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OPTIMUM X-RAY YIELDS IN BETA-EXCITED X-RAY SOURCES*

*Subtask under Biological and Medical Aspects of Ionizing Radiation, USAMRL Project No. 6-59-08-014, Subtask, Effects of Low, Medium and Massive Doses.

RESEARCH AND DEVELOPMENT DIVISION
OFFICE OF THE SURGEON GENERAL
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OPTIMUM X-RAY YIELDS IN BETA-EXCITED X-RAY SOURCES*

by

J. G. Kereiakes, O. E. Weir, and A. T. Krebs

from

Radiobiology Department
US ARMY MEDICAL RESEARCH LABORATORY
FORT KNOX, KENTUCKY

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ABSTRACT

OPTIMUM X-RAY YIELDS IN BETA-EXCITED X-RAY SOURCES

OBJECT

To systematically investigate the influence of source physical conditions on the characteristic X-ray yield in beta-excited X-ray sources.

RESULTS AND CONCLUSIONS

The K X-ray yield excited by beta-particles in various target materials increased with increasing target thickness up to a maximum, after which the yield decreased because of X-ray absorption by target material. Optimum K X-ray yields were noted for P^{32} beta-particles at target thicknesses of about 77, 180, and 280 mg/cm^2, respectively, for Sn, Ta, and Pb targets. Sn, Ta, and Pb target thicknesses of about 80, 205, and 310 mg/cm^2, respectively, were found to give optimum K X-ray yields for Sr^{90} - Y^{90} betas. The K X-ray intensities were increased by from 110 to 160 per cent by the addition of source backing of same thickness as that providing maximum X-ray yields. Increase of backing to a thickness greater than that required to absorb maximum beta energies further increased maximum X-ray intensities from 25 to 50 per cent. Increased K X-ray yield efficiency extends the use of these sources to certain practical applications in low energy region (below 100 kev) where no suitable gamma-emitting isotopes presently exist.

RECOMMENDATIONS

It is recommended that source physical conditions presented in this study be used, along with image intensifying systems, to extend the possible use of beta-excited X-ray sources to certain practical applications where increased X-ray intensity is desired.

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J. G. Kereiakes, Physicist
O. E. Weir, Sp-3
A. T. Krebs, Physicist

