THE GAMMA-RAY SPECTRA OF IRIDIUM 192 AND IRIDIUM 194

By

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This thesis describes an investigation of the complex gamma-ray spectra accompanying the decay of iridium 192 and iridium 194. Precision energy measurements of twenty-one gamma-rays in Ir 192 and fourteen gamma-rays in Ir 194 have been made using the 50 cm. double focusing beta-ray spectrometer. In addition, the angular correlation function for the cascade gamma-rays of Ir 194 has been determined. A number of new radiations have been found in each spectrum and decay schemes are proposed for each nuclide.

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I INTRODUCTION

Since the discovery of natural radioactivity at the beginning of this century, the gamma radiations emitted in the decay of radioactive nuclei have been the subject of much study. It is now well known that these radiations are produced by transitions between nuclear energy states and thus a study of gamma spectra provides direct information concerning the excited states of nuclei.

While the simpler spectra have been quite completely studied, until recently the techniques of measurement have not been sufficiently precise to enable the rather complex spectra associated with most heavy nuclei to be resolved. This thesis deals with precise measurements of the energies and intensities of the gamma-rays emitted in the decay of the two iridium isotopes, 70 day Ir 192 and 19 hr. Ir 194 and decay schemes for each nuclide are proposed in it.

The earliest attempts to measure gamma energies were based on their absorption in lead or on a study of the energies of the Compton secondaries ejected from materials exposed to the radiation. Neither of these methods are very useful when a complex spectrum of radiations is present. With the development of high resolution beta-ray spectrometers, of moderate or good transmission, it has become possible to make very precise measurements of gamma-ray energies by studying the photoelectrons ejected by these radiations from thin metallic foils.

A group at McMaster University has specialized in the techniques of this sort of measurement using a large Siegbahn type beta-ray spectrometer of radius of curvature 50 cms.(1) The author has extended these techniques by the use of uranium foils with a consequent

increase in detection sensitivity by a factor of 1.5. At the present time it is quite possible to determine the energy of a transition which occurs in less than 2 x 10^{-4} quanta per disintegration to within 0.1% accuracy.

Whereas it is often possible to propose a decay scheme on the basis of energy and intensity measurements alone, it is necessary to augment this information if the multipolarities of the gamma-rays and the spins of the states from which they originate are to be found. The three methods of making assignments of spin or multipolarity are (i) lifetime measurements, (ii) internal conversion measurements and (iii) angular correlation measurements. This thesis will describe angular correlation measurements for Ir 194. It is planned to carry out internal conversion measurements on both spectra in the future.

II EXPERIMENTAL WORK

This section of the thesis will describe in turn (i) the development of thin uranium radiators, (ii) the techniques of precision gamma-ray energy measurements, (iii) the methods of handling large gamma sources, (iv) the automatic equipment developed for angular correlation measurements and (v) the angular correlation experiments.

(i) The Construction of Uranium Radiators

In a study of the photoelectrons ejected from a thin metallic foil, it is important to obtain the maximum practical yield from the source available. This yield determines the lower limit of detection of weak radiations and hence the range of application of the method.

The yield of photoelectrons from a foil is directly proportional to the intensity of the gamma radiation, the area and thickness of the foin and the photoelectric crossection τ. It also depends strongly upon the source-radiator geometry. The photoelectrons from the front face of the foil will emerge with an energy $E_\gamma - E_B$ where E_B is the binding energy of the particular K, L, M or N shell of an atom in the metallic foil. The electrons from the interior will be degraded in energy as they pass through the radiator. This degration remains approximately constant at about 1 kev. per mgm./cm.^{2} radiator thickness in the 0.3 to 2 Mev. region. Thus, with a radiator of thickness t mg./cm.^{2} the ejected photoelectrons have a spread in momentum of about t kev. for the region of interest in this study.

The electron peak focused by the spectrometer will have a width determined either by the electron momentum spread or by the momentum band admitted by the instrument, whichever is larger.

A radiator of zero thickness would give the ideally shaped electron peak but its yield would be zero. Thus, a reasonable compromise must be achieved between the need for a good photoelectron yield and good resolution in the spectrometer at the particular electron momentum to be studied. With the high resolution spectrometer used here, the momentum spread in the focused image is about 0.5% of the measured momentum. For this instrument, there is no advantage in using a radiator of such thickness that the momentum spread due to degradation is over twice this figure. Increasing the radiator thickness beyond this point merely widens the peaks without increasing their heights. For complex spectra such as those of iridium, this widening causes the merging of adjacent peaks and a consequent loss of effective resolution.

Since the photoelectric crossection τ is roughly proportional to the fifth power of the atomic number of the radiator metal, it is obvious that large yields of these secondary electrons may only be obtained with materials of high Z. The metals most commonly used in making these foils are tin (Z = 50), platinum (Z = 78), gold (Z = 79) and lead (Z = 82), primarily because of their availability and malleability. Although the photoelectric crossection of uranium (Z = 92) is 1.8 times that of lead, it has not been generally available as a radiator material. The following paragraphs describe the method used in making thin uranium foils.

The zapon spreading technique has been described by R. W. Dodson et al. (2). The basic principle of this method is as follows: a solution of nitrate of the substance to be deposited is mixed with a

dilute solution of zapon lacquer in a suitable solvent. The resulting mixture is spread on the foil backing, allowed to dry and ignited to remove organic substances and to convert the nitrate to oxide.

Yellow uranyl nitrate $UO_2(NO_3)_2.6H_2O$ was first dissolved in ether and then added to a dilute solution of zapon in acetone. The concentration of the zapon solution was not very critical but it was found that a 1% solution was satisfactory for films up to 5 mg./cm.^{2} thickness while a 5% solution was needed to provide the bonding necessary for thicker films. The concentration of uranium in solution must be kept low if the deposited films are to be of uniform thickness. Very low concentrations of the order of 5 mg. of uranyl nitrate per ml. of zapon solution seemed most effective in obtaining satisfactory radiators.

Aluminum foil of 9.5 mgm./cm.^{2} thickness and area considerably larger than that of the desired radiator was used as the film backing. The solution of uranyl nitrate and zapon was applied to the aluminum with a thin brush and allowed to dry. This foil was then flashed by placing the aluminum, film up, on a hot plate at dull red heat. The yellow nitrate immediately oxidized to the dark black U_3O_8 and the residue was polished with a soft tissue after removal from the plate. This procedure was repeated approximately twenty times for each milligram/cm.^{2} thickness of uranium oxide deposited. Yellow flaking at this stage indicated too great a concentration of uranyl nitrate while an excess of greyish ash indicated insufficient dilution of the zapon lacquer. Care was taken to avoid cracking or bending the aluminum backing, since it expanded less than the deposited uranium upon flashing. It was necessary that the foil surface be perfectly

smooth before the application of a fresh film of the solution. Then properly applied, the oxide surface was uniformly coloured.

After obtaining a foil of the desired thickness, the most uniform area of the deposited film was selected and the 0.8 x 3 cm. radiator cut from it. This was then mounted on a 220 mg./cm.^{2} aluminum plate for use in the spectrometer.

Using the foregoing technique, uranium foils from trace amounts up to 10 mg./cm.^{2} may be made. Foils of greater thickness appear to contain considerable amounts of zapon residue (> 2%).

Figures 1 and 2 illustrate the variations of resolution and peak height with different radiator thicknesses from 1.9 to 20.1 mgm./cm.^{2} at an electron momentum of 3088.6 Hρe. The peak heights obtained are roughly 1.5 times as high as those from lead radiators of the same thickness. This improvement is somewhat less than the 1.8 figure expected from the relative photoelectric crossections because of the organic residue and oxygen content of the foil.

(ii) Gamma-Ray Energy and Intensity Measurements

The "spec'-pure" iridium metal used in source preparation was obtained from Johnson, Matthey and Co., Ltd., and was of 99.995% tested purity. Traces of osmium, platinum, palladium, ruthenium and rhodium were reported as the detected impurities although none of these elements gives rise to activities whose half lives or energies, known at the present time, could be confused with those studied in iridium. The pure iridium metal has two isotopes of masses 191 and 193 with relative abundances of 38.5% and 61.5% respectively. Their thermal neutron crossections are 1000 and 130 barns, an (n,γ) reaction

during pile neutron irradiation producing respectively the 70 day Ir 192 activity and the 19 hour Ir 194 activity (3).

Three sources were obtained for gamma-energy studies after irradiation in the Brookhaven pile. The first of these contained 43 mgms. of iridium metal sealed in a 18 aluminum capsule, the metallic powder resting only a few thousandths of an inch from the front surface of the capsule. This gave approximately a line source of 2 cms. length and 0.1 cm. width. The accompanying source used for coincidence studies contained 2.4 mg. of metal in a similar capsule. Since investigations by C. McMullen (4) revealed the presence of annihilation radiation associated with the Cu^{64} impurity in the 18 aluminum after neutron irradiation, subsequent sources were sealed in quartz.

In an attempt to obtain high Ir 194 : Ir 192 activity ratios for the study of the heavier isotope, the second and third sources used for energy measurements contained 100 mgms. of metal sealed in quartz, and were irradiated only 12 hours in a flux of approximately 3×10^{12} neutrons/cm.^{2}/sec. This produced sources for which a favourable activity ratio existed for 48 hours after delivery to this laboratory.

Each of the three sources obtained for spectrometer studies had nominal strengths of 750 mc. upon shipment from the Brookhaven Laboratories. Since each was received by air express in less than 12 hours time, its effective strength was approximately 500 mc. when spectrometer measurements began.

The 1.9 mgm./cm.^{2}, 10.3 mgm./cm.^{2} and 20.1 mg./cm.^{2} uranium

radiators were used during the course of the investigation. Scanning was carried out in both spectra with the thicker radiators while precise measurements of the lower energy peaks in each isotope necessitated the use of the 1.9 mg./cm.^{2} radiator with its accompanying improvement in resolution. Figure 7 illustrates the complexity of the lower energy region of the Ir 192 external conversion spectrum and the need for very high resolution in measuring these peaks or detecting the presence of radiations from the Ir 194 isotope.

The irradiated sample was attached to a 1 gm./cm.^{2} platinum plate in order to stop all primary beta particles (~ 2.2 Mev. for Ir 194) from reaching the vacuum chamber. The uranium radiator used was then mounted on the front side of the platinum plate and the unit attached to the mounting plate in the spectrometer. Thus, a readily reproducible and fixed source-radiator geometry could be maintained with successive sources. For the Ir 192 beta particles, 220 mgms./cm.^{2} of aluminum absorber satisfactorily replaced the platinum with greatly decreased attenuation of the low energy gamma-rays.

The beta-ray spectrometer was calibrated before and immediately after the investigation of each source, using the photoelectric peaks due to conversion of the well known gamma-rays of cesium and cobalt in uranium. These peaks possess momenta of 3088.6 and 5507.6 Hρ respectively. The binding energies of the K and L shells necessary for calculation of the gamma-ray energies were obtained from the tables of critical x-ray absorption energies reported by Hill, Church and Mihelich (5).

The magnetic field of the instrument was measured by means of

the combination of a flip coil positioned in the magnet gap and a Leeds and Northrup type R galvanometer of sensitivity 3 x 10^{-10} amps per m.m. deflection. The readings were made on a 100 cm. lamp scale at a distance of 200 cms. from the galvanometer mirror. A five position range selector switch on the flip coil gave the desired sensitivity over the momentum spectrum studied, all readings being reduced by intercalibration factors for comparison with the cobalt 60 calibration at 5507.6 Hρe for the 1.3325 Mev. radiation. Corrections of the order of 0.1% had to be made for non-linearity of the galvanometer scale. The correction curve calculated by C. C. McMullen (4) is presented in Figure 4.

In studying the Ir 194 activity from each source, measurements were carried out for a minimum of 48 hours after source arrival, while the strong lower energy radiation could be studied for over twice this time. Peaks measured over such a period gave satisfactory confirmation of the half-life of decay. After the short lived radiation had decayed over ten half-lives, the region studied was scanned once more, to check the contributions of the Ir 192 or of any long-lived impurities to the region of interest. Since the energy available in the 192 decay has been set at 1.58 ± 0.03 Mev. (6), the high energy region studied in the Ir 194 isotope (with an available energy of 2.18 Mev. (7)) is free from extraneous radiations.

The energy measurements were made by comparing the point of inflection of the high energy edge of each peak with that of the external conversion peak of the calibration line in cobalt 60. A typical peak, that of the 0.4678 Mev. radiation of Ir 192, is shown

in Figure 3. Since the electron peaks in the 300 kev. quantum region of the Ir 192 spectrum were not completely resolved, it was necessary to use graphical analysis to obtain the separate peaks. This can be done with reasonable confidence since the shape of each peak in this region was well known for the radiators used.

In calculating intensities, all peak heights were corrected for decay and absorption. This method of analysis provides a check on the validity of the half-life assigned to the peak under study. Using the Deutsch formula (8) for intensities, and assuming that the momentum band admitted by the spectrometer is much less than the momentum width of the focused line, the intensity of a gamma-ray is given by the expression

$$I = c \frac{n_p}{\tau \beta^3 p}$$

where "c" is an instrumental constant, "n_p" is the number of counts at the peak, "τ" is the photoelectric crossection for a photon of that energy, "p" is the momentum of the monoenergetic photoelectrons studied and "β" the ratio of their velocity to that of light. Values for τ were obtained by extrapolation from the curves given by Davisson and Evans (9) for all elements up to Z = 83.

The validity of the Deutsch formula for intensities is somewhat doubtful in the high energy region ($>$ 1.4 Mev.) for the following reasons. The assumption is made that the photoelectrons are emitted isotropically whereas they are, infact, ejected from the radiator strongly in the forward direction. It also assumes that the momentum band focused by the instrument is less than the momentum spread of the peak. This assumption becomes less valid as

the gamma energy increases. The first effect tends to overestimate the intensities of the high energy gamma-rays while the second tends to underestimate them. It is possible that these effects may cause errors of the order of 25% in comparing gamma intensities over the entire range studied from 0.1 to 2.1 Mev.

