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ELECTRONS IN SAMARIUM 145, GOLD
195, AND MERCURY 203.

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DIRECTIONAL CORRELATIONS BETWEEN X RAYS AND INTERNAL
CONVERSION ELECTRONS IN SAMARIUM 145, GOLD
195, AND MERCURY 203

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

John Robert Brannan, B.S.

* * * * * * *

The Ohio State University
1969

Approved by

M. L. Proll
Adviser
Department of Physics
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Finally, a word in memoriam to a man who contributed considerably to the Gamma Spectroscopy Group and whose persuasion originally caused me to become Professor Pool's advisee, for better or for worse, the late Russell P. Sullivan.
VITA

September 5, 1938  Born - Dayton, Ohio

1961 . . . . .  B.S., The Ohio State University, Columbus, Ohio

1961-1962 . . .  Assistant Instructor, Department of Mathematics, The Ohio State University, Columbus, Ohio

1964-1966 . . .  Assistant Professor of Physics, Findlay College, Findlay, Ohio

1967-1968 . . .  Research Associate, Department of Physics, The Ohio State University, Columbus, Ohio

FIELDS OF STUDY

Major Field: Physics

Studies in Nuclear Physics. Professors M. L. Pool and Richard G. Seyler

Studies in Electromagnetism. Professor L. Carlton Brown

Studies in Quantum Mechanics. Professor Robert L. Mills

Studies in Classical Mechanics. Professor Wave H. Shaffer

Studies in Mathematics. Professors Earl John Mickle and Frank W. Carroll
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INTRODUCTION

The purpose of this study was to determine if a directional correlation exists either between x rays and internal conversion electrons or between pairs of x rays in the radioactive decay of certain isotopes.

In order to clarify which x rays or combinations of x rays are being discussed here, consider briefly the processes of internal conversion and electron capture. Internal conversion and gamma-ray emission are competing modes of transition between nuclear energy levels. The difference in energy between the levels and the angular momentum change are imparted to an orbital electron in the case of conversion or to a photon in the case of gamma-ray emission. Electrons that are ejected in this manner from the K shell (or L, or M, . . . shell) will be referred to as K- (or L-, or M-, . . .) conversion electrons throughout this report. K-conversion electrons are experimentally distinguishable from L-conversion electrons because their energies, the nuclear transition energy less the binding energy of their original shells, are different. Since internal conversion involves an interaction between the nucleus and an orbital electron, K conversion is usually more probable than L
conversion, and L conversion is more probable than M conversion, and so forth. In about $10^{-14}$ seconds or less the hole created in one of the inner atomic levels by the internal conversion event moves to the outer level of the atom producing in the process a cascade of x rays and Auger electrons.\(^1\) In the atomic domain, the Auger electrons are the counterpart of internal conversion electrons; that is, they compete with electromagnetic radiation in energy level transitions. The ejected Auger electron carries away the energy of an atomic transition, but it also leaves behind an additional hole which causes another cascade. Auger electron emission predominates over x-ray emission except for K x rays from atoms having atomic numbers greater than thirty and for L x rays from the heaviest elements.\(^2\) For the three daughter elements included in this study promethium (daughter of samarium 145), platinum (gold 195), and thallium (mercury 203) the percentages of K-shell vacancies that are followed by Auger electrons rather than by K x rays are approximately 10 per cent, 5 per cent, and 5 per cent respectively.

The important results are that a K-conversion electron is promptly followed by a cascade that probably


includes a K x ray and might include an L x ray, and an L-conversion electron might be accompanied by an L x ray but not by a K x ray. The L x ray following K conversion might be preceded either by a K x ray or by an Auger electron.

Electron capture is a process competing with positron emission in isobaric nuclear transformations when the Q value of the transformation is greater than 1.02 MeV. When the Q value is less than that amount, positron emission is not possible, but electron capture can still occur. A neutron and a neutrino are formed from the interaction of a nuclear proton and an orbital electron resulting in a reduction of the atomic number of the nucleus by one unit. The terms K capture, L capture, and so forth, describe which electron was involved.

A hole in the orbital electron levels is created by this process, and a cascade of x rays and Auger electrons ensues. These x rays are characteristic of the daughter nucleus, and they are not experimentally distinguishable from those associated with an internal conversion transition from an excited level of the daughter unless that level has a mean life-time larger than the resolving time of the experimenter's coincidence circuitry. However, the terms "capture x rays" and "conversion x rays" will be used in order to facilitate discussion.
When the isotope under study was a beta emitter, the investigation consisted in seeking anisotropy of conversion x ray emission with respect to either the direction of conversion electron emission or the direction of emission of another conversion x ray in cascade with the first one. K- and L-conversion electrons and K and L x rays were each observed as distinct entities in these experiments.

With isotopes that decay by electron capture, it was not possible to determine whether an x ray being observed was "conversion" or "capture" unless it was a K-capture x ray in coincidence with an L-conversion electron. An observed anisotropy between K and L x rays, for example, would indicate that at least one of several combinations of K and L x-ray coincident pairs was responsible, but not which one.

Basically, the method of investigation used in this study was to place a thin sample of a selected isotope at the intersection of the axes of two cylindrically symmetric detectors and then measure count rates of particular types of radiation, such as K x rays and L-conversion electrons, entering one detector in coincidence with an L (or K) x ray entering the other detector. Anisotropy, or the absence of it, was determined by comparing the coincidence count rate obtained when the detector axes were at 180° relative to each other with the rate obtained with the axes at 90°.

It was not within the scope of this work to investigate any directional correlation in greater detail nor to
seek an isotropy between capture x rays and gamma rays.

One theoretical article states that the angular distribution of x rays will be anisotropic when capture occurs from the $L_{III}$ subshell or when internal conversion occurs in the $L_{III}$ subshell.\(^3\)

The apparatus that was available for this study was not capable of resolving $L_{III}$-conversion electrons from $L_I$- and $L_{II}$-conversion electrons, nor could one L x ray, such as $L_{q_1}$, be resolved from other L x rays. However, three of the four most intense L x-rays (i.e., $L_{a_1}$, $L_{a_2}$, and $L_{\beta_2}$) are caused by transitions to the $L_{III}$ subshell from higher levels. These transitions are $M_V$ to $L_{III}$, $M_{IV}$ to $L_{III}$, and $N_V$ to $L_{III}$ respectively. The only remaining L x-ray component of significant intensity is $L_{\beta_1}$, which is from an $M_{IV}$ to $L_{II}$ transition. Therefore an anisotropy resulting from $L_{III}$ capture or $L_{III}$ conversion was expected to modify observably the composite L x-ray coincidence results provided that L x-ray radiation following K capture or K conversion was not anisotropic in the opposite sense.

Two previous experimental studies have been done on the subject of directional correlation of x rays and internal conversion electrons. One attempted to find a directional correlation between the K-conversion electrons and

the K-conversion x rays of the 88-keV level of silver 109. No such correlation was observed in this case. A second and more thorough study involving the electron-capture decay of cerium 139 concluded that directional correlations did exist for L x rays in coincidence with K-conversion electrons, L-conversion electrons, K x rays, and the lanthanum 166-keV gamma ray; but no directional correlation existed between the K x rays and any of the others except the L x rays.

A description of the apparatus used in this study and some of its capabilities are given in Chapter I. Chapter II includes the characteristics of the three isotopes chosen for this study and a description of the experimental procedure. The methods of processing and analyzing the data are explained in Chapter III, and the results are tabulated in Chapter IV. The data are contained in the graphs that are collected in the Appendixes.

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5P. R. Measel, dissertation, The Ohio State University, 1967.
CHAPTER I

THE APPARATUS

In this chapter the equipment and materials used during the course of the study are described starting with an outline of the entire data collection system and followed by discussion of its components in some detail. Attention is given to the capabilities of the equipment, how the components are joined to make a system, what features or modifications might distinguish this system from those in other laboratories, and the characteristics of the apparatus that will be useful in understanding the descriptions in Chapter II of the data collection procedures.

I. ELECTRONIC COMPONENTS

Introduction. A block diagram of the primary data collection system is shown in Figure 1. In brief, its main components and their functions are as follows:

1. Two of several available detectors each with an appropriate preamplifier for producing a voltage pulse proportional in amplitude to the amount of
Figure 1.—Data Collection system for coincidence measurements.
energy released by a photon or electron within the active volume of the detector.

2. The main amplifiers that provide pulse shaping as well as voltage and power gain.

3. Single channel analyzers, gates, and other logic circuits that provide the means of selecting only the pulses from a detector that are within a preset voltage interval and that arrive within a prescribed time interval with respect to the arrival time of a selected pulse from another detector.

4. A multichannel pulse-height analyzer that stores a pulse as an additional count in one of four hundred memory storage locations, referred to as channels, corresponding to the peak voltage of the pulse and to controls that might limit the selection to a subgroup of the four hundred channels.

5. A routing unit that permits the simultaneous use of subgroups of the multichannel analyzer as independent units each recording the results of different requirements set by separate single channel analyzers.

6. Both a paper tape punch and a typewriter for reading out and recording the data.

Detectors. Specifically, for electron spectroscopy a TMC Model W-80-2AA lithium-drifted silicon detector
was used. It had an active area of 80 square millimeters and a depleted depth of 2 millimeters. The resolution (full width at half maximum) for the cesium 137 K-conversion electron was 17 keV. Since 1.1-MeV electrons have a range of 2 millimeters in silicon, that energy was an upper limit for the linear detection of electrons. Electron spectra for energies above about 100 keV were distinct because the efficiency for gamma-ray detection at those energies was relatively low. Below that energy, however, the peaks from internal conversion electrons were sometimes adversely affected by the proximity of peaks due to K x rays. At room temperature no radiations below about 25 keV were discernible because of the noise produced by leakage currents in the detector. By cooling the detector with dry ice, the noise level could be reduced to approximately 20 keV, which resulted in a slight improvement in the resolution obtainable at low energies.

Used with this device was a Tennelec Model TC 130 field effect transistor preamplifier. The input resistance was changed from the $10^9$ ohm value supplied by the manufacturer for use with cooled detectors to a value of $2 \times 10^7$ ohms because of the higher leakage currents resulting from room temperature operation. The x-ray detector for electron-x ray coincidence was a Type K968SHG.5 "Integral Line" assembly manufactured by the
Harshaw Chemical Company. It contained a 1/8-inch by 31/32-inch diameter cleaved thallium activated sodium iodide crystal mounted on a Amperex XP-1010 photomultiplier tube and having a 0.005-inch berylium entrance window. The assembly was mounted inside a 2 7/8-inch diameter by 9-inch aluminum cylinder which also contained a transistor preamplifier and the voltage-divider network for the photomultiplier. The resolution obtainable with this assembly was 3.3 keV for the 6-keV iron K x ray.

A second x-ray detector, which was used for the x-ray-x-ray coincidence measurements, was a 1-inch by 1/4-inch cleaved sodium iodide crystal with a 0.005-inch entrance window of berylium. It was mounted on an EMI 9656R photomultiplier and was housed along with its preamplifier in an aluminum cylinder nearly identical to the one containing the 1/8-inch crystal. The resolution at 5 keV was about 5 keV.

Also available for coincidence work at higher energies were two scintillation detectors each having a 2-inch by 1 3/4-inch diameter sodium iodide crystal on an EMI 6097B photomultiplier tube and each one mounted in a manner similar to the x-ray detectors.

For high resolution gamma-ray energy measurements a lithium-drifted germanium detector, Solid State Radiations Model 100-LDG-1000-T, was used. It had an active area of 100 square millimeters and a depletion depth of
1000 microns. The cryostat housing this detector had a 0.015-inch aluminum window.

Accurate intensity and energy measurements were possible with the use of a 3-inch thick by 3-inch diameter sodium iodide crystal in a 32-inch cubical lead cave as described by Heath.¹

A 3-inch well crystal was also available and used for checking coincidence peaks.

**Pulse-shaping amplifiers.** The main amplification and pulse-shaping was done by means of resistance-capacitance coupled operational amplifier circuits in Sturrup Model 1415 RC amplifiers from Canberra Industries, Incorporated. Time constants of 0.5 microseconds and 0.25 microseconds were used for the first differentiation and the integration of the pulse respectively. These determine the frequency response of the amplifier and the fall time and rise time of the output pulse. The above values were determined by Measel² to provide the best combination of energy resolution and coincidence timing performance. A second differentiation time constant of 0.5 microseconds was used to make the output pulse bipolar which permitted slightly better coincidence timing through the use of the


zero-crossing detectors in the single channel analyzers discussed below. The second differentiation could be omitted, however, resulting in a unipolar pulse and slightly better energy resolution. The amplifier output wave forms are shown in Figure 1, page 8.

Single channel analyzers. The timing single channel analyzers, Sturrup Model 1435, produced a rectangular output pulse when the maximum voltage of a pulse from the RC amplifier was within the range $V$ to $V + \Delta V$ which was set by the front panel controls termed "baseline" and "window width." A front panel switch that permitted the removal of the upper limit was part of the module. The time of initiation of the output pulse was determined either by a threshold discriminator triggered by the leading edge of the input pulse in the case of the "unipolar" timing mode or by a zero crossing detector in the case of the "bipolar" timing mode. In either case the output could be delayed by any amount from zero to one thousand nanoseconds by a ten-turn potentiometer on the front panel. Note that "unipolar timing," i.e., leading edge timing, can be performed by the single channel analyzer for either type of pulse, unipolar or bipolar. "Bipolar timing" requires a bipolar pulse.

In the leading edge mode of timing larger pulses would trigger the leading edge discriminator sooner because
of their steeper slopes. Thus the timing was energy dependent; a phenomenon referred to as "walk." The zero-crossing point, however, in a bipolar pulse was nearly independent of energy, but for low voltage pulses which cross zero with small slopes the zero crossing detector was influenced more by noise resulting in a timing fluctuation called "jitter."

