones labeled as types 1 through 4 and we show the variation that occurs within each spectra. There is obviously an overlap region between types; for example, curves F and G are very nearly the same. By using the analysis technique we describe, the spectra type obtained for spectra that have shapes in this region could be identified as either Type 1 or Type 2 depending on the variations in count rate or instrument reading recorded for that source.

The Type 4 sources shown as Q, R and S are sources having two major beta energies being emitted by a single isotope or from two isotopes in a decay chain such as ^{90}Sr and ^{90}Y. They can be combinations of any of the other spectra types, for example, curve Q appears to be a Type 2 source on top of a Type 1 source and curve S appears to be a Type 3 on top of a Type 1 source. Another kind of the Type 4 source category are those shown in curves T, U and V, where there is only one predominant beta. Using the technique described later, these spectra would be analyzed as having only the one predominant energy and therefore, the energy obtained experimentally may be different than the published E_{max}. A review of the branching ratio should be made if the energy obtained does not agree with the expected energy based on the published E_{max}. The information on E_{max} obtained using this report, however, is appropriate for personnel exposures where the E_{max} of the predominant beta is usually desired. Later, we describe how to determine the E_{max} of spectra similar to curves Q, R and S.

Absorption curves were calculated for many of the spectra given by Mantel for the beta spectra of Types 1 through 4. A comparison of shapes of the absorption curves in the first decade shows that most of the Type 2 spectra are essentially straight lines, but the Type 1 and 3 spectra are curved with the Type 1 curves above and the Type 3 below the straight line curves of Type 2.

The Type 4 sources have absorption curves which have inflections in the curves and are obviously from two (or more) betas. The curves have a definite bend at the point where the first beta is absorbed. The absorption curves calculated for all the isotopes are different and we decided to use a typical or average curve for each source type. In Fig. 4 we show the average absorption curves used for the first three spectral types. These curves were used to develop additional curves, shown later, which were used to obtain the beta energy. The use of average curves will result in an error in the E_{max} evaluated for a specific beta depending upon how well the actual and average curves compare. This error is apparently small based on the good experimental results we obtained.

Experimental Method

Instruments

To cover a wide range of dose rates, we used the Eberline Instrument Corporation Model RO-7 survey instrument and the Eberline Model E-120, GM equipped with the HP-210 pancake probe. Both had thin probe windows and were readily available to us at Lawrence Livermore National Laboratory (LLNL) (Fig. 5). The probe of the RO-7 has a window thickness of 7 mg/cm^2 and the window of the pancake probe varies from 1.5 to 2.0 mg/cm^2. The pancake probe was used with the protective screen wire over the probe face. The pancake probe is a GM instrument and the RO-7 is an ionization instrument.

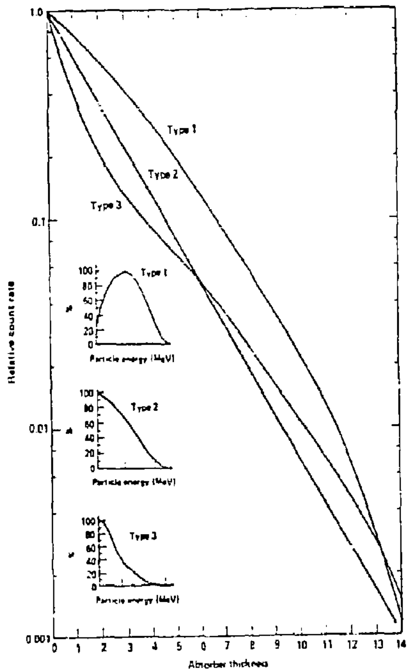

Fig. 4 Typical or averaged curves for each spectra type. These curves were used to develop other curves which are used to determine the beta energy and spectral type of a source.

The dose rate ranges of the instruments are considerably different with the RO-7 range being from 100 mR to 200 R/h while the pancake probe reads full scale at ∿50 mR/h. Corrections must be made for dead time losses in the scaler results from the pancake probe, unless the dose rates are low <1.0 mr/h, (we made corrections to all of our scaler results).

