D-D AND D-T NEUTRON EXCITATION OF

ENERGY LEVELS IN Cs^{133}

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CHAPTER I

INTRODUCTION

The energy levels of the Cs^{133} nucleus have been studied by three methods. Earliest information came from the study of radiations from Ba^{133} (1, 2, 4, 5, 8). The excited Cs^{133} nucleus is produced when Ba^{133} decays by capturing an orbital electron. The Cs^{133} nucleus in the process of decaying to ground state emits a gamma ray with each transition. An analysis of these gamma rays by scintillation pulse-height and coincidence-counting techniques provided some information for an energy-level scheme up to 0.44 Mev, the highest level produced by Ba^{133} decay. Some levels in this energy range might exist but would not be observed because they are not accessible from Ba^{133} except by forbidden transitions.

Direct excitation of the Cs^{133} nucleus by the method of Coulomb excitation also produces an excited nucleus which decays to ground state with the emission of a gamma ray for each transition. Such an experiment using alpha particles for bombarding particles has been conducted by at least two groups (3, 9). Because of their high charge and low velocity for a given energy, alpha particles are eminently suited for the electric excitation of nuclei such as Cs^{133} since the condition for the simplified classical treatment of the process, $2Z_1Z_2e^2/\hbar v \gg 1$ (Z_1e and Z_2e are the charges of projectile

and target, v is the relative velocity), is well satisfied in this region of the periodic table. Another advantage is in the reduced background due to the relative ineffectiveness of alpha particles in exciting the characteristic K x-radiation. The analysis of gamma rays produced by this method has led to the assignment of four transitions in Cs^{133}.

Another method of direct excitation is the inelastic scattering of neutrons. Neutron inelastic scattering occurs when a neutron forms a compound nucleus of extremely short half-life and then emerges with a slightly lower energy, leaving the target nucleus in an excited state. Decay by gamma rays then occurs as in the Ba^{133} decay and Coulomb excitation methods. Interpretation of the resulting spectrum is complicated, however, in this type of experiment by the presence of background induced by the neutrons. The initial experiment of this type at North Texas State College was conducted by Young (10). In this experiment Young used 14 Mev neutrons obtained from the D (t,n) He^4 reaction produced by the North Texas State College 100 Kv Cockcroft-Walton accelerator to bombard a CsI crystal. Analysis of the resulting spectrum indicated the existence of .56 Mev and .75 Mev levels in Cs^{133}. Lamb (6) carried on an experiment differing from Young only in that 2.5 Mev neutrons were used instead of 14 Mev neutrons. Levels of .175 Mev and .44 Mev were reported from this experiment. Both Lamb and Young used single-channel analyzers to obtain pulse-height spectra. Instability of the

equipment made accurate calibration impossible. Poor counting statistics resulted from the use of low beam currents which were necessary for the preservation of targets. In an attempt to eliminate the difficulties encountered by Lamb and Young and clarify some of the unidentified features in their spectra McDonald (7) repeated their experiments using an RcLiac 128-channel pulse-height analyzer instead of the single-channel analyzer. With this equipment McDonald was able to obtain a complete spectrum during an interval of five minutes for 14 Mev neutrons or twenty minutes for 2.5 Mev neutrons with excellent counting statistics in either case. These spectra showed sixteen probable transitions in cesium, iodine, and sodium. Results were inconclusive, however, since higher levels of excitation were not present in these spectra and the energy measurements were not precise in the low energy range. Also the presence of the .08 Mev cesium level was not firmly established.

The purpose of this experiment was to make positive assignment of the Cs^{133} energy levels excited by the inelastic scattering of neutrons. An experimental procedure similar to that used by McDonald (7) was employed (for details see Chapter III). The variation of counting rates, variation of target position, and use of iodine and sodium scatterers were utilized in an attempt to produce spectra which could be resolved with a high degree of certainty.

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CHAPTER II

INSTRUMENTATION

The gamma-ray spectra were determined by the use of an RCLiac 128-channel pulse-height analyzer belonging to Southern Methodist University. A thallium-activated cesium iodide crystal (Harshaw 6D4) was used as both a scatterer and detector while obtaining all Cs^{133} spectra. The crystal was attached to a Dumont 6292 photomultiplier which was used in a RCL Model 11029-1-1 probe. The amplified signals from the probe were passed to the RCLiac where they were analyzed and recorded. Data from all channels were read from the scope display and manually recorded at the end of each data run. A similar system except for the substitution of a thallium-activated sodium iodide crystal for the thallium-activated cesium iodide crystal was used while obtaining all spectra of sodium and iodine gamma rays.

