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INTERNAL CONVERSION ELECTRONS FROM PRIMARY FISSION FRAGMENTS

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May 1965

The Proceedings of the International Conference on the Internal Conversion Process

INTERNAL CONVERSION ELECTRONS FROM PRIMARY FISSION FRAGMENTS*

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As a result of studying prompt neutrons accompanying the spontaneous fission of ^{252}Cf , Bowman, Thompson and Nakamura developed a multidimensional pulse-height analyzer in which successive pulse heights or time delays from various detectors are recorded, via a 256 channel analog to digital converter, as, successive binary numbers on magnetic tape. Subsequently, the magnetic tape, with the primary three (or more) dimensional information, may be sorted, event by event, on the IBM 7094 computer. Various programs of the computer permit the spectrum in one dimension to be displayed in association with any combination of pulse heights in the other two dimensions.

The study of spontaneous fission then became concerned with gamma-ray spectroscopy. The possibility of examining the radiation in coincidence with specific fission fragment pairs gave rise to the hope that the earlier featureless continuous gamma-ray spectra could be resolved into discrete structure. In addition, one might be able to observe Doppler shifts in the energies of the gamma rays due to the motion of the fragments and in this way ascertain which members of the pairs of fragments emitted the gamma rays. Some information on the lifetimes involved might also be obtained. We also hoped to ultimately gain some nuclear spectroscopic information on the energy levels in the region of nuclei near the double magic ^{132}Sn . Now, as a result of the experiments to be summarized here, we have indeed seen many completely resolved gamma rays in the energy region up to about 500 keV, and the expected Doppler shifts have been observed for those gamma rays which are emitted in less than a nanosecond, the approximate flight time from fission source to detector. The timely development of lithium-drifted germanium detectors for gamma-ray spectroscopy has greatly enhanced this research.

To gain additional information on the atomic numbers of the emitting fragments and on multipolarities we turned to studies of conversion electrons. One

of us (Rand Watson) is pursuing this problem as his thesis research at Berkeley. We considered measuring conversion electrons in a conventional double-focusing, prismatic, beta-ray spectrometer and rejected the idea because of the enormous length of counting time that would be involved with such a single-channel instrument. Instead, we decided to measure the energies of conversion electrons in a cooled, lithium-drifted silicon detector storing the pulse height from fission detector 1, pulse height from fission detector 2 and pulse height from the silicon electron detector on magnetic tape with the multidimensional pulse-height analyzer. Similar experiments have been carried out by Darrah Thomas and co-workers at Princeton.

In order to achieve the best resolution in the electron spectra, we wished to shield this detector from direct radiation by fission fragments. At the same time, we wanted to achieve as high an electron collection geometry as possible. We decided to make use of a rather high magnetic field arrangement of the sort proposed earlier by Malmfors for a time-of-flight beta-ray spectrometer. In our apparatus, the source is situated in a field of magnitude about 6 kilogauss with a high gradient ($n \sim 4$). These conditions are produced in the fringing field of a 100 KVA C-magnet. In such a geometry, electrons leaving the source in any direction in the plane perpendicular to the magnetic lines of force will describe trochoidal orbits, circling and gradually precessing around in the fringing field at a constant average distance from the center of the magnet. In addition to this 180° acceptance angle in the radial direction, there is also a certain amount of axial focusing arising from the same effect that causes mirroring of particles trapped in the Van-Allen belt about the earth; that is, the electron orbits that are moving up out of the plane at not too steep an angle will be turned back at the higher field values above and below the plane. Figure 1 shows a photograph of the apparatus. A small vacuum chamber is located between the flared conical-pole faces of the large C-magnet. The electron detector, with its liquid nitrogen coolant reservoir, is in the vertical position from the center of the magnet. The source is inserted on the probe in the horizontal direction as shown in the picture, and the connections to the fission detectors lie on either side of the source along the direction of the magnetic field. The second figure is a schematic drawing of the apparatus, and in the side view, one can see the position of the lead shield which blocks the passage of gamma rays and fission fragments from the source into the electron detector.