APPROVED: A.T. Krebs.
A. T. KREBS
Head, Radiobiology Department

APPROVED: Floyd A. Odell
FLOYD A. ODELL
Technical Director of Research

APPROVED: Joseph R. Blair
JOSEPH R. BLAIR
Lt Colonel, MC
Commanding

OPTIMUM X-RAY YIELDS IN BETA-EXCITED X-RAY SOURCES

I. INTRODUCTION

Low energy X- and gamma-ray sources are finding considerable practical applications in many fields. However, isotopes emitting gamma rays in the region below 100 kev are scarce. This has led to the alternative of investigating the possible use of beta-excited X-radiation. Beta-particle emission has been shown to be accompanied by the emission of low energy gamma-radiation (1 through 7). This radiation may be composed of: 1) internal bremsstrahlung, arising from the interaction of nuclear beta particles with the radiation field of the nucleus; 2) external bremsstrahlung, produced in the deceleration process of beta-particles by absorber nuclei; and 3) characteristic X-radiation produced by the interaction of beta particles with orbital electrons of the source material and/or absorber material. The experimental work with internal and external bremsstrahlung is in reasonable agreement with the theories of Bethe and Heitler (8), Knipp and Uhlenbeck (9), and Bloch (10). That appreciable quantities of characteristic X-radiation can be excited by beta-particles in target material was first noted in detail by Edwards and Pool (11) and later by Siegbahn and Slatis (12). The yield of characteristic K X-rays has been quantitatively investigated by Liden and Starfelt (13), Leboeuf and Stark (14), and Reiffel (15) for various beta-emitters and target materials. Leboeuf and Stark found characteristic X-rays to be excited in yields of the order of 1×10^{-2} photons per incident beta for Sr^{90} - Y^{90} and 3×10^{-3} photons per incident beta for Pm^{147}. Reiffel found, for a typical transmission-target design, a nominal yield value of 1/10 mc of X-rays per millicurie of beta particles for emitters such as P^{32} and Y^{90}. Liden and Starfelt concluded that it is possible to get more than 20 photons in the K X-ray peak per 100 disintegrations if a beta-emitter with 3 Mev maximum beta energy is used together with a high atomic number target of optimum thickness. But the high-energy bremsstrahlung is also increased in this high-efficiency arrangement. Based on their studies, Liden and Starfelt suggested the use of these relatively monoenergetic beta-excited X-ray sources for industrial thickness measurements, medical and industrial radiography, and for energy calibration of scintillation spectrometers. The above ideas have been realized in the studies of Reiffel (15), Reiffel and Humphreys (16), Kereiakes and Krebs (17 through 20), and Daggs (21) for industrial and diagnostic radiography; Leboeuf and Stark (14) for gamma scintillation photometry; Kereiakes et al (22) for energy calibration of scintillation spectrometers; and Leveque et al (23) for industrial thickness measurements. Although the intensity of these sources cannot compete with normally used X-ray sources, the above results clearly demonstrate their utilization in certain practical applications.

The determination of proper beta-excited X-ray source fabrication has led to systematic investigations of K X-ray yields under varied source conditions. Starfelt et al (24) have noted the dependence of the X-ray yield on such factors as atomic number of target, target thickness, and beta-particle maximum energy. Reiffel (15) has advocated the use of a reflection target arrangement to improve the monoenergetic characteristics of the emitted spectrum. The work presented in this report was specifically directed towards determining the extent to which the X-ray yield efficiency is modified by certain source physical conditions.

II. EXPERIMENTAL

The experimental setup (Fig. 1) was so arranged that various thicknesses of target material could be studied with and without backing material. Three beta-emitting isotopes (strontium^{90}-yttrium^{90}, thallium^{204}, and phosphorus^{32} were used. The Sr^{90}-Y^{90} radiation consists of 0.61 Mev betas resulting from the decay of Sr^{90}-Y^{90} and 2.18 Mev betas produced in the decay of Y^{90} to stable zirconium. The half-life of Sr^{90} is 28 years, that of Y^{90} about 62 hours. The radiation from Tl^{204} (4 year half-life) consists of 0.76 Mev betas produced in the decay to stable lead. Phosphorus^{32} emits 1.70 Mev betas and has a half-life of 14.3 days. The beta-ray emitters were evaporated on very thin Mylar films. Various thicknesses of target material, Sn, Ta, and Pb, were placed over each beta-emitter (with no backing material) and thickness giving optimum K X-ray yield determined. In all cases a sufficient thickness of lucite was used to stop the betas penetrating the target material. Thicknesses of material was then added as backing to determine the influence on the K X-ray yield. The X-rays were detected with a NaI(Tl) crystal, 1-1/2 in. diameter by 1 in. thick and modified to have a 3 mil Al window, mounted on a DuMont 6292 photomultiplier tube. The pulses from this tube were amplified and then analyzed with a single channel pulse-height analyzer.

III. RESULTS AND DISCUSSION

K X-ray excitation of Sn, Ta, and Pb by Tl^{204}, P^{32}, and Sr^{90}-Y^{90} beta-particles are shown in Figures 2 through 8. In all cases the yield increases with increasing target thickness up to a maximum, after which the yield decreases because of X-ray absorption by the target material.