Calibrations were made immediately before and after each run. Sources used for calibration were Ba^{133}, Na^{22}, and Cs^{137}. The use of Ba^{133} as a calibration source made possible an accurate interpretation of the neutron-excited levels which were the same as those produced in Ba^{133} decay.

The neutron flux was monitored with a National Radiac MF3-2 scintillator crystal using circuitry similar to that

used in earlier experiments at North Texas State College (1, 2). Unexplained fluctuations in neutron-monitor data experienced by others using this system led to a check of the system at the beginning of this experiment. The responses of the monitor to gamma rays from Co^{60} and to neutrons from a radium-berylium source were determined experimentally (see figures 4 and 5). The gamma rays were found to create no response in the range of either the 2.5 Mev or 14 Mev neutrons. The monitor system was thereafter considered reliable.

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CHAPTER III

EXPERIMENTAL PROCEDURE

The 2.5 Mev and 14 Mev neutrons obtained from the $D(d,n)He^3$ and $D(t,n)He^4$ reactions, respectively, were produced by the North Texas State College Cockroft-Walton accelerator. The neutrons were inelastically scattered by each of the systems described below.

Thallium-activated CsI crystal: The crystal in this system serves as both a scatterer and a scintillator which offers a three-fold advantage. First, the crystal contains the target nuclei under investigation thus eliminating the need for a costly pure-cesium scatterer. Second, external background radiation can be eliminated to a large extent, since the gamma radiation under investigation is both originated and detected within the crystal. Third, this crystal is one of the best gamma-ray scintillators available due to the high cross section for photoelectric interactions presented by the high nuclear charges of both cesium and iodine. Analysis of these scintillations provides a gamma-ray spectrum for cesium and iodine.

Thallium-activated CsI crystal with iodine scatterer: The preceding arrangment is altered by the addition of an iodine scatterer. The scatterer consists of a loose one-half-inch-thick layer of iodine packed around and in front

of the crystal inside the electrostatic shield. The spectra obtained from this arrangement exhibit iodine peaks which are increased relative to spectra obtained without the iodine scatterer.

Thallium-activated NaI crystal: As in the case of the CsI crystal this crystal acts as both a scatterer and a scintillator. This produces a spectrum which contains gamma-ray peaks for both sodium and iodine.

Thallium-activated NaI crystal with iodine scatterer: This arrangement consists of the NaI crystal with an iodine scatterer in the same manner as the CsI with iodine scatterer system described above. The iodine levels in these spectra are relatively more intense than those in spectra obtained using only the thallium-activated NaI crystal.

Thallium-activated NaI with sodium scatterer: The NaI crystal was used in conjunction with a ring-shaped sodium scatterer. The sodium ring was constructed by melting a bar of pure sodium in paraffin and pouring the mixture into a thin-walled mold made from sheet copper. The relatively light paraffin flowed to the top of the mold and was removed after the sodium hardened. The resulting sodium ring presented a scatterer of one inch thickness around the circumference of the crystal through its entire depth. The presence of this scatterer produced sodium levels of greater relative intensity than those found in other spectra obtained using the NaI crystal.

Using both the 2.5 Mev and 14 Mev neutrons all scattering arrangements were employed at a position approximately 20 centimeters from the neutron source. The reduced counting rate encountered in these experiments required data runs of thirty minutes or more and yielded poor results since background became of great importance at the high energies. These experiments were repeated with the crystals at a position approximately 3 centimeters in front of the neutron source. In this position data runs of ten minutes duration produced data in which the background was unimportant. Data produced during these runs are shown in Figures 1, 2, and 3.

The Cockcroft-Walton accelerator was operated in the range from 75 Kv to 80 Kv throughout the experiment and produced an intense flux of neutrons. The occasional arcs produced during data runs appeared to have little or no effect on the instrumentation as calibrations rarely showed a drift of over one channel.

CHAPTER IV

RESULTS AND CONCLUSIONS

Representative spectra obtained from these experiments are shown in Figures 1 through 3. Several spectra are shown in each figure for the purpose of comparison of peak shapes. Energy calibrations have been normalized for all the spectra in any one figure, but neutron flux and background have not.

