25-Minute Isomer of Se^{83}†

R. G. COCHRAN AND W. W. PRATT
The Pennsylvania State University, University Park, Pennsylvania
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Se^{83} was produced by irradiation of a selenium sample, enriched to 75% in The Se^{82} isotope, in the Pennsylvania State University research reactor. The gamma-ray spectrum of the 25-minute isomer was investigated by means of a 3-in. thick×3-in. diameter NaI(Tl) crystal scintillation spectrometer. Gamma rays of energy 2.294±0.030 Mev, 1.880±0.015 Mev, 1.309±0.005 Mev, 1.058±0.005 Mev, 0.833±0.005 Mev, 0.712±0.010 Mev, 0.524±0.012 Mev, 0.358±0.005 Mev, and 0.225±0.005 Mev were found. The beta-ray spectrum was investigated by means of a plastic scintillator. In order to eliminate a competing activity from Se^{81} it was found essential to restrict the observation of beta rays to those in coincidence with the Se^{83} gamma-ray spectrum. A coincidence circuit of 0.25-microsecond resolving time was developed for this purpose. The beta-ray spectrum was found to be complex with end-point energies of approximately 0.45 Mev, 1.0 Mev, and 1.7 Mev. From these data, together with gamma-gamma coincidence measurements, a decay scheme is proposed.

INTRODUCTION

In a previous paper[1] an investigation of the decay scheme of the 70-second isomer of Se^{83} was reported. The present paper describes a study of the 25-minute isomer of this isotope. A summary of previous investigations of Se^{83} is included in reference 1.

GAMMA-RAY SPECTRUM

For the measurement of the gamma-ray spectrum a 3-in. diameter×3-in. thick NaI(Tl) scintillator on a DuMont-6363 photomultiplier tube was employed in conjunction with an Atomic Instrument Company 20-channel analyzer. The crystal was shielded in a lead block 10 in.×10 in.×13.5 in. with a collimating hole $1\frac{1}{4}$ in. in diameter and $2\frac{3}{4}$ in. long extending through the shield to the center of the crystal. The gamma-ray source was placed outside the shield approximately on the axis of the collimating hole. The source consisted of 200 mg of enriched[2] (75.74%) Se^{82} exposed to thermal neutrons in The Pennsylvania State University research reactor.

For energy calibration of the spectrometer, sources of Hg^{203}, Au^{198}, Cs^{137}, Co^{60}, and Na^{24} were employed. To measure the gamma-ray energies accurately it was found essential to take into account the dependence of the spectrometer calibration on the counting rate. To this end the pulse height associated with each gamma ray was measured for several source-to-counter distances, with consequently different counting rates, and the resulting curve giving pulse height as a function of counting rate was extrapolated to zero counting rate. The extrapolated pulse height so obtained was taken as the pulse-height characteristic of the gamma ray in question. This procedure was followed with each calibration source to obtain an energy calibration curve, and was also followed with each unknown Se^{83} gamma ray. The pulse-height variation involved in a typical case was 2–3%. To study the consistency of the gamma-ray energies obtained in this way, measurements were made both with the 3-in. diameter×3-in. thick crystal and also with a similarly shielded 2-in. diameter×3-in. thick crystal. In addition some of the gamma-ray energies were measured using a composite source of Se^{83} plus two or more calibration gamma rays. The energy values obtained agreed consistently within the errors quoted below.

To measure the relative intensities of the Se^{83} gamma rays, the peak amplitude of each gamma ray was determined in a standard geometry and compared with the peak amplitude of gamma rays originating in calibration sources of known intensity. The calibration sources em-