Graphs showing K X-ray peak intensity as a function of target thickness are given in Figure 9. As shown there is a broad maximum from which target thickness providing optimum K X-ray yield can be determined. The optimum thickness values for P^{32} and Sn, Ta, and Pb targets are about 77, 180, and 280 mg/cm^2, respectively. For Sr^{90}-Y^{90}, Sn, Ta, Pb target thicknesses of 80, 205, and 310 mg/cm^2, respectively, were found to give optimum K X-ray yields. Figure 10 shows the X-ray intensities excited by the beta-particles of Tl^{204}, P^{32}, and Sr^{90}-Y^{90} in various thicknesses of Sn. A Sn target thickness of 55 mg/cm^2 gave optimum K X-ray yield for Tl^{204} betas. The optimum target thickness increases with increasing maximum beta energy but appears to level off at a value of about 80 mg/cm^2 for Sn. However, despite this leveling off of the optimum target thickness with increasing maximum beta energy, the X-ray yields should still increase because of the energy spectrum characteristics of beta-emitters.

Figures 2 through 8 also indicate the magnitude by which the X-ray yield can be increased depending on the backing conditions. Since the primary objective was to increase K X-ray intensity, only same material was used for backing as that used for target. Table 1 gives the percentage increase of the X-ray intensity with addition of two different backing material thicknesses. For these calculations, the internal bremmstrahlung intensity at the specific characteristic X-ray energy was subtracted from the observed beta-excited X-ray intensities. Backing material of same thickness as that providing maximum yield shown in Figures 2 through 8 and thickness greater than that required to absorb all beta-particles were used. The K X-ray intensities were increased by at least 110 to 160 per cent in all cases by the addition of source backing of equal thickness as that providing maximum X-ray yields. Increase of backing to a thickness greater than that required to absorb maximum beta energies further increased the K X-ray intensities by 25 to 50 per cent.

The presented findings definitely show that source configuration can greatly increase the efficiency of beta-excited X-ray sources. Proper source arrangement should have a target thickness providing optimum K X-ray yield with a low atomic number absorber, as lucite, serving to absorb betas penetrating the target. Backing (same material as target) of at least the thickness absorbing maximum beta energies should be used. The backing itself can increase the X-ray intensity by 150 to 180 per cent. It should be pointed out, however, that this backing also increases the continuous bremsstrahlung spectrum, which is not desired. Reiffel (15) has proposed a source configuration in which a second target could be so positioned that it can be bombarded by the X-radiation from the source. This setup results in a source of almost complete monoenergetic X-radiation, although the efficiency is decreased. The source backing conditions, as presented in this study, along with image intensification systems, would help to increase the K X-ray yield and extend the use of these sources to certain practical applications in the low energy region (below 100 kev) where no suitable gamma-emitting isotopes presently exist. Their stability, economy, portability, and independence of power requirements are added advantages of these sources. Moreover, by source fabrication to allow interchanging of target materials and beta-emitting isotopes, X-ray sources capable of giving various relatively monoenergetic X-ray energies are possible, in contrast to fixed gamma energies of presently available isotopes.

IV. CONCLUSIONS

Source conditions can greatly increase the X-ray yield efficiency in beta-excited X-ray sources. Proper source configuration should have a target thickness providing optimum K X-ray yield with a low atomic number absorber, as lucite, serving to absorb betas penetrating target. Backing (same material as target) of at least thickness absorbing maximum beta energies should be used. The backing itself can increase the X-ray intensity by 150 to 180 per cent. Increase of the K X-ray yield of beta-excited X-ray sources extends their use to certain practical applications in the low energy (below 100 kev) region.

V. RECOMMENDATIONS

It is recommended that source physical conditions presented in this study be used, along with image intensifying systems, to extend the possible use of beta-excited X-ray sources to certain practical applications where increased X-ray intensity is desired.