Figures 1 and 2 are samples of spectra obtained during the inelastic scattering of 2.5 Mev neutrons. Figure 1, covering the energy range from .03 Mev to .40 Mev, shows the spectra of NaI, NaI with a sodium scatterer, NaI with an iodine scatterer, CsI, and CsI with an iodine scatterer.

In Figure 1 a sharp contrast is noted between the spectra obtained with the iodine scatterer and those without it. In both the CsI and NaI spectra obtained with the iodine scatterer a peak appears at .057 Mev. This energy level is assigned to iodine for the following four reasons. It appears in the spectra of both NaI and CsI. Iodine levels of .056 Mev and .062 Mev have been reported by Mathur (7) and Van Loef and Lind (12) respectively. It appears in all the 14 Mev spectra of both CsI and NaI. The iodine scatterer makes this peak more intense in the 14 Mev spectra. In the 2.5 Mev spectra obtained without an iodine scatterer an extremely intense peak appears between .03 Mev and .05 Mev.

The magnitude of this peak is such that the .057 iodine level does not appear in these spectra. This peak apparently is due to background since the presence of an iodine scatterer, which is also a good shield, eliminates this peak. It was noted during this experiment that the iodine scatterer eliminated the strong .079 Mev level from Ba^{133} decay when used as a calibration source. Hence it appears the iodine scatterer would be able to absorb intense low energy background radiation.

Also in Figure 1 a peak is noted at .079 Mev in the spectrum of CsI with iodine scatterer but not in the spectrum of NaI with iodine scatterer. This peak also appears in the 14 Mev spectra of CsI and CsI with iodine scatterer but not in any of the 14 Mev NaI spectra in Figure 3. An energy level of .079 Mev has been observed in the decay of Ba^{133} and in Coulomb excitation of Cs^{133} (2, 4, 9, 10). Therefore, this energy level is assigned to cesium.

In Figure 1 a peak is found at .175 Mev in both of the CsI spectra but in none of the NaI spectra. A peak at .175 Mev also appears in the 14 Mev spectra of CsI which will be discussed later in this chapter. A .175 Mev level in cesium has been reported earlier by Lamb (6) and McDonald (8). Hence this level is assigned to cesium.

In the NaI spectra of Figure 1 a strong peak appears at .20 Mev. The broadness of the .175 cesium peak in the CsI spectra of the same figure indicates the presence of a

peak somewhere in the .20 Mev region. A .20 Mev peak also appears in all of the 14 Mev spectra of Figure 3 and is relatively more intense in those obtained using an iodine scatterer. The .20 Mev level in iodine has been observed by other experiments (3, 7, 11, 12). This level is therefore attributed to iodine.

In Figure 1 the NaI spectra reveal a broad peak in the neighborhood of .40 Mev. McDonald (8) obtained a similar result in his work and suggested that it was the summation of the well known .40 level in iodine, the .44 Mev level in Na^{23} and a third unknown level between .45 Mev and .55 Mev. The results of the current experiment are best shown in Figure 2. The NaI spectrum indicates peaks at .40 Mev, .44 Mev, and .47 Mev. The spectrum of NaI with sodium scatterer shows the same peaks but the .44 Mev peak is greatly enhanced by the sodium scatterer. The NaI-with-iodine-scatterer spectrum consists of a broad peak in this region which gives little information. The only assignments made from these data are the .44 Mev to sodium and the .40 Mev to iodine. The .40 Mev iodine level has been observed by others (3, 11, 12) in neutron spectra as has been the .44 Mev sodium level (1, 5, 11). The data appear to confirm the level at .47 Mev reported by McDonald (8) and indicate that it is probably due to iodine. However, since there exists no such reported level in iodine and the

results of using an iodine scatterer were negative, any assignment made to this energy level would be questionable.

Figure 3 shows spectra obtained using 14 Mev neutrons. These cover the energy range from .03 Mev to .40 Mev for CsI, CsI with iodine scatterer, NaI, NaI with iodine scatterer, and NaI with sodium scatterer. The counting rate was low for all of the spectra due to an attempt to prevent the pulse-height analyzer from overloading.

A peak appears in all of the spectra in Figure 3 at .057 Mev. It is more intense in those spectra obtained while using iodine scatterers. This is the .057 Mev iodine level mentioned earlier in the discussion of the 2.5 Mev spectra.