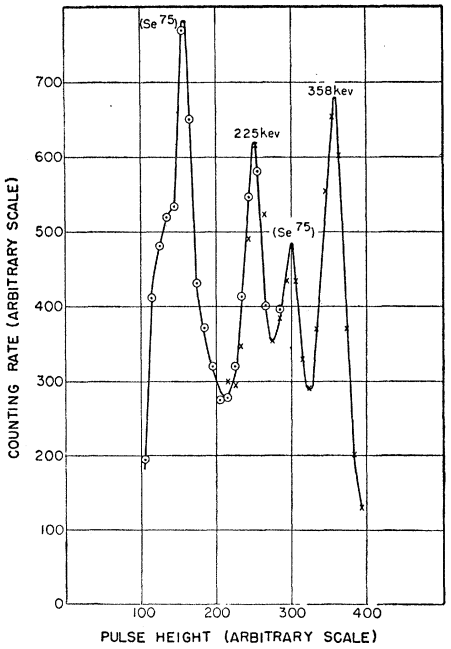

FIG. 1. Partial gamma-ray spectrum of Se^{83}. The circles and crosses refer to different runs, adjusted in scale to match.

† This work was supported in part by a grant from The National Science Foundation.
[1] R. G. Cochran and W. W. Pratt, Phys. Rev. **109**, 878 (1958).
[2] Obtained on loan from the Oak Ridge National Laboratory, Oak Ridge, Tennessee.

ployed were Cs^{137} (0.662 Mev) and Co^{60} (1.17 Mev and 1.33 Mev) calibrated by the National Bureau of Standards, Au^{198} (0.411 Mev) calibrated in a 2π proportional counter, and Na^{24} (1.37 Mev and 2.75 Mev). The Na^{24} standardization was accomplished by matching the peak amplitude of the 1.37-Mev gamma ray with that of the Co^{60} 1.33-Mev gamma ray, thus giving a gamma ray of known intensity at 2.75 Mev. In all cases where sources of more than one gamma ray were involved, the Compton background was subtracted from the low-energy gamma ray peaks by a method similar to that of Lazar *et al.*[3] The relative intensities were also studied by the alternative method of comparing the areas under the photopeaks rather than the peak amplitudes. The

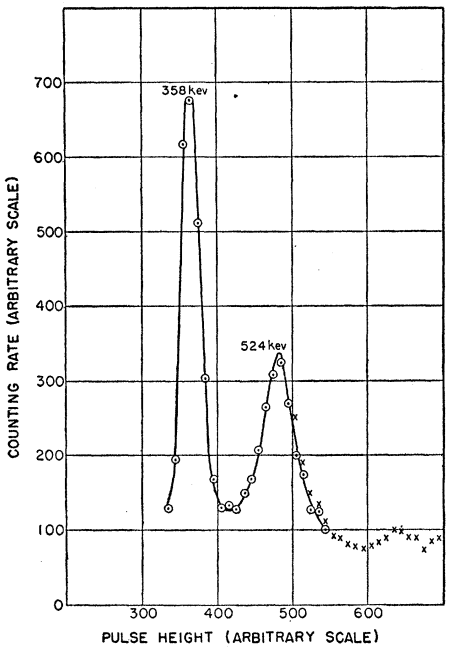

FIG. 2. Partial gamma-ray spectrum of Se^{83}.

relative intensities obtained by these methods agreed within the errors quoted below.

The gamma-ray spectrum associated with the 25-minute isomer is shown in Figs. 1–4. With the exception of the two peaks at 95 kev and 280 kev, which are believed to be attributable to other Se isotopes, all of the gamma rays shown were observed to decay with an approximate half-life of 25 minutes. A comparison of the shape of this spectrum with the shape of known monochromatic gamma-ray spectra indicates that none of the labeled peaks are associated with the escape of Compton-scattered or annihilation photons. The energies and relative intensities of the observed gamma rays are shown in Table I.

[3] Lazar, Kelley, Hamilton, Langer, and Smith, Phys. Rev. **110**, 513 (1958).

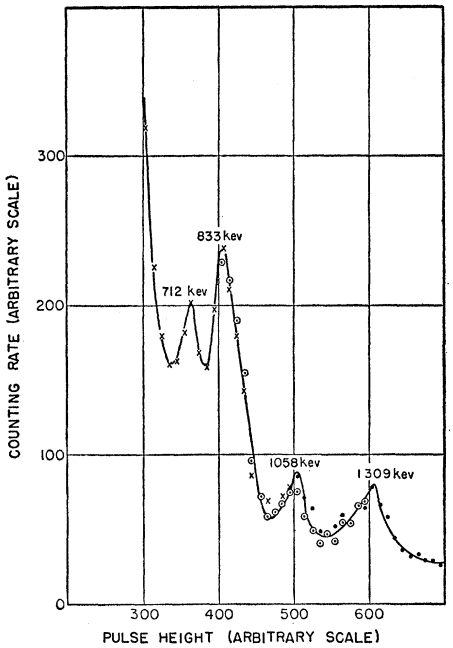

FIG. 3. Partial gamma-ray spectrum of Se^{83}.