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TABLE 1

PER CENT INCREASE OF K X-RAY INTENSITY FOR VARIOUS BACKING CONDITIONS

Beta Emitter	Backing Material	Backing Thickness[1] mg/cm^2	Increase in X-ray Intensity %	Backing Thickness[2] mg/cm^2	Increase in X-ray Intensity %
Sr^{90}-Y^{90}	Sn	89	118	1326	168
	Ta	219	126	1100	156
	Pb	317	134	1196	168
P^{32}	Sn	102	111	1020	161
	Ta	219	144	877	176
	Pb	317	160	1081	183
Tl^{204}	Sn	67	129	351	143

[1] Thickness giving maximum K X-ray yields shown in Figures 2 through 5.

[2] Thickness greater than that which absorbs all beta-particles.

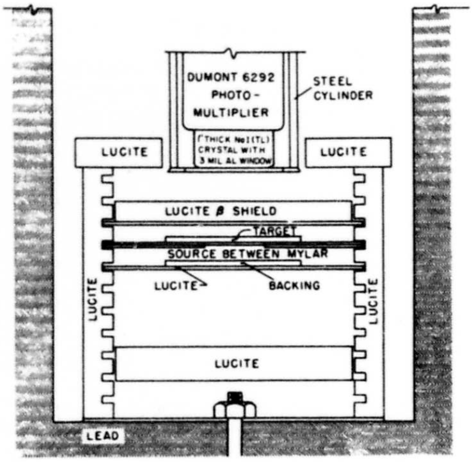

Fig. 1. Experimental arrangement for measuring beta-excited X-ray intensities.

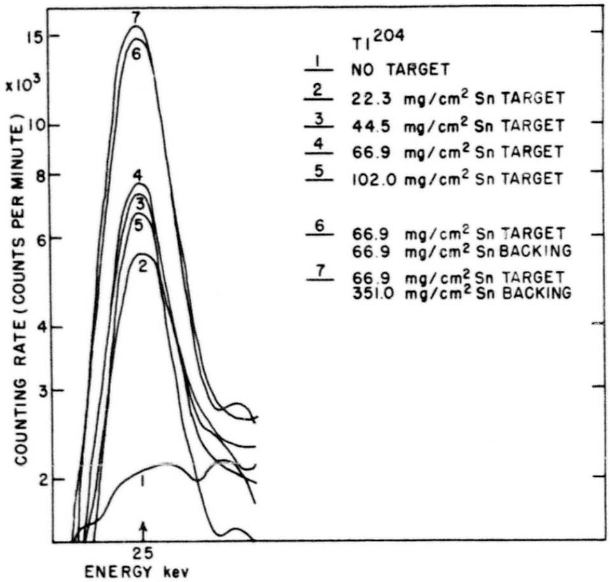

Fig 2. K X-ray intensities excited by Tl^{204} betas in various target thicknesses of Sn.

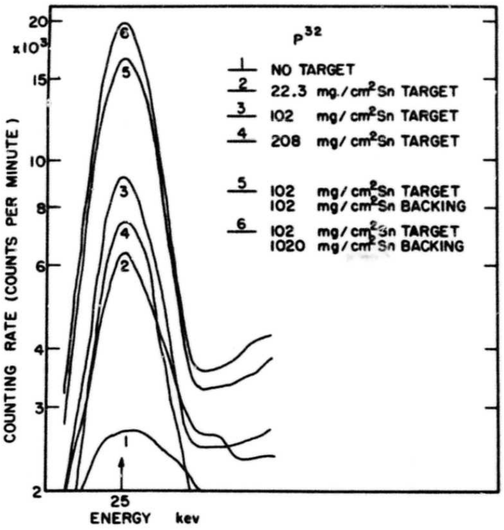

Fig 3. K X-ray intensities excited by P^{32} betas in various target thicknesses of Sn.