Both the CsI spectra in Figure 3 show a peak at .079 Mev while none of the NaI spectra show such a peak. As reported in the discussion of the 2.5 Mev data this level will be assigned to cesium.

All of the NaI spectra obtained using 14 Mev neutrons show a peak at .135 Mev. As may be noted in Figure 3 the use of an iodine scatterer greatly enhances this peak. An iodine transition of .135 $\pm$ .01 Mev was reported by McDonald (8) and one of .145 Mev was reported by Van Loef and Lind (12) and by Mathur (7). This level is therefore assigned to iodine.

Another peak was observed at .16 Mev in only the NaI spectra. This peak was not enhanced by the use of an iodine scatterer but became slightly more intense when a sodium scatterer was used. This appears to be a new transition in sodium.

A level at .175 Mev appears in both the CsI spectra but in none of the NaI spectra. This level was reported earlier by both Lamb (6) and McDonald (8) and assigned to cesium.

A level at .200 Mev appears in all the 14 Mev spectra and is more intense in those obtained using an iodine scatterer. This level in iodine also appeared in the 2.5 Mev spectra for NaI and was assigned to iodine.

All spectra in Figure 3 show peaks at .25 Mev and .33 Mev with the latter peak being rather broad. The use of iodine and sodium scatterers yielded negative results, and since there are no reported transitions for iodine at these levels, they must remain unassigned.

This experiment succeeded in the clarification of two points which were left in doubt by earlier experiments. First, a reduced counting rate does not help the spectrum obtained by the inelastic scattering of 14 Mev neutrons. Second, conclusive proof was obtained that the .08 Mev level in cesium can be produced by neutron excitation.

Several questions still exist concerning the NaI spectra. The level at approximately .47 Mev remains unresolved although it is probably due to iodine. A new and previously unreported level at .16 Mev in sodium also appears probable. The large reduction in low energy background observed in spectra obtained with the iodine scatterer also indicates that it might prove useful to use a sodium scatterer of geometry similar to the iodine scatterer.

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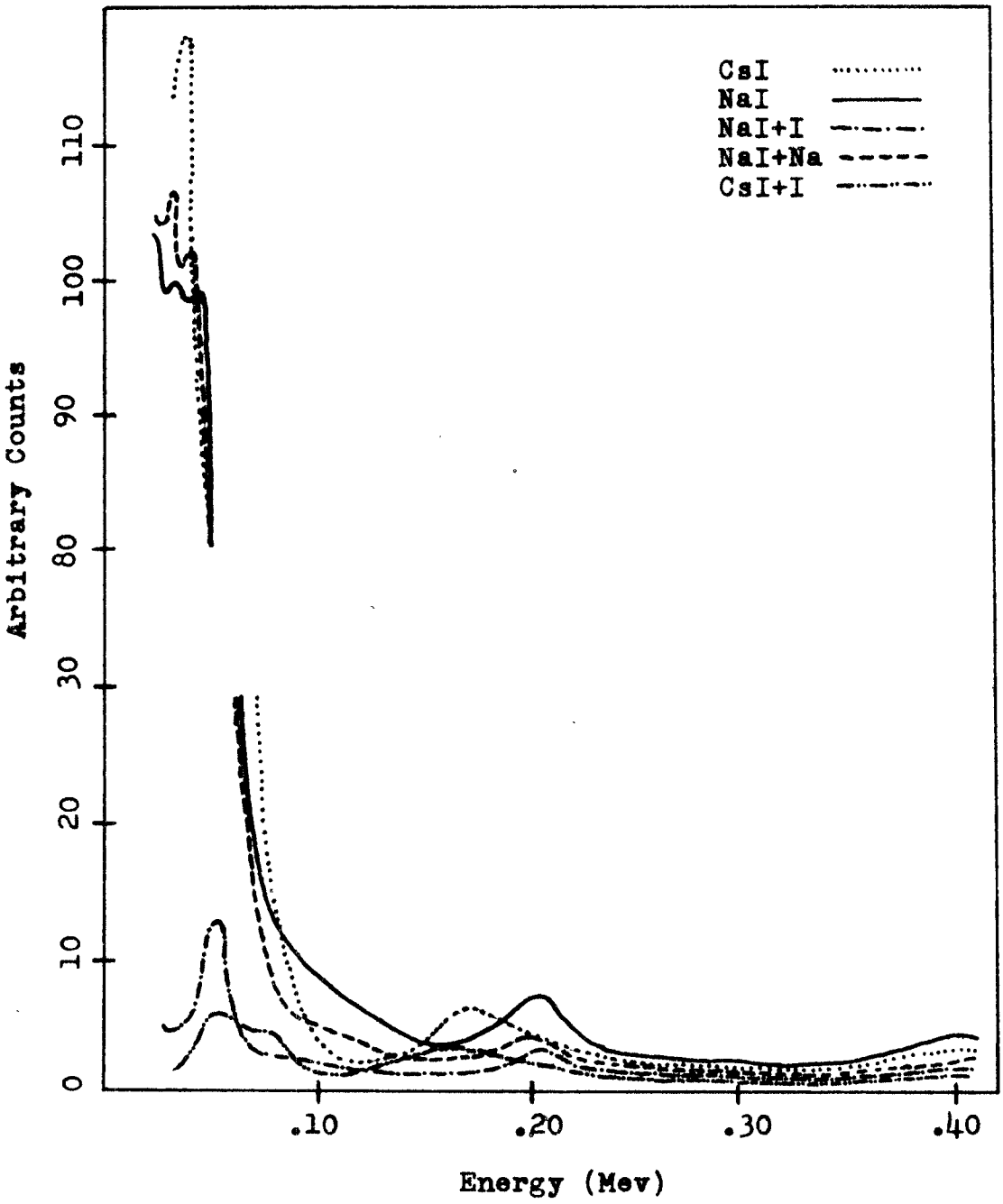