The electron energy spectrum in coincidence with all fission events is shown in Fig. 3, and there is a suggestion of structure but no clearly resolved peaks. Figure 4 shows the electron spectra associated with particular fission mass ratios; that is, these curves are electron-energy spectra associated with particular pulse-height ratios from the fission detectors. More precisely, the computer analysis is more sophisticated than this; corrections are made for neutron evaporation so as to maximize the spectrum for the indicated mass number range on the figure. One now sees a number of peaks clearly, although there is evidently incomplete resolution in many cases. To facilitate analysis of these multidimensional spectra, we have cut the individual spectra in plastic templates and have placed them in slots according to the mass number so as to give a three-dimensional surface as shown in the photograph in Fig. 5. Figure 6 is selected to display the spectrum from the mass (103-105)--mass (143-145) fragment pair in which the heavy fragment is in the region of Ba. We have indicated certain shoulders on this spectrum, for under a different arrangement of the fission source in the apparatus we are able to bring out very clearly resolved structure in the region of these shoulders. The fission fragments are moving with velocities of about 10^9 cm/sec. Therefore, gamma rays or conversion electrons emitted with a half life of the order of a nanosecond will often be emitted while the fragments are still in motion. By placing the source off the median plane and close to one of the fission detectors, the high magnetic field prevents those electrons leaving the immediate region of the source from reaching the electron detector, and only those electrons emitted along the portion of the flight path crossing the median plane of the apparatus will precess around to register in the silicon electron detector. In this way, complete separation of the electrons emitted by single members of the pairs of fragments may be achieved. Examples of the spectra of some of these delayed electrons (~ 1 nanosecond after fission) for the same mass intervals given in Fig. 6 (143-145 and 103-105) are shown in Fig. 7. It can be seen that the shoulders indicated in the previous spectrum are now clearly resolved and identified with their respective light or heavy fragments.

The delayed electrons in Fig. 7 also show much better peak shapes, perhaps due to the fact that there is no absorbing material through which these trochoidal orbits must pass and cause energy loss. The disadvantage of this type of spectrometer, as Malmfors found, was that many of the orbits will re-enter a source backing, and this is a difficulty we cannot avoid in the measurement of

the prompt electron spectrum with the source in the median plane. However, in the case of the delayed electrons we have a truly nonabsorbing source in which energy loss from degradation in the source backing cannot occur. The electron lines are still not quite as narrow as can be realized with conversion-electron standards such as ^{203}Hg . This is mainly attributable to line broadening due to the motion of the fragments. We select primarily electrons emitted at 90° with respect to the fission fragment motion, but there is a certain acceptance of angles less than or greater than 90° , and the electron energies from such trajectories will be shifted by the motion of the fragment.

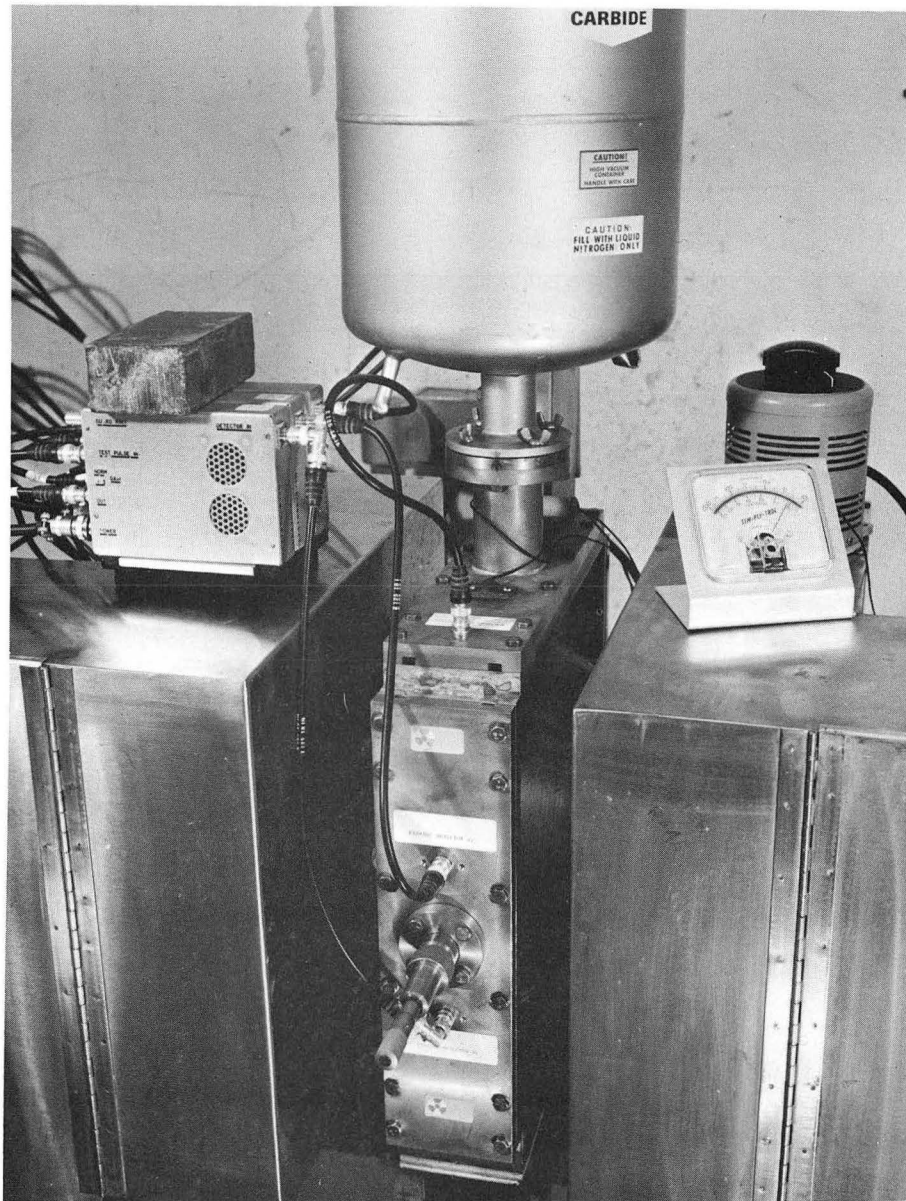
The peaks at 155.5 keV and 189.5 keV in the mass 143-145 interval are believed to be K and L lines of an E2 transition in ^{144}Ba based on the K to L ratio and observed lifetime. Figure 8 shows the corresponding gamma-ray spectra in this region with the gamma rays labeled alphabetically--the top spectrum with the heavy fragment moving toward the detector, the middle spectrum with the gamma rays emitted at 90° and the bottom spectrum with the light fragment moving toward the gamma-ray detector (heavy fragment away). Many of these gamma rays have been identified with either the heavy or the light fragment on the basis of Doppler shifts and relative intensities. They are stipulated as such by the letter H or L, respectively, following their identification letter. Those peaks having components in the unshifted position (indicating gamma emission after the fragment had stopped in the detector) are labeled with the letter U following their identification letter. We believe that the ^{144}Ba K and L conversion lines in the previous figure are associated with the gamma transition of 197.5 keV labeled "O" in Fig. 8. The transmission coefficients in the electron detector have not yet been measured precisely enough to determine a conversion coefficient but we hope to do this in the near future. We intend to analyze the gamma-ray angular distribution for further information on multipolarities and on fragment spins. We will also be looking for binding energy shifts and conversion coefficient changes resulting from the fact that the internal conversion occurs from ions with charges ~ 20 and not from neutral atoms.