Absorbers

The absorbers we used to distinguish between betas and gamma rays consisted of acrylic (Lucite). We used the ∿1 cm thick Lucite "beta filter" shown in Fig. 5 provided by Eberline with the RO-7 instrument. The pancake probe was used with two 0.48 cm-thick disks with an 8.8 cm radius (the o.d. of the probe housing), giving us a nominal 1-cm thick beta filter equivalent to the RO-7 beta filter. This thickness of Lucite should stop all betas with E_{max} <2.0 MeV and greatly reduce the number of higher-energy betas. The readings of the instruments without the Lucite filters was assumed to be beta plus gamma and the filtered readings were the gamma readings.

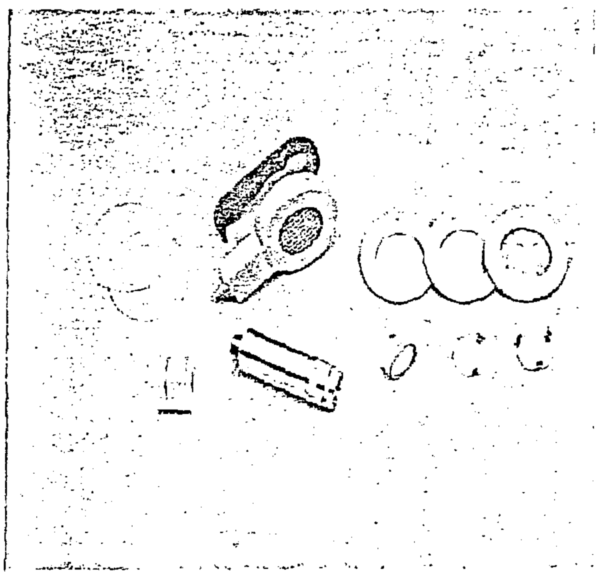

Fig. 5 Eberline HP-210 pancake probe and the Eberline RO7BM. The Lucite beta shields are on the left and the aluminum asorbers are on the right.

To determine the beta energies, aluminum absorbers of three thicknesses were prepared for both instruments (Fig. 5). The absorbers for the pancake probe were mounted on aluminum rings 0.5-cm thick. The o.d. of the ring is 8.8 cm (o.d. of the probe housing) and the i.d. is 5.4 cm (0.2 cm larger than the window opening of the probe housing). Aluminum sheets (series 1100) of 6.42, 33.4 and 277 mg/cm^2 were glued to these rings. The absorbers were always used with the aluminum sheets at contact with the probe housing.

The RO-7 absorbers were mounted on three 0.56-mm thick aluminum rings with an o.d. of 3.5 cm (o.d. of the probe housing) and an i.d. of 2.85 cm ($\sim$0.2 cm larger than the opening in the housing for the probe). The rings had three tabs which were bent to hold the ring and absorber to the RO-7. Aluminum sheets of the same thickness used above were glued on the probe side of the rings.

Procedure

To determine the beta energy and spectral type of a source, five measurements of the dose rate or counting rates are required. These readings are made with the bare probe, Lucite-covered probe, and with each of the three aluminum absorbers. All readings must be made at the same source-to-detector distance and should have reasonably good counting statistics. Counting times with the pancake probe depend upon the source strength. The RO-7 dose rates were read off the display. At low-dose rates, the digital display is limited to one significant figure and we found that making small changes in the source-to-probe distance and obtaining several sets of data was helpful. Each set of data was evaluated and we used an average value for E_{max}.

The dose or count rates obtained with the bare and Lucite-covered probes are used to determine the beta component of the dose by subtracting the shielded probe reading from the bare probe reading. The assumption is made that the bare probe correctly reads the beta- and gamma-dose rate and the Lucite-shielded probe correctly reads the gamma-dose rate. This assumption ignores the gamma absorption in the Lucite, the small component of high-energy beta that penetrates the 1-cm thick beta shield, secondary electrons produced by gamma interactions in the source or in the air, geometry factors caused by the Lucite shield and possibly other variables. All of these factors are usually small and this assumption is adequate for field work.

The X- and gamma-ray component of the instrument readings must be removed first by subtracting the reading of the Lucite-covered probe from each of the other readings. Then, the ratio (or relative readings) of the beta readings with each aluminum absorber and the readings without absorber is determined. This is done by dividing the beta reading of the instrument with the aluminum absorbers by the beta reading of the instrument without absorber. The relative readings for each of the three absorbers is then plotted on the solid lines in Fig. 6 which was derived from the curves shown in Fig. 4.