(iii) Precautions in Handling Large Sources

In order to examine the upper region (E > 600 kev.) of the iridium 192 spectrum, an abnormally large (> 1 curie) source was needed in order to obtain satisfactory counting rates over the weak peaks present here. A 3 curie source was obtained through the courtesy of Dr. D. C. Brunton of Isotopes Products Ltd., Oakville, Ontario. This necessitated special health safeguards if it was to be used in the Siegbahn spectrometer. In order to minimize the effects of scattered radiations from this source, a lead disc, 2.5 cms. thick was moulded and machined to fit behind the radiator mounting plate on the spectrometer source-holder, with a 0.6 x 3 cm. slot in its front surface to accommodate the aluminum capsule containing the active iridium metal. In this manner, a minimum of 2 cms. of lead immediately surrounded the source on the three sides about the vacuum chamber. Considering the radiation released by the entire source of 3 curies, this amount of lead reduced the activity by a factor of 40 on the exterior of the source assembly. Further shielding by 15 cms. of lead between source and detector minimized the effects of scattered radiations on the counting rates and gave satisfactory protection to the operator. Constant monitoring with pen-type electroscopes and film badges throughout the runs, indicated that sources of this

radiation intensity could be safely studied with the present source mounting arrangement.

In order to safeguard against serious contamination of the instrument, the source capsule was sealed in place by cementing a 10 mgm./cm.^{2} thick sheet of aluminum foil over the source receptacle in the lead disc. Tongs could readily be thrust through this cover when removing the capsule and the receptacle decontaminated, if necessary, by washing with acetone.

(iv) Angular Correlation Experiments

A determination of the angular correlation between the direction of emission of the first and second gamma-rays of a gamma cascade can often be used to assign spins to the three nuclear states involved in the cascade. Experimentally, this calls for the measurement of the number of coincidences produced by this cascade as a function of the angle θ between the two detectors.

The theoretical correlation function may be expressed as

$$W(\theta) = 1 + a \cos^2 \theta + b \cos^4 \theta + \ldots\ldots \qquad (10)$$

The quantity

$$W(\theta) - 1 = \frac{N(\theta) - N(90)}{N(90) - N \text{ chance}}$$

is obtained directly from coincidence counting and can be used to determine the parameters a and b of the first expression.

A comparison of the experimental values of these parameters with those given by Hamilton (11) or Lloyd (12) is often sufficient to assign unique values to the spins of the states involved in the cascade. When several competing cascades are present, an interpretation of the correlation is much more difficult.

In these experiments, the detectors consisted of stilbene crystals of dimensions 2.5 x 0.7 x 0.7 cm. fastened to 1P21 photomultipliers. The crystals were placed on the arms of a laboratory prism spectroscope at a distance of 9 cms. from the source. The irradiated metal to be studied was mounted on the spectrometer axis in the same horizontal plane as the crystal centres. Each crystal and associated 1P21 was wrapped in aluminum foil to exclude light and the crystals were further covered with 1 gm./cm.^{2} of lead to reduce the contributions of scattered radiations to the chance coincidence rates.

In five of the seven runs recorded, one counter was covered with an additional 15 gm./cm.^{2} of lead to exclude the strong unwanted radiation from Ir 192 in the 300 kev. region. Although this reduced the absolute coincidence rate by a factor of more than two, it ensured that the greatest contribution to this rate would be from the Ir 194 decay gamma-rays in which coincidences between the high energy radiations (~ 1.46 Mev.) and a low energy gamma-ray (0.327 Mev.) were expected.

The source consisted of 0.7 mg. of irradiated iridium metal enclosed in a quartz vial 8 m.m. long and 1 m.m. crossection. Counting was carried out with consecutive periods of 10 minutes on signal and 5 minutes on chance for each angular setting of the detectors. Counting for each position at angle θ was alternated with counting at the 90 degree position. In this way, corrections for decay were made unnecessary.

The chief problem faced in studying the angular correlation

of 19 hour Ir 194 activity was posed by the presence of the 70 day Ir 192 radiations. The largest practical source strength for the circuit used was about 2.7 mc., (i.e., $\frac{1}{2\tau}$ where τ represents the the resolving time of the circuit). Since the "coincidence-producing" gamma-rays were expected to occur in about 25% of the cases (13), a source of ~10 mc. Ir 194 activity was ordered. In order to maintain this usable strength over as long a period as possible, a single 0.7 mg. source was used for the first 16 hours of counting and then the source strength doubled by adding a second source of the same size. By choosing a 12 hour irradiation in the Brookhaven reactor at a flux of 3×10^{12} n/cm.^{2}/sec., it was possible to begin the experiment with an Ir 194 : Ir 192 ratio of about 11:1. This ratio fell with the 19 hour half-life and gave a suitable counting condition for the Ir 194 component for more than 48 hours. During this time at least three useful runs over a series of six equally spaced angles between 90° and 180° were made for each source.

To correct for the Ir 192 contribution to the coincidence rate, the measurements were repeated four days later with the circuit operating continiously throughout the intervening interval. This observed rate was then subtracted from the total rates to give the Ir 194 component. The correction for Ir 192 coincidences at the beginning of the experiment was about 9% of the total rate when one counter was covered with 16 gms./cm.^{2} of lead and 20% of the total rate when both counters were covered with 1 gm./cm.^{2} of lead. These contributions increased to approximately 30% in each case at the end of the run. Drifts in the coincidence circuit over a 7 day period were inevitable but since these were applied only to the relatively

small Ir 192 contribution, the gamma-gamma correlation function was reasonably well reproduced in different runs. No correlation function was observed for Ir 192, under the conditions of these experiments.

(v) The Automatic Recording of Correlation Data

Although the procedure outlined in section (iv) is satisfactory, it is very time consuming, and a plan of converting this equipment to automatic recording was instituted by R. J. Donnelly during 1952. The methods he devised for recording pulses and introducing the chance cable for determinations of Nchance are described in his M.Sc. thesis (14). With this unit, the chance cable may be alternately introduced into or removed from the fast output of one pre-amplifier so that a continuous record may be obtained of the true and chance coincidences counted for one position of the scintillation detectors. Such an arrangement is quite adequate for runs of long duration.

However, for a rapidly decaying source, e.g., 19 hour Ir 194, coincidence measurements require resetting of the moveable detector at intervals of a few minutes in order that suitable statistics may be obtained for each counting position. For thissource, it was found that the frequent manual resetting exposed the operator to excessive beta and gamma radiation. It was therefore decided to make the operation sufficiently automatic to require attention only at intervals of a few hours, in the manner described below.

The coincidence detectors were clamped to the fixed and moveable arms of a small optical spectrometer as already described. The "telescope" arm was then driven through a very low ratio gear train and slip clutch by a 1/50 horsepower, 60 c/sec. motor. The

entire unit was mounted on a solid base and could be positioned at will with respect to the coincidence circuits. Spring clips mounted on the large gear attached to the spectrometer table, controlled the preset values of θ, the angle subtended by the detectors at the source.

A schematic diagram of the control unit is shown in Figure 5.

The cam assembly for the timer control unit is driven by a 2 r.p.m. motor. Cam A operates a double-pole double-throw micro-switch arrangement as illustrated. This serves to reverse the polarity of the field windings in the table motor. Cam B operates a S.P.S.T. micro-switch that is closed a short time after cam C has engaged the chance cable relay. In normal operation, ten minutes signal and five minutes chance readings are taken on each position, alternately switching from 90° to θ° in each 15 minute period. Thus, the motor field-winding leads are simply reversed in each successive fifteen minute interval (Cam A); the chance cable is then engaged (Cam C) and the motor activated so that position switching may be carried out during the "chance" period (Cam B). Precautions were taken to properly ground the motor case and spectrometer table in order to eliminate spurious counts introduced while the drive motor was in operation. With this equipment, the apparatus required attention only when a new value of θ was to be selected.

III A SURVEY OF THE LITERATURE

(i) Iridium 192

The most recent determinations made on the decay rates of the Ir 192 activity indicate a half-life of 74.7 ± 0.3 days. (13, 15, 16, 17.)

The earliest energy measurements reported on this isotope were those of Mandeville and Fulbright (18, 19). The momentum distribution of the Compton secondaries arising from the gamma-rays emitted in the disintegration of Ir 192 after slow neutron irradiation of the iridium sample, were studied by coincidence counting methods with a magnetic spectrograph. From the end points of the Compton distribution so determined, the energies of the gamma-rays involved were calculated. Since gamma-rays of energy < 0.5 Mev. could not be studied with this instrument, the shape of the Compton distribution was interpreted as characteristic of a single gamma-ray whose energy, calculated from an end-pt. determination was given as 0.63 ± 0.02 Mev. Using the same source on a magnetic lens spectrometer, M. Deutsch (20) reported photoelectric lines corresponding to gamma peaks at 0.307, 0.467 and 0.603 Mev. These preliminary measurements did not reveal the great complexity of the gamma-ray spectrum.

The first "precision" measurements (~ 2% accuracy) made on the Ir 192 gammas were those of P. W. Levy with an 180° beta-ray spectrometer (21). In this study, 12 conversion lines were measured. All of these were assigned to the beta decay branch using the K, L and M binding energies of platinum for the gamma energy determinations. The maximum energy of the spectrum as determined from a Kurie plot

was fixed at 0.67 Mev. Conversion lines masked the end point rather badly and left open the possibility that the spectrum could contain several components of nearly the same energy.

In a series of investigations, J. M. Cork (22, 23, 24), using photographic detection with a semi-circular focusing magnetic spectrometer, measured 45 conversion lines in the beta spectrum and used the K-L-M differences for tungsten or platinum to identify 17 separate gamma-ray energies. These radiations all possess energies less than 0.650 Mev. A decay scheme incorporating most of the gamma-rays observed was proposed.

Due to the considerable disagreement between the results of Levy (21) and the earlier measurements of Cork (22), the energy region under 300 kev. was studied by Hill and Meyerhoff (25) using a high dispersion 180° photographic beta-ray spectrograph. The five strong electron lines in this region (Table IV) were measured and agree within 1% accuracy with the present energy measurements of improved precision. Further work with this instrument was carried out by Schoof and Hill (26).

Two investigations of this isotope have been reported in references 27 and 28 from the U.S.S.R. The energy measurements of Bashilov et al. (27) were made from internal conversion studies while the intensity measurements reported by Shipnel and Porafontov (28) were obtained from a study of the external conversion spectrum. These determinations are listed in Table IV.

Recently, du Mond et al. (29) using a curved-crystal gamma-ray spectrometer have carried out a series of very precise gamma energy measurements. The energies and intensities of eleven of the

strongest lines in the Ir 192 decay process have been determined by these workers with an accuracy of 0.01%. The topological method of enumerating these level schemes is described in their paper and the resulting energy level schemes proposed for the Pt 192 decay on the basis of these determinations are shown in Figure 11. Due to the variation in sensitivity of the spectrometer used with energy, these workers feel that the relative intensities of lines having greatly different energies may not be reliably compared.

An investigation of gamma-gamma coincidences with a scintillation crystal spectrometer carried out by Roulston and Pringle (6) led them to accept Cork's proposed decay scheme. They found evidence for several gamma-rays in the 600 to 1200 kev. region which were necessary to explain the observed coincidences, and suggested the existence of a new level at 1.356 Mev. to explain their data. It will be seen later that their experiments are consistent with the decay scheme proposed in the present work.

It was mentioned earlier that coincidence experiments revealed no strong correlation present in the iridium 192 spectrum. However, work reported by Deutsch and Wright (30), using a fast coincidence circuit, suggested the existence of an isomeric state at 0.240 Mev. of half-life $< 3 \times 10^{-9}$ seconds. In the light of the present investigation, the significance of these measurements is not clear.

Thus, a survey of the literature of Ir 192 (Table IV) reveals a series of energy measurements which agree well for energies < 600 kev. and only one investigation (6) of the high energy region. The reported intensity measurements are, however, in very poor agreement, indicating

the need for further study. In Table IV, the results of these groups of workers are compared with the measurements obtained in the present investigation.

(ii) Iridium 194

The difficulties involved in attempting to study the radiations emitted in the decay of Iridium 194 following an (n, γ) reaction in iridium metal are evidenced by the small number of investigations carried out on this isotope. As sources of very high specific activity are now available with improved pile neutron flux densities, the procurement of good Ir 194 gamma sources for study has been somewhat facilitated.

Early investigations by C. M. Wichter (7), using a solenoidal beta-ray spectrometer of resolution ~6% with a cyclotron produced source, gave an end-pt. determination of 2.18 ± 0.04 Mev. The shape of the beta-spectrum indicated a complex decay scheme as did the plotted Fermi and Kurie curves. The half-life was measured at 19.5 hours in this study and the measurements made indicated only one weak lower energy group with an end-point at approximately 0.600 Mev.

Absorption measurements of the Ir 194 radiations made by Goodman and Pool (13) indicated a beta end-point at 2.07 Mev. with gamma radiations of energy 1.65 Mev. and 0.38 Mev. On the basis of the scheme proposed here, approximately 80% of the disintegrations took place by the direct beta transition to the ground state of stable Pt 194. A half-life of 19.0 ± 0.2 hours for this isotope was obtained from this investigation. This value has been used for decay corrections in the present work.

From coincidence absorption experiments, Mandeville and Scherb (31)

found a gamma-ray of energy 1.43 Mev. which was in cascade with a low energy gamma-ray. The end-point of the low energy beta group was estimated to be 0.48 Mev. Spectrometer measurements carried out by Caldwell (32) indicated there were no conversion electrons of energy less than 0.273 Mev. in Ir 194.