FOOTNOTES

*This work was done under the auspices of the U.S. Atomic Energy Commission.

FIGURE CAPTIONS

- Fig. 1. Photograph of the electron-fission fragment detector apparatus.
- Fig. 2. Schematic diagram of the electron-fission fragment detector apparatus showing detector positions, shielding, and cross section of the magnet pole-faces.
- Fig. 3. Prompt electron spectrum in coincidence with all fission events (unsorted with respect to fragment mass).
- Fig. 4. Prompt electron spectra in coincidence with specific fission fragment pairs.
- Fig. 5. Three-dimensional surface of the prompt electron spectra in coincidence with specific fission fragment pairs.
- Fig. 6. Prompt electron spectrum in coincidence with the mass (103-105)--mass (143-145) fission fragment pair.
- Fig. 7. (Top curve). Delayed electron spectrum in coincidence with the mass 143-145 fission fragments. (Bottom curve). Delayed electron spectrum in coincidence with the complementary mass 103-105 fission fragments.
- Fig. 8. Gamma-ray spectra in coincidence with the mass (143-145)--mass (103-105) fission fragment pair with the heavy fragment moving toward (top), at 90° (center) and away (bottom) from the gamma-ray detector. The gamma-ray peaks are labeled alphabetically followed by the letter L, H or U for peaks in a light fragment Doppler shifted position, a heavy fragment Doppler shifted position or an unshifted position, respectively.