BETA-RAY SPECTRUM

To measure the Se^{83} beta-ray spectrum a 2-in. diameter×1-in. thick plastic scintillator[4] on a DuMont-6292 photomultiplier tube was employed in conjunction with the 20-channel analyzer. The scintillator was shielded from light with a 0.75-mil aluminum window. A thick sheet of aluminum with a 1-in. diameter aperture was placed directly before the scintillator to prevent beta rays from striking near the edge of the detector. This was found to improve the resolution by a small but observable amount. Beta-ray sources consisted of deposits of about 100 $\mu g/cm^2$ placed between two layers of Scotch cellophane tape. The contribution to the beta-ray counting rate due to gamma rays was obtained by shielding the scintillator completely with an appropriate thickness of aluminum.

Using the Cs^{137} internal conversion peak, the Au^{198} beta-ray end point (and when necessary the Al^{28} beta-

TABLE I. Gamma rays from 25-minute Se^{83}. Errors quoted are based on consistency of separate measurements.

Energy (Mev)	Relative intensity
0.225±0.005	14±2
0.358±0.005	22±5
0.524±0.012	19±3
0.712±0.010	8±3
0.833±0.005	13±2
1.058±0.005	5±2
1.309±0.005	8±2
1.880±0.015	5±2
2.294±0.030	3±2

[4] Nuclear Enterprises Ltd., plastic phosphor NE102.

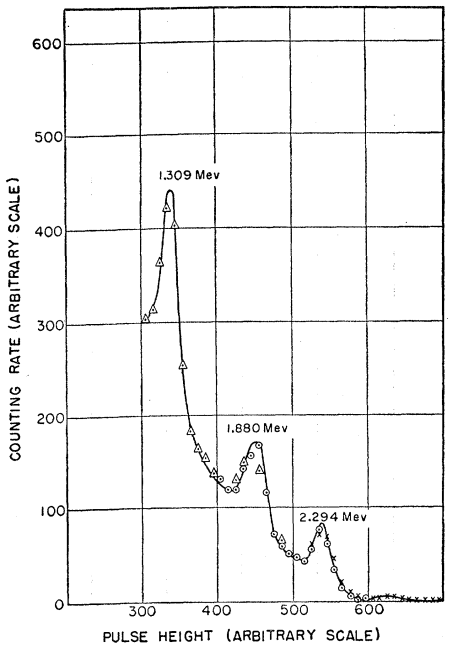

FIG. 4. Partial gamma-ray spectrum of Se^{83}.

ray end point) a calibration curve for the beta-ray spectrometer is obtained. This curve is linear, within the accuracy of end-point determinations, over the energy range of interest. Figure 5 shows a Fermi plot of the spectrum from a relatively thick (1 mil) Au^{198} source. Except for the deviations near the end point, which are attributable to spectrometer resolution, the Fermi plot is linear over almost half of the energy range. The linearity obtained using a much thinner (700 A) Au^{198} source is only slightly better.

Decay curves obtained for the Se beta rays in the region from 0.1 to 1.5 Mev are shown in Fig. 6. One set of points was obtained using a source of normal Se, the other using a source of enriched (75.74%) Se^{82}. The two decay curves are seen to be almost identical. They can both be fitted fairly accurately with an appropriate mixture of the 18- and 57-minute half-lives characteristic of Se^{81}. Beta-ray pulse-height distributions in the same