The single channel analyzers had four triangular "fast coincidence" output generators, four rectangular pulse "slow coincidence" outputs, and two rectangular "routing" outputs. In revised versions of the Sturrup modules, the fast triangular pulse generators were omitted from the Model 1435 and added to the Model 1440 fast coincidence unit. With the newer Model 1440 either the fast or the slow coincidence outputs from the Model 1435 could be used, and both of these, but not the routing outputs, included the zero to one thousand nanosecond delay feature. The three types of outputs were each triggered by different parts of the single channel analyzer's circuits. Because each of these subcircuits had different recovery times, the routing output might not be generated every time that there was a coincidence output pulse. To prevent data from being misrouted for this reason, the "slow

---

\(^3\)In the system used for this investigation, the fast coincidence unit and one of the three single channel analyzers were the newer types.
coincidence" outputs were used to drive both the fast coincidence unit and the routing unit.

As shown in Figure 1, page 8, parallel outputs from the single channel analyzers went to the fast coincidence unit and the routing unit. Not shown are leads to a Tektronix 585 oscilloscope which was used while setting up an experiment to monitor the system at several points. Leads from analyzers A, B, and C go directly to inputs A, B, and C respectively of the fast coincidence unit in order that it could be made to respond to each of these either individually or in pairs. The diode network connecting analyzers A and B to input D provided for "A or B" logic. "A and B" was separated from "A or B" at a later stage by the routing unit.

**Fast coincidence unit.** The Sturrup Model 1440 fast coincidence unit had five inputs each connected to a fast triangular pulse generator, an "and" gate with five "in-out" switches, and a univibrator to generate the output pulse. The "and" gate triggered the univibrator only when all of the triangular pulses for which the corresponding switch was set to the "in" position overlapped except that the fifth pulse was inverted and its presence would inhibit the gate for anti-coincidence operation. There was a potentiometer control on the front of the unit which was coupled to a discriminator that passed only an upper portion
of the triangular pulses. Since the width of the remainder depended upon this discriminator level, the potentiometer controlled the resolving time of the fast coincidence unit.

Plots of coincidence count rate versus the amount of delay added to one of the single channel analyzers yielded resolving time curves like the ones shown in Figure 2. "Resolving time" here refers to what is designated as "2\tau" in the literature, and is the width of the curve at half maximum. Tests of this type using relatively noise free pulses from an Ortec Model 204 pulse generator inserted at the inputs of the main amplifiers showed that the equipment was capable of timing precision approaching 3 or 4 nanoseconds and that resolving times of 8 to 97 nanoseconds were possible under these conditions.

Figure 2 also shows the effect of noise on coincidence timing. The two broadest curves were obtained by connecting the pulse generator to the silicon detector and x-ray detector preamplifier inputs. In all four cases the count rate at the input was 3,600 pulses per minute, but the curves do not reach that number to the extent that some of the timing fluctuations are greater than the resolving time of the fast coincidence unit.

Figure 3 shows coincidence count rate versus relative delay time where the coincidences were between internal conversion electrons via the silicon detector and K x rays in the 1/8-inch scintillation detector from a
Figure 2. --Resolving time curves using pulse generator.
Coincidence counts between 624-keV electrons (Si detector) and 32-keV x rays (Nal detector).

--- Resolving time dial--100 nsec.
--- Resolving time dial-- 50 nsec.

Figure 3. --Resolving time curves using cesium 137.
cesium-137 standard source. In one case the resolving
time dial on the Model 1440 was set at its maximum value,
100 nanoseconds, and for the other curve it was set at 50
nanoseconds. Similar measurements were performed using
unipolar timing and combinations of unipolar and bipolar
timing. The results were nearly identical with bipolar-
bipolar timing having approximately one per cent better
resolution than the other combinations. The capability
of the system was clearly limited by the noise in the
detectors and preamplifiers; therefore, in order to mini­
mize the loss of true coincidence events, all subsequent
data collection was done with the resolving time of the
Model 1440 set at its maximum value.

**Delay amplifier.** The linear signal, that is the
output of one of the RC amplifiers, was delayed by an Or­
tec Model 427 delay amplifier, a module that provided a
gain of approximately unity for any amount of delay from
0 to 4.75 microseconds in 0.25-microsecond increments.
For most experiments a delay of 1.50 microseconds was
necessary to compensate for the time required for the
single channel analyzers and the fast coincidence unit
to complete their logic functions.

**Biased amplifier and pulse stretcher.** The output
of the delay amplifier was connected to a Sturrup Model
1460. This module contained a biased amplifier, a linear gate, and a pulse stretcher.

The biased amplifier would amplify only the portion of a pulse that was above an adjustable discriminator level. The gain settings available were 1, 2, 5, 10, and 20. The result was that a bottom segment of a spectrum could be discarded and the remaining part expanded to fill the channels in the analyzer for examination in greater detail.

The gate in the Model 1460 would pass the linear signal on to the stretcher only during the presence of the output pulse from the fast coincidence unit. The requirement that the linear signal must not precede the fast coincidence output at this point was met by having the delay amplifier in the circuit.

The amplifier built into the pulse-height analyzer was not used after the installation of the Model 1415 RC amplifier in separate nuclear instrument modules. Although the short, fast-rising pulses from the newer amplifiers were advantageous for coincidence timing, they were too short for proper linear operation of the analog to digital converter. The pulse stretcher in the Model 1460 contained circuits which detected the crest of an incoming pulse and maintained that voltage level for 1.25 microseconds. This permitted the converter to perform as desired and maintained the linearity between channel address
in the memory and energy released in the detector.

**Multichannel analyzer.** The RIDL Model 34-12 multichannel analyzer was capable of storing spectra in a 400-channel memory up to $10^5$ counts per channel, or in subgroups of 100 or 200 channels. It also provided for external routing, that is, the subgroup into which any given count is added may be determined by an external signal supplied to one of the BNC connectors for that purpose located on the rear panel of the analyzer.

**Routing unit.** The routing signals were produced by a modified RIDL Model 30-17 mixer-amplifier. Connectors were added to bring the output signals from the single channel analyzers into the routing circuitry while bypassing the built-in amplifiers of the unit. A routing signal would be generated at one of the output terminals of the Model 30-17 only if both the output from the appropriate single channel analyzer and the dead time gate pulse from the multichannel analyzer were present. The latter one occurred only when a pulse reached the analog-to-digital converter, thereby eliminating the generation of routing pulses when coincidence conditions were not satisfied or during the conversion of a previous pulse. It was necessary, therefore, that the outputs of the single channel analyzers remain on long enough for the linear signal to pass through the delay amplifier, the Model 1460, and the initial stages of the
multichannel analyzer. The single channel analyzers were adjusted to give three-microsecond outputs in order to meet this requirement. In the event that a pulse triggered an output in both single channel analyzers A and B (see Figure 1, page 8), then the routing unit would generate an output pulse at D provided that the dead time gate pulse was present also. This prevented the counts of such events from being stored with the others and permitted separate storage and observation of these overlap events if desired. The D output was connected to a blocking input on the multichannel analyzer when it was desired to have the latter reject such pulses of uncertain character.

Readout equipment. The readout of the multichannel analyzer was through a RIDL serial readout unit to an IBM typewriter and a Tally Model 420 paper tape punch.

Additional facilities. There was also a RIDL Model 34-12B 400 channel pulse height analyzer that was used for many of the measurements that did not involve the coincidence equipment. The vertical deflection of the display on its cathode ray tube could be either linear or logarithmic. A Mosely Autograf X-Y recorder that would reproduce semilogarithmic plots of the data was one of readout accessories in addition to an IBM typewriter.

Data could be transferred from the memory core to a magnetic tape with an RIDL Model 52-35 digital magnetic
tape recorder. Data also could be transferred into the memory from either a punched paper tape or a magnetic tape and in either case multiplied by .01, 0.1, 1.0 or 10 during the transfer. These accessories were frequently used for transferring coincidence data by means of punched tape to the Model 34-12B in order to produce a plot of the data on the Autograf. The Autograf could not be used with the other analyzer because it did not have the logarithmic display.

II. DETECTOR AND SAMPLE MOUNTING

Vacuum chamber coincidence apparatus. Figure 4 shows the vacuum chamber built by Gillespie for the silicon detector and the cylindrical extension at the bottom fabricated by this investigator to hold the sample and permit coincidence measurements with the axis of the x-ray detector at either 90° or 180° to the axis of the silicon detector.

Both the bottom and the lateral windows in the aluminum extension were originally machined on a lathe to 0.017 inch. Experiments showed that this thickness absorbed approximately one-third of the 9-keV L x rays from the decay of gold 195. Therefore, when work was begun with this isotope, one-inch holes were drilled in the bottom and one side of the cylinder and covered with aluminum foil. A

A. Lead to preamplifier
B. Potting material
C. Nylon
D. Styrofoam
E. O-ring
F. Brass
G. Dry ice (optional)
H. Steel cylinder
I. Steel cold finger
J. Polyethylene sleeve
K. To vacuum pump
L. Detector
M. Sample
N. Gasket
O. Aluminum
P. Lucite
Q. 0.017 inch (cylindrical) aluminum window
R. 1 inch dia. foil window
S. X-ray detector in 90° position
T. X-ray detector in 180° position
U. 1/8 inch NaI crystal

One-half scale

Figure 4. Sectional view of silicon detector vacuum chamber.
piece of one-mil foil ruptured in a vacuum test situation, and although the break was at a place where the foil had been creased, two-mil foil was selected and glued on with an epoxy cement.

Two x-ray detectors are shown in the diagram to illustrate what is meant by "90°" and "180°" throughout this report. Only one scintillation detector was used in conjunction with the silicon device, and at any given time it was placed at either the 90° position or the 180° position. A wooden jig, not shown in the diagram, was constructed to hold the x-ray detector in either position, and both this jig and a frame holding the silicon detector housing were bolted to a small table. Spacers between a backstop on the jig and the detector were first used to adjust the distance between source and crystal, but later they were replaced by long No. 10 machine screws threaded through the backstop.

During the data collection with gold 195 the arrangement shown in Figure 4 was used, except that the dry ice was omitted. Although the detector was at room temperature, the chamber was evacuated to eliminate energy loss from the 84-keV conversion electrons.

For samarium 145 dry ice was used, and the windows in the aluminum extension were again made thinner to pass the 5.4-keV (promethium) L x rays since approximately 35 per cent absorption occurred in the two-mil aluminum.
Beryllium disks having a thickness of 157 mg/cm$^2$ were available, but tests indicated that they absorbed nearly one-half of the L x rays. Advised that machining beryllium was difficult and hazardous, tests with mylar were conducted as a possible substitute.

One-mil mylar has supported pressure differentials of at least fifty pounds per square inch across holes considerably larger than one inch in diameter, but because the silicon detector was sensitive to visible light, an opaque form of mylar was sought.

Pieces of two-mil black colored mylar laminated with one-mil aluminum were obtained and tested for absorption of x rays with the aluminum intact, with all but a semitransparent layer removed by hot ferric chloride solution, and with essentially all of the aluminum removed. Even the uncoated black mylar absorbed 25 per cent of the x rays compared with 10 per cent for two mils of clear mylar indicating that the dye used in the former contained elements of relatively high atomic number.

The final selection was one-mil clear mylar to support the atmospheric pressure, and for opaqueness, a layer of common black typist's carbon paper held in place by masking tape. The mylar was bonded to the aluminum with a 50-50 mixture by volume of Shell Epon 828 and Thiokol Polymer. The absorption of 5.4-keV x rays in the carbon paper was scarcely measureable.
New coincidence apparatus. A different apparatus, shown in Figure 5, for holding source and detectors during directional coincidence measurements when vacuum operation was not required was constructed in time for use with mercury 203. The new arrangement was less awkward to use than the older one and had far less matter in the vicinity of the source and, therefore, less scattering. It consisted of a 39-inch by 36-inch by 1-inch wooden platform, two lucite detector carriages that pivot about a common axle at the platform's center, a 27-inch square by 13-inch high double corrugated cardboard wall surrounding the detectors and sealed to the platform with opaque black plastic tape, and a corrugated cardboard lid that was removable for access to the apparatus. The carriage for the silicon detector also had a stand to hold a sample upright and centered over the pivot, and both carriages had removable lucite stands that would hold two of the standard 3 1/4-inch by 2 1/2-inch Al, Cu, or Pb absorbers. The centers of the source and detectors were 4 1/2 inches above the platform, and the source to detector distances were variable from 1 to 6 inches. As in the older arrangement the source was placed during coincidence measurements to be at 45° to both detectors and facing away from the x-ray detector so that radiation to it passed through the mylar backing of the source for both the 90° and 180° configurations.

A transistor socket was installed on the end of
Figure 5. -- Lucite directional coincidence assembly.
the FET preamplifier so that the silicon device could be mounted directly on it. The base of a miniature vacuum tube shield was fastened to the end of the preamplifier around the socket and dented inward just enough to hold the silicon detector firmly in place. The BNC connector on the preamplifier was retained to facilitate alternate use with the vacuum chamber as before.

The performances of the silicon detector before and after the socket installation were compared using Cesium 137. No change in performance was detected.

A double shutter was also installed on the end of the preamplifier in order to prevent light from reaching the silicon detector when the lid was removed from the apparatus. A long slender aluminum rod extended from the shutter, along the length of the preamplifier, and through the cardboard wall around the apparatus for controlling the shutter from the outside. The shutter consisted of two moving vanes of black cardboard sandwiched between three layers of black construction paper having 7/8-inch diameter apertures all contained in a 3-inch by 3 1/4-inch paste-board box.

Scintillation detector coincidence apparatus. Finally the x ray-x ray coincidence data from gold 195 and mercury 203 and the gamma-gamma test with cobalt-60 were made with the use of the apparatus shown in Figure 6. The scintillation detectors are mounted 20 inches above a table on
Figure 6. -- Gamma-ray coincidence apparatus.
posts which are clamped to rails in such a way that they can be moved along the rails to vary the source to detector distance. One of the rails is pivoted at the center of the table and can be moved from 90° to 180° with respect to the fixed rail. The sample is held by a clamp on the end of a rod at the same height as the detectors and directly over the pivot. A second fixed rail is fastened to the table at 270° with respect to the first one.