ZN-5046

Fig. 1

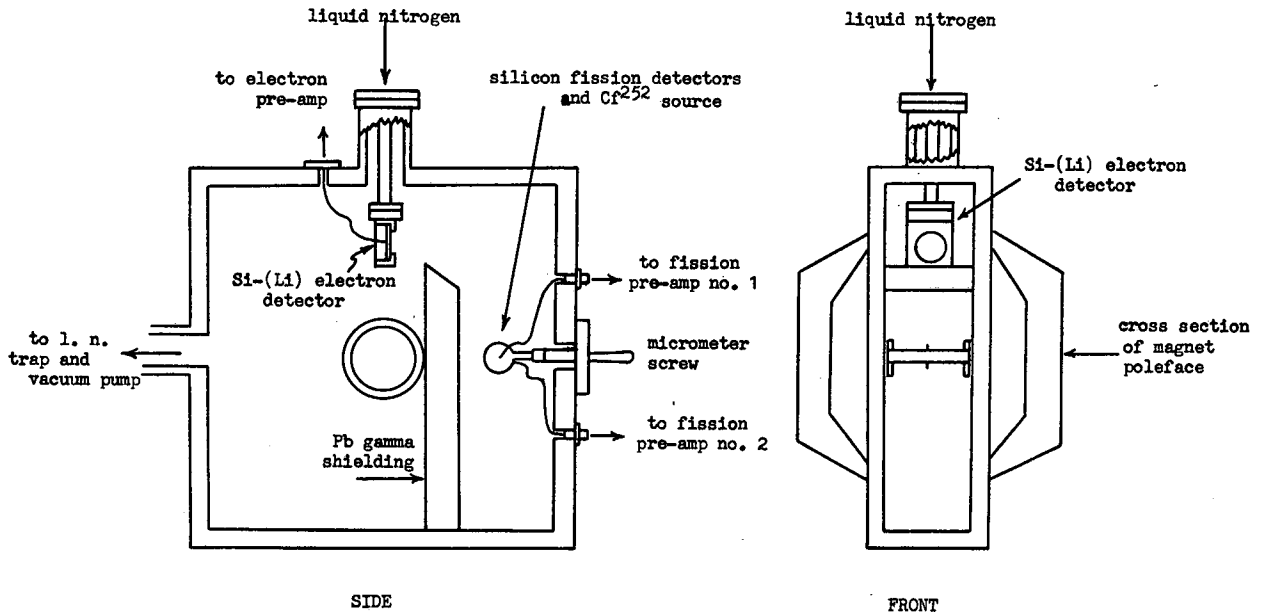
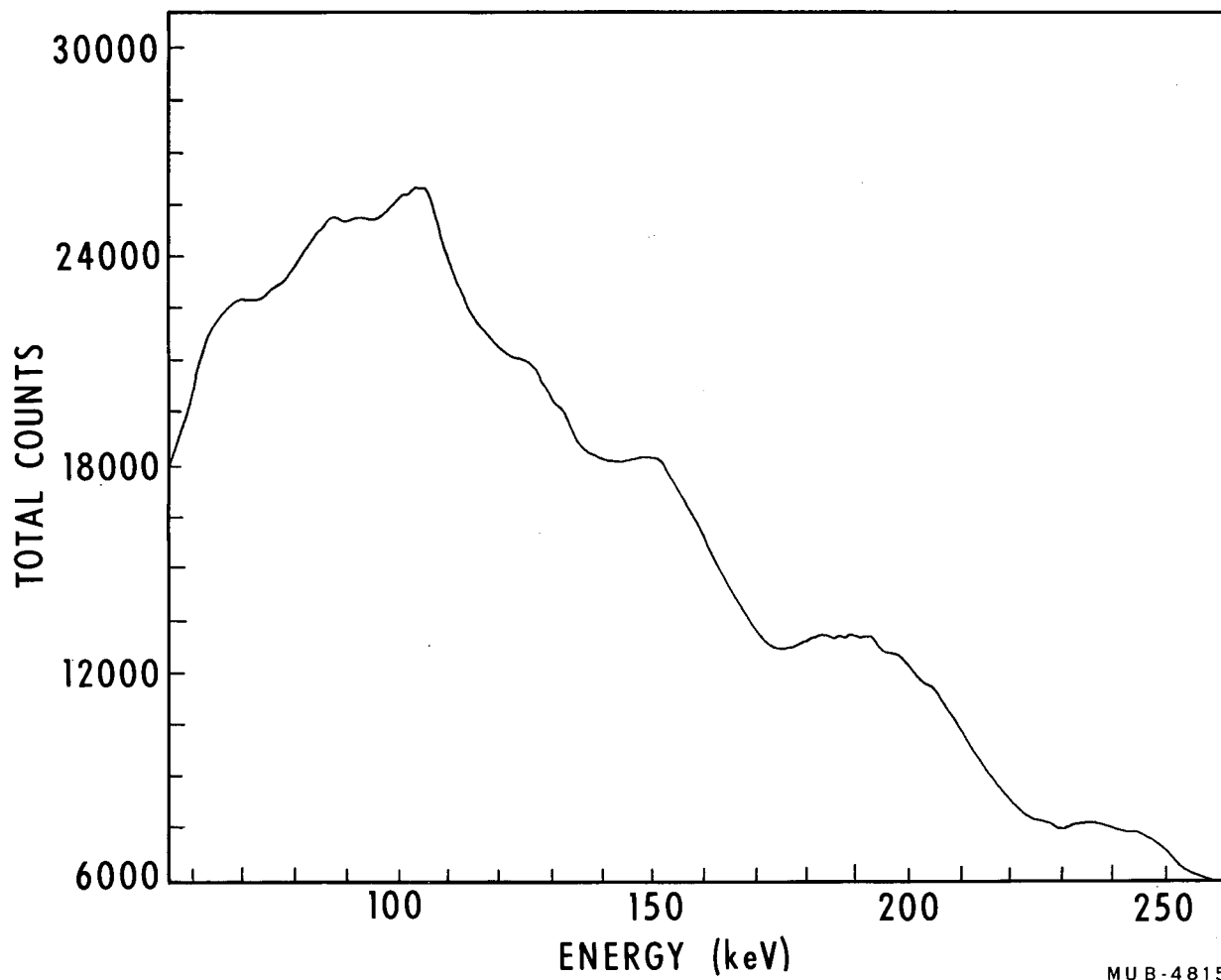