Using the photo-disintegration of beryllium and deuterium as threshold detectors of high energy gamma radiation, P. R. Wilson (33) showed that the number of gamma quanta per disintegration, with energy greater than 1.7 Mev. is 1.4×10^{-3}, whereas the number with energy greater than 2.2 Mev. is 2×10^{-6}.

The only precision gamma energy measurement available in the literature is that reported by Cork (23) who gives 0.3275 Mev. for the low energy radiation in Ir 194.

The contradictions presented by the results quoted above suggested the need for a careful re-investigation of the entire spectrum. On the basis of the rather poorly established decay scheme suggested by the above experiments, angular correlation measurements of the 1.4 - 0.328 Mev. cascade have been carried out by Whittle and Jastram (34) and Kraushaar and Goldhaber (35), who both assigned spins 2 - 2 - 0 to the three levels involved.

IV EXPERIMENTAL RESULTS

(i) Iridium 192

Using the three sealed gamma sources of the type described earlier, a detailed study of the energies of the gamma-rays associated with the 70 day activity was made, using the Siegbahn spectrometer. With the first source of 745 m.c. Ir 192 activity, measurements were made up to 0.600 Mev., scanning this region first, with the 10.3 mg./cm.^{2} and then with the 1.9 mg./cm.^{2} uranium radiator. The reproducibility of some of these measurements and those made using subsequent sources is illustrated in Table I.

TABLE I

NOMINAL ENERGY MEV.	SOURCE 1		SOURCE 2		SOURCE 3		
	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 3
mg./cm.^{2} RADIATOR	10.3	10.3	1.9	1.9	1.9	1.9	1.9
0.295	.2953	.2955	.2950	.2951	.2952	-	-
0.308	.3081	.3085	.3077	-	.3077	.3077	.3077
0.316	.3162	.3165	.3165	.3165	.3159	.3162	.3162
0.468	.4678	.4680	.4679	.4680	.4677	.4677	.4674
0.485	.4859	.4843	.4839	-	.4860	.4862	-

It is seen that the deviations between runs fall within the expected limit of 0.1 percent (2 (ii)). Since all energy measurements were made from the external conversion peaks in uranium, photoelectrons arising from the K shell possessed an energy of $h\nu$ - 115.04 kev. (5). Thus, for the 0.136 Mev. gamma-ray, listed by other workers, photoelectrons of only 21 kev. energy were ejected from the radiator.

Scattering within the coincidence counter and absorption by the 200μgm./cm.^{2} plastic counter window was serious at this energy so that no accurate measurement of this peak was possible although the peak was observed.

This region was also explored with a 1.9 mgm./cm.^{2} radiator using sources #2 and #3 which contained about 50 mc. of iridium 192 activity. Some of these measurements are tabulated in Table I.

Since the results of Roulston and Pringle (6) and of Bashilov et al. (27) had given indications of the presence of very weak high energy radiations, a 3 curie source was obtained to investigate this region with the hope of securing precision energy measurements of these gamma-rays. The 0.8854 Mev. peak observed, using this source, appeared as a relatively strong line (320 particles/min.) and accurate measurements were also obtained for four other much weaker radiations. In all, the energies of 20 separate gamma-rays were obtained from K conversion peaks in uranium. The results of these experiments are shown in Table II.

TABLE II ENERGY MEASUREMENTS IN IRIDIUM 192

MEAN GAMMA ENERGY MEV.	RELATIVE INTENSITY	MEAN GAMMA ENERGY MEV.	RELATIVE INTENSITY
0.1595 ± .0020	1.2	0.4678 ± .0003	100.
0.1731 ± .0020	1.6	0.4854 ± .0004	5.1
0.2059 ± .0015	3.2	0.5894 ± .0005	7.5
0.2814 ± .0010	2.2	0.6049 ± .0005	11.4
0.2952 ± .0001	66.7	0.6133 ± .0010	7.8
0.3079 ± .0001	72.2	0.7452 ± .0005	.04
0.3163 ± .0001	190.	0.7831 ± .0005	.04
0.3759 ± .0015	2.4	0.8854 ± .0009	.70
0.4308 ± .0025	6.7	1.0617 ± .0020	.13
0.4386 ± .0020	2.1	1.1567 ± .0030	.05

The quoted errors represent the standard deviations in the means of several determinations. Where only one measurement was made, the error has been arbitrarily set at 0.1%. Relative intensities are calculated with the Deutsch formula (see 2 (ii)), using the 0.4678 Mev. gamma-ray normalized to the value 100. This radiation was selected as a standard because its K peak was clearly separated from all other peaks in the spectrum (see Figure 3). However, it will be seen later that a gamma-ray of the same energy exists in Ir 194 so all Ir 192 measurements were made for this study after this short lived activity had disappeared. The seven measurements made on this peak all agree well within the expected accuracy and suggest the usefulness of this radiation as a secondary calibration standard, using the value quoted by du Mond et al. of 467.984 ± 0.061 kev. The intensity measurement

of the 0.3163 Mev. gamma-ray is of doubtful reliability, as the peak counting rates for this radiation were of the order of 10^4 particles per minute and a study of the counting losses expected with the detector used has not as yet been made.

(ii) Iridium 194

Measurements carried out on two strong gamma sources of about 750 mc. Ir 194 activity using the 20 mg./cm.^{2} radiator revealed the presence of a complex gamma spectrum in the energy region above 1 Mev. (see Figures 9 and 10). The radiations measured are listed in Table III with their associated mean deviations and relative intensities. In this spectrum, the relative intensity calculations were referred to the well defined K peak of the 1.4648 Mev. gamma-ray.

TABLE III ENERGY MEASUREMENTS IN IRIDIUM 194

MEAN GAMMA ENERGY MEV.	RELATIVE INTENSITY
0.2925 ± 0.0015	44.7
0.3276 ± 0.0001	318.6
0.466 ± 0.002	45.0
0.491 ± 0.002	9.0
1.1487 ± 0.0002	26.9
1.1805 ± 0.0003	15.7
1.2159 ± 0.0003	3.0
1.3391 ± 0.0008	3.5
1.4648 ± 0.0007	10.0
1.5079 ± 0.0007	3.2
1.6168 ± 0.0013	2.9
1.6664 ± 0.003	0.90
1.8016 ± 0.0021	2.4
2.1079 ± 0.003	0.60

The K peak for the 0.2925 Mev. radiation was not completely resolved from the peak of the 0.2952 Mev. Ir 192 gamma-ray. However, by subtraction of the Ir 192 spectrum in this region it was possible to get a good measurement of both its energy and intensity. Similarly, the measurements of the 0.466 and 0.491 Mev. radiations were made difficult by the presence of the 0.4678 and 0.4854 Mev. gamma-rays in Ir 192 which strongly masked their presence. Since the former peaks were weaker, the subtraction process was not as successful giving poorer accuracy in the energies calculated.

For the region below 0.5 Mev., the 1.9 mg./cm.^{2} radiator was used. The relative intensities for the four gamma-rays in this region were related to those obtained with the 20 mg./cm.^{2} radiator in the high energy region through the 0.3276 Mev. gamma-ray which was measured under both conditions (see Figure 6). For this radiation, both the 1.9 and the 20 mg./cm.^{2} radiator satisfied the condition of the Deutsch formula.

The details of the angular correlation experiment carried out in Ir 194 have been quite completely described in an earlier section. In studying only the one 0.9 mgm. source, about 4000 coincidence counts were obtained for each position of θ, while with the two 0.7 mgm. sources in the second experiment, approximately 10,000 coincidence counts for each position, were recorded. The same correlation function was obtained in both cases and the results are presented in Figure 14.

TABLE IV A COMPARISON OF THE IR 192 GAMMA-RAY ENERGY MEASUREMENTS

NOMINAL ENERGY MEV.	SCHOOF & HILL (26)	BASHILOV ET AL. (27)	SHIPNEL ET AL. (28)	J.M. CORK (23)	Du MOND ET AL. (29)	NABLO	EWAN & THOMPSON (36)
0.136	0.137	0.137	-	0.1359	0.1363	- *	0.1365
0.156	-	-	-	0.156	-	0.1595	0.1577
0.173	-	-	-	0.173	-	0.1731	-
0.201+	-	0.202	-	0.2011	0.2013	- *	-
0.206+	0.208	0.207	0.207	0.2057	0.2057	0.2059	0.2054
0.281+	-	-	0.277	0.283	-	0.2814	0.2818
0.295	0.295	0.296	0.296	0.2949	0.2959	0.2952	0.2957
0.308	0.308	0.309	0.308	0.3077	0.3085	0.3079	-
0.316	0.317	0.317	0.315	0.3161	0.3165	0.3163	0.3160
0.376	-	-	-	-	-	0.3759	-
0.401	-	0.401	0.401	0.400	-	- **	0.4010
0.417	-	0.420	0.417	0.4151	-	- **	0.4155
0.431	-	-	0.432	-	-	0.4308	-
0.438	-	0.440	-	0.438	-	0.4386	0.4355
0.468	0.469	0.468	0.467	0.4674	0.4680	0.4678	0.467
0.485+	0.488	0.486	0.478	0.484	0.4848	0.4854	-
0.589	0.592	0.590	0.586	0.5886	0.5884	0.5894	0.588
0.604	0.607	0.605	0.606	0.6037	0.6045	0.6049	-
0.613	0.615	0.613	0.614	0.6112	0.6129	0.6133	0.612
0.745						0.7452	0.765
0.783						0.7831	-
0.885		0.880				0.8854	-
1.062						1.0617	-
1.157						1.1567	1.135

* The absence of these measurements is explained in section 4.

** Due to the very strong L shell photoelectron peaks produced in uranium by the 0.308 and 0.316 Mev. radiations, these weak peaks were masked and could not be accurately measured.

+ These radiations are assigned to the K Capture branch from the results of Cork et al.

V INTERPRETATION OF RESULTS

(i) Iridium 192

Table IV presents a comparison between the measurements reported here and those given by a number of other workers for the energies of the Ir 192 radiations. The excellent agreement between the present values and the more accurate determinations of du Mond et al. for the strong lines in the spectrum is gratifying. It also gives support for the limits of error quoted for the weaker lines measured in this work. Although these gamma-rays have not been observed by any other workers, some evidence for their existence is found in the coincidence measurements of Roulston and Pringle who require such radiations to interpret their observations.

Ewan and Thompson (36) have studied the internal conversion lines following the decay process of Au 192, which leads only to excited states in Pt 192. Since the beta decay of Ir 192 leads to these excited states as well, it might be expected that many of the gamma-rays appearing in the K-Capture decay of Au 192 would be the same as those observed in the β^- decay of Ir 192. Therefore, the results of the experiments of Ewan and Thompson are presented in column 8 of Table IV. It is evident that there is generally good correspondence between the lines found by them and those reported in this study, (column 7).

Since Ir 192 decays both by K-Capture to Os 192 and by β^- emission to Pt 192, the energy of a gamma-ray cannot be computed from its internal conversion line in experiments such as those of Cork, until a decision has been made as to whether the platinum or osmium

binding energy is to be used. If the lines corresponding to conversion in each of the K, L, and M shells are found, this can be done with confidence, but for many of the weaker lines a unique choice is impossible. Both the present measurements and those of du Mond involved no uncertainty of this sort so that when Cork's energies are found to agree with these, the assignment made by him is presumably correct. However, all radiations assigned to K-Capture in iridium 192 should be missing from the measurements of Ewan and Thompson. From this argument, it is clear that the 0.2013 and the 0.4854 Mev. radiations fall in the K-Capture branch. The 0.2059 Mev. radiation would be also assigned in this manner from a comparison of Cork's results with those of du Mond and of this investigation but its presence in Ewan's data conflicts with this assignment. Either Cork or Ewan's measurements are in error or radiation of this energy is present in both branches.

The 0.2814 and 0.287 Mev. radiations given in column 7 of Table IV require discussion. In the present measurements, the K peak for the latter energy fell on the low energy edge of the very strong K peak from the 0.295 Mev. gamma-ray. Hence, its energy and intensity are both somewhat in doubt. Cork's value of 0.283 Mev. was based on the conversion of the radiation in osmium; had he placed it in the β^- branch, the energy of this gamma-ray would have been 0.288 Mev. Thus, Cork's line at 0.283 Mev. may actually correspond to the 0.287 Mev. line observed in this work, while the 0.2814 Mev. line may not have been sufficiently converted for observation in Cork's experiment.

In the light of this evidence and the measurements reported from this work, it appears that Cork's proposed decay scheme for the K-Capture branch is not valid. It has not been possible to suggest

an alternative scheme from the results of these experiments.

Table V gives the intensities reported by five recent studies of the Ir 192 decay for the ten strongest gamma-rays in the low energy region. All intensities are normalized to the 0.4678 Mev. line. Good agreement is noted between the intensity figures reported in this study (Table II) and those given by Shipnel et al. (28). Du Mond and

TABLE V A COMPARISON OF THE IR 192 GAMMA-RAY INTENSITY MEASUREMENTS

NOMINAL ENERGY MEV.	Du MOND ET AL. (29)	SCHOOF & HILL (26)	SHIPNEL ET AL. (28)	J.L. WOLFSON (37)	NABLO
0.136	1.3	60			
0.206	2.5	6.7	3.1		3.2
0.295	127	47	62	50	67
0.308	123	20	62	55	72
0.316	330	133	77	110	190
0.467	100	100	100	100	100
0.485	3.7	< 13	4.6		5.1
0.589	3.7	< 20	7.7	10	7.5
0.604	4.7	27	13		11.4
				30	
0.613	1.7	27	4.6		7.8

his co-workers suggest that the poor agreement of their line intensities with those of other workers may be due, in part, to the variation of sensitivity with energy of the crystal spectrometer they used.