Fig. 1 Typical CsI and NaI Spectra Produced by 2.5 Mev Neutrons

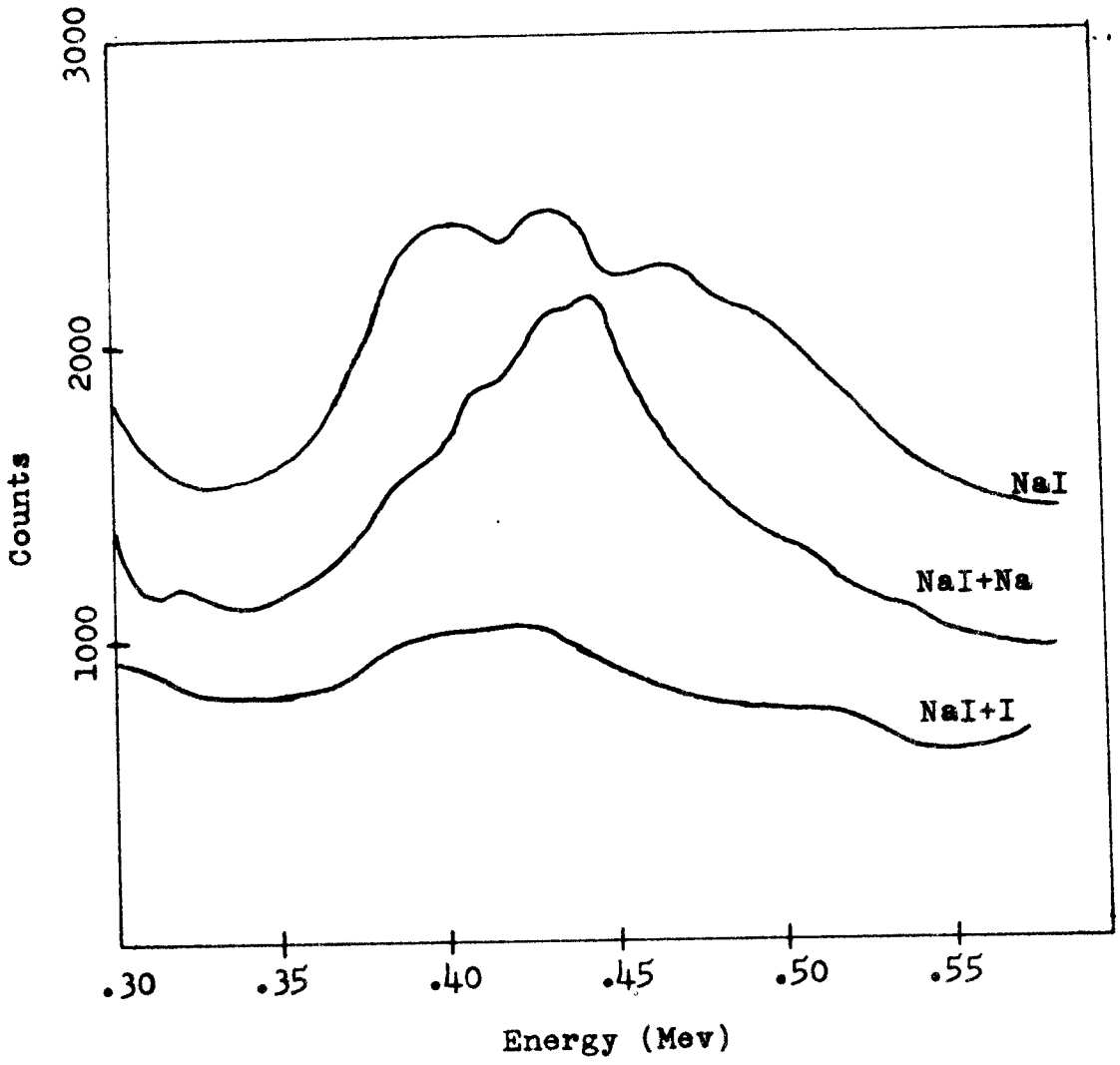

Fig. 2 Typical NaI Spectra Produced