Figure 1

ELECTRON-FISSION COINCIDENCE SPECTROMETER

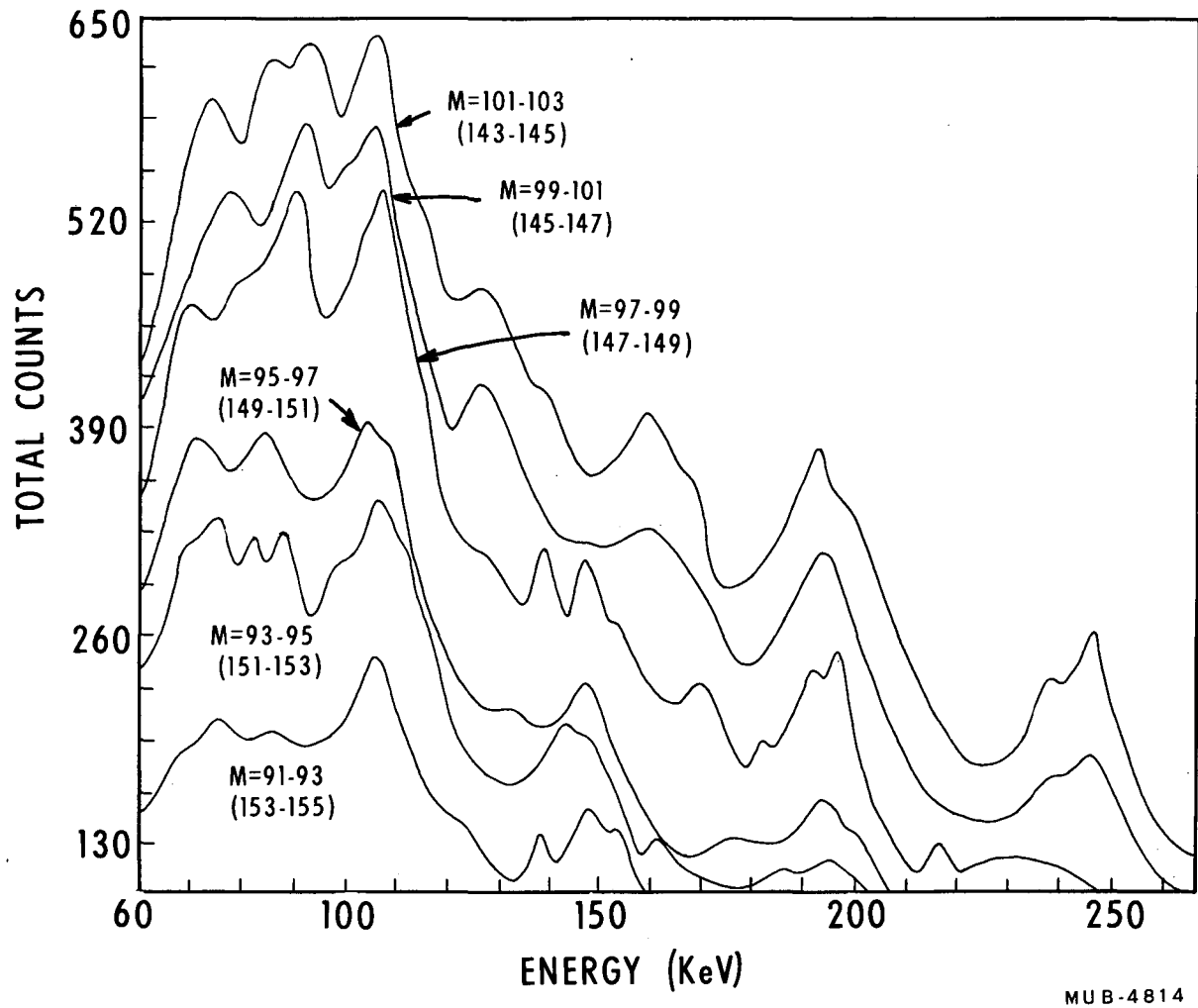
MUB-4827

Fig. 2