The decay scheme originally proposed by Cork has been substantiated by the measurements of du Mond and those of this investigation. However,

the measurements of the energies of the weak gamma-rays in the high energy region has made it possible to put Cork's decay scheme to a much more critical test and also to establish a new level at 1.1597 Mev. In addition, these experiments confirm the existence of the level at 1.359 Mev. which was required by Roulston and Pringle to account for their results.

The decay scheme proposed in this investigation is shown in Figure 12. It involves the following levels:

(0) the ground state
(1) 0.3165 Mev.
(2) 0.6129 Mev.
(3) 0.7844 Mev.
(4) 0.9210 Mev.
(5) 1.1597 Mev.
(6) 1.2023 Mev.
(7) 1.3592 Mev.

TABLE VI ENERGY LEVEL FITTING FOR THE PROPOSED DECAY SCHEME OF IR 192

EXPERIMENTAL GAMMA ENERGY	ASSIGNED TRANSITION	CALCULATED ENERGY	ERROR (EXP'TL. - CALC.)
[1]0.1363	4 - 3	0.1366	-.0003
[2]0.1595	7 - 6	0.1569	+.0026
0.1731	3 - 2	0.1715	+.0016
1,*0.2013	7 - 5	0.2025	-.0012
*0.2059	K Capture		
*0.2814	6 - 4	0.2813	+.0001
0.2952	2 - 1	0.2964	-.0012
0.3079	4 - 2	0.3081	-.0002
0.3163	1 - 0	0.3165	-.0002
0.3759	5 - 3	0.3753	+.0006
[3]0.417	6 - 3	0.4179	-.001
0.4308	-	-	-
0.4386	7 - 4	0.4382	+.0004
0.4678	3 - 1	0.4679	-.0001
0.4854	K Capture		
0.5894	6 - 2	0.5894	.0000
0.6049	4 - 1	0.6045	+.0004
0.6133	2 - 0	0.6129	+.0004
0.7452	7 - 2	0.7461	-.0009
0.7831	3 - 0	0.7844	-.0013
0.8854	6 - 1	0.8858	-.0004
1.0617	-	-	-
1.1567	5 - 0	1.1597	-.0030

[1] These are measurements given by du Mond (see Table IV).

[2] The probable error in this measurement is set at ±.002 Mev. (see Table IV).

* Arguments concerning the assignments of these gamma-rays are given in Section V.

[3] This is the energy given by V. S. Shipnel et al. for this radiation (see Table IV).

Table VI shows the transition assignment for each of the gamma-rays and the difference between the measured value and the energy calculated from the levels of the decay scheme. Only two of the twenty-three lines observed are not classified. The difference between the experimental and calculated values is, in general, less than 1 kev.

It has been established that the β^- end-point is at 0.67 Mev. and Roulston and Pringle showed that the total transition energy is about 1.58 Mev. Hence, it can be assumed that there are no beta transitions to levels 0, 1 or 2. The algebraic sum of the intensities of the gamma-rays involving levels 1 and 2 should therefore be zero while the sum for level 0 should correspond to the total probability of beta decay. An examination of these sums in the proposed decay scheme shows that the ground state transition involves an intensity of 198 while the algebraic sums for levels 1 and 2 are respectively 19 and 6. Under the assumption that the probability of β^- decay is represented by the intensity figure of 198, the values 19 and 6 represent errors of 5% and 4% respectively in the intensity measurements. It may therefore be assumed that no beta transitions go to the 0, 1 or 2 levels.

For the levels 3, 4, 5, 6 and 7, similar arguments show that the relative intensities of the beta transitions to these states are represented by 39 ± 8, 140 ± 7, 2.1 ± 0.1, 10.4 ± 0.6 and 3.6 ± 0.2 respectively. The sum of the beta intensity measurements is 195 ± 15 which is in excellent agreement with the figure 198 obtained from ground state considerations. It may therefore be said that the intensity measurements provide excellent support for the proposed decay scheme.

From the relative intensities of the beta-groups it is possible to determine the log ft values for transitions from Ir 192 to each of the seven levels in Pt 192, using the half-life of 74 days, i.e., 6.4×10^6 sec. From the intensities quoted in the last paragraph, it would appear that 20% of the transitions proceed to level 3. This would indicate that the ground state of Ir 192 lies at 0.78 + 0.67 = 1.45 Mev. above the ground state of Pt 192. Earlier workers have assumed that the 0.67 Mev. beta group fed level 4 at 0.92 Mev. which gives 1.59 Mev. for the Ir 192 - Pt 192 energy difference. The log ft values as computed for both possibilities together with the beta branching ratios are given in Table VII.

TABLE VII

ENERGY LEVEL NUMBER	BETA INTENSITY TO EACH LEVEL	LOG ft IR 192-PT 192 = 1.45 MEV.	LOG ft IR 192-PT 192 = 1.59 MEV.
0	<.01	>11.6	>11.5
1	<.1	>10.2	>10.1
2	<.03	>10.3	>10.1
3	0.20	9.2	8.9
4	0.71	8.3	8.0
5	0.01	9.2	8.9
6	0.052	9.3	8.0
7	0.018	8.2	7.2

From this table, it would appear that either alternative is acceptable on the basis of ft values since the upper levels have ft

values appropriate to allowed or first forbidden transitions (37). The intensities of the beta transitions to levels 0, 1 and 2 are probably much lower than the estimates based on the gamma-intensities given in Table VII. These high energy groups would have been detected by earlier workers, even if they represented only one percent of the 0.67 Mev. group.

Since the 0.3165 Mev. level represents the first excited state of Pt 192, it almost certainly has spin two and even parity (39). The fact that no β^- transitions to this level occur, indicates that the spin of Ir 192 must be at least four. It is therefore reasonably certain that the spin of level 2 is not greater than two, while the spins of the upper levels 3 and 4 are probably either three or four. The fact that a weak transition exists between levels 3 and 0 indicates the choice of spin three for level 3 while the absence of the transition from level 4 to the ground state suggests a spin four for this upper level. The excited state 5 with transitions to the ground state and to level 3 necessitates a lower spin, probably two, with no direct β^- transition to this level. (The gamma-ray intensities are not of sufficient accuracy to decide this point.) This assumption of a spin of two for level 5 requires the presence of a 43 kev. gamma-ray, feeding it from level 6. No measurements in this region are available. For both levels 6 and 7, the direct transitions to the ground state are missing, indicating that they fall into the group with higher spins, probably three or four. It must be admitted that this discussion represents no more than speculation. However, with a decay scheme available, it is now important to measure the internal conversion coefficients of the stronger gamma-rays. The interpretation of these

coefficients should be sufficient to settle the spins of most of these levels.

(ii) Iridium 194

Since no precision energy measurements of the Ir 194 spectrum have been reported except Cork's value of 0.3275 Mev. for the strongest radiation, little support may be expected from the literature for the contents of Table III. This table gives the energies and intensities of ten gamma-rays above 1 Mev. and four in the 0.3 to 0.5 Mev. range. A complete exploration of the range below 1 Mev. has not yet been made so this list is probably quite incomplete.

The most striking disagreement between these results and the evidence in the literature concerns the relative intensities of the 0.3276 Mev. and 1.4 Mev. radiations. Kraushaar and Goldhaber (35), on the basis of scintillation spectrometer observations, state that these radiations are of roughly equal intensity but give no details of their experiment. The present work shows that the intensity of the 0.3276 Mev. gamma-ray is twenty-five times as great as the sum of the intensities of the 1.46 and 1.51 Mev. gamma-rays. No explanation of this discrepancy is evident.

Steffen (38) has studied the K-Capture process in Au 194 which leads to Pt 194 and reports gamma-rays of the following energies and intensities: 0.291 Mev. (2.5), 0.328 Mev. (2.0), 0.466 Mev. (weak), 1.48 Mev. (2.3) and 2.1 Mev. (1). These energies were obtained from internal conversion lines and the intensities from the analysis of a lead absorption curve. These radiations were all found in the present investigation with general agreement as to intensities except, again,

for the 0.328 Mev. line. This difference is not, perhaps, surprising since the intensities of the gamma-rays in the Au 194 decay may be expected to differ from those in Ir 194.

The total intensity of the gamma-rays of energy above 1.7 Mev. obtained in this work is 2×10^{-3} photons per disintegration, in good agreement with Wilson's figure of 1.4×10^{-3} (33).

Even with a partial knowledge of the gamma spectrum, it has been possible to fit thirteen of the fourteen measured gamma-rays into a decay scheme involving the eight excited states shown in Figure 13. This scheme resembles that proposed by Mandeville and Scherb (31) only in the assignment of the level at 0.3276 Mev. as the first excited state (39). The only line not placed in the proposed scheme is the 1.4648 Mev. radiation which is the strongest radiation of energy greater than 1.2 mev. Its value is 9 kev. too low to be the transition between the 1.8016 and the 0.3276 Mev. levels, as assigned by earlier workers. It probably represents a transition to one of the three lowest levels in the decay scheme, for which the cross-over gamma-ray is too weak to have been detected.

At the present time, it is impossible to interpret the angular correlation data presented in an earlier section of this thesis. They are in reasonable agreement with the similar measurements of Whittle and Jastram (34) and of Kraushaar and Goldhaber (35). Their interpretation of their experiments would seem to be incorrect on the basis of the proposed decay scheme shown here.

Further experiments on the beta spectrum as well as an extension of these gamma-ray energy measurements are planned for the immediate future.

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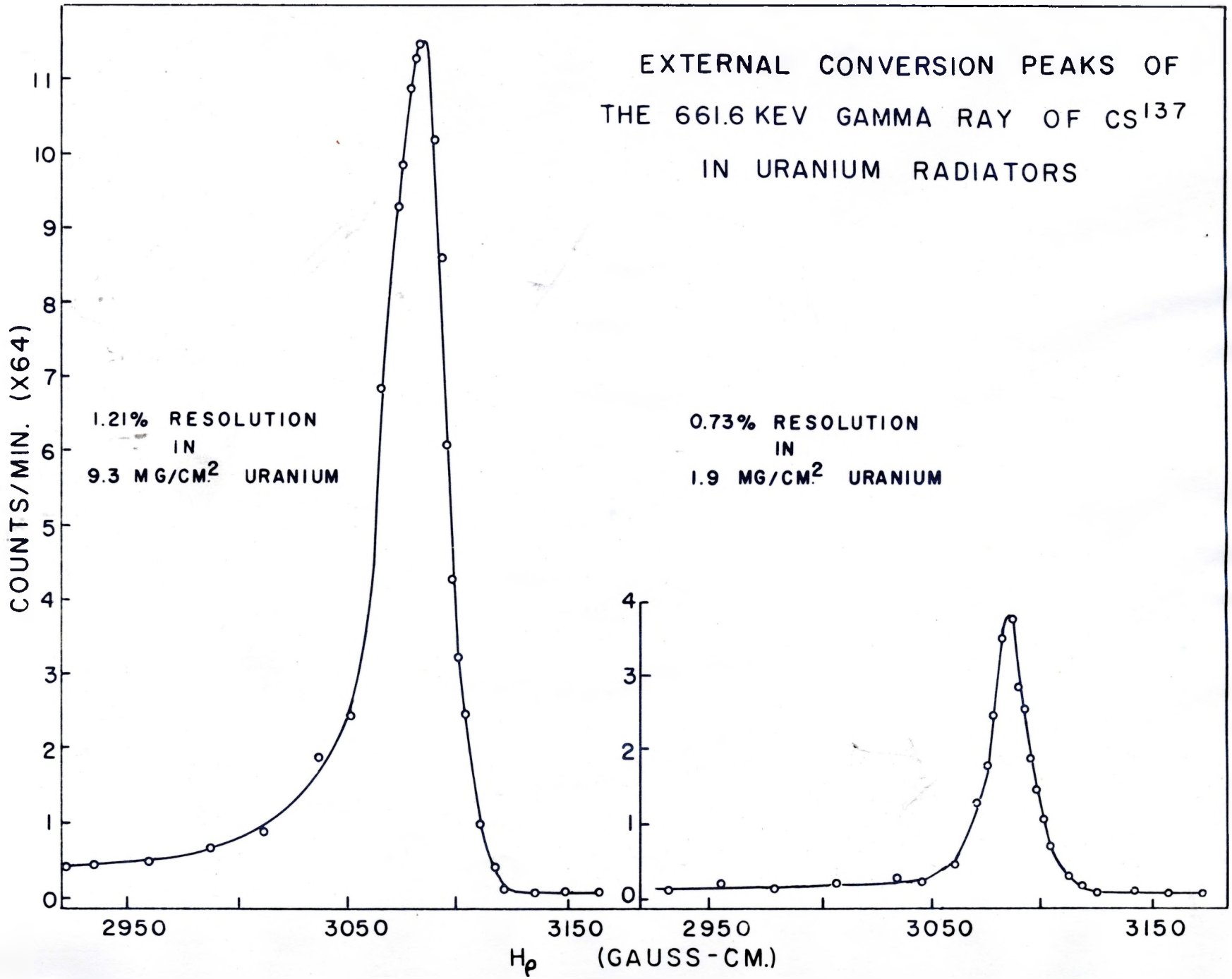

EXTERNAL CONVERSION PEAKS OF
THE 661.6 KEV GAMMA RAY OF CS^{137}
IN URANIUM RADIATORS
1.21% RESOLUTION
IN
9.3 MG/CM.^{2} URANIUM
0.73% RESOLUTION
IN
1.9 MG/CM.^{2} URANIUM
COUNTS/MIN. (X64)
0
1
2
3
4
5
6
7
8
9
10
11
2950
3050
3150
H_ρ (GAUSS-CM.)