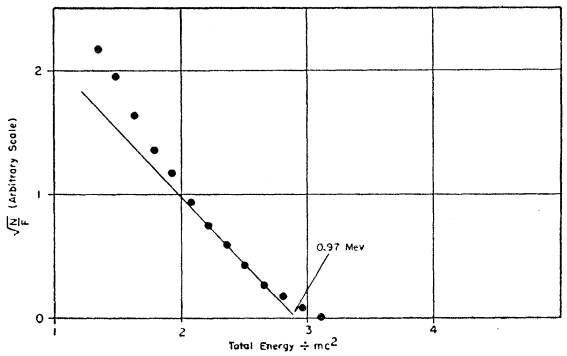

FIG. 5. Fermi plot of Au^{198} beta spectrum.

energy region, measured 15 minutes after exposure, are shown in Fig. 7; the semilogarithmic scale is used to facilitate a comparison of the shape of the curves. The pulse-height distributions are also seen to be almost identical. We believe the data of Figs. 6 and 7 to indicate that the presence of competing activities, mainly Se^{81}, even in the enriched isotope, is so serious as to make it impractical to determine the Se^{83} beta-ray spectrum in this way.

Since no gamma rays greater than 0.1 Mev have been observed from Se^{81},[5] the beta rays from Se^{81} may be eliminated by requiring that only those beta rays be detected which are in coincidence with higher energy gamma rays. Consequently, measurements of the beta-ray spectrum were made in which the 20-channel ana-

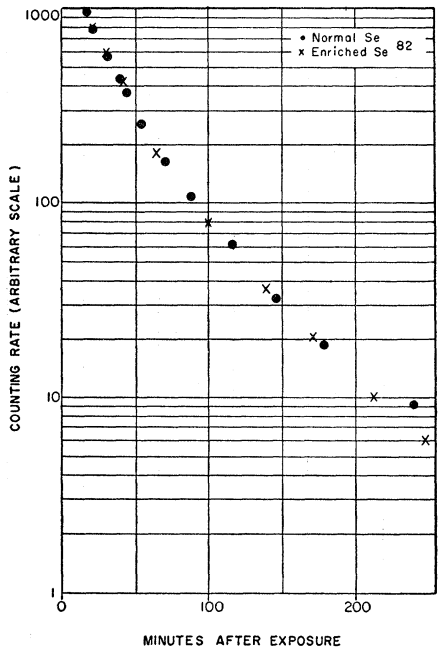

FIG. 6. Decay curve of Se beta rays in the region from 0.1 to 1.5 Mev. Probable errors in counting rate are comparable with the size of the point markers.

lyzer, fed from the beta-ray detector, was gated by coincident gamma rays of energy 350 kev or greater. Pulse-height distributions of these beta rays are shown in Fig. 8, both for a source of normal Se and a source enriched in Se^{82}. These two pulse-height distributions are seen to be essentially the same as each other, but to differ substantially from those obtained without the coincidence method. Although it is difficult to make accurate half-life measurements due to the low counting rates, the counting rate of the coincident beta rays appears to decay with a single half-life close to 25

[5] *Nuclear Level Schemes, A=40 to A=92*, compiled by Way, King, McGinnis, and van Lieshout, U. S. Atomic Energy Commission Report TID-5300 (U. S. Government Printing Office, Washington, D.C., 1955).

minutes. It is believed that these beta rays represent the spectrum characteristic of the Se^{83} 25-minute isomer.

A Fermi plot of the coincident beta-ray spectrum from the enriched source is shown in Fig. 9. The contribution to the counting rate due to gamma rays has been subtracted. Comparison with the Au^{198} Fermi plot indicates the spectrum to be complex with a predominant end-point energy in the vicinity of 1 Mev but with at least one weak higher energy component. Assuming a single higher energy component, the end point obtained from this and other similar measurements is 1.7±0.2 Mev. The contribution from this beta-ray group to the lower energy part of the spectrum is obtained by modifying the straight-line extrapolation shown in Fig. 9 to give a Fermi plot distortion similar to that observed for the Au^{198} spectrum (Fig. 5). The