Sample preparation. Each sample was deposited on a disk of aluminized mylar in a method similar to the one described by Gillespie. The coated side of the mylar was glued with colloidal graphite to an aluminum planchet ring having an outer diameter of 2 1/8 inches and an inner diameter of 1 1/2 inches. The graphite and the aluminum layer on the mylar helped prevent the build-up of electrostatic charge in the source due to the emission of electrons. A drop of the radioisotope solution was placed in the center of the disk on the aluminum side and allowed to dry by evaporation. The amount of activity was then gauged with a Geiger counter and more drops were added until the desired amount was obtained.

After the final drying a thin film of zapon was applied over the treated and surrounding areas. Although some investigators use solvents to dilute zapon lacquer---

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in order to get thin films, a different technique was used for all of the samples in this report. A single drop of zapon lacquer thinned only to a syrupy consistency was released onto the surface of a large dish of water where it would usually spread to an area of several square centimeters and begin drying at the edges. The drying was visibly observable due to the wrinkling of the film. Quickly, two pin points were inserted into the inner boundary of the hardened ring, and upon the separation of the pins, the boundary would be torn and the fluid zapon in the center would then spread over several times its original area. Without hesitation, a circular wire loop was raised to make uniform contact with the bottom surface of the film in an area that had not yet hardened. An upward meniscus was maintained to assure positive contact and prevent wrinkling of the film within the ring, but care was exercised that contact with the water was not broken. After hardening, the film was lifted from the water. The excess film outside of the loop would usually cling to the area inside; therefore, it was helpful to be judicious about choosing which side of the loop was separated from the surface of the water first. Frequently, the film would tear upon lifting and the procedure would be repeated. Untorn films were inspected by observing interference patterns in the reflected light. Gold or redish colored areas indicated a thick film and these were discarded. A film
that showed either a blue color or almost no color was placed top side down over the mylar disk where its adhesion was contingent only upon contact. The outer portion of the film that had doubled over was then brushed delicately to the edge of the circle with a ball of wet cotton where the separation of it and the wire loop were done with a knife blade. Tests of these films indicated that they absorbed approximately 500 eV from transmitted electrons.

Cardboard slide boxes were used to contain and protect the samples whenever they were not being used.
CHAPTER II

EXPERIMENTAL PROCEDURE

In the first part of this chapter are the characteristics of the isotopes that were selected for study. Following these are some experiments that were indirectly related to the primary objective of this investigation. The procedure for collecting the coincidence data is then outlined, and finally, before turning to the analysis of the data in Chapter III, the results of a test on the standard isotope for gamma-ray directional correlation, cobalt 60, are included.

I. CHARACTERISTICS OF THE SELECTED ISOTOPES

Selection. The selection of isotopes for use in this study was based on the following criteria:

1. An uncomplicated decay scheme where the majority of transitions to the ground state of the daughter nucleus are from a single level without branching or cascading was desired. This was to minimize the number of different points in the decay where x rays might be generated; and thus, enhance the chances of detecting any directional correlation.
that might be present between a single pair of radiations.

2. The major transition should have a conversion coefficient of at least 0.01, and larger coefficients were greatly preferred.

3. There should be no beta-ray continuum high enough in energy to obscure the observation of the internal conversion electrons.

4. In order that the L x rays would be adequately detected with the equipment available, isotopes with atomic numbers less than fifty were rejected.

5. Other factors of lesser importance were half-life and availability. For the first attempts, at least, the half-life should be between several days and several months. Exceedingly long half-lives would not permit sufficient activity without the sources either being too thick for electron spectroscopy or too large in area for directional precision. Availability refers particularly to the degree of purity obtainable.

The catalog of isotopes by K. Way was examined, and tin 113 and gold 195 were initially selected on the basis of their energy-level diagrams. Later, after it

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became available, the Table of Isotopes\textsuperscript{2} was thoroughly searched, and samarium 145 and mercury 203 were added to the study.

The Nuclear Science and Engineering Corporation supplied the gold 195. The samarium 145 and mercury 203 were purchased from New England Nuclear Corporation. All three had a radiometric purity greater than 99 per cent, and all came in acidic solutions.

The spectra. Figures 7 through 15 show the spectra of the chosen isotopes of samarium, gold, and mercury as measured by the silicon and 1/8-inch sodium iodide devices. The energy level diagrams shown are from the Table of Isotopes.\textsuperscript{3} It should be noted that the left-hand "shoulder" of each of these plots does not represent a characteristic of either the detector or the isotope, but rather the effect of the baseline control in the single channel analyzer.

In Figures 7 and 8 it can be seen that the 5.4-keV L x-ray is not entirely separated from the 10.0-keV iodine-escape peak in spectra taken with the 1/8-inch scintillation detector. The number of escape counts, which are actually K x-ray counts, included within the L x-ray gate

\textsuperscript{2}C. Michael Lederer, Jack M. Hollander, and Isadore Perlman, Table of Isotopes (John Wiley and Sons, Inc., New York, 1967).

\textsuperscript{3}Ibid., pp. 86, 118, and 121.
Figure 7.—Response of 1/8-inch NaI detector to samarium 145.
Figure 8.--"Gating" spectrum of samarium 145 on 1/8-inch NaI detector.
was approximately 14 per cent of the total number of counts in the gate. Their contribution to coincidences with the L x-ray gate can be calculated using the results of coincidences with the K x rays in the K x-ray gate.

In the samarium-145 spectrum taken with the silicon detector, Figure 9, only the 38.6-keV x ray, the 61-keV gamma ray, and 53.6-keV L-conversion electron are discernible. The appearance of the electron peak required the conditions of vacuum and a cooled detector. The 15.8-keV conversion electron is blanketed by the detector noise, and that portion of the spectrum was not recorded. The 31.2-keV Auger electron contributed to the spectrum in the vicinity of channel 42, but its intensity was insufficient to cause a definite peak there.

The energy-level diagram in Figure 10 shows 41 per cent electron capture to the 0.129-MeV level and 58 per cent to the 0.099-MeV level; a situation that is not in good agreement with the first criterion listed on page 37. The older catalog from which gold 195 was selected listed these percentages as 10 and 90 respectively.\(^4\)

The silicon detectors response to gold 195 along with this investigators interpretation of its components are shown in Figure 12. The 99-keV gamma ray was determined by the use of absorbers to reach at its crest about

\(^4\)K. Way, op. cit.
Figure 9.--"Normal" spectrum of samarium 145 on silicon detector.
Figure 10.--Response of 1/4-inch NaI detector to gold 195.
Figure 11.—"Gating" spectrum of gold 195 on 1/8-inch NaI detector.
Figure 12.--"Normal" spectrum of gold 195 on silicon detector.
2 per cent of the total counts in channel 71, and therefore, it was too small to appear in the Figure.

In contrast to gold 195, the energy-level diagram of mercury 203 is almost ideally uncomplicated, and the K- and L-conversion electron peaks are distinctly resolved (See Figures 13-15). The end point of the continuous beta-ray spectrum at 213 keV is greater than the energy of the K-conversion electron, 193.6 keV, but the relative intensities of the two are favorable in the singles spectrum and even more favorable in the coincidence spectra.

II. PRELIMINARY OBSERVATIONS

Calibration and identification of spectral components. Before taking any coincidence data with a new isotope the responses of several detectors to its radiations were carefully determined. Its spectrum was recorded with the silicon and germanium solid state detectors and with the 1/8-inch and 3-inch scintillation crystals. Standard or other familiar sources were used in each case for energy calibration. Following calibration, thin aluminum foils were used to absorb electrons in order that the electromagnetic contribution to the silicon detector's response could be determined. Thicker foils were used with the x-ray detector to verify the nature of the peaks in that detector's response. With gold 195, for example, half-thickness measurements agreed with expected values
Figure 13.--Response of 1/4-inch NaI detector to mercury 203.
Figure 14.—"Gating" spectrum of mercury 203 on 1/8-inch NaI detector.
Figure 15.—"Normal" spectrum of mercury 203 on silicon detector.
for the 9-keV L x ray and the 67-keV K x ray, but the absorption of a peak in the 30-40 keV region corresponded to 67 keV. This demonstrated that most of the counts in the latter peak were iodine-escape events from the K x ray rather than the 31-keV gamma ray transition is platinum 195.

During these preliminary experiments it was determined which conversion electrons could be observed, whether the absorption in air was excessive, and whether cooling the silicon detector was justified. The gold-195 spectrum was measured with a cooled detector, but the small increase in resolution was judged to be not significant. The absorption of the 84-keV conversion electrons in air, however, was very significant. On the other hand, the 54-keV conversion electron from the decay of samarium 145 did not appear as a peak above the continuum between the 39-keV x ray and the 61-keV gamma ray unless the detector was cooled.

Preliminary tests also revealed the presence of a significant concentration of tin 119 in the samples of tin 113. Although the effect of this impurity was very small with respect to the total activity in a singles spectrum measurement, its contribution to a coincidence measurement was relatively large. For this reason, and also because the 3.3-keV L x ray was only marginally detectable, tin 113 was dropped from this study.
Compensation for the geomagnetic field. After taking some coincidence runs with gold 195 it was discovered that certain inconsistencies in the data were related to changes in the gain of the 1/8-inch x-ray detector. The data was discarded and some tests performed which revealed that the gain of the detector depended upon its orientation with respect to the earth's magnetic field. Both the orientation of the detector axis and rotation around its axis influenced the gain. With the detector axis in the 90° position the rotational orientation that yielded the maximum gain was determined, and the detector housing was marked to make that orientation easily repeatable. After moving the detector axis to the 180° position another mark was applied corresponding to a rotation that resulted in a gain less than the maximum possible at 180° but equal to the maximum at 90°. Due attention was given to the complete orientation of the x-ray detector in all subsequent experiments.

III. DATA COLLECTION

Preparation for data collection. In setting up the apparatus for a coincidence measurement first the source and the x-ray detector were placed in their respective mounts. Vacuum and dry ice were then applied, if appropriate, and the bias voltage of the silicon detector was
increased from zero to two hundred volts.\textsuperscript{5}

With only channel C of the fast coincidence unit switched to "in," and with the delay amplifier input switched to "normal," the multichannel analyzer would receive and store the "normal singles spectrum" (see Figure 1, page 8.) Obtaining this spectrum also required adjusting the delays, with the aid of the oscilloscope, to have the signal reach the linear gate while it was open, and, of course, adjusting the gain of the RC amplifier to cause the desired portion of the spectrum to fill 100 channels in the multichannel analyzer.

Although the fast coincidence unit could have been omitted with the gate disabled, all "singles" spectra were recorded in the "self-coincidence" fashion described above. Since during any coincidence measurement the storage of a count from the normal detector would be subject to all of the operating conditions of the single channel analyzer and fast coincidence modules, it was desired to have these same conditions apply during a singles measurement. In other words, when a requirement of coincidence with a pulse from another detector was

\textsuperscript{5}Energy resolution was a slowly varying function of voltage, and this particular bias value for best resolution was determined experimentally by measuring the resolution of the cesium-137 K-conversion electron peak versus detector bias.

A potential of 1400 volts was maintained on the x-ray detectors at all times except during equipment repairs.
added, that was to be the only requirement added. Operating in a self-coincidence mode also permitted the use of the baseline and window width controls of the single channel analyzer to prevent pulses that were either too low, such as noise, or higher in energy than the region of interest from reaching the multichannel unit. The analog-to-digital converter required a time of one-half microseconds per channel and was by far the slowest stage in the entire system. Nonessential pulses were prevented from reaching it whenever feasible.

Similarly, switching the delay amplifier to "gating," having only channel A "in," and adjusting the appropriate gain and delays permitted the storage of the "gating singles spectrum."

With the aid of the live display of spectrum storage on the cathode ray tube of the multichannel analyzer, the baseline and window width controls of single channel analyzer A were adjusted to bracket the L x-ray peak. The portion of the spectrum that was recorded in this manner was referred to as the "L x-ray gate," or simply "gate A." After having adjusted this gate, the gating singles spectrum would be observed by switching a toggle on the single channel analyzer from "window" to "baseline." This removed the upper limit on which pulses would be accepted and permitted the storage of the entire spectrum above the lower edge of the gate without readjusting the controls.
With channel B of the fast coincidence unit "in" and with proper adjustment of the delay control of single channel analyzer B, its baseline and window width controls were then set to bracket the K x-ray portion of the gating spectrum. This portion was referred to as the "K x-ray gate" or "gate B."

With only channel D of the fast coincidence unit "in," and with the multichannel analyzer set for internal routing, both gates A and B would be stored in the same subgroup. When the "store in" control of the multichannel analyzer was set to "external routing," gate A was stored in one subgroup and gate B in another. With the delay amplifier switched to "normal" and both channels C and D "in," external routing caused pulses from the normal detector that were coincident with gate A to be stored in one subgroup and those coincident with gate B to be stored in another.

After the adjustment of the gains and the gates, the optimum relative delay was determined by measuring count rate versus delay setting. Both detectors were moved closer to the source for a higher coincidence count rate. The delay amplifier input was switched to gating so that the number of coincidence events would be stored in relatively few channels rather than spread over the entire "normal" spectrum. Channels C and D were switched "in" and external routing was not used. Therefore, the number of
counts in each gate that were coincident with any event in the normal spectrum were stored within the same subgroup. After ten minutes of storage, the data was typed. The delay setting of single channel analyzer C was changed, and another ten minutes of counts were stored in another subgroup. Plotting the total number of counts in each gate versus delay time aided in finding the relative delay times for maximum coincidence count rates. Delay C was adjusted to the optimum relative delay between B and C, and then delay A was adjusted relative to C.

Repositioning the detectors was the last step in the preparations for taking the directional correlation data. Usually the final source to detector distances were a compromise between having a small solid angle for precise directional information and a large solid angle in order to get statistically significant data in a reasonable amount of time.