FIG. 1

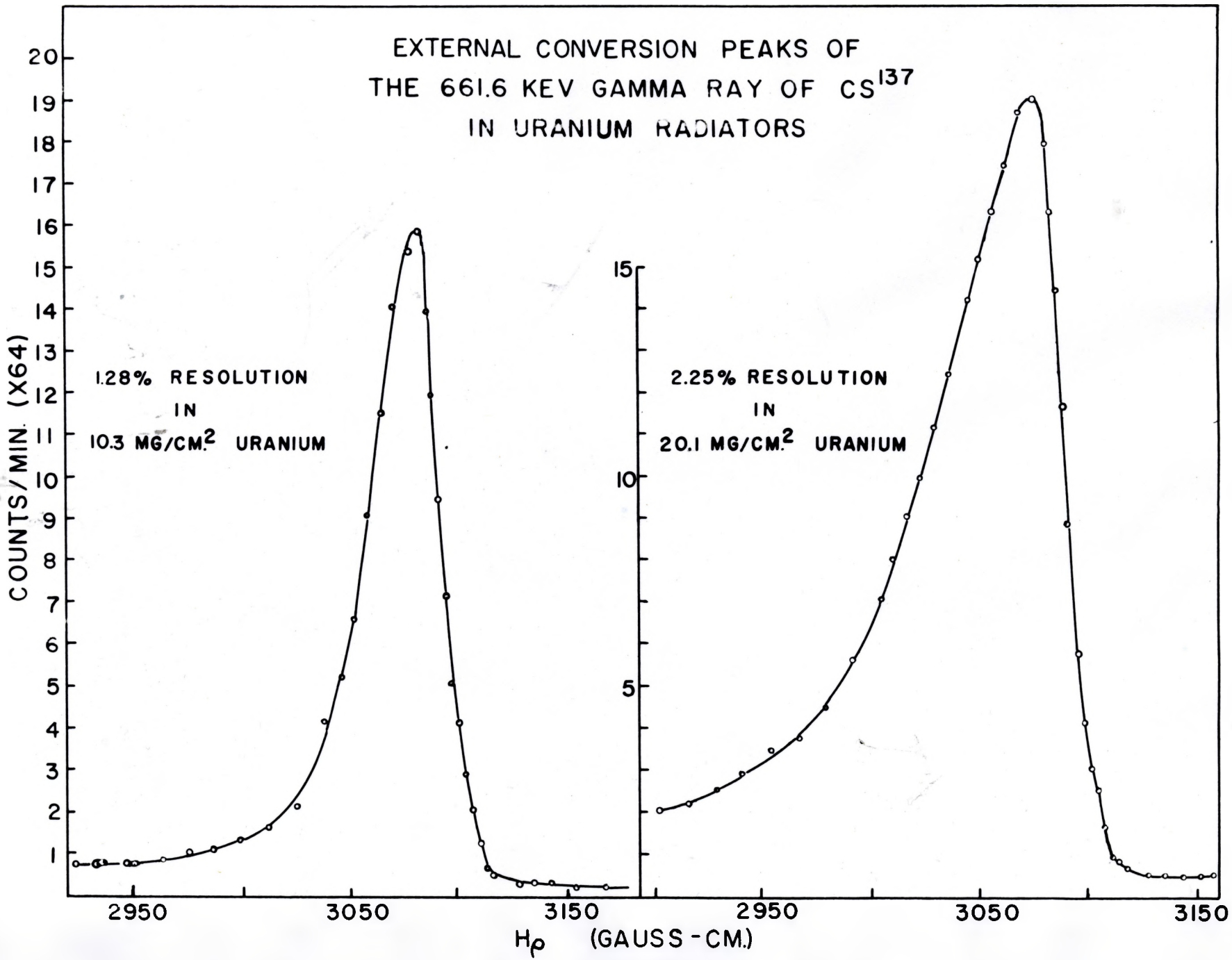

EXTERNAL CONVERSION PEAKS OF
THE 661.6 KEV GAMMA RAY OF CS^{137}
IN URANIUM RADIATORS
1.28% RESOLUTION
IN
10.3 MG/CM.^{2} URANIUM
2.25% RESOLUTION
IN
20.1 MG/CM.^{2} URANIUM
COUNTS/MIN. (X64)
$H\rho$ (GAUSS - CM.)
2950
3050
3150

FIG. 2

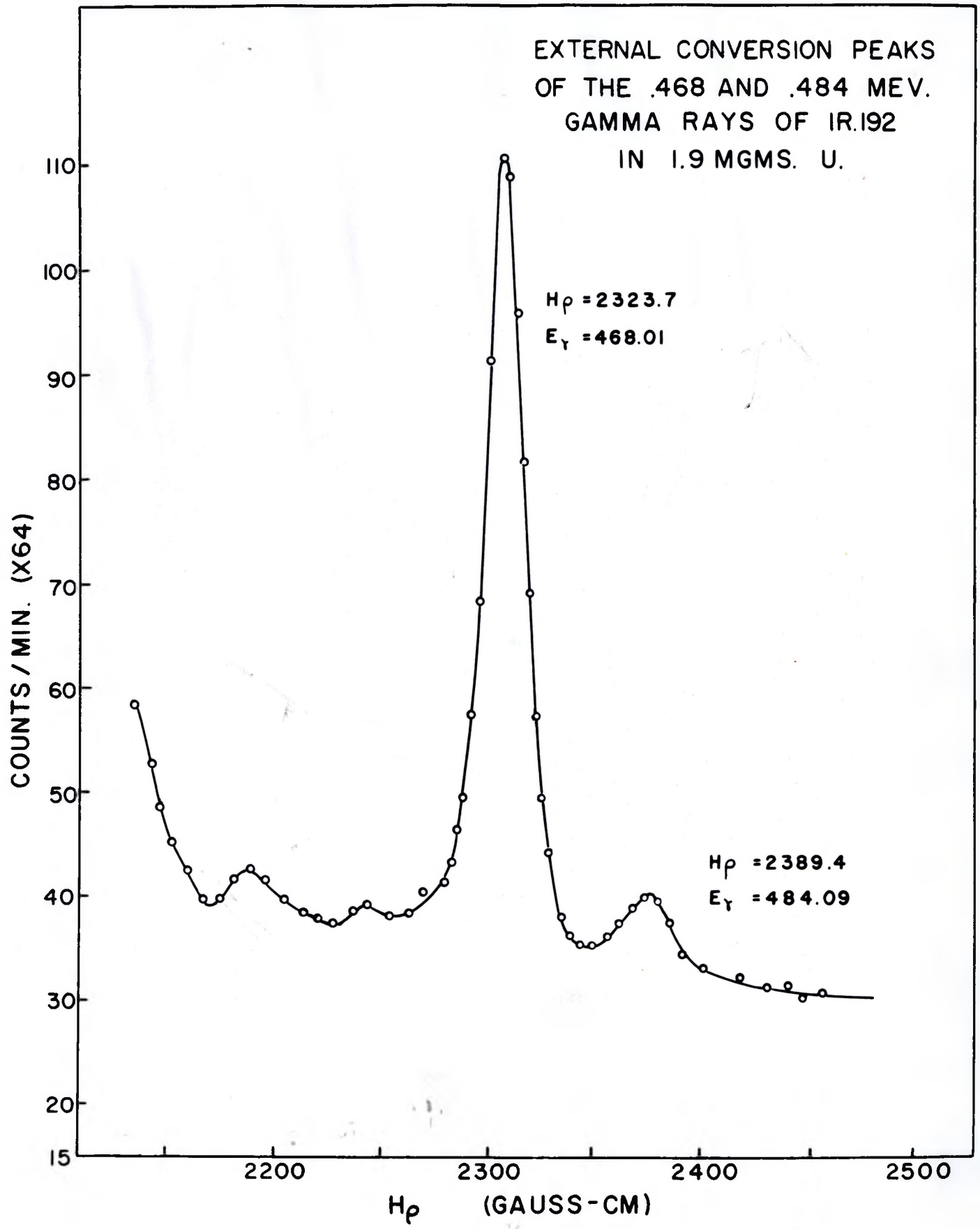

EXTERNAL CONVERSION PEAKS
OF THE .468 AND .484 MEV.
GAMMA RAYS OF IR.192
IN 1.9 MGMS. U.
Hρ = 2323.7
Eγ = 468.01
Hρ = 2389.4
Eγ = 484.09
COUNTS / MIN. (X64)
110
100
90
80
70
60
50
40
30
20
15
2200
2300
2400
2500
Hρ (GAUSS-CM)

FIG. 3

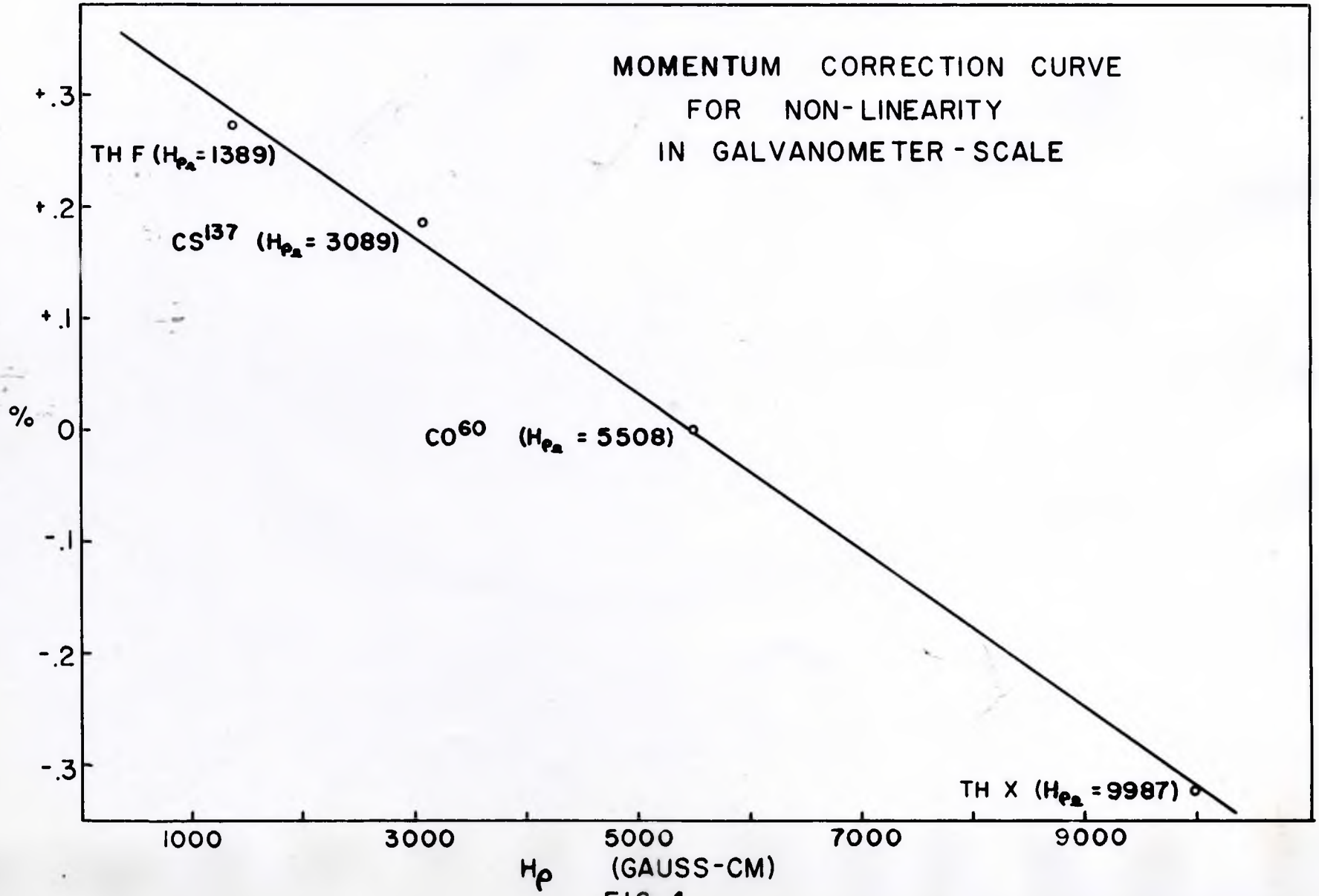

MOMENTUM CORRECTION CURVE
FOR NON-LINEARITY
IN GALVANOMETER-SCALE
TH F ($H_{\rho a}$ = 1389)
CS^{137} ($H_{\rho a}$ = 3089)
CO^{60} ($H_{\rho a}$ = 5508)
TH X ($H_{\rho a}$ = 9987)
+.3
+.2
+.1
%
0
-.1
-.2
-.3
1000
3000
5000
7000
9000
H_ρ (GAUSS-CM)