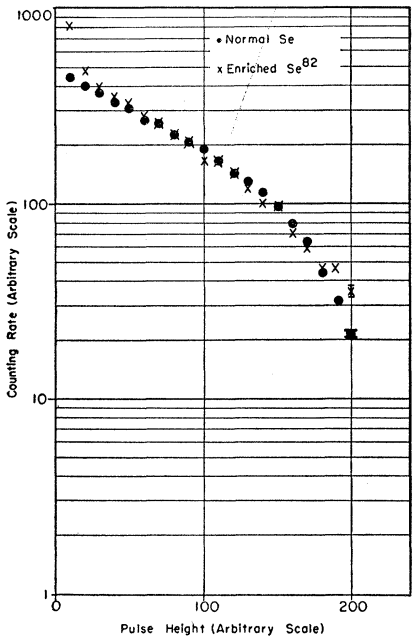

FIG. 7. Pulse-height distribution of Se beta rays in the region from 0.1 to 1.5 Mev.

counting rates associated with this distorted Fermi plot are then subtracted from the observed counting rates to obtain the low-energy beta-ray spectrum. The Fermi plot obtained after thus eliminating the 1.7-Mev beta-ray group is shown in Fig. 10. The end point of the predominant beta-ray group obtained from this and other similar measurements is 1.0±0.1 Mev. The deviation of the experimental points from the straight line below 0.4 Mev ($\epsilon=1.8$) is substantially greater than that obtained for the Au^{198} spectrum (Fig. 5) of approximately the same end-point energy. This deviation is believed to represent a third beta-ray group of end-point energy in the vicinity of 0.5 Mev. Assuming the distortion of the straight line Fermi plot in Fig. 10 to be similar to that obtained for Au^{198} (Fig. 5) the contribu-

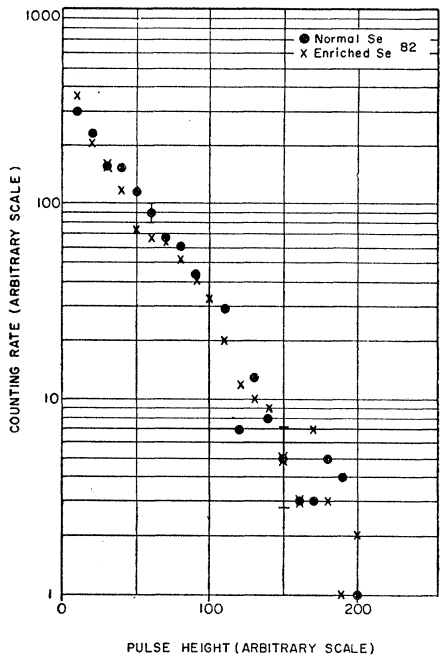

FIG. 8. Pulse-height distribution of Se^{83} beta rays in the region from 0.1 to 1.5 Mev.

tion from the 1-Mev beta-ray group is deducted from the lower energy counting rates with the resulting Fermi plot shown by the open circles in Fig. 10. The low-energy end point obtained from this and other similar measurements is 0.45±0.15 Mev.

BETA-RAY SPECTRUM OF THE 70-SECOND ISOMER

The beta-ray spectrum of the 70-second isomer has been reinvestigated by methods similar to those described above. A Fermi plot of the spectrum in the vicinity of the upper energy end point indicates an end-point energy of 3.75±0.15 Mev. When the beta-ray spectrometer is employed to observe those beta rays in coincidence with the 2-Mev gamma ray, a Fermi plot

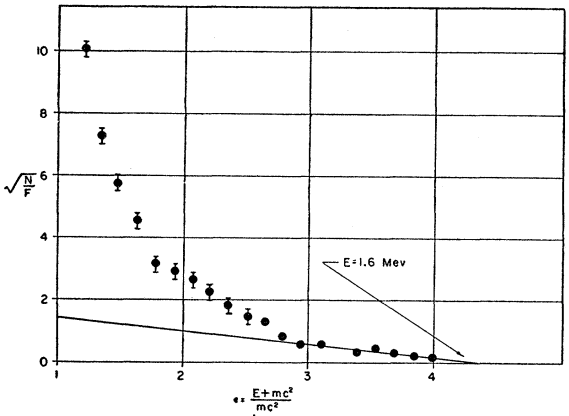

FIG. 9. Fermi plot of Se^{83} beta spectrum.