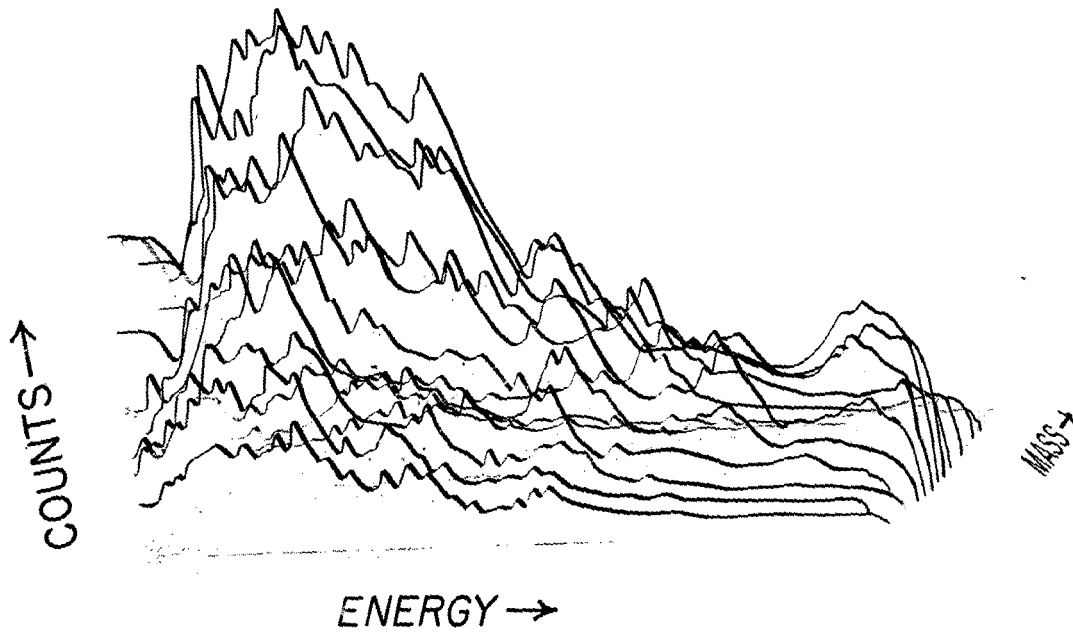
MUB-4815

Fig. 3



MUB-4814

Fig. 3



ZN-4601

Fig. 5