If the source is a Type 1 source, the points plotted on the solid lines in Fig. 6 will be at the same beta energy. (If the relative reading is >0.95 or <0.05, that piece of data is probably not useful and does not need to be plotted.) If the data points do not give the same energy on the solid line, the source is not a Type 1 source. Then, in order to determine the type source, the points are plotted on the dashed curve for Type 2 sources and the dot/dash curve for Type 3 sources. The type of line on which the data points give the same energy (align vertically) is the type of source being evaluated and the energy where alignment occurs is the E_{max} of the predominant beta in the spectrum.

In some cases, the data aligned reasonably well on two of these three curves. This means the source spectra is between the types indicated and the E_{max} is also between the two values of E_{max} obtained on the figures. Usually, additional reading or counting times will give data which will favor one type of spectra over the other.

If the spectra is a Type 4 source, alignment will not occur. The results with the thin absorber indicate a low energy and the medium and thick absorbers indicate progressively higher energies. The fact that this is a Type 4 source can be useful in health physics work. One can use this technique to evaluate the higher energy component of Type 4 sources by removing the lower energy component with an appropriate absorber, (see complete text for details, HA82c). The energy of the beta determined with the additional absorber will be slightly less than the original beta energy and a correction for this may be designed. (Again see complete text.)

When using Fig. 6 care is required to assure that the correct curves for each spectral type are being used. It is easy to get confused and use a combination of curves; for example, plot the data from the thin absorber on a Type 2 line and the medium absorber on a Type 1 line.

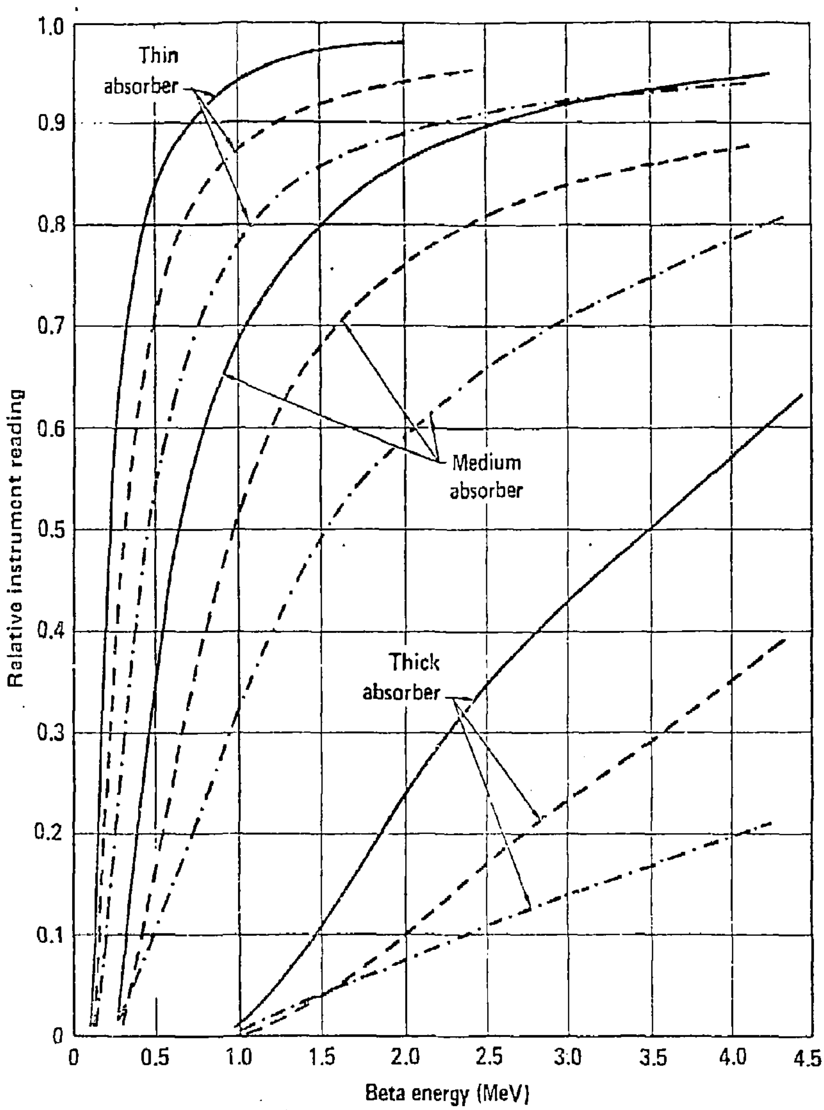

Fig. 6 Curves used to determine the energy and spectral type of beta sources from the decrease in instrument reading (relative instrument reading) caused by each of three absorber thicknesses. The beta energy and type is obtained when the relative instrument readings for each absorber thickness indicate the same energy (align vertically) on lines for one of the spectral types. Type 1 is symbolized by a solid line; Type 2 by a dashed line; and Type 3 by a dot/dash line.