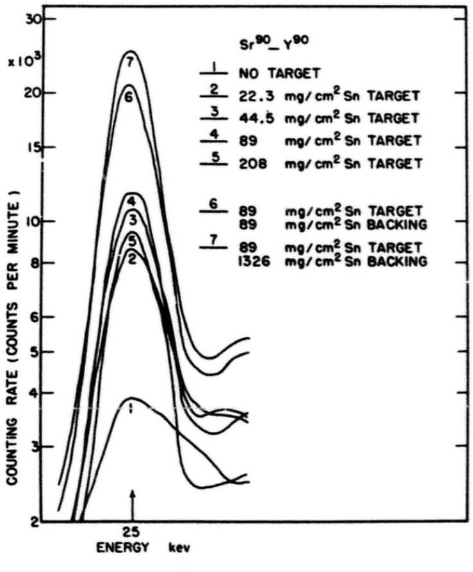

Fig. 4. K X-ray intensities excited by Sr^{90}-Y^{90} betas in various target thicknesses of Sn.

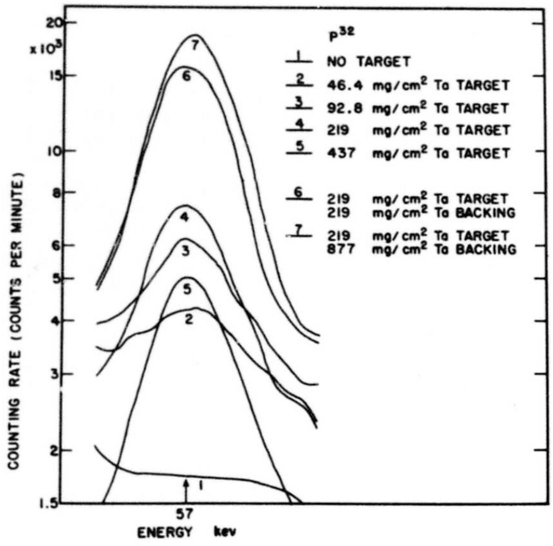

Fig. 5. K X-ray intensities excited by P^{32} betas in various target thicknesses of Ta.

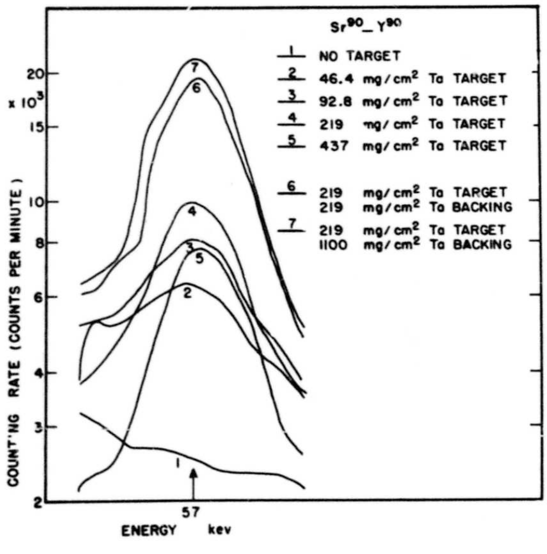

Fig. 6. K X-ray intensities excited by Sr^{90}-Y^{90} betas in various target thicknesses of Ta.

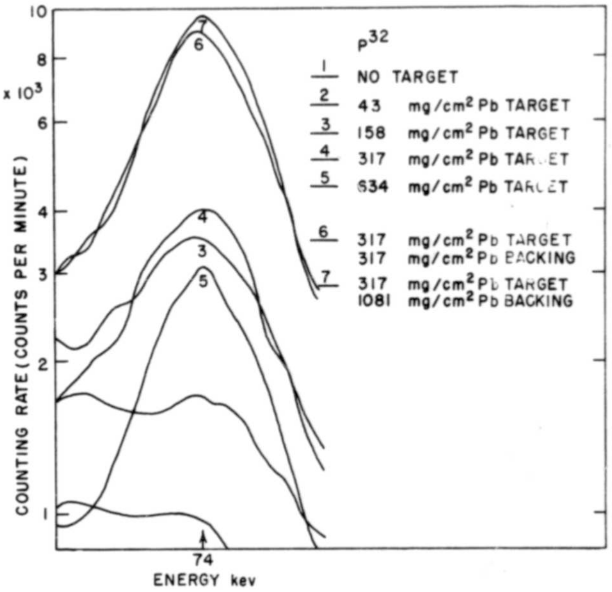

Fig 7. K X-ray intensities excited by P^{32} betas in various target thicknesses of Pb.