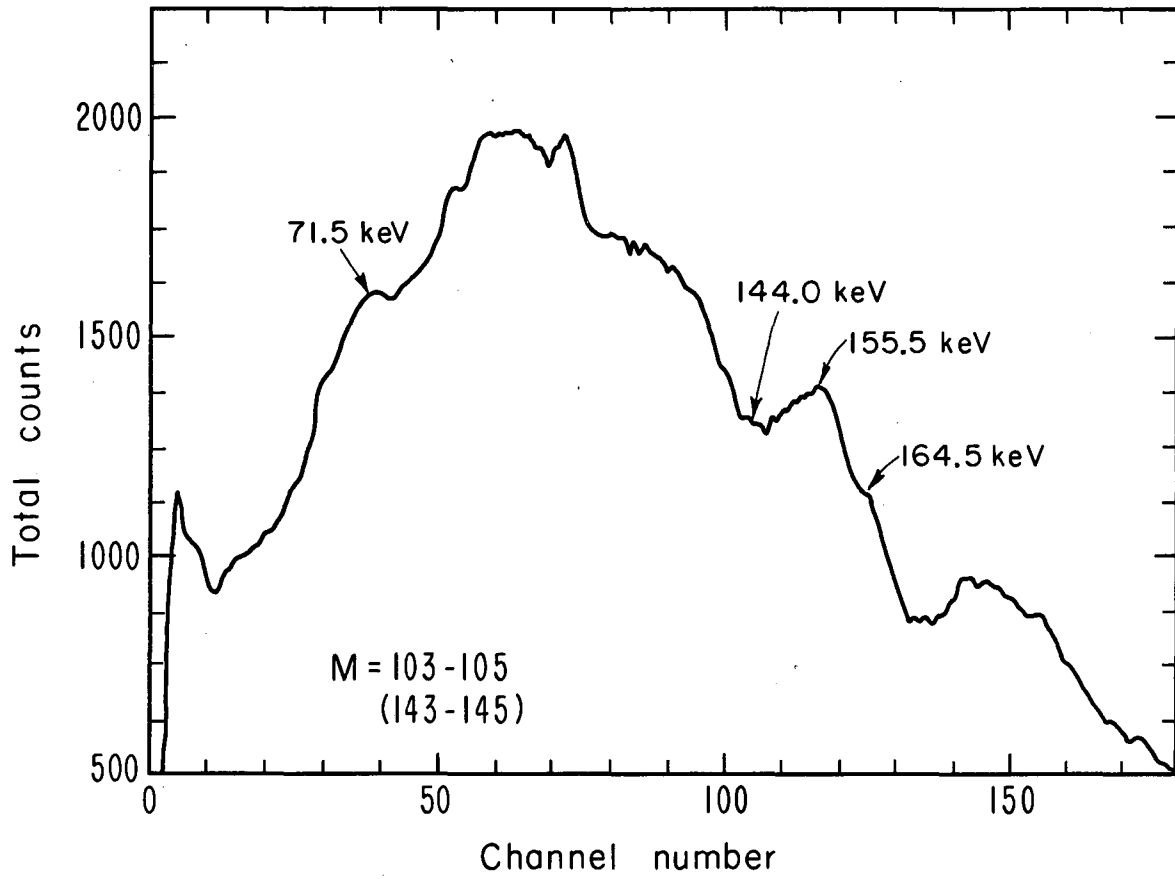
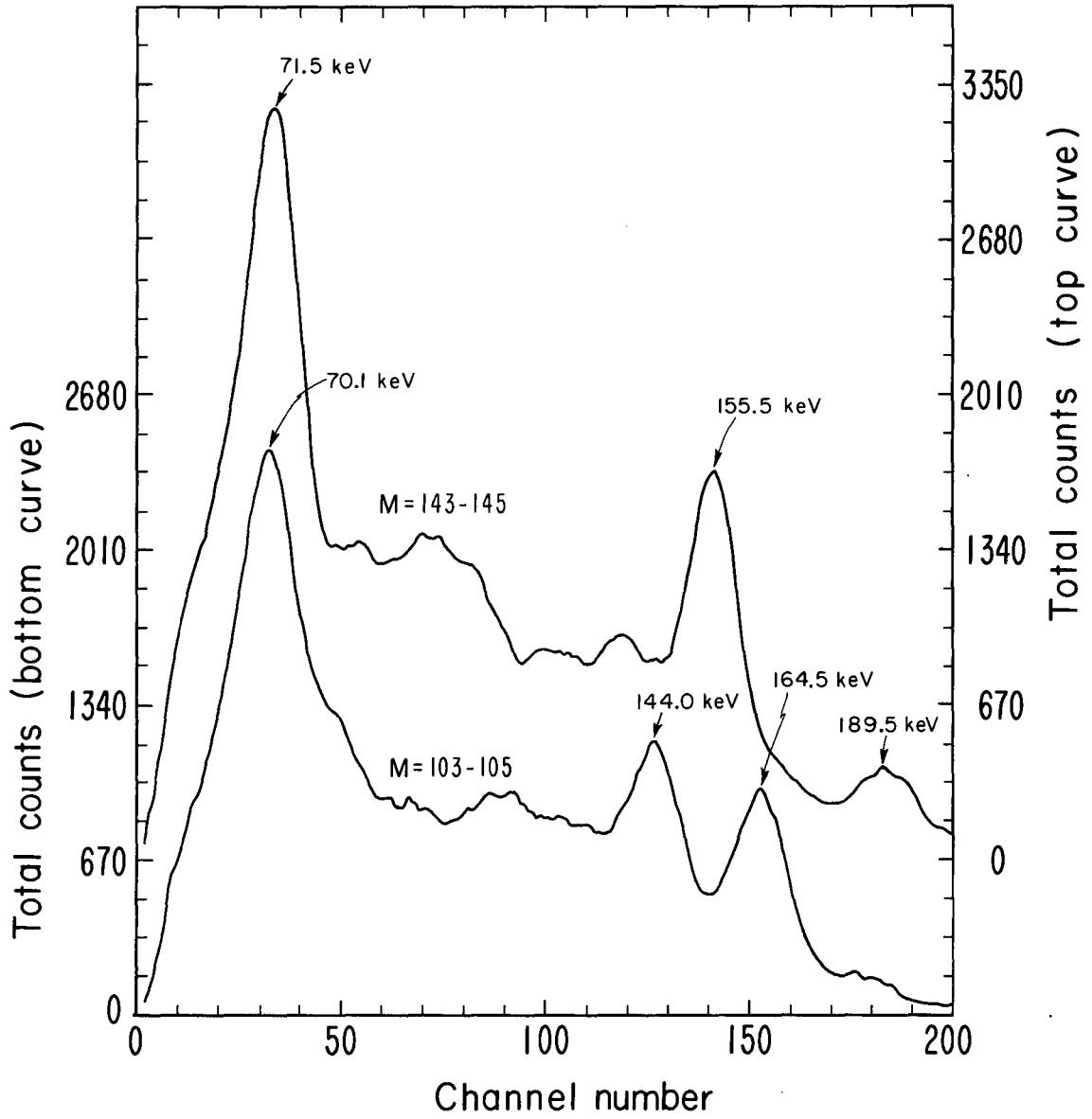
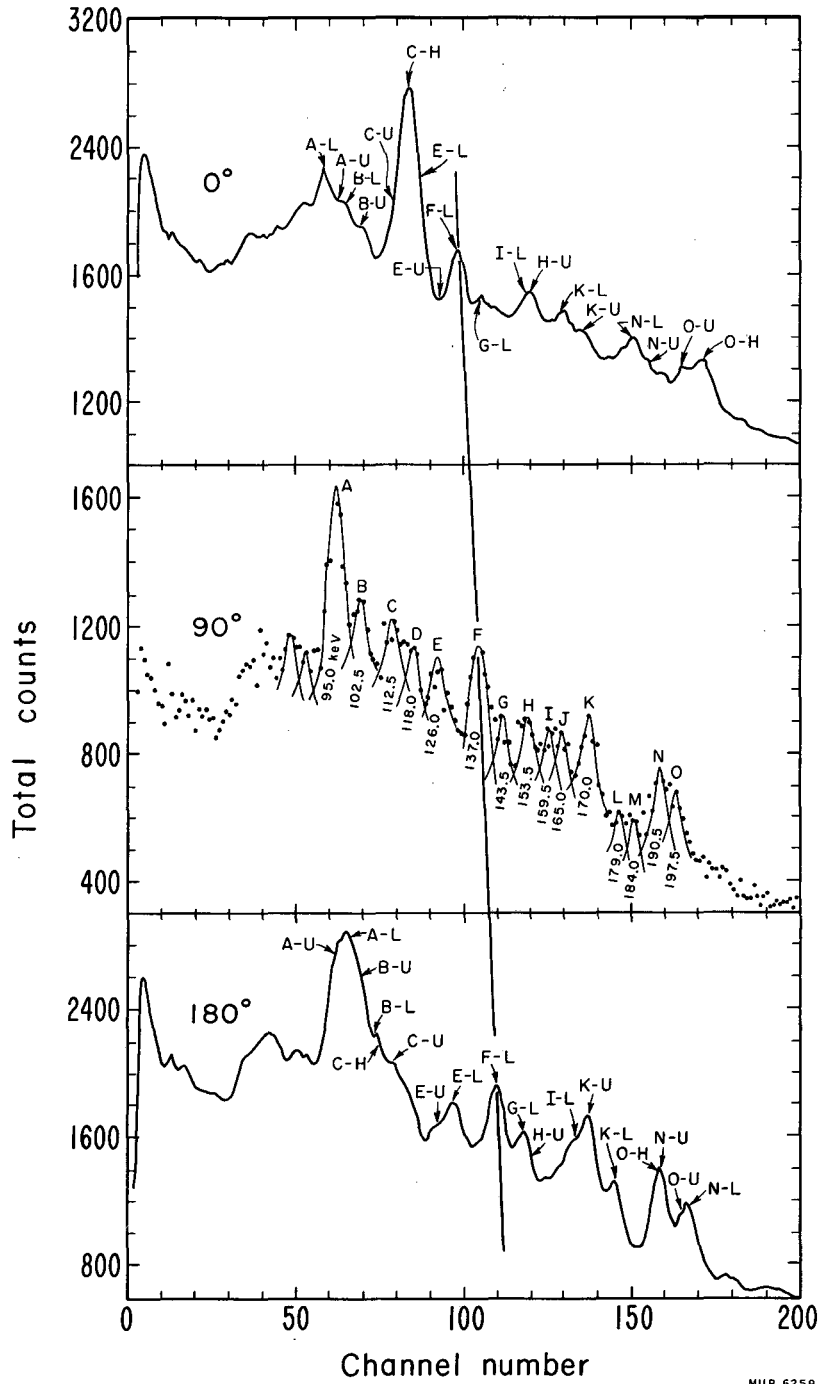


Fig. 6



MUB-6258

Fig. 7



MUB-6259

Fig. 8

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