The sequence of the data collection. With a few exceptions, the following set of measurements constituted a "coincidence experiment" and were taken in the order given:

1. The normal singles spectrum.
2. The gating singles spectrum at 90°.
4. Simultaneous 90° coincidence with each gate using external routing.
5. The normal singles spectrum at 90°.

7. Gates A and B at 180°. This followed moving the x-ray detector to the 180° position and making small trial and error adjustments in its distance from the source in order to get approximately the same singles count rate as observed in step 6.

8. The gating singles spectrum at 180°.

9. The normal singles spectrum.

10. The 180°-coincidence spectra with each gate.

11. The normal singles spectrum.


13. The "random coincidence spectrum," which was achieved by increasing the delay settings on single channel analyzers A and B by 800 nanoseconds each before making an otherwise regular coincidence measurement.

Singles counts were of 1, 5, or 10 minutes duration and did not vary for a given detector, normal or gating, throughout the thirteen steps. Steps 4 and 10 were usually of 1,000 minutes duration with gold 195 and mercury 203 and of 100 minutes duration with samarium 145.

Several sets began with the x-ray detector at 180° and ended with it at 90°. In some experiments the steps 1 through 12 were repeated one or more times with no adjustment of amplifier gains, detector distances (except as noted in step 7), or detector biases.
While using dry ice with samarium 145, moisture would collect on the lead between the silicon detector and its preamplifier causing a large buildup of leakage current and noise after 10 to 15 hours of operation. This happened in spite of the fact that the volume around the lead wire was filled with potting material and later repotted. It was for this reason that short coincidence measurements were taken and the twelve steps repeated as often as possible in order to divide the usable running time between the two angles. When the spectrum became noticeably distorted from the noise, the silicon detector bias and the dry ice were removed allowing the apparatus to warm up and dry out for about one day.

Step 13 was never included in the samarium measurements, and it was occasionally omitted from the experiments with other isotopes. For the several times that the random coincidence rate was measured, the measured count rate was compared with the calculated random coincidence rate. The two values always agreed to within statistical expectations.

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6 The calculated random coincidence count rate in a group of channels equals the product of the resolving time, the total gate count rate, and the singles count rate of the same group of channels in the normal spectrum.
IV. A TEST

As a test of the technique, two coincidence experiments were done using two 2-inch sodium iodide detectors and a cobalt-60 source. The gates were set on the well known 1.17-MeV and 1.33-MeV gamma rays of nickel 60. The number of counts in the 1.17-MeV peak that were coincident with the 1.33-MeV gate were totaled as were the number of 1.33-MeV counts coincident with the 1.17-MeV gate giving two independent measurements of the same characteristics. The coincidence count totals were corrected for slight differences in solid angles between the 90° and the 180° detector positions, and the number of random coincidences were subtracted. The theoretical ratio of the coincidence rate at 180° to the rate at 90° is 1.17 for these two gamma rays. The average of the four values obtained in this test was 1.12 ± .02.

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CHAPTER III

ANALYSIS OF THE DATA

The raw data obtained in the manner described in the preceding chapter was in the form of typewritten print-out sheets from the multichannel analyzer. These contained series of pairs of numbers, the channel address numbers and the number of "counts" stored in each channel. Although the radiations that resulted in these data were essentially monoergic and the number of different energies included was not large, there was not a simple relationship between the number of particles of a certain type detected and the number of counts in a particular channel or group of channels. A plot of counts versus channel number would show "peaks" corresponding to the energies of the relatively more intense radiations in the spectrum, but the number of counts in any channel within one peak would be in part due to the detection of higher energy particles. The primary reason for this is that in many instances a particle interacts with a detector with part of its energy escaping in the form of x rays, compton photons, or electrons.

If the peaks were not close together, the ratio
of the number of counts due to a higher energy particle to
the number of counts due to a particle corresponding in
energy to a given peak is usually small in a channel close
to the maximum of the peak. But since the object of this
investigation was to compare the number of particles of a
particular type (e.g., K x ray, L-conversion electron, and
so forth) detected "at 180°" with the number detected "at
90°" while assuming that all particles in the coincidence
spectrum might not be equally anisotropic, it was desirable
to have a systematic method of estimating how many of the
counts in a given peak could be attributed to the detec-
tion of particles of the corresponding energy. If the
peaks in the spectrum were not well separated, such a sys-
tem was absolutely essential.

The method used for obtaining this estimate is
described in the following section. Samarium 145 spectra
are used in the discussion for the sake of explicitness.
Figure 16 shows a normal singles spectrum of the samarium
isotope taken with the silicon detector and the components
attributed to that spectrum by this stripping process.

I. SPECTRUM-STRIPPING PROCESS

Plotting the data. Each datum point from a print-
out was first plotted carefully on two-cycle semilog graph
paper. The paper size was eleven inches by fourteen inches,
and it was ruled ten divisions per inch along the axes of
Figure 16. -- Stripping process on $^{145}\text{Sm}$ "normal" singles spectrum.
145\textsuperscript{Sm} NORMAL SINGLES SPECTRUM
ON SILICON DETECTOR. -70\degree C.
1 MINUTE; 3 CENTIMETERS.
RUN / 409,432. 21 MAY 1968
the abscissa. However, two divisions per channel were used rather than one division in order to reduce the slopes of the resulting curves and, thereby, facilitate reading the ordinates of points on the curves. The number of counts, \( n \), in each channel in the region of interest was plotted with a vertical bar extending from \( n - \sqrt{n} \) to \( n + \sqrt{n} \). A separate plot was prepared for each coincidence measurement.

Smooth curves were then drawn through or near the data points. In regions where the numbers of counts were high and, therefore, the statistics were "good," primary emphasis was placed on the smoothness of the curves and on minimizing the deviations between the curves and the raw data. In regions where the numbers of counts were low, emphasis was placed on the shapes and lateral positions of sections of the curves. Fitting curves to the data in cases of "poor" statistics consisted largely in moving sections of curves either up or down, and the lateral position of a peak was determined by its energy unless this was definitely at variance with the raw data.

After a curve was satisfactorily constructed, its ordinate for each channel was determined, and these numbers became the data for the spectrum-stripping operations.

The monoergic curve. From other experiments with the silicon detector where monoergic peaks can be observed
relatively well separated from other radiations, such as the K-conversion electron from mercury 203 measured in coincidence with K x rays, a curve representing the response of the silicon detector to particles of a single energy was derived. The width of the curve and the relative height of the peak with respect to the back-scatter portion were adjusted for a given isotope and series of measurements to be appropriate for the gain and resolution in effect at that time. A sum curve was prepared to represent the detector's response to the composite of Kα and Kβ x rays. The relative intensities of these two components were determined from measurements with the lithium-drifted germanium detector which was capable of resolving them; whereas the silicon detector could not resolve these components.

The stripping process. Starting with the peak of highest energy, the 61 keV gamma ray, the monoergic curve was drawn under the total spectrum curve making the two coincide along the upper right hand portion of the former. The ordinates of the curve representing the gamma ray were determined from the graph and then subtracted from the ordinates of the total spectrum curve, channel by channel. The differences, which constituted a new total-spectrum curve for the remaining peaks were plotted from their high energy extreme to about six channels beyond the energy of the next peak, the 53.6 keV L-conversion electron.
The monoergic curve was then drawn under these new points, causing it to coincide with them along its top and upper righthand portions. The ordinates of the 53.6-keV curve were determined graphically and new difference ordinates computed. The composite K x-ray curve was then fitted to the remainder.

**Precision.** The fact that the three curves could be placed such that the sums of their ordinates did equal the total curve in most cases without any significant numbers of counts "left over" in the regions between the peaks gave confidence in the validity of the procedure. However, any of the curves could be moved or changed by about two per cent and a satisfactory fit could still be obtained. The smaller peaks could be moved even more.

It would require a ten per cent change in the height of the 61-keV peak to effect only a two per cent change in the net height of the 53.6-keV peak due to the placement of the backscatter portion of the 61 keV-peak. Similarly a ten per cent change in the placement of the 53.6-keV peak would alter the height of the K x-ray peak by only one per cent. Therefore, the spectrum-stripping process apparently gave estimates of the numbers of counts attributable to particular particle energies with an accuracy of approximately ninety-eight per cent.
Definition of "net counts." After the K x-ray peak and the L-conversion electron peak were constructed, the sums of the eleven highest ordinates in each of them were computed. Adding the counts of several channels reduced the statistical uncertainty of the results, and restricting the channels used to those having a relatively high number of counts limited the percentage error due to improper placement or shape of the backscatter "tails" of higher energy peaks. The sum for a particular peak was referred to as the number of "net counts" in that peak.

Treatment of the data from the other isotopes. The stripping of the electron-x-ray coincidence spectra of gold 195 was done in essentially the same manner as the samarium spectra. The monoergic curve for the 115.5-keV L-conversion electron was constructed before the construction of the 126-keV M-conversion peak because of the very poor statistics of the latter. The final placement of the monoergic curve for the 95.1-keV M-conversion electron was determined only after one or two trial solutions because of the extent of the overlap from the peaks on both sides. The Kβ x-ray peak was not determined independently of the Kα x-ray, but was fixed at 22 per cent of the height of the latter.

The mercury-203 electron-x-ray coincidence spectra were treated a little differently from the others. The processing of the mercury data was done before the
stripping procedure used with gold and samarium was derived. The two peaks in the mercury-203 spectra were separated so far that the only overlap was backscattered electrons from the L-conversion electron under the K-conversion electron peak. Also under the K-conversion electron peak was part of the continuous beta-ray spectrum. Using a method comparable to that of Gillespie, curves were constructed to represent the portions of the spectra that were caused by the beta-rays and the backscattered electrons under the K-conversion electron peaks and by the backscattered electrons under the L-conversion electron peaks. The "net counts" remaining after these curves were constructed and their ordinates subtracted from the total curve represented the number of events where the total energy of a conversion electron had been absorbed in the active volume of the silicon detector.

X ray-x ray directional correlation experiments were performed with the gold-195 and mercury-203 isotopes using 1/8-inch and 1/4-inch scintillation detectors. Since low energy electrons cannot penetrate the coverings on the sodium-iodide crystals, and because the efficiencies of these thin crystals are high for x rays and moderately low for the higher energy gamma rays, the x ray peaks in the spectra taken with these detectors are high, well defined,

\(^1\)C. M. Gillespie, dissertation, The Ohio State University, 1966, pp. 49-52.
and over relatively low backgrounds. Spectrum-stripping for these experiments consisted in no more than subtracting straight line approximations to the backgrounds and subtracting the number of random coincidence counts.

II. NORMALIZATION

Rationale. If the radioactive source is emitting x rays of a given energy at the rate $R$, and if $P_g$ is the probability that one x ray will enter the scintillation detector and cause a pulse having an amplitude within the limits of the gate settings, then the count rate $G$ in that gate will be

$$G = R P_g.$$ 

$P_g$ is dependent upon several factors such as the thickness of the sodium iodide crystal, the x-ray energy, the source-detector geometry, the width of the gate, the noise level (which affects resolution and the amount of pulse pile up), and so forth. Similarly,

$$N = R P_n$$

will be the count rate of electrons in a given number of channels if the electrons are emitted at the rate $R$ and if $P_n$ is the probability that an electron will produce a pulse in the silicon detector of appropriate amplitude. If the x ray and the electron are emitted in coincidence
at the rate $R$, then the measured coincidence rate $C$ will be

$$C = RP_g P_n W(\theta);$$

where $\theta$ is the angle formed by the detector axes, and $W(\theta)$ is the directional correlation factor. Aside from $W(\theta)$, the product $P_g P_n$ is just the probability that both the x-ray and the electron from a single disintegration will be appropriately registered by their respective detectors.

If $N$, $G$, and $C$ are measured at one time when the probabilities for detection are $P_n$ and $P_g$, if $N^\prime$, $G^\prime$, and $C^\prime$ are subsequently measured when the probabilities are $P_n^\prime$ and $P_g^\prime$, and if $\theta^\prime = \theta$, then

$$\frac{N}{N^\prime} = \left(\frac{P_n}{P_n^\prime}\right),$$

$$\frac{G}{G^\prime} = \left(\frac{P_g}{P_g^\prime}\right),$$

$$\frac{C}{C^\prime} = \left(\frac{P_n}{P_n^\prime}\right)\left(\frac{P_g}{P_g^\prime}\right) = \frac{N}{N^\prime}\frac{G}{G^\prime}.$$  

This assumes that $R$ is constant and that $P_n$ and $P_g$ both have slowly varying time dependences.

**Application.** Before comparing net coincidence counts at different angles, the result

$$C = \frac{N}{N^\prime}\frac{G}{G^\prime}C^\prime$$

was used in the analysis of the data to correct for changes
in the factors that affect \( P_n \) and \( P_g \) (e.g., changes in source-detector distance, drifts in gain, or shifts in gate width). When a coincidence experiment included just one coincidence measurement at each angle, as in three of the gold-195 experiments, \( C' \) was the number of net counts in a peak at 180°. \( N \) was the average of two numbers, the number of normal singles counts in a fixed set of channels before the 90° coincidence measurement and the number of counts in the same channels after the 90° coincidence measurement. \( N' \) was the corresponding average of counts before and after the 180° coincidence measurement. \( G \) and \( G' \) were the averages of the numbers of counts in the gate before and after the 90° coincidence measurement and before and after the 180° coincidence measurement respectively. The number obtained, \( C \), was called the "normalized" number of counts in the peak at 180°. The number of random coincidence counts was subtracted from \( C \) and also from the net counts at 90°. These two differences were then compared in order to determine the amount of anisotropy.

In the experiments that included two or three coincidence measurements at each angle the terms in the last equation were defined differently. Instead of being the average of two singles counts at 90°, \( N \) and \( G \) were rounded-off averages of all the singles counts at both 90° and 180°. \( N' \) and \( G' \) were each the averages of the before and after singles counts accompanying a single coincidence.
measurement, but not necessarily one at 180°. C' and C were the net counts and the "normalized" net counts respectively for a given peak in a given coincidence measurement, either at 90° or at 180°. This procedure resulted in a set of 90° and 180° coincidence counts, each normalized to the averages of the normal singles counts and of the gate counts.