Discussion

The results obtained with numerous sources of all four types (see HA82c) indicate that the known and evaluated source types and energies agree reasonably well and are adequate for health physics work. In most cases where differences were found, they could be explained by source shielding or other factors.

The sources which have no beta, with one exception (^{207}Bi), gave readings with the thick absorber which were less than the count rate of the instrument with the Lucite shield. Only ^{235}U gave a similar negative reading among the beta sources. The negative reading is caused by their being very few betas or electrons compared to the abundance of X rays and low-energy gammas and the thick aluminum absorber being a more efficient absorber of X- and gamma-rays than the 1-cm thick Lucite. When negative readings with the thick aluminum absorber are obtained, the beta dose is low compared to X- and gamma-ray dose and will not contribute significantly to the health physics exposure problems with the source. The ^{207}Bi source has high energy electrons and does not align as a beta source. This is because the electrons are monoenergetic or line sources and therefore have a unique curve which drops rapidly beyond a fairly well-defined absorber thickness.

Field Surveys Using a Single Absorber

One goal of our study was to develop a technique where a single absorber thickness could be used to evaluate the exposure problems caused by beta particles in health physics field work. What is needed is an estimate of the beta energy which can be used to evaluate the effectiveness of clothing for shielding and determine the type of personnel dosimetry that is required.

The curves on Fig. 5 indicate that the only absorber that would cover the entire energy range is the medium-thickness absorber. Unfortunately the three curves (one for each source type) for the medium absorber are appreciably separated at low energies and are spread further apart at higher energies which limits the accuracy that could be obtained using a single filter.

We selected a 25% and 75% criterion which we felt could be determined in the field without having to use a calculator. A decrease in reading of 25% or less would indicate high-energy betas and a drop of 75% or greater (<25% remaining) would indicate low-energy betas. From Fig. 5 the energies at 25% (which correspond to the 75% decrease) are 0.43, 0.60, and 0.82 MeV for Types 1, 2 and 3, respectively. We selected an approximate value of 0.5 MeV which gives more weight to the more frequently encountered Type 1 sources. At the higher energies, a 25% drop corresponds to energies of 1.25, 1.9 and 3.5 MeV for the Type 1, 2 and 3 sources. We selected an approximate value of 1.5 MeV, again giving more weight to the Type 1 sources.

The field procedure consists of three dose-rate readings: (1) the bare probe, (2) the beta (Lucite) shielded probe and (3) the medium absorber reading. The reading with the beta shield (x and gamma rays) is subtracted from both the bare probe reading to obtain the beta dose rate and from the reading with the absorber. The beta dose rate and dose rate with absorber are compared and the amount of decrease caused by the absorber is determined. If it is small $<25\%$ the beta energy is high and is assumed to be >1.5 MeV. If the decrease is large, $>75\%$, the beta energies are low <0.5 MeV. Readings between 25 and 75% would indicate beta energies between 0.5 and 1.5 MeV.

If experience in the field indicates that the beta spectra are mostly of a given type, the energies used in this evaluation can be changed to give values in line with the actual spectra being encountered. This may be necessary in some cases since many field spectra are composites and would fall into the Type 2 or 3 spectra category.

The single-absorber method indicates beta energies from sources having low energy X rays even if no betas or electrons are present (see for example the ^{241}Am results). For health physics purposes, this is not a serious problem since the X rays are being absorbed at the same rates as the beta particles and would present the same type of exposure problems.

Analysis of the beta energy using the single-filter technique gives a good estimate of the actual energy for the sources. However, its accuracy in a field location would depend upon the particular isotope or combination of several isotopes being evaluated, as well as the errors usually associated with field work. The technique is easy to use and a health physics technician making field surveys should be able to obtain the information necessary to evaluate protective clothing and personnel dosimetry requirements.

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