by 2.5 Mev Neutrons

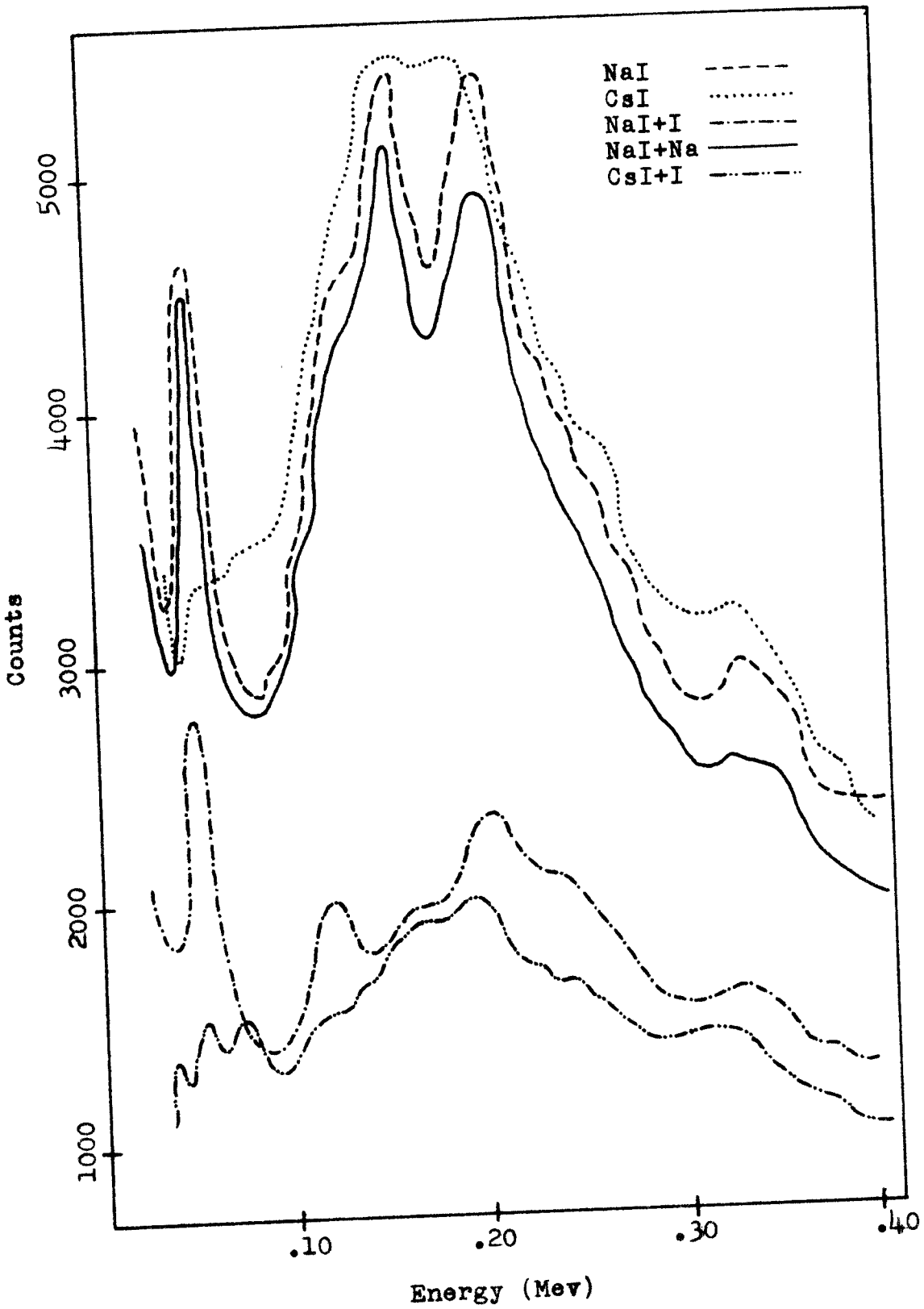

Fig. 3 Typical CsI and NaI Spectra Produced by 14 Mev Neutrons