FIG. 4

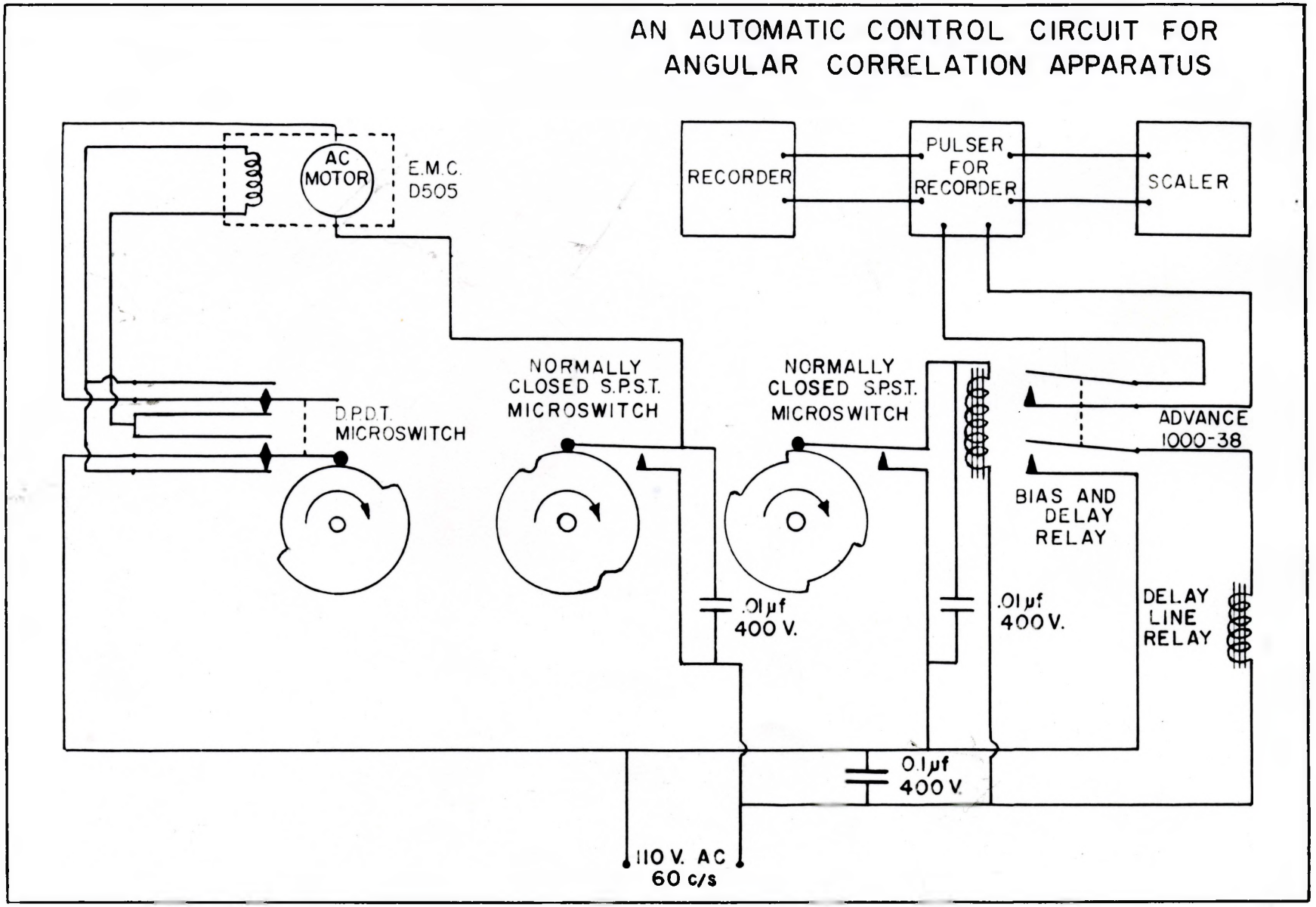

AN AUTOMATIC CONTROL CIRCUIT FOR
ANGULAR CORRELATION APPARATUS
AC
MOTOR
E.M.C.
D505
RECORDER
PULSER
FOR
RECORDER
SCALER
D.P.D.T.
MICROSWITCH
NORMALLY
CLOSED S.P.S.T.
MICROSWITCH
NORMALLY
CLOSED S.P.S.T.
MICROSWITCH
ADVANCE
1000-38
BIAS AND
DELAY
RELAY
.01μf
400 V.
.01μf
400 V.
DELAY
LINE
RELAY
0.1μf
400 V.
110 V. AC
60 c/s

FIG. 5

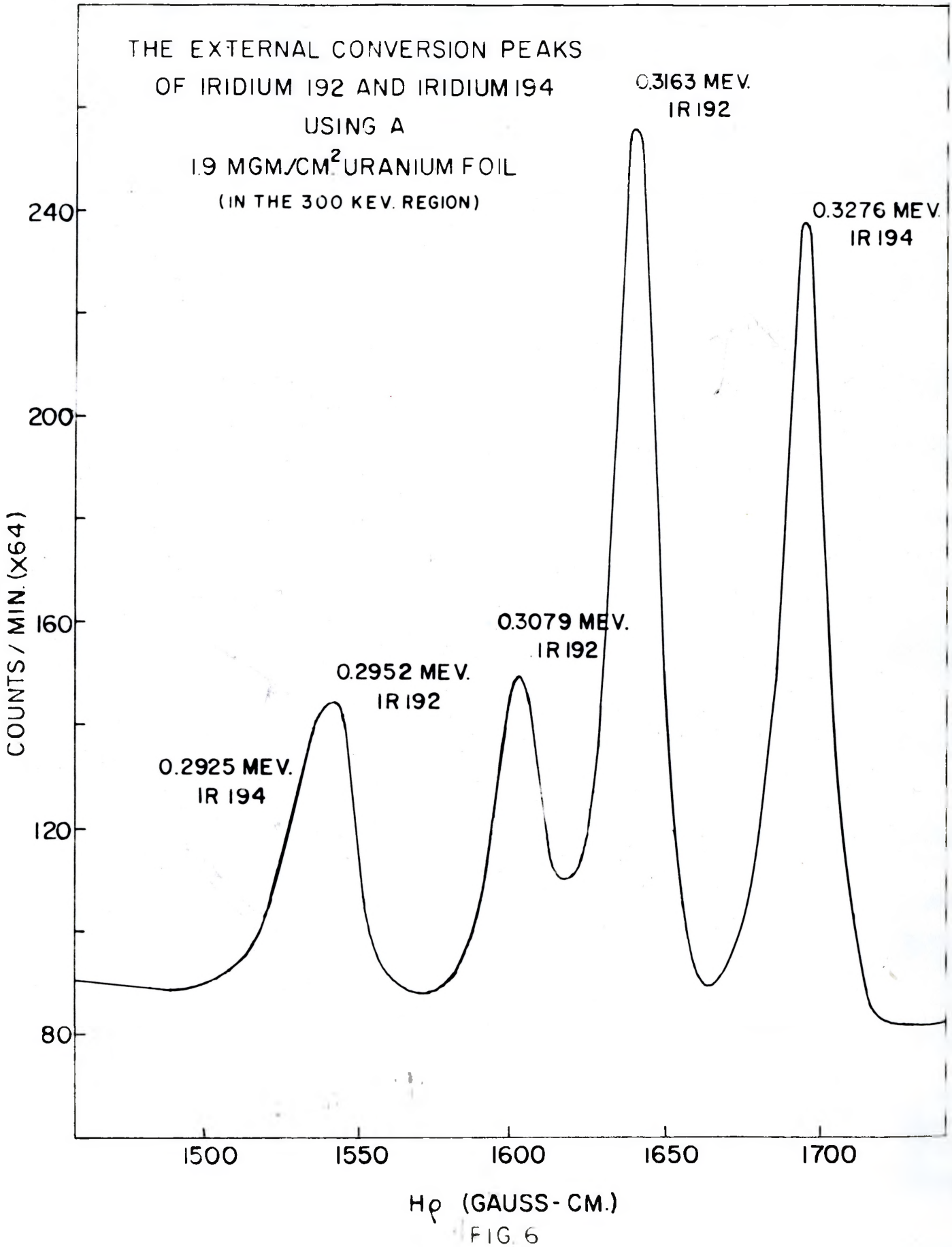

THE EXTERNAL CONVERSION PEAKS
OF IRIDIUM 192 AND IRIDIUM 194
USING A
1.9 MGM/CM^2 URANIUM FOIL
(IN THE 300 KEV. REGION)
0.3163 MEV.
IR 192
0.3276 MEV.
IR 194
0.3079 MEV.
IR 192
0.2952 MEV.
IR 192
0.2925 MEV.
IR 194
COUNTS / MIN. (X64)
240
200
160
120
80
1500
1550
1600
1650
1700
Hρ (GAUSS - CM.)

FIG. 6

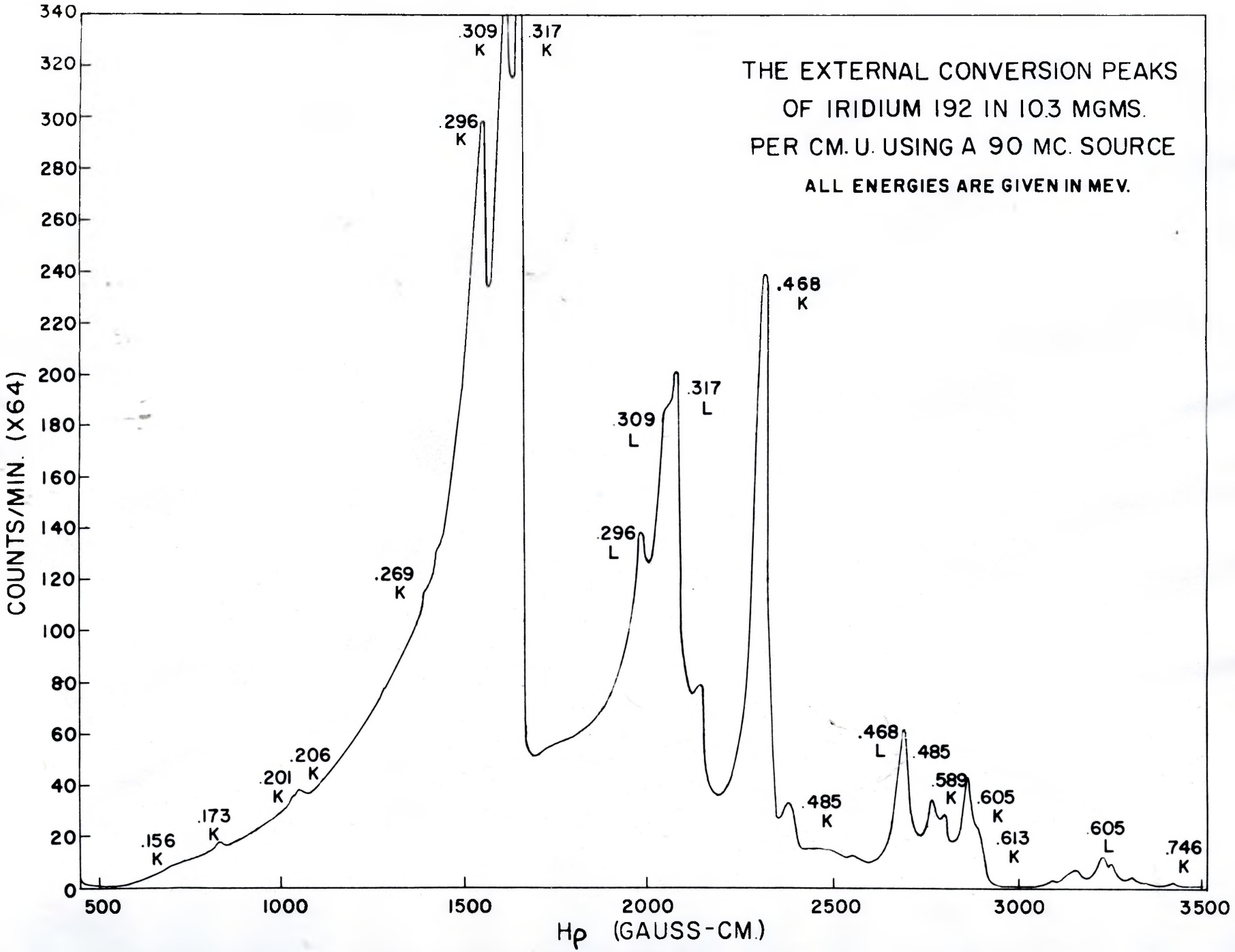
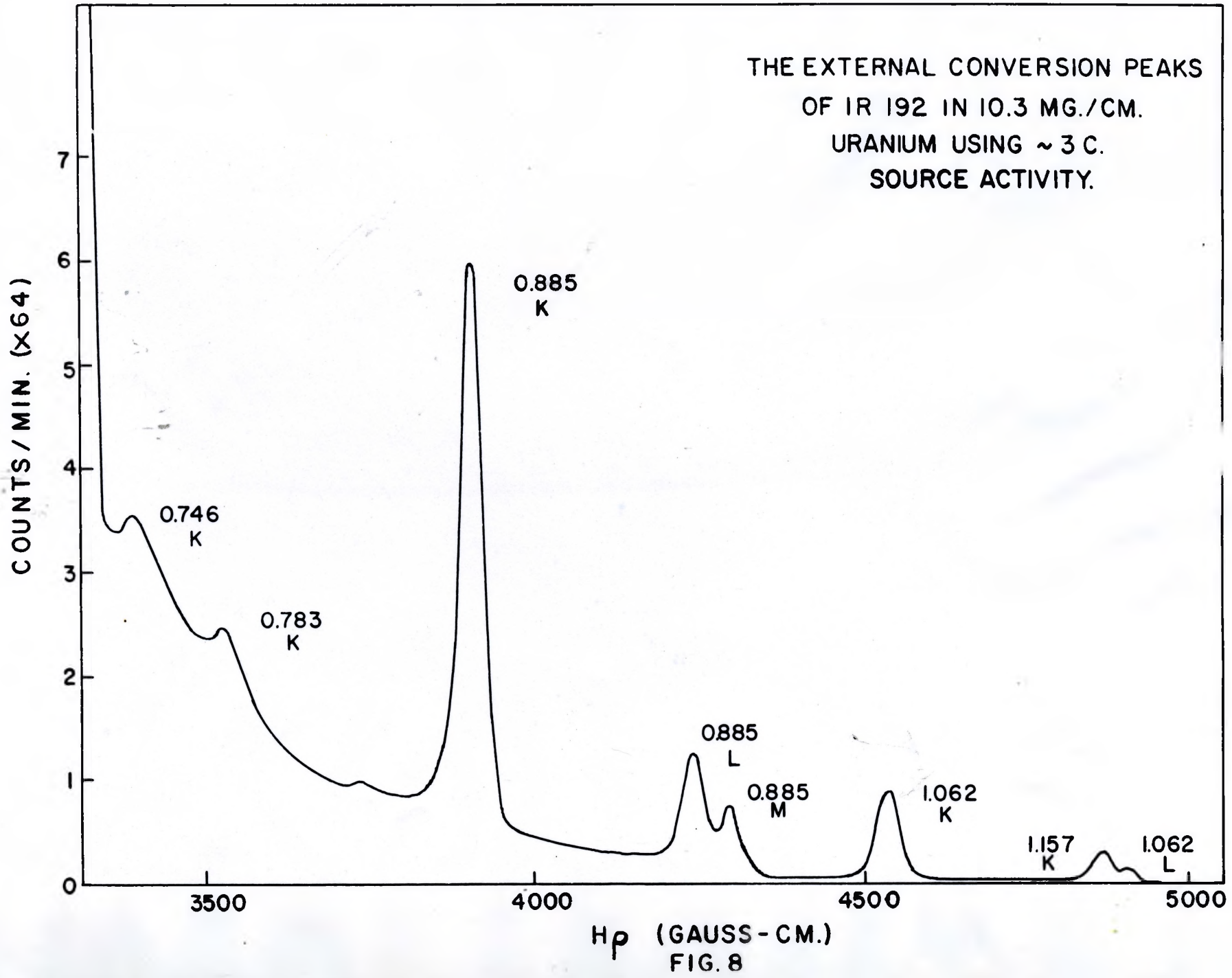