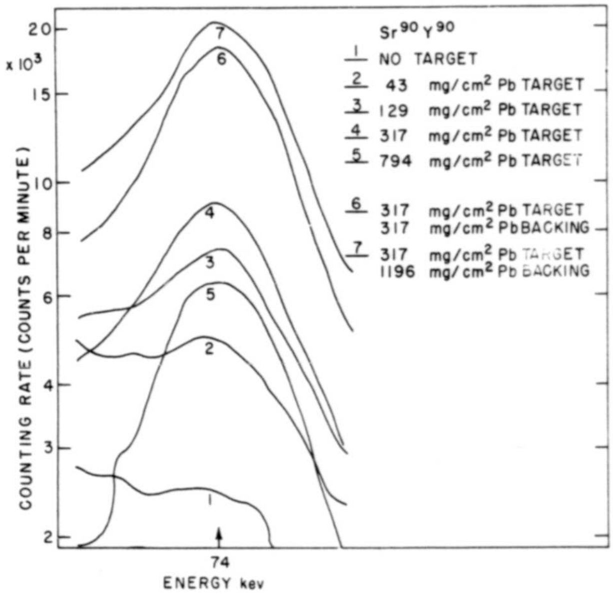

Fig. 8. K X-ray intensities excited by Sr^{90}-Y^{90} betas in various target thicknesses of Pb.

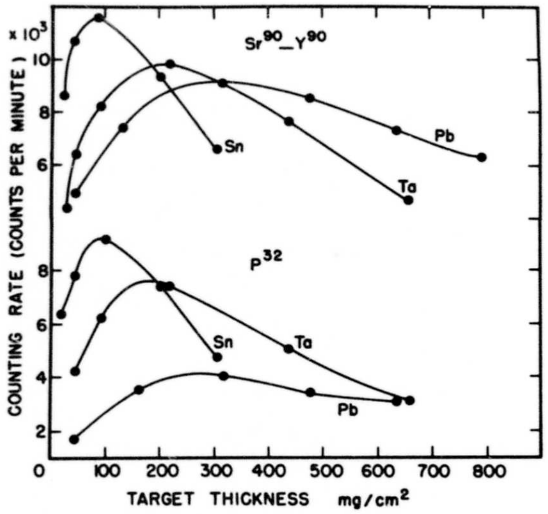

Fig. 9. K X-ray intensities excited by P^{32} and Sr^{90}-Y^{90} betas in various thicknesses of Sn, Ta, and Pb targets.

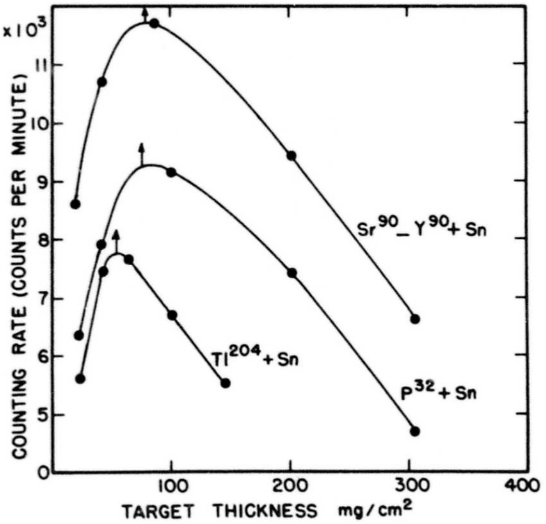

Fig. 10. K X-ray intensities excited by Tl^{204}, P^{32}, and Sr^{90}-Y^{90} betas in various target thicknesses of Sn.