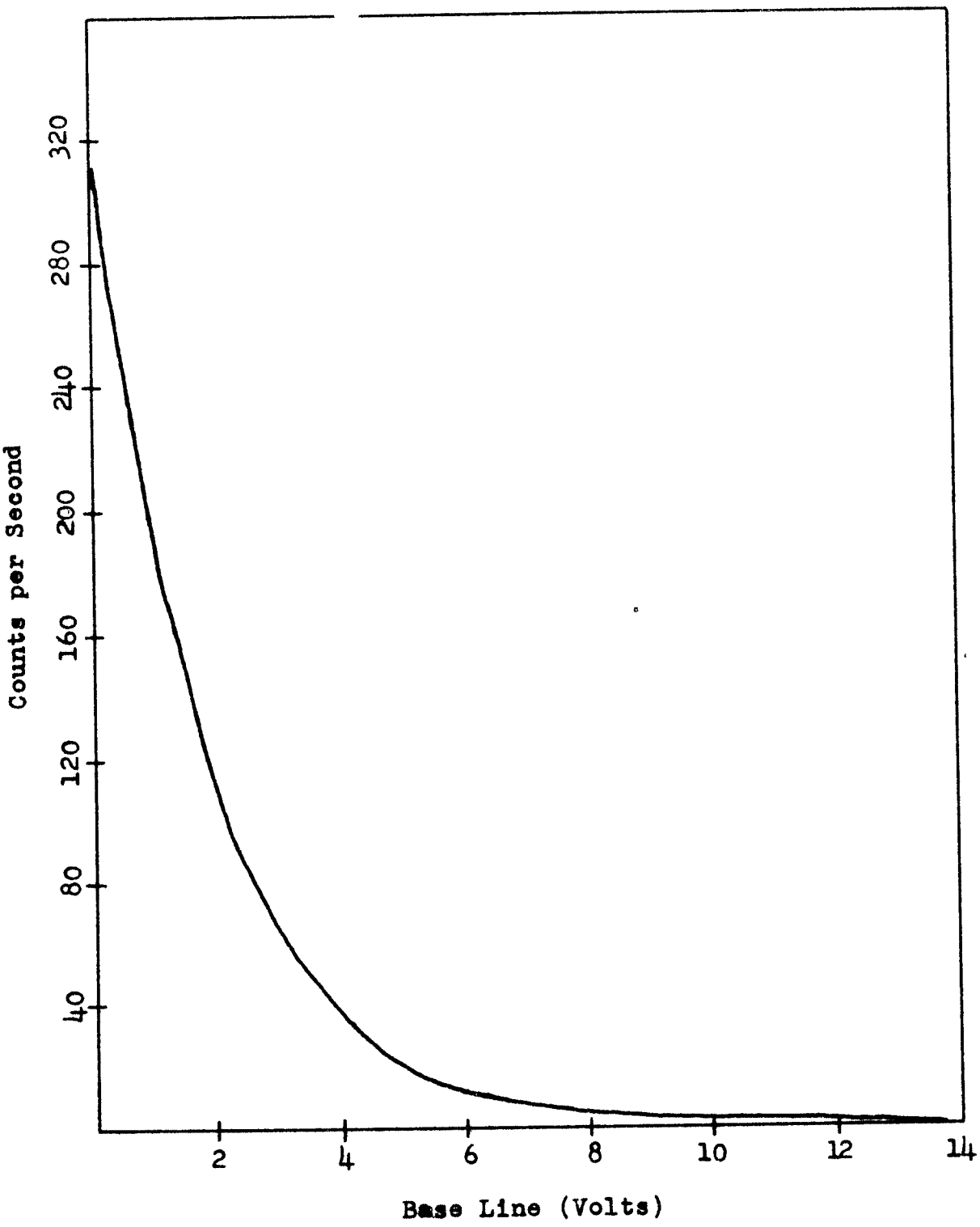

Fig. 4 Sensitivity of the Fast-Neutron Crystal Detector to Co^{60} Gamma Rays

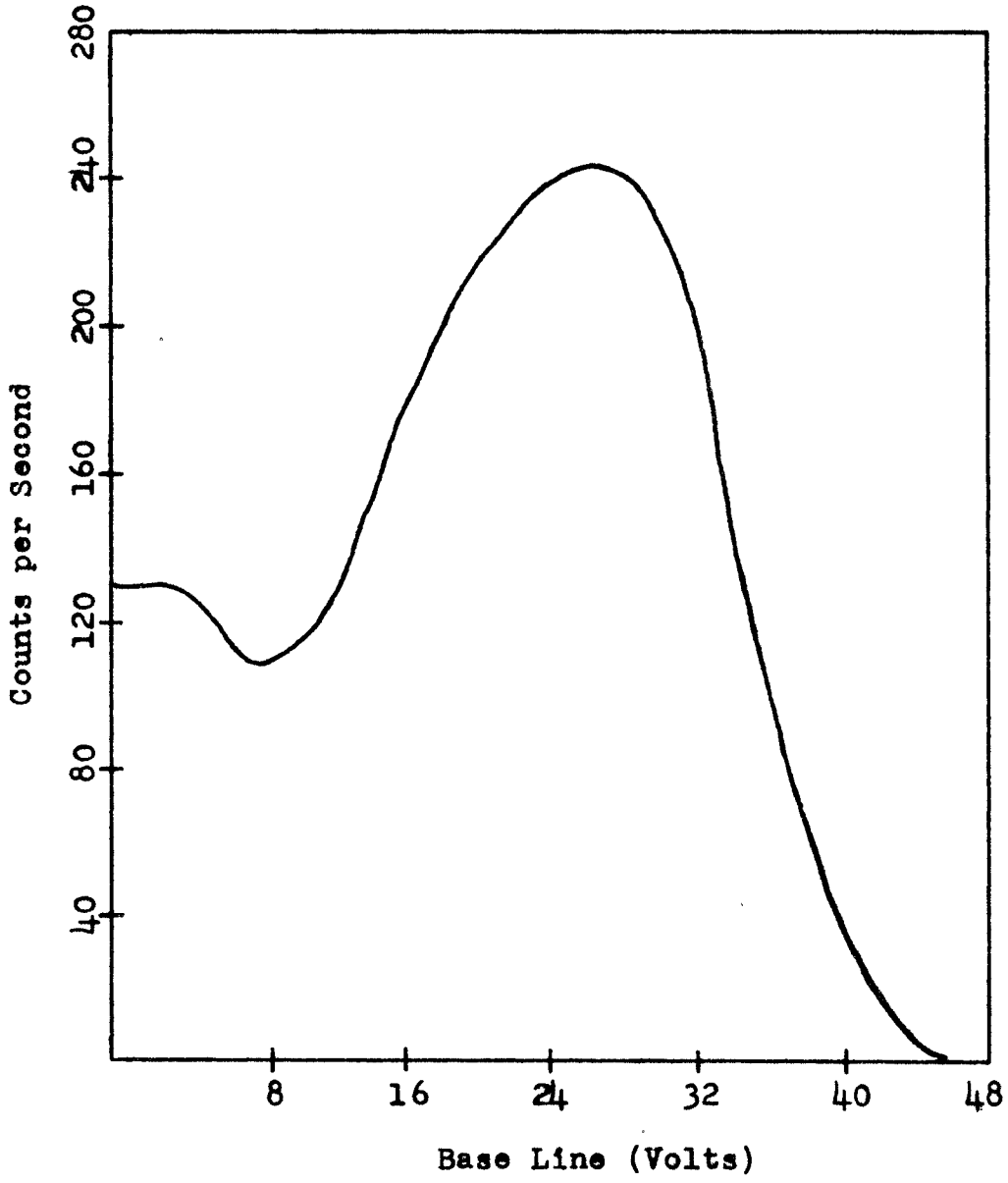

Fig. 5 Response of the Fast-Neutron Crystal Detector to Radium-Beryllium Neutrons

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