THE EXTERNAL CONVERSION PEAKS
OF IRIDIUM 192 IN 10.3 MGMS.
PER CM. U. USING A 90 MC. SOURCE
ALL ENERGIES ARE GIVEN IN MEV.
COUNTS/MIN. (X64)
Hρ (GAUSS-CM.)
.156 K
.173 K
.201 K
.206 K
.269 K
.296 K
.309 K
.317 K
.296 L
.309 L
.317 L
.468 K
.485 K
.468 L
.485
.589 K
.605 K
.613 K
.605 L
.746 K

FIG. 7


THE EXTERNAL CONVERSION PEAKS
OF IR 192 IN 10.3 MG./CM.
URANIUM USING ~ 3 C.
SOURCE ACTIVITY.
COUNTS / MIN. (X64)
0
1
2
3
4
5
6
7
0.746
K
0.783
K
0.885
K
0.885
L
0.885
M
1.062
K
1.157
K
1.062
L
3500
4000
4500
5000
Hρ (GAUSS - CM.)
FIG. 8

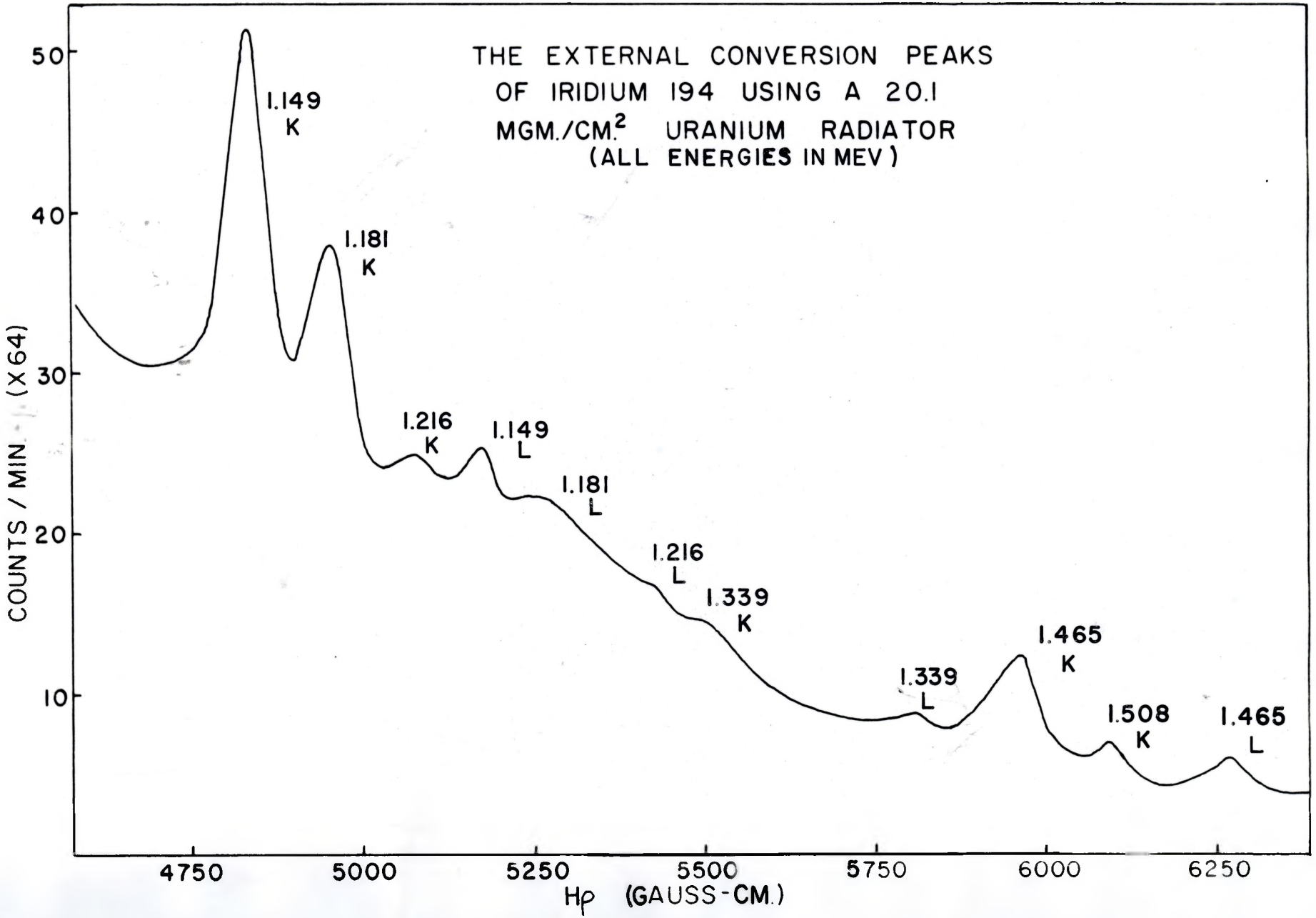

THE EXTERNAL CONVERSION PEAKS
OF IRIDIUM 194 USING A 20.1
MGM./CM.² URANIUM RADIATOR
(ALL ENERGIES IN MEV)
1.149 K
1.181 K
1.216 K
1.149 L
1.181 L
1.216 L
1.339 K
1.339 L
1.465 K
1.508 K
1.465 L
COUNTS / MIN (X64)
50
40
30
20
10
4750
5000
5250
5500
5750
6000
6250
Hρ (GAUSS-CM.)

FIG 9

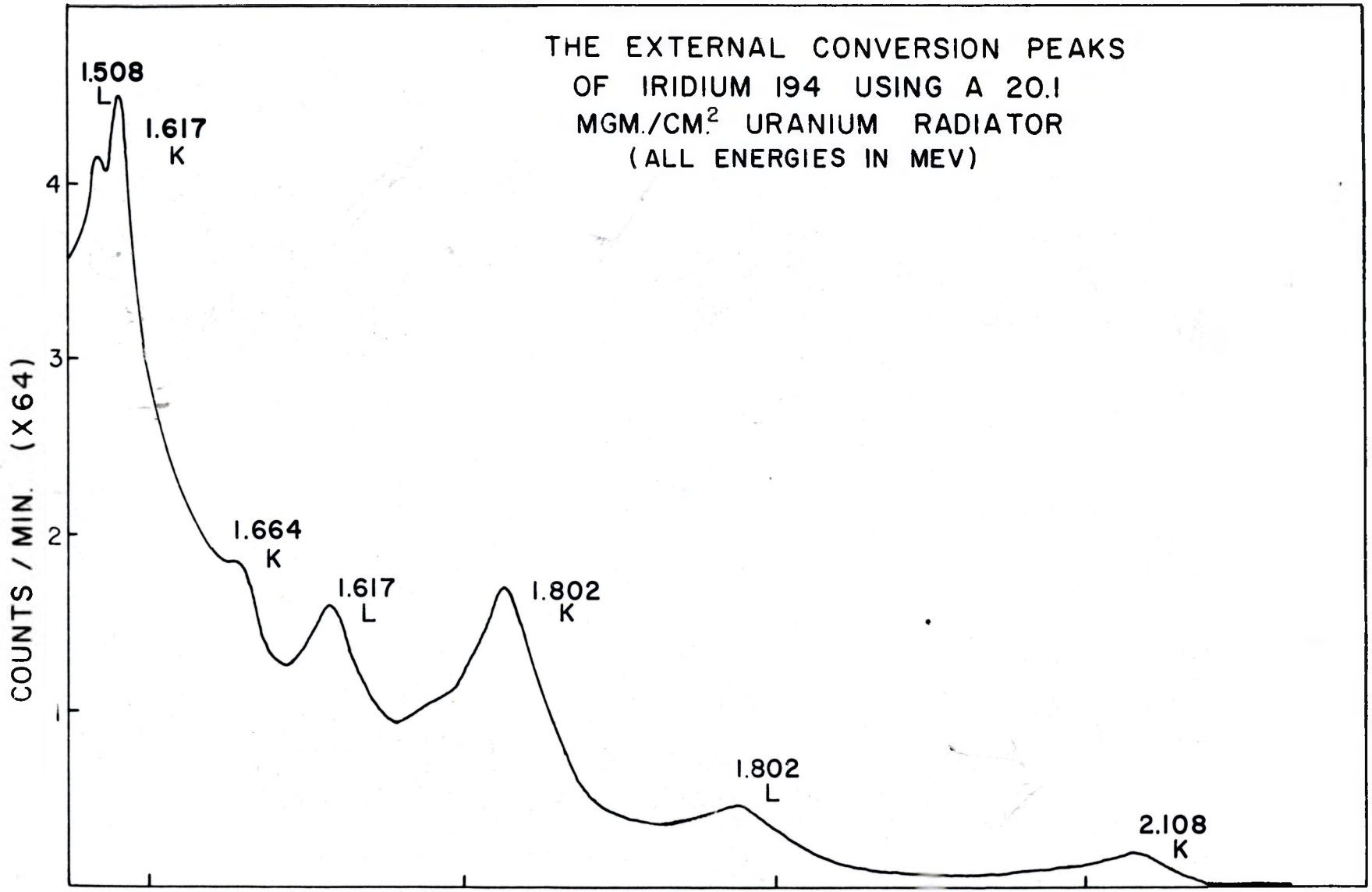

THE EXTERNAL CONVERSION PEAKS
OF IRIDIUM 194 USING A 20.1
MGM./CM.² URANIUM RADIATOR
(ALL ENERGIES IN MEV)
1.508
L
1.617
K
1.664
K
1.617
L
1.802
K
1.802
L
2.108
K
COUNTS / MIN. (X64)
4
3
2
1
6500
7000
7500
8000
Hρ (GAUSS-CM)