The work sheets in the appendices list the number of gate counts before the coincidence measurement, the number of gate counts after it, the "standard" number (i.e., G, either the 90° average or the average of both 90° and 180° gates), and the "stand./avg." (G/G', the "standard" divided by the average of the other two). Also listed on the work sheets adjacent to each peak are the before and after normal singles counts for that peak (the average of these two is N'), the "standard" normal singles counts (N), and the "ratio" (N/N'). The "normalized" number of counts listed for a given peak is the triple product of:

1) the "net counts" for that peak, 2) the corresponding "ratio," and 3) the gate counts factor, "stand./avg." For example in Plate I, page 92, the number of "net counts" in the L-conversion electron peak is 1,028, the "ratio" is

\[ \frac{4,000}{\frac{1}{2}(4,652 + 3,812)} = 0.9452, \]

and in the caption to the graph is

"stand./avg." = \[ \frac{102,000}{\frac{1}{2}(106,680 + 103,000)} = 0.9729. \]
The number of normalized counts in the peak is

\[(1,028)(0.9452)(0.9729) = 945.\]

The number of random coincidence counts in each case was also "normalized" to the "standard" numbers of net normal singles counts and gate counts. The spectrum-stripping process was used to determine the number of net singles counts in a normal spectrum.
CHAPTER IV

RESULTS AND CONCLUSIONS

As described in Chapter III the analysis of the data was part graphical and part analytical. Reproductions of the work sheets upon which the graphical analyses were performed are shown in the appendixes. Also on these work sheets are the numbers of singles counts connected with each measurement and the ratios of average and "standard" singles counts that were used in the normalization of the data. The random coincidence counts are subtracted from the normalized counts on the work sheets, and the remainders are tabulated in the first section of this chapter.

The definition of the anisotropy $A$,

$$A = \frac{W(180°)}{W(90°)} - 1,$$

is equivalent to

$$A = \frac{C(180°) - \text{random}}{C(90°) - \text{random}} - 1$$

where $W(θ)$ is the directional correlation factor and $C$ is the number of normalized net coincidence counts.\(^1\) The

anisotropies are also included in the tables in this chapter.

The results are summarized in the second section, and then the chapter ends with a few suggestions pertaining to further research in this area.

I. THE RESULTS

Samarium 145. Before calculating the anisotropies in the samarium data, the number of coincidence counts due to K x rays within the L x-ray gate were determined and subtracted from the total number of counts in coincidence with the L x-ray gate. This calculation was simplified by using the normalized coincidence counts and the "standard" numbers of singles counts rather than the pre-normalized numbers.

The method of calculation is explained in the following example: Plate I on page 92 shows 855 L-conversion electrons in coincidence with 102,000 counts per minute in the K x-ray gate. Plate V, page 96, shows 205.7 L-conversion electrons in coincidence with 21,000 counts per minute in the L x-ray gate. The normal singles count rates in these two cases are identical because the measurements were taken simultaneously by using the routing unit. It was graphically estimated that 14 per cent or 2,940 of the 21,000 events in the L x-ray gate were due to the overlap
of the iodine-escape peak with the L x-ray peak. Since 102,000 K x rays per minute result in 855 coincidence counts with L-conversion electrons, 2,940 K x rays per minute should result in

\[
\frac{2,940}{102,000} \times 855 = 0.0288 \times 24.6
\]

coincidence counts. The 24.6 counts are subtracted from 205.7 leaving 181.1 L-conversion electrons in coincidence with L x rays in the L x-ray gate at 180°.

Plate II on page 93 and Plate VI on page 97 show data taken at 90°. In coincidence with the K x-ray gate are 825 counts, and 221.5 L-conversion electrons are in coincidence with the L x-ray gate. In this case

\[
(0.0288) \times 825 = 23.8
\]

counts in coincidence with the L x-ray gate are actually in coincidence with K x rays in that gate. This leaves a remainder of 197.7 L-conversion electrons in coincidence with L x rays at 90°. Any directional correlation involving K x rays is automatically compensated for in this procedure.

Table 1 lists the terms and the results of the calculations for each of the coincidence measurements of samarium 145. The identification of coincidence measurements in Table 1 and in the appendixes are by means of the "run numbers," such as 409,434a, which are the serial numbers
<table>
<thead>
<tr>
<th>Run No.</th>
<th>Ratio of K x rays in L-gate to counts in K-gate</th>
<th>No. of K x-ray counts from silicon detector in coincidence with:</th>
<th>No. of L-conversion electron counts from silicon detector in coincidence with:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>All counts in K-gate</td>
<td>K x rays in L-gate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>counts (2)</td>
<td>counts (3)</td>
</tr>
<tr>
<td>434 A--180°</td>
<td>0.0288</td>
<td>2,770 ± 61</td>
<td>80</td>
</tr>
<tr>
<td>434 A--90°</td>
<td>0.0288</td>
<td>2,835 ± 61</td>
<td>82</td>
</tr>
<tr>
<td>434 B--180°</td>
<td>0.0288</td>
<td>2,829 ± 61</td>
<td>82</td>
</tr>
<tr>
<td>434 B--90°</td>
<td>0.0288</td>
<td>2,930 ± 62</td>
<td>84</td>
</tr>
<tr>
<td>433 A--180°</td>
<td>0.0298</td>
<td>2,954 ± 61</td>
<td>88</td>
</tr>
<tr>
<td>433 A--90°</td>
<td>0.0298</td>
<td>2,903 ± 61</td>
<td>87</td>
</tr>
<tr>
<td>433 B--180°</td>
<td>0.0298</td>
<td>2,983 ± 62</td>
<td>89</td>
</tr>
<tr>
<td>433 B--90°</td>
<td>0.0298</td>
<td>2,952 ± 61</td>
<td>88</td>
</tr>
<tr>
<td>432 A--180°</td>
<td>0.0329</td>
<td>3,088 ± 63</td>
<td>102</td>
</tr>
<tr>
<td>432 A--90°</td>
<td>0.0329</td>
<td>2,945 ± 62</td>
<td>97</td>
</tr>
<tr>
<td>432 B--180°</td>
<td>0.0329</td>
<td>3,049 ± 62</td>
<td>100</td>
</tr>
<tr>
<td>432 B--90°</td>
<td>0.0329</td>
<td>3,067 ± 63</td>
<td>101</td>
</tr>
<tr>
<td>432 C--180°</td>
<td>0.0329</td>
<td>3,027 ± 62</td>
<td>100</td>
</tr>
<tr>
<td>432 C--90°</td>
<td>0.0329</td>
<td>3,122 ± 63</td>
<td>103</td>
</tr>
</tbody>
</table>
of entries in a log for the multichannel analyzer. Further identification within a given run number is in terms of which gate, L x ray or K x ray, was involved and whether the measurement was "at 90°" or "at 180°."

Column 1 in Table 1 is the ratio of the number of K x rays in the L-x ray gate to the number of counts in the K x ray gate. For Run No. 409,434 this is the fraction 2,940/102,000 given in the above example. For Run No. 409,433 the number in column 1 is

\[ 0.14 \times \frac{21,300}{100,000} = 0.0298, \]

and the corresponding fraction for Run No. 409432 is

\[ 0.14 \times \frac{23,500}{100,000} = 0.0329. \]

Columns 2 and 4 in the table are the numbers of normalized net K x-ray counts in coincidence with the K x-ray gate and the L x-ray gate respectively. Column 3 is the product of the numbers in Column 1 and Column 2, and Column 5 is the difference between the numbers in Columns 4 and 3. Columns 6 through 9 pertain to L-conversion electron counts in a fashion identical to the treatment of K x-ray counts in Columns 2 through 5.

The results from the work sheets and from Table 1 are listed in Table 2. For samarium 145 these include K x-ray and L-conversion electron counts in the silicon detector that are in coincidence with gate counts in the
TABLE 2.—Net normalized K x-ray and L-conversion electron counts in the silicon detector spectrum of samarium 145 in coincidence with x-ray counts in the 1/8-inch scintillation detector.

<table>
<thead>
<tr>
<th>Run No. 409</th>
<th>In coincidence with K x-ray gate</th>
<th>In coincidence with L x-ray gate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K x rays</td>
<td>L-conversion electrons</td>
</tr>
<tr>
<td></td>
<td>180°</td>
<td>90°</td>
</tr>
<tr>
<td></td>
<td>--COUNTS--</td>
<td>--COUNTS--</td>
</tr>
<tr>
<td>434A</td>
<td>2,770 ± 61</td>
<td>2,835 ± 61</td>
</tr>
<tr>
<td>434B</td>
<td>2,829 ± 61</td>
<td>2,930 ± 62</td>
</tr>
<tr>
<td>Sub Tot.</td>
<td>5,599 ± 86</td>
<td>5,765 ± 87</td>
</tr>
<tr>
<td>Diff.</td>
<td>-166 ± 122</td>
<td>-36 ± 64</td>
</tr>
<tr>
<td>433A</td>
<td>2,954 ± 61</td>
<td>2,903 ± 61</td>
</tr>
<tr>
<td>433B</td>
<td>2,983 ± 62</td>
<td>2,952 ± 61</td>
</tr>
<tr>
<td>Sub Tot.</td>
<td>5,937 ± 87</td>
<td>5,855 ± 86</td>
</tr>
<tr>
<td>Diff.</td>
<td>82 ± 122</td>
<td>17 ± 68</td>
</tr>
<tr>
<td>432A</td>
<td>3,086 ± 63</td>
<td>2,945 ± 62</td>
</tr>
<tr>
<td>432B</td>
<td>3,049 ± 62</td>
<td>3,067 ± 63</td>
</tr>
<tr>
<td>432C</td>
<td>3,027 ± 62</td>
<td>3,122 ± 63</td>
</tr>
<tr>
<td>Sub Tot.</td>
<td>9,164 ± 108</td>
<td>9,134 ± 109</td>
</tr>
<tr>
<td>Diff.</td>
<td>30 ± 153</td>
<td>28 ± 78</td>
</tr>
<tr>
<td>Total</td>
<td>20,700 ± 163</td>
<td>20,754 ± 164</td>
</tr>
<tr>
<td>Anisotrop.</td>
<td>-0.003 ± 0.011</td>
<td>-0.001 ± 0.019</td>
</tr>
</tbody>
</table>
1/8-inch sodium iodide detector. The differences between the results at 180° and at 90° are included in the table for each complete coincidence experiment to facilitate comparison. The anisotropies were not calculated for each experiment and then averaged because a simple average of this type would give equal weight to each experiment regardless of its degree of statistical uncertainty. Instead, the anisotropy was calculated by subtracting one from the total number of coincidence counts at 180° divided by the total number at 90°.

The error limits shown in Table 2 and elsewhere in this report are the calculated "standard errors" associated with Poisson distributions. If a graphical analysis used in this study had no uncertainty that was independent of the statistical variations in the data, then the error limits in the tables would represent a 68 per cent probability of including the "true value." If the uncertainty of a graphical analysis was completely independent of the statistical variations in the data, then the "standard error" would be approximately 41 per cent larger than the value given since the graphical uncertainties and the original statistical uncertainties are roughly equal in magnitude. The error limits given in the tables would then be interpreted as having only a 48 per cent probability of including the "true values." In fact, the graphical uncertainty is partly dependent upon the statistical nature
of the original data and partly independent of it, and, therefore, the correct interpretation of the error limits given in this report is someplace between these two extremes.

**Gold 195.** Table 3 lists the numbers of L- and M-conversion electron counts in the silicon detector that are coincident with L or K x-ray counts in the 1/8-inch gating detector. The 84.6- and 95.1-keV conversion electrons result from transitions to the ground state from the 98.8-keV level of platinum 195, and the 115.5- and 126-keV conversion electrons are due to transitions to the ground state from the 129-keV level.

The x-ray counts in the 1/4-inch scintillation detector that were in coincidence with x-ray gate counts in the 1/8-inch detector are presented in Table 4. Although the results of Run No. 409,407 are included in the table, they were rejected and not included in the total counts and anisotropy calculation because of their excessive variance with the results of the other coincidence experiments. The cause or causes of this and other inconsistencies in the gold 195 x-ray-x-ray results were not known.

The numbers of coincidence counts listed in Table 4 were taken from the work sheets in the appendixes as were the numbers in the preceding tables. Unlike the others, however, graphical methods were not used to obtain these-
TABLE 3.—Net normalized L- and M-conversion electron counts in the silicon detector spectrum of gold 195 in coincidence with X-ray counts in the 1/8-inch scintillation detector.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>84.6-keV L-c.e.</th>
<th>95.1-keV M-c.e.</th>
<th>115.5-keV L-c.e.</th>
<th>126-keV M-c.e.</th>
</tr>
</thead>
<tbody>
<tr>
<td>409</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>180°</td>
<td>90°</td>
<td>180°</td>
<td>90°</td>
</tr>
<tr>
<td><strong>---COUNTS---</strong></td>
<td><strong>---COUNTS---</strong></td>
<td><strong>---COUNTS---</strong></td>
<td><strong>---COUNTS---</strong></td>
<td><strong>---COUNTS---</strong></td>
</tr>
<tr>
<td>In Coincidence with K X-ray Gate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>401 Diff.</td>
<td>6,704 ± 82 27 ± 116</td>
<td>1,934 ± 44 49 ± 63</td>
<td>164.8 ± 12.9 3.9 ± 18.2</td>
<td>30.4 ± 5.7 31.5 ± 5.8</td>
</tr>
<tr>
<td>400 Diff.</td>
<td>4,907 ± 70 38 ± 99</td>
<td>1,168 ± 34 27 ± 48</td>
<td>73.3 ± 8.8 -7.3 ± 12.7</td>
<td></td>
</tr>
<tr>
<td>389A Diff.</td>
<td>2,020 ± 45 38 ± 99</td>
<td>702 ± 27 27 ± 27</td>
<td>83.3 ± 9.3 91.2 ± 9.7</td>
<td></td>
</tr>
<tr>
<td>388 Sub Tot. Diff.</td>
<td>4,062 ± 64 -80 ± 92</td>
<td>1,369 ± 37 59 ± 53</td>
<td>174.5 ± 13.4 -7.3 ± 19.1</td>
<td></td>
</tr>
<tr>
<td>388 Diff.</td>
<td>1,748 ± 42 1,840 ± 43</td>
<td>516 ± 23 521 ± 23</td>
<td>80.2 ± 9.1 0.4 ± 12.9</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17,421 ± 132 17,528 ± 133</td>
<td>4,987 ± 71 5,073 ± 72</td>
<td>492.8 ± 22.5 503.1 ± 22.8</td>
<td>41.6 ± 6.7 42.8 ± 6.8</td>
</tr>
<tr>
<td>Anisotropy</td>
<td>-0.006 ± 0.011</td>
<td>-0.017 ± 0.020</td>
<td>-0.021 ± 0.063</td>
<td>-0.028 ± 0.218</td>
</tr>
</tbody>
</table>

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## TABLE 3.—Continued

<table>
<thead>
<tr>
<th></th>
<th>84.6-KEV L-C.E.</th>
<th>95.1-KEV M-C.E.</th>
<th>115.5-KEV L-C.E.</th>
<th>126-KEV M-C.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>409-</td>
<td>180° 90°</td>
<td>180° 90°</td>
<td>180° 90°</td>
<td>180° 90°</td>
</tr>
<tr>
<td></td>
<td>COUNTS</td>
<td>COUNTS</td>
<td>COUNTS</td>
<td>COUNTS</td>
</tr>
<tr>
<td>401</td>
<td>8,931 ± 95</td>
<td>9,173 ± 96</td>
<td>1,307 ± 36</td>
<td>1,420 ± 38</td>
</tr>
<tr>
<td></td>
<td>-242 ± 135</td>
<td></td>
<td>-113 ± 52</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>8,055 ± 90</td>
<td>8,463 ± 92</td>
<td>1,210 ± 35</td>
<td>1,217 ± 35</td>
</tr>
<tr>
<td></td>
<td>-408 ± 129</td>
<td>-7 ± 49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>389A</td>
<td>2,654 ± 52</td>
<td>2,783 ± 53</td>
<td>532 ± 23</td>
<td>545 ± 24</td>
</tr>
<tr>
<td></td>
<td>2,678 ± 52</td>
<td>2,712 ± 52</td>
<td>560 ± 24</td>
<td>565 ± 24</td>
</tr>
<tr>
<td></td>
<td>5,332 ± 74</td>
<td>5,495 ± 74</td>
<td>1,092 ± 33</td>
<td>1,110 ± 34</td>
</tr>
<tr>
<td></td>
<td>-163 ± 105</td>
<td>-18 ± 47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>388</td>
<td>2,168 ± 47</td>
<td>2,306 ± 48</td>
<td>264 ± 17</td>
<td>270 ± 17</td>
</tr>
<tr>
<td></td>
<td>-138 ± 67</td>
<td>-6 ± 24</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24,486 ± 157</td>
<td>25,437 ± 160</td>
<td>3,873 ± 62</td>
<td>4,017 ± 64</td>
</tr>
<tr>
<td></td>
<td>3,873 ± 62</td>
<td>4,017 ± 64</td>
<td>1,390.9 ± 37.4</td>
<td>1,505.3 ± 38.9</td>
</tr>
<tr>
<td></td>
<td>96.0 ± 10.2</td>
<td>114.7 ± 10.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.037 ± 0.009</td>
<td>-0.036 ± 0.022</td>
<td>-0.076 ± 0.034</td>
<td>-0.163 ± 0.111</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**In coincidence with L x-ray gate**
TABLE 4.—Net normalized K and L x-ray counts in the 1/4-inch scintillation detector spectrum of gold 195 in coincidence with x-ray counts in the 1/8-inch scintillation detector.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>IN COINCIDENCE WITH K X-RAY GATE</th>
<th>IN COINCIDENCE WITH L X-RAY GATE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K X RAYS</td>
<td>L X RAYS</td>
</tr>
<tr>
<td></td>
<td>180°</td>
<td>90°</td>
</tr>
<tr>
<td>406</td>
<td>18,138 ± 136</td>
<td>18,189 ± 136</td>
</tr>
<tr>
<td>407</td>
<td>25,655 ± 167</td>
<td>23,303 ± 154</td>
</tr>
<tr>
<td>408</td>
<td>12,835 ± 114</td>
<td>12,005 ± 111</td>
</tr>
<tr>
<td>409</td>
<td>26,985 ± 166</td>
<td>26,589 ± 165</td>
</tr>
<tr>
<td>410</td>
<td>11,515 ± 111</td>
<td>11,739 ± 112</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>69,473 ± 267</td>
<td>68,522 ± 266</td>
</tr>
<tr>
<td><strong>Anisotropy</strong></td>
<td>+0.014 ± 0.006</td>
<td>+0.026 ± 0.005</td>
</tr>
</tbody>
</table>

*Not including Run No. 409-407.*
results. The "Gross Counts" that appears beneath an x-ray coincidence peak in Appendix D is the sum of the counts in an arbitrarily selected number of channels at the top of that peak. These sums were determined through the use of the typewritten print-out sheets rather than from a plot of the data.

**Mercury 203.** Table 5 shows the results of the measurements of K- and L-conversion electrons in the silicon detector in coincidence with x rays in the 1/8-inch gating detector. Since electron capture does not occur with this isotope, there were no non-random coincidences between K x rays and L-conversion electrons. K-conversion electrons are in coincidence with L x rays, however, since the L x rays are included in the cascade of photons and Auger electrons that follows a vacancy in the K shell.

The results of the x ray-x ray coincidence experiments using the 1/4-inch (normal) and the 1/8-inch (gating) sodium iodide detectors are listed in Table 6. There are no counts tabulated as being in coincidence with a K x-ray gate in Run No. 409,440 because the delay of the single channel analyzer for the K x-ray gate was improperly set during that experiment.

As in the gold 195 x ray-x ray experiments, the "Gross Counts" were determined from the typewritten print-out sheets. With the mercury 203 x ray-x ray data, shown
TABLE 5.—Net normalized K- and L-conversion electron counts in the silicon detector spectrum of mercury 203 in coincidence with X-ray counts in the 1/8-inch scintillation detector.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>409-</th>
<th>In coincidence with K x-ray gates:</th>
<th>In coincidence with L x-ray gates:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>K-conversion electrons</td>
<td>K-conversion electrons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>180° 90°</td>
<td>180° 90°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>--COUNTS--</td>
<td>--COUNTS--</td>
</tr>
<tr>
<td>446</td>
<td>Diff.</td>
<td>4,135 ± 67</td>
<td>4,088 ± 67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>47 ± 95</td>
<td></td>
</tr>
<tr>
<td>447</td>
<td>Diff.</td>
<td>2,012 ± 46</td>
<td>1,922 ± 45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90 ± 64</td>
<td></td>
</tr>
<tr>
<td>448</td>
<td>Diff.</td>
<td>2,765 ± 54</td>
<td>2,814 ± 54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-49 ± 76</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>8,912 ± 98</td>
<td>8,824 ± 97</td>
</tr>
<tr>
<td>Anisotro.</td>
<td></td>
<td>-0.0100 ± 0.0157</td>
<td></td>
</tr>
</tbody>
</table>
TABLE 6.—Net normalized K and L x-ray counts in the 1/4-inch scintillation detector spectrum of mercury 203 in coincidence with x-ray counts in the 1/8-inch scintillation detector.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>K x rays</th>
<th>L x rays</th>
<th>K x rays</th>
<th>L x rays</th>
</tr>
</thead>
<tbody>
<tr>
<td>440</td>
<td>180⁰</td>
<td>90⁰</td>
<td>180⁰</td>
<td>90⁰</td>
</tr>
<tr>
<td><strong>Counts</strong></td>
<td><strong>Counts</strong></td>
<td><strong>Counts</strong></td>
<td><strong>Counts</strong></td>
<td><strong>Counts</strong></td>
</tr>
<tr>
<td><strong>Diff.</strong></td>
<td><strong>Diff.</strong></td>
<td><strong>Diff.</strong></td>
<td><strong>Diff.</strong></td>
<td><strong>Diff.</strong></td>
</tr>
<tr>
<td>441</td>
<td>3,365 ± 67</td>
<td>3,481 ± 66</td>
<td>9,348 ± 105</td>
<td>8,917 ± 100</td>
</tr>
<tr>
<td>442</td>
<td>3,988 ± 70</td>
<td>3,945 ± 69</td>
<td>11,354 ± 111</td>
<td>10,751 ± 109</td>
</tr>
<tr>
<td>443</td>
<td>3,737 ± 68</td>
<td>3,611 ± 66</td>
<td>10,067 ± 107</td>
<td>9,611 ± 103</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
</tr>
<tr>
<td><strong>Anisot.</strong></td>
<td><strong>Anisot.</strong></td>
<td><strong>Anisot.</strong></td>
<td><strong>Anisot.</strong></td>
<td><strong>Anisot.</strong></td>
</tr>
</tbody>
</table>

*Not measured.*
in Appendix E, a background level, which consisted primarily of compton events, was determined graphically and then subtracted from the number of gross counts.

II. SUMMARY

Several experiments were performed in order to determine the existence of directional correlations involving L and K x rays in the isotopes samarium 145, gold 195, and mercury 203. The anisotropies that were calculated from the results of these experiments serve as measures of the extent of the directional correlations.

The measured values of the anisotropies are summarized in Table 7. The terms "weak," "moderate," "strong," and "none" are relative and are arbitrarily assigned according to the magnitudes of the measured anisotropies and the limits of error. The interpretation of "uncertain" was applied to the 126-keV M-conversion electron results because the total data consisted of relatively few counts. The method used to calculate the error limits might not apply properly to measurements on the order of 20 counts.

It was not possible to make strict generalizations from these results. However, with only four or five exceptions anisotropies involving L x rays were 0.02 or larger, and anisotropies involving K x rays, but not L x rays, were 0.02 or less. Only the case of L x rays in coincidence with L x rays from the decay of gold 195 was
TABLE 7.—Summary of the anisotropies.

<table>
<thead>
<tr>
<th>Gate</th>
<th>Normal</th>
<th>Anisotropy</th>
<th>Interpretation of correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Samarium 145</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K x ray</td>
<td>K x ray</td>
<td>$-0.003 \pm 0.011$</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>L-c.e.</td>
<td>$+0.001 \pm 0.019$</td>
<td>None</td>
</tr>
<tr>
<td>L x ray</td>
<td>K x ray</td>
<td>$+0.015 \pm 0.024$</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>L-c.e.</td>
<td>$-0.047 \pm 0.041$</td>
<td>Weak</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gold 195</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K x ray</td>
<td>K x ray</td>
<td>$+0.014 \pm 0.006$</td>
<td>Weak</td>
</tr>
<tr>
<td></td>
<td>L x ray</td>
<td>$+0.026 \pm 0.005$</td>
<td>Weak</td>
</tr>
<tr>
<td></td>
<td>84.6-keV L-c.e.</td>
<td>$-0.006 \pm 0.011$</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>95.1-keV M-c.e.</td>
<td>$-0.017 \pm 0.020$</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>115.5-keV L-c.e.</td>
<td>$-0.021 \pm 0.063$</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>126.0-keV M-c.e.</td>
<td>$-0.028 \pm 0.218$</td>
<td>Uncertain</td>
</tr>
<tr>
<td>L x ray</td>
<td>K x ray</td>
<td>$+0.019 \pm 0.004$</td>
<td>Weak</td>
</tr>
<tr>
<td></td>
<td>L x ray</td>
<td>$+0.003 \pm 0.010$</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>84.6-keV L-c.e.</td>
<td>$-0.037 \pm 0.009$</td>
<td>Weak</td>
</tr>
<tr>
<td></td>
<td>95.1-keV M-c.e.</td>
<td>$-0.036 \pm 0.022$</td>
<td>Weak</td>
</tr>
<tr>
<td></td>
<td>115.5-keV L-c.e.</td>
<td>$-0.076 \pm 0.034$</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>126.0-keV M-c.e.</td>
<td>$-0.163 \pm 0.111$</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Mercury 203</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K x ray</td>
<td>K x ray</td>
<td>$+0.005 \pm 0.015$</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>L x ray</td>
<td>$+0.051 \pm 0.009$</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>K-c.e.</td>
<td>$+0.010 \pm 0.016$</td>
<td>None</td>
</tr>
<tr>
<td>L x ray</td>
<td>K x ray</td>
<td>$+0.055 \pm 0.006$</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>L x ray</td>
<td>$-0.031 \pm 0.030$</td>
<td>Uncertain</td>
</tr>
<tr>
<td></td>
<td>K-c.e.</td>
<td>$-0.041 \pm 0.025$</td>
<td>Weak</td>
</tr>
<tr>
<td></td>
<td>L-c.e.</td>
<td>$-0.131 \pm 0.037$</td>
<td>Strong</td>
</tr>
</tbody>
</table>
clearly an exception to this generalization. It is apparent from Table 7 that nearly all of the anisotropies that involve an internal conversion electron are negative, which means that the 90° coincidence count rate was higher than the rate at 180°. Nearly all of the correlations between pairs of x rays were positive with the only significant exception being the L x ray-L x ray results from mercury 203.

It should be noted that L x rays in coincidence with K x-ray gate counts and K x rays in coincidence with L x-ray gate counts were two independent and simultaneous measurements of the same physical characteristic. This situation occurred with gold 195 and mercury 203 when two scintillation detectors were employed.

III. SUGGESTIONS FOR FURTHER RESEARCH

Although the experimental apparatus that was used for this study performed the functions that were required, several improvements can be suggested. The most obvious of which is that a detector-source arrangement designed for directional correlation measurements be used instead of one designed for 180° coincidence experiments only. To permit cooling of the detector, a vacuum chamber is necessary, and to minimize the amount of scattering material near the source, the chamber should be relatively large. The distances between the source and the detector must be
variable and the angular position of at least one detector must be variable. Unless the detector for x rays can be placed within the vacuum chamber, the thinnest window that will withstand one atmosphere pressure differential must be used. There must be a means of conducting heat away from the silicon detector, and preferably the first stage of the preamplifier should be cooled also. Provisions for inserting absorbers between source and detector would be useful, and provision for moving the detector without bringing the silicon device to room temperature and releasing the vacuum would make experiments much more manageable. Since coincidence measurements in more than two directions might be desired, the source configuration should be axially symmetric, which probably means rotating the source. The design and construction of such an apparatus would be no minor task.

For work with isotopes where the energy of the internal conversion electrons is not much greater than the x-ray energy, better resolution for electron detection would be helpful. Using a thinner silicon detector would reduce the efficiency for x-ray detection substantially without affecting the detection of electrons.

For lighter elements a capability of detecting lower energy x rays is needed, but a more critical use of the present equipment might extend the lower limit to
about 2.5 or 3.0 keV versus the present limit of about 3.5 or 4.0 keV.

With elements having atomic number $Z$ between 52 and 60 the iodine-escape peak from the K x rays falls under the L x-ray peak, but this could be circumvented by using a solid-state x-ray detector. The germanium-escape peak would produce a similar problem in the vicinity of $Z = 40$. Some solid-state x-ray detectors would resolve the $K_\alpha$ and $K_\beta$ x-ray peaks, and for heavier elements $L_\alpha$ and $L_\beta$ x rays could be resolved also.

The increased resolution that could be achieved through the use of a solid-state x-ray detector would permit expansions of the scopes of research projects such as this one, but their use would be accompanied by significant drawbacks. The solid-state detectors produce a very high rate of low energy noise pulses, and although the discriminators in the single channel analyzers prevent these pulses from getting through the linear gate, the amplifiers and some of the circuitry of the single channel analyzers are exposed to the full noise count rate. This noise causes jitter in the coincidence timing, and it also must be considered in connection with the recovery times of the amplifiers. These problems can be reduced through the use of amplifiers with "base-line recovery" circuits, by cooling the input stage of the preamplifier, and possibly by refinements in the development of solid-state detectors.
IV. CONCLUSIONS

Directional correlations were found to exist between the following pairs of radiations:

I. The promethium 145 (daughter of samarium 145) L x ray and the L-conversion electron.

II. The platinum 195 (gold 195) K x ray and the K x ray.

III. The platinum 145 L x ray and
   A. The K x ray.
   B. The 84.6-keV L-conversion electron.
   C. The 95.1-keV M-conversion electron.
   D. The 115.5-keV L-conversion electron.

IV. The thallium 203 (mercury 203) L x ray and
   A. The K x ray.
   B. The K-conversion electron.
   C. The L-conversion electron.

Within the limits of precision of these experiments directional correlations were found not to exist between the following pairs of radiations:

I. The promethium 145 K x ray and
   A. The K x ray.
   B. The L x ray.
   C. The L-conversion electron.

II. The platinum-195 K x ray and
   A. The 84.6-keV L-conversion electron.
   B. The 95.1-keV M-conversion electron.
C. The 115.5-keV L-conversion electron.

III. The platinum-195 L x ray and the L x ray.

IV. The thallium-203 K x ray and
   A. The K x ray.
   B. The K-conversion electron.

The data obtained was considered inconclusive for the purpose of determining directional correlations between:

I. The platinum-195 126-keV M-conversion electron and
   A. The K x ray.
   B. The L x ray.

II. The thallium-203 L x ray and the L x ray.

Since this investigation employed both scintillation and solid-state particle detectors, some conclusions were reached in regard to the advantages and disadvantages of both types for use in this kind of research problem. Some of the requirements of the apparatus that would be useful for further research on the question of directional correlations involving x rays and internal conversion electrons were also stated.
APPENDIX A.

Samarium 145 electron-x ray work sheets.
Coincidence spectra and coincidence and singles data from the lithium-drifted silicon detector (normal) and the 1/8-inch sodium iodide detector (gating).

Plates I-XXVIII.
Run 409, 434a. 25 May 1962.

135 Ba, Si detector spectrum in coincidence with K x-ray at 180°, 100 minutes.

Dist: Si—3 cm, NaI—7 cm.
Counts in gate: Before—106,680,
After—103,006, Standard—208,000.

Stand./avg. = 0.9789
Run #495,434a. 25 May 1966.

245Sm: 31 detector spectrum in coincidence with K x ray at 90°, 166 minutes.

Dist: 31--3 cm, NaI--7 cm.
Stand./Avg.--6.5622

PLATE II
Run 0: 409,434a. 25 May 1968.
145 em. Si detector spectrum
in coincidence with K x ray
at 90°, 100 minutes.

Dist: Si--3 cm, NaI--7 cm.
Counts in gate: Before--107,884,
After--99,515, Standard--108,000.
Stand./Avg.--0.9836
PLATE VII

Run # 409,434b. 25 May 1968.
180 cm; Si detector spectrum in coincidence with L x ray at 180°, 100 minutes.
Dist: Si—3 cm, NaI—7 cm.
Counts in gate: Before—23,394,
After—20,368, Standard—21,000.
Stand./Avg.—c. 9600
Run # 409,433a. 23 May 1968.

$^{145}$Sm; Si detector spectrum in coincidence with x-ray at $90^\circ$, 100 minutes.

Dist: Si--3 cm, NaI--7 cm.
Counts in gate: Before--100,408,
After--99,799, Standard--100,000.
Stand./Avg.--0.9990
Run # 409, 439b. 23 May 1968.
145Sm; Si detector spectrum
in coincidence with x-ray
at 180°, 100 minutes.

Dist: S1—3 cm, S2—7 cm.
Counts in gate: Before—101,396,
After—94,603, Standard—100,000.
Stand./Avg.—1.0204

PLATE XI
Run # 409,433b. 23 May 1968.

146m, 81 detector spectrum
in coincidence with L x ray
at 90°, 100 minutes.

Dist: 81--3 cm, H11--7 cm.
Counts in gate: Before--41,416,
Stand./avg.--0.9998

PLATE XIV
Run # 409,433a, 23 May 1966.
145Sm; Si detector spectrum in coincidence with L x ray at 180°, 160 minutes.
Dist: S1--3 cm, H1--7 cm.
Counts in gate: Before=21,603,
After=21,581, Standard=21,300.
Stand./Avg. = 0.9665
Run # 409, 432a, 23 May 1968.
125\text{cm}; SI detector spectrum in coincidence with L x ray at 90°, 10C minutes.

Dist: SI-3 cm, Mal-7 cm.
Counts in gate: Before--80,732, after--21,374, standard--21,300,
Stand./avg.:--1.0177
Run # 409.432a. 21 May 1968.

145 Sm; Si detector spectrum
in coincidence with K x ray
at 180°, 100 minutes.

Dist: 81--3 cm. Wa1--7 cm.
Counts in gate: Before--100,995,
After--100,710, Standard--100,000.
Stand./avg.--0.9916
Run # 409,432a. 21 May 1968.
145 cm; Si detector spectrum in coincidence with a ray at 90°, 100 minutes.
Dist: Si—3 cm, H基金—7 cm.
Counts in gates: Before—100,866, After—100,894, Standard—100,000.
Stand./Avg.—0.9913

PLATE XVIII
Run # 409.45Kb. 21 May 1968.

145\text{mBq} Sr detector spectrum
in coincidence with X-ray
at 180°, 100 minutes.

Dist: 31--7 cm.  61--7 cm.
Counts in gate: Before--101, 180,
After--100, 561, Standard--100,000.
Stand./Avg.--0.0014

PLATE XIX
Run # 409, 437b, 21 May 1968.
113mCm: Si detector spectrum in coincidence with X-ray at 90°, 100 minutes.

Dist: Si-3 cm, NaI-7 cm.
Counts in gate: Before--101,168, After--98,298, Standard--100,000.
Stand./Avg.--1.0087

PLATE XX
Run # 409,438c.  22 May 1968.
135Cs; Si detector spectrum
in coincidence with K x ray
at 180°, 100 minutes.

Dist: Si—3 cm, NaI—7 cm.
Counts in gate: Before—100,460,
After—100,250, Standard—100,000.
Stand./Avg.—0.9965
Plate XXVIII

Run 8409. 329 cr. 22 May 1968.

185 Day 31 detector spectrum in coincidence with X-ray at 90°, 100 minutes.

SL: Si—5 cm, Al—7 cm.

Counts in gate: Before—83,600, after—83,063, Standard—83,500,

Stand./Avg.—1.0140
APPENDIX B.

Gold 195 electron-x ray work sheets. Coincidence spectra and coincidence and singles data from the lithium-drifted silicon detector (normal) and the 1/8-inch sodium iodide detector (gating).

Plates XXIX-XLVIII.
PLATE XXXII

195 Au: Si detector spectrum
in coincidence with 1 x ray
at 90°. 1000 minutes.

Dist: 81-9 cm. NaI-9 cm.
Counts in gate: Before—5637,
After—5318, Standard—5374.
Stand./Avg.—1.0000
SINGLES

Before 9760 After 9765
STAND. 9760 RATIO 1.0000

SINGLES

Before 2295 After 2295
STAND. 2295 RATIO 1.0000

Run # 46940. 6 Dec. 1967.
195 Au; 51 detector spectrum
in coincidence with K x ray
at 90°, 1000 minutes.

Dist: 51--2 cm, Bal--9.5 cm.
Counts in gate: Before--10,075,
After--10,035, Standard--10,050.
Stand./Avg.--1.0000

Plate XXXIV
Run #409,400. 6 Dec. 1967.
100 Au, 51 detector spectrum in coincidence with 1 x ray at 180°, 1000 minutes.

Dist: 51—8 cm, Bal—9.5 cm.
Counts in gates: Before—5787, After—5647, Standard—5610.
Stand./avg.—0.9654

PLATE XXXV
PLATE XXXVII

Run on 409-389m, 14 Sept. 1967

155Au: Si detector spectrum

In coincidence with X ray
at 180°, 1000 minutes.

Dist: Si—3 cm, NaI—8 cm.
Counts in gate: Before—157,886,
After—168,616, Standard—178,915.

Stand./Avg.—1.066

PLATE XXXVII
Run # 496.38; Dec. 13, 1967

\( ^{195} \text{Au} \); Si detector spectrum

in coincidence with X-ray

at 90°, 1000 minutes.

Dist: 31--3 cm, Kal: 8 cm.

Counts in gate: Before--194,850,

After--192,870, Standard--179,915.

Stand./Avg.--0.9410

PLATE XXXVIII
Run: 8, 9, 36, 6, 1 Dec. 1967

Selected detector spectrum in coincidence with K x-ray at 204, 400 minutes.

D: Si-3 cm, NaI-6 cm.

Counts in gate: Before--162,616;

After--165,516, Standard--172,515.

Stand./Avg. --1.053

PLATE XXXIX
Run # 400,389b. 17 Dec. 1967
195 Au; Si detector spectrum
in coincidence with X-ray
at 90°, 1000 minutes.

Dist: 81 -- 3 cm, NaI -- 8 cm.
Counts in gate: Before -- 156,670,
After -- 164,604, Standard -- 178,915.
Stand./Avg. -- 0.9846

PLATE XL
Hun # tc<,,36£« 25 Aug. 1567.

In coincidence with K x-ray at 160°, 1.64 minutes.

Counts in gate before: 52,555.
Counts in gate after: 52,651.

Standard: 56,166

Before: 52,555

Plate LXV
Run # 409,386. 26 Aug. 1967.

\[ ^{195} \text{Au; Si detector spectrum in coincidence with } k \text{ x ray at } 90^\circ, \text{ 1000 minutes.} \]

Dist: Si—3 cm, NaI—9 cm.
Counts in gate: Before—57,109, After—55,267, Standard—56,188.
Stand./Avg.—1.0000

PLATE XLVI

\( ^{195} \text{Au} \); Si detector spectrum

in coincidence with L \( \alpha \) ray

at \( 180^\circ \), 1000 minutes.

Dist: Si--3 cm, NaI--9 cm.

Counts in gate: Before--23,956,


Stand./Avg.----0.9929

**SINGLES**

**BEFORE** 1047 **AFTER** 1047

**STAND. 1047** **RATIO** 0.9746

**CHANNEL**

**221** NET CTR.

**2.174** NORMALIZED

**2.184 RANDONS**

**2.191**

**STAND.**

**CHANNEL**

**231** NET CTR.

**2.315** NORMALIZED

**2.316 RANDONS**

**2.317**

**STAND.**

**CHANNEL**

**271** NET CTR.

**2.715** NORMALIZED

**2.716 RANDONS**

**2.717**

**STAND.**

**CHANNEL**

**517** NET CTR.

**5.175** NORMALIZED

**5.176 RANDONS**

**5.177**

**STAND.**

**CHANNEL**

**PLATE XLVII**

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APPENDIX C.

Mercury 203 electron-x ray work sheets. Coincidence spectra and coincidence and singles data from the lithium-drifted silicon detector (normal) and the 1/8-inch sodium iodide detector (gating).

Plates XLIX-LX.
Run # 409,446, 26 July 1968.
203Rn: Si detector spectrum in coincidence with x ray at 180°, 1000 minutes.

Dist: Si--3 cm, NaI--6.5 cm.
Counts in gate: before--14,713,
After--13,786, Standard--13,118
Stand./Avg. --0.9806
20388: Si detector spectrum in coincidence with K x-ray at 90°, 1000 minutes.

Distance: Si--3 cm, NaI--6.5 cm.
Counts in gate: Before--12,179, After--11,794, Standard--13,118.
Stand./Avg.--1.0944

2C3_n: Si detector spectrum in coincidence with L x ray at 180°, 1000 minutes.

Dist: Si--3 cm, NaI--6.5 cm.
Stand./Avg.--0.9236

PLATE LI
Run # 409, 446. 25 July 1966.

203Hg: S1 detector spectrum in coincidence with L x ray at 90°. 1000 minutes.

Dist: S1—3 cm, NaI—6.5 cm.
Stand./Avg.—1.078C

PLATE LII
Run # 409.447. 27 July 1966.
20.3 mCi, 51 detector spectrum
in coincidence with L x ray
at 180°, 1000 minutes.

Dist: Si--5.5 cm, NaI--7 cm.
Counts in gate: Before--6012,
After--5641, Standard--5968.
Stand./avg.--1.006

---

PLATE LV
Run 409,447. 28 July 1966.

Si detector spectrum in coincidence with L x ray at 90°. 1000 minutes.

Dist: Si—5.5 cm, NaI—7 cm.
Counts in gate: Before—6025,
After—5965, Standard—5960.
Stand./avg. — 0.9994

PLATE LVI
Run # 609,440. 1 Aug. 1968.
Si detector spectrum
in coincidence with K x ray
at 180°, 1000 minutes.

Dist: Si -- 6 cm, NaI -- 8 cm.
Counts in gate: Before -- 10,660,
After -- 10,963, Standard -- 10,001.
Stand./avg. -- 0.9560
Run # 4:9,446. 2 Aug. 1968.
203Ag; Si detector spectrum
in coincidence with K X ray
at 90°, 1000 minutes.

Dist: Si--6 cm, NaI--6 cm.
Counts in gate: Before--9619,
After--9262, Standard--10,601.
Stand./Avg.--1.0463

PLATE LVIII
Run # 409.448. 1 Aug. 1966.

203Hg: Si detector spectrum in coincidence with L x ray at 90°, 1000 minutes.

Dist: Si--6 cm, NaI--8 cm.
Counts in gate, Before--4511, After--4511, Standard--4736.
Stand./Avg.--1.0363

PLATE LX
APPENDIX D.

Gold $^{195}$ x-ray-x ray work sheets. Coincidence spectra and coincidence and singles data from the 1/4-inch sodium iodide detector (normal) and the 1/8-inch sodium iodide detector (gating).

Plates LXI-LXXX.
Run # 409,406. 26 Dec. 1967

40 Na I spectrum of 195 Au in
coincidence with K x rays at
180°, 100 minutes. Dist: 3 in.
Na I—5 cm, 1/8 Na I—5.5 cm.

Counts in gate: Before—26,106;
After—25,006; Stand.—27,587.5
Stand./Avg.—1.0795

Gross Cts. 23,828
Normalized 25,855
Random 103

25,752 ± 161
9.4-keV L x-ray
Singles counts
Before 22,479
After 22,265
Stand. 22,372
Ratio 1.0000

Run # 409,406. 26 Dec. 1967
1/4" NaI spectrum of 195Au in
coincidence with K x-rays at
90°, 100 minutes. Dist: 1/2" NaI=5 cm; 1/8" NaI=5.5 cm.
Counts in gate: Before=26,678,
After=28,497, Stand.=27,587.5
Stand./Avg.=1.0000

67-keV K x-ray
Singles counts
Before 38,151
After 38,289
Stand. 38,220
Ratio 1.0000

Gross Ct. 25,012
Normalized 25,012
Random 103
24,909 ± 158

Gross Ct. 18,365
Normalized 18,365
Random 176
18,189 ± 136
Run f 409,406. 26 Dec. 1967
\( \frac{1}{4} \) NaI spectrum of 195Au in coincidence with L x-rays at 180°, 100 minutes. Dist: \( \frac{1}{4} \) NaI--5 cm, 1/8 NaI--5.5 cm.

Counts in gate: Before--23,007, After--22,861, Stand.--25,040.
Stand/Avg.--1.0918

67-keV K X-ray
Singles counts
Before 37,807
After 38,288
Stand 38,220
Ratio 1.0045
Run #409406, 26 Dec. 1967
1st NaI spectrum of 195Au in coincidence with L x-rays at 90°, 100 minutes. Dist: 1" NaI=5 cm, 1/8" NaI=5.5 cm.

Counts in gate: Before=24,747, After=25,333, Stand.=25,040. Stand./Avg.=1.0000

9.4 keV L x-ray
Singles counts
Before 22,479
After 22,265
Stand. 22,372
Ratio 1.0000

67 keV K x-ray
Singles counts
Before 38,215
After 38,289
Stand. 38,220
Ratio 1.0000

Gross Cs. 44,577
Normalized 44,577
Random 160
44,417 ± 212

Gross Cs. 6,131
Normalized 6,131
Random 93
6,038 ± 79
9.4-keV L x-ray
Singles counts
Before 21,086
After 20,740
Stand. 20,118.5
Ratio 0.9620

67-keV K x-ray
Singles counts
Before 36,268
After 35,277
Stand. 37,456.5
Ratio 1.0471

Counts in gate: Before—31,719,
After—31,911; Stand.---33,789.5
Stand./Avg.---1.0621
9.4-keV L x-ray
Singles counts
Before 20,153
After 20,084
Stand. 20,118.5
Ratio 1.0000

67-keV K x-ray
Singles counts
Before 37,451
After 37,462
Stand. 37,456.5
Ratio 1.0000

Run #409,407. 27 Dec. 1967
1/2" NaI spectrum of 195Au in coincidence with K x-rays at 90°, 100 minutes. Dist: 1/2" NaI—5 cm, 1/8" NaI—5 cm.

Counts in gate: Before—33,354, After—34,225, Stand.—33,769.5
Stand./Avg.—1.0000

Gross Ct. 23,514
Normalized 23,514
Random 211

23,303 ± 154
Run # 409,407. 27 Dec. 1967

\[ \begin{array}{ll}
\text{9.4-keV L x ray} & \\
\text{Singles counts} & \\
\text{Before} & 21,086 \\
\text{After} & 20,740 \\
\text{Stand.} & 20,118.5 \\
\text{Ratio} & 0.9620 \\
\end{array} \]

\[ \begin{array}{ll}
\text{67-keV K x ray} & \\
\text{Singles counts} & \\
\text{Before} & 36,268 \\
\text{After} & 35,277 \\
\text{Stand.} & 37,456.5 \\
\text{Ratio} & 1.0471 \\
\end{array} \]

Counts in gate: Before - 23,750, After - 23,712, Stand. - 25,017.

Gross Count, Normalized 7,743
Random 84
7,768 ± 89

Gross Count 51,700
Normalized 57,067
Random 156
56,917 ± 239

PLATE LXVII
Run #409,407, 27 Dec. 1967
\( \frac{3}{4} \) NaI spectrum of \( ^{195}\text{Au} \) in coincidence with \( \text{L x rays} \) at
90°, 100 minutes. Dist: \( \frac{3}{4} \) m
NaI--5 cm, 1/8 m NaI--5 cm.

Counts in gate: Before--25,014,
After--25,017.
Stand./Avg. = 1,0000

Gross Ct. 6,639
Normalized 6,639
Random 84
\( \frac{6,555 \pm 82}{5,093 \pm 213} \)
Run # 409,408, 1 Jan. 1968

$^{195}$Au spectrum of NaI in coincidence with K x-rays at 180°, 100 minutes. Dist: 3° NaI—5 cm, 1/8° NaI—5 cm.

Counts in gate: Before—28,684, After—26,144, Stand.—29,958.5

Ratios:
- 9.4-keV L x-ray:
  - Before: 13,743
  - After: 13,872
  - Stand.: 13,556
  - Ratio: 0.9618

- 67-keV K x-ray:
  - Before: 36,368
  - After: 35,277
  - Stand.: 37,456.5
  - Ratio: 1.0471

Gross Cts.
- 9.4-keV L x-ray: 15,718
- 67-keV K x-ray: 11,775

Normalized:
- 9.4-keV L x-ray: 16,864
- 67-keV K x-ray: 12,965

Random:
- 9.4-keV L x-ray: 68
- 67-keV K x-ray: 130

Random Error:
- 9.4-keV L x-ray: $\pm 130$
- 67-keV K x-ray: $12,835 \pm 114$
9.4-keV L x-ray
Singles counts
Before 13,520
After 13,592
Stand. 13,556
Ratio 1.0000

Run # 409,408. 1 Jan, 1968
\( \frac{1}{4} \) NaI spectrum of \(^{195}\)Au in coincidence with K x rays at 90°, 100 minutes. Dist: \( \frac{1}{4} \) NaI=5 cm, \( \frac{1}{8} \) NaI=5 cm.

Counts in gate: Before=29,968,
After=29,949, Stand.=29,958.5
Stand./Avg.=1.0000

67-keV K x-ray
Singles counts
Before 26,121
After 25,966
Stand. 26,043.5
Ratio 1.0000

Gross Ct. 12,135
Normalized 12,135
Random 130
\( 12,005 \pm 111 \)

Gross Ct. 16,229
Normalized 16,229
Random 58
\( 16,181 \pm 128 \)
Run 409,408, 1 Jan. 1968
3rd NaI spectrum of 198Au in coincidence with L x rays at 180°, 100 minutes. Dist: 3NaI—5 cm, 1/8 NaI—5 cm.

Counts in gate: Before—21,977, After—21,993, Stand.—22,300.
Stand./Avg.—1.0143

9.4-keV L x ray
Singles counts
Before 13,743
After 13,872
Stand. 13,556
Ratio 0.9818

67-keV K x ray
Singles counts
Before 36,268
After 35,277
Stand. 37,456.5
Ratio 1.0471

Gross Ct. 24,567
Normalized 25,107
Random 97

Gross Ct. 3,621
Normalized 3,606
Random 50

0 20 40 CHANNEL NO.

PLATE LXXI
Run # 409,408, 1 JAN. 1968
NaI spectrum of 195Au in coincidence with L x rays at 90°, 100 minutes. Dist: 1/4
NaI—5 cm, 1/8 NaI—5 cm.

9.4-keV L x-ray
Singles counts
Before 13,520
After 13,592
Stand. 13,556
Ratio 1.0000

Counts in gate: Before—22,280,
After—22,320, Stand—22,300.
Stand/Avg—1.0000

67-keV K x-ray
Singles counts
Before 26,121
After 25,966
Stand. 26,043.5
Ratio 1.0000

Gross Ct. 23,859
Normalized 23,859
Random 97
\[ \frac{23,782}{155} = 155 \]
Run # 409,409, 5 Jan. 1968

\[ \text{NaI spectrum of } ^{195}\text{Au in coincidence with K x rays at 180°, 100 minutes. Dist: } \frac{1}{4}\text{° NaI—4.5 cm, } \frac{1}{8}\text{° NaI—5 cm.} \]

Counts in gate: Before—39,726, 
After—39,713, Stand—38,541. 
Stand./Avg.—0.9731

\[ \begin{align*}
\text{Counts} \\
\text{Gross} & : 28,877 \\
\text{Normalized} & : 27,255 \\
\text{Random} & : 270 \\
\text{Stand.} & : 26,985 \pm 166
\end{align*} \]
Run # 409,409, 5 Jan. 1968
\( \frac{1}{4} \text{NaI spectrum of }^{195} \text{Au in coincidence with } K \text{ x rays at}
90^\circ, 100 \text{ minutes. Dist: } \frac{1}{2} \text{ cm. NaI—}4.5 \text{ cm, } \frac{1}{8} \text{ NaI—}5 \text{ cm.}

Counts in gate: Before—38,714,
After—38,368, Stand.—38,541.
Stand./Avg.—1,0000

Gross Cts. 26,659
Normalized 26,659
Random 270

\frac{39,393 \times 199}{26,589 \times 165}
Run #409, 5 Jan. 1968
1/4" NaI spectrum of 795 Au in coincidence with K X rays at 180°, 100 minutes. Dist: 1/4" NaI=5 cm, 1/8" NaI=6 cm.
Counts in gate: Before = 32,554, After = 33,116, Stand. = 32,409. Stand./Avg. = 0.9870

67-keV K X ray
Singles counts
Before = 43,103
After = 43,183
Stand. = 41,966.5
Ratio = 0.9727

Gross Cts. = 10,005
Normalized = 9,610
Random = 123

Gross Cts. = 67,670
Normalized = 64,970
Random = 227

\[
\frac{9,487 \pm 99}{9,487} = 1.000
\]
Run #409,409, 5 Jan. 1968
1/4 NaI spectrum of 195Au in coincidence with L x rays at 90°, 100 minutes. Dist: 3
NaI—4.5 cm, 1/4 NaI—5 cm.
Stand./Avg.—1.0000

Gross Cts. 52,963
Normal 9,633
Random 123
\[ 9,510 \pm 99 \]
Run #409,410, 11 Jan. 1968

$^{199}$Au spectrum of $K$ x rays in coincidence with $K$ x rays at 180°. Composite of four 200 minute measurements alternated with 90° coincidence measurements. Dist: $\frac{1}{8}$ \( \text{NaI} \rightarrow 7 \text{ cm}, \frac{1}{8} \text{ NaI} \rightarrow 7 \text{ cm} \).

Counts in gate: Total—148,842, Standard—146,630, Stand./Avg.—0.985

Gross Cts. 13,015
Normalized 13,001
Random 224
$12,777 \pm 115$

67-keV K x-ray

Singles counts
Before Total 140,284
After
Stand. 140,662
Ratio 1.0027

Gross Cts. 12,093
Normalized 11,945
Random 430
$11,515 \pm 111$
Run # 409,410, 11 Jan. 1968
\( \frac{1}{2} \) NaI spectrum of 195Au in coincidence with K x rays at 90\(^\circ\).
Composite of four 200 minute measurements alternated with 180\(^\circ\) coincidence measurements. Dist: \( \frac{1}{2} \) NaI—7 cm, 7/8 NaI—11 cm.

Counts in gate: Total—146,630, Standard—146,630,
Standard/Avg.—1.0000

Gross Ct. 12,169