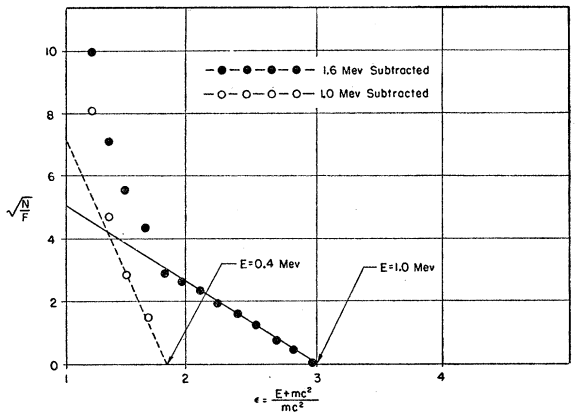

FIG. 10. Fermi plot of Se^{83} beta spectrum.

results which yields an end-point energy of 1.75±0.10 Mev. These two beta-ray groups are presumably those previously[1] determined to have end-point energies of 3.4 and 1.5 Mev, respectively.

DECAY SCHEME OF 25-MINUTE Se^{83}

In a previous paper[1] it was reported that the gamma rays emitted from the 70-second isomer are 0.350±0.006 Mev, 0.650±0.005 Mev, 1.01±0.02 Mev, and 2.02±0.05 Mev. The present work indicates that the 25-minute isomer emits a gamma ray of 0.358±0.005 Mev but no other gamma rays which might be identical with those from the 70-second isomer. A careful comparison of the 0.35-Mev gamma rays observed in the 70-second and 25-minute isomers shows no detectable difference in energy, and they are consequently assumed to represent the same transition. The fact that the two isomers show no other gamma rays in common implies that the 0.35-Mev gamma ray represents a transition to the ground state of Br^{83}.

We have been able to construct one, and only one, decay scheme for the 25-minute isomer which is consistent with the three observed beta-ray end points, the observed gamma-ray energies and intensities, and the assumption that the 0.35-Mev gamma ray represents a ground-state transition. This decay scheme, together

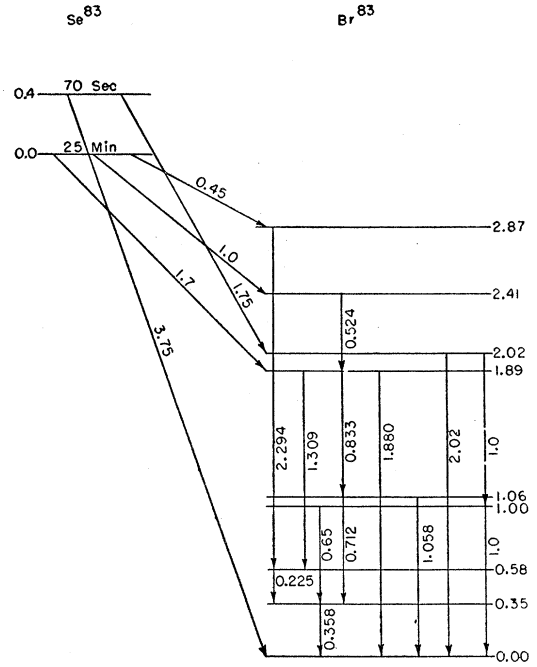

FIG. 11. Decay scheme of Se^{83}. All energies are in Mev.

with the decay scheme of the 70-second isomer, is shown in Fig. 11.

GAMMA-GAMMA COINCIDENCE MEASUREMENTS

To investigate further the decay scheme of the 25-minute isomer, γ-γ coincidence measurements have been performed in which the 20-channel analyzer, fed by the 3-in.×3-in. NaI detector, was gated by pulses from the 2-in.×3-in. detector feeding through a single-channel analyzer. Due to the complexity of the gamma-ray spectrum, with a consequent overlapping of photopeaks and Compton distributions from different gamma rays, it has been found difficult to obtain definitive results in most cases. However, it is believed that coincidences have been established with reasonable certainty between the following pairs of gamma rays: 0.358—2.294 Mev, 0.358—1.309 Mev, 0.524—1.880 Mev. Each of these results is consistent with the decay scheme of Fig. 11.