FIG. 10

ALTERNATIVE ENERGY LEVEL SCHEMES FOR PT 192

DU MOND ET AL PHYS. REV., 88, 775, 1952

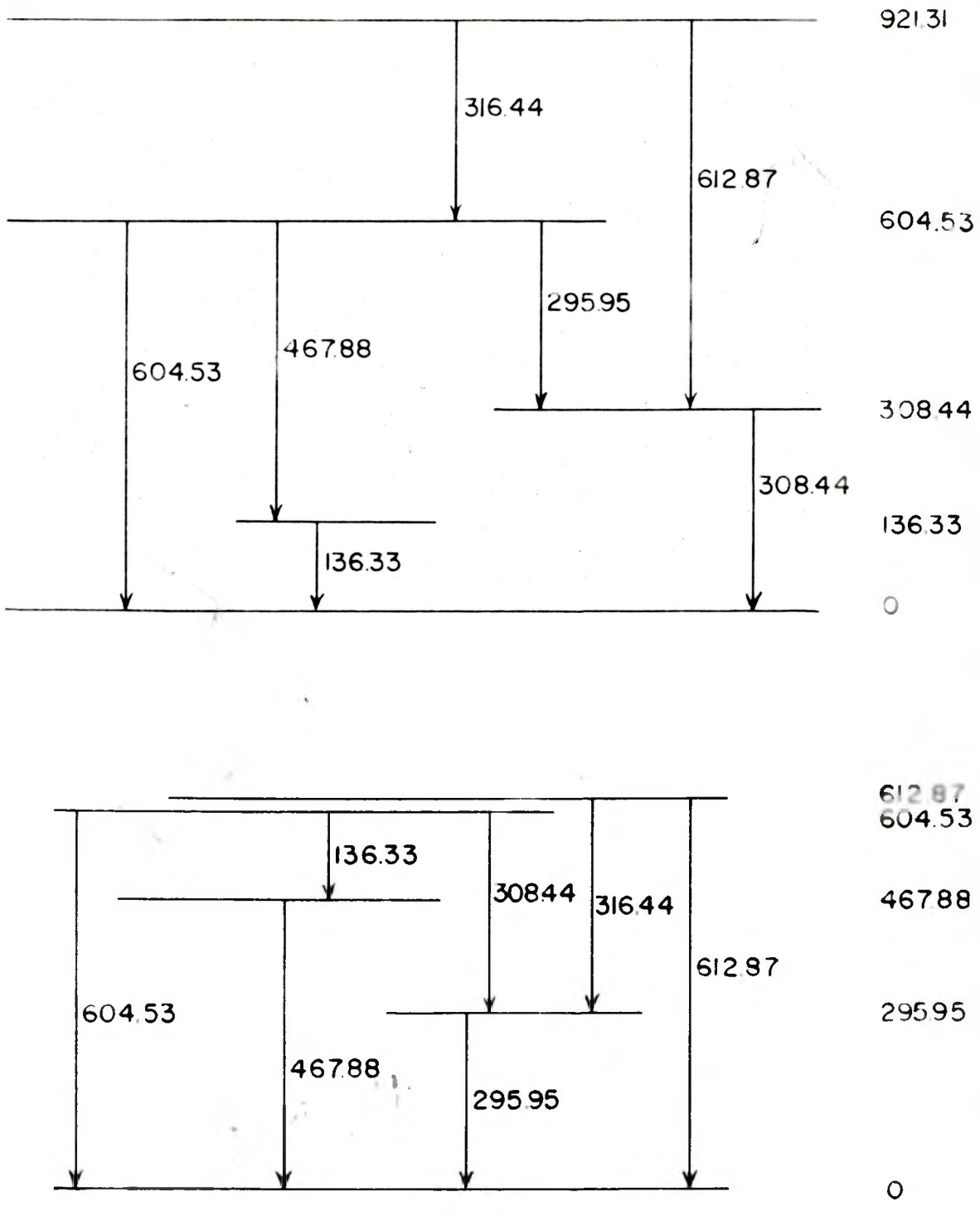


FIG. 11

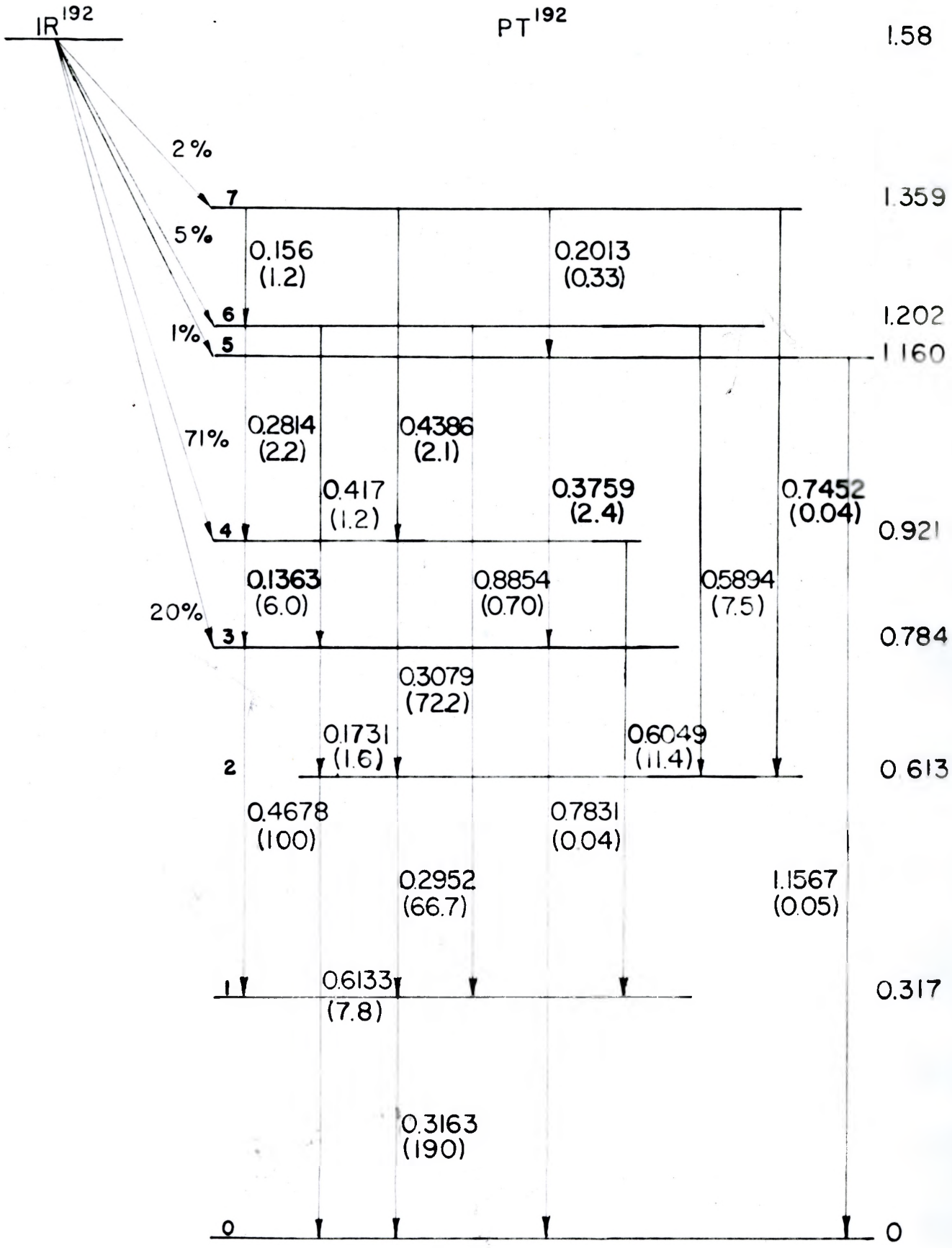

IR192
PT192
1.58
2%
7
1.359
5%
0.156
(1.2)
0.2013
(0.33)
6
1.202
1%
5
1.160
71%
0.2814
(2.2)
0.4386
(2.1)
0.417
(1.2)
0.3759
(2.4)
0.7452
(0.04)
4
0.921
0.1363
(6.0)
0.8854
(0.70)
0.5894
(7.5)
20%
3
0.784
0.3079
(72.2)
0.1731
(1.6)
0.6049
(11.4)
2
0.613
0.4678
(100)
0.7831
(0.04)
0.2952
(66.7)
1.1567
(0.05)
1
0.6133
(7.8)
0.317
0.3163
(190)
0
0

FIG. 12

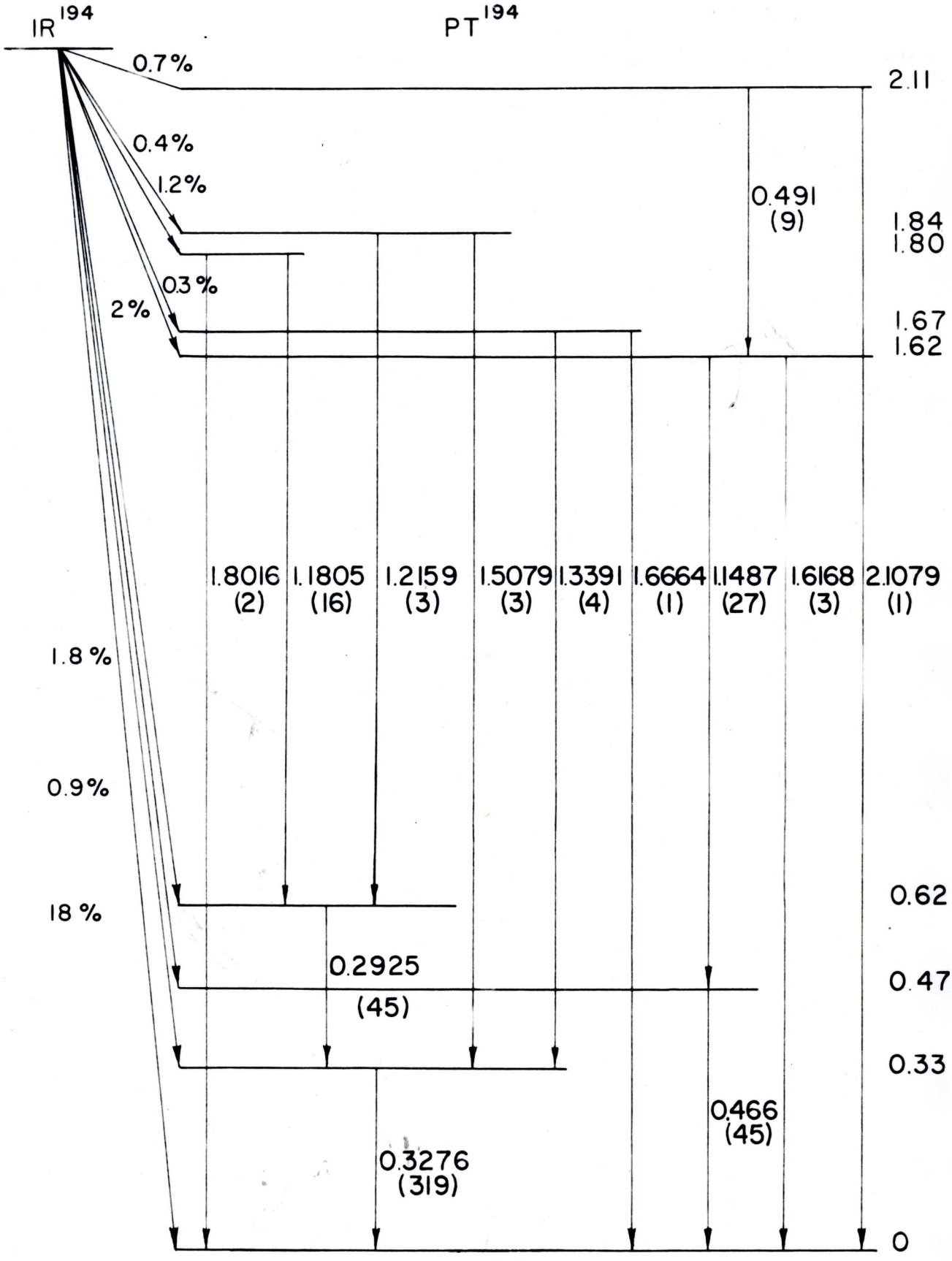

IR 194
PT 194
0.7%
2.11
0.4%
1.2%
0.491
(9)
1.84
1.80
0.3%
2%
1.67
1.62
1.8016
(2)
1.1805
(16)
1.2159
(3)
1.5079
(3)
1.3391
(4)
1.6664
(1)
1.1487
(27)
1.6168
(3)
2.1079
(1)
1.8%
0.9%
18%
0.62
0.2925
(45)
0.47
0.33
0.466
(45)
0.3276
(319)
0

FIG. 13

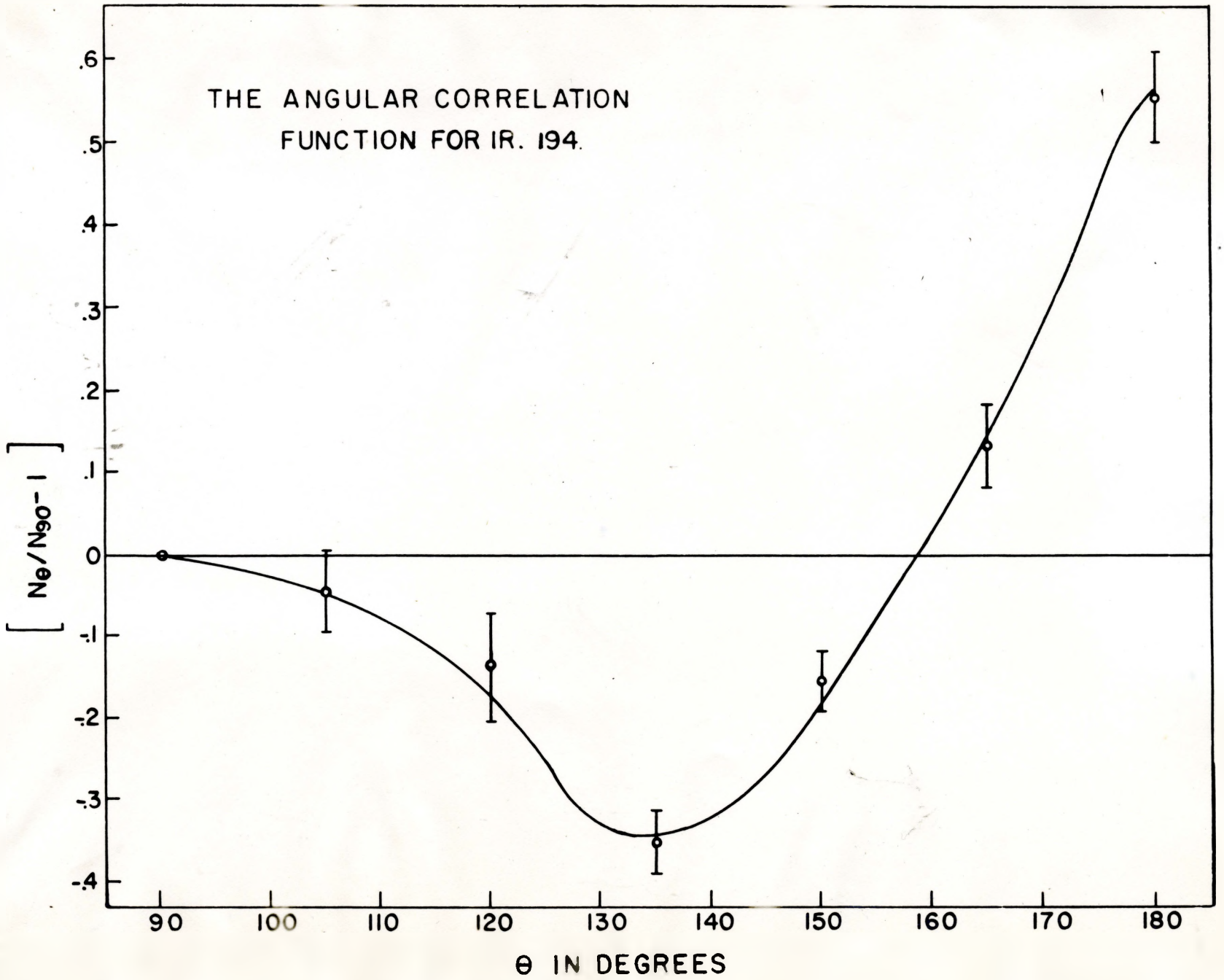

THE ANGULAR CORRELATION
FUNCTION FOR IR. 194.
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
[Nθ/N90 - 1]
90
100
110
120
130
140
150
160
170
180
θ IN DEGREES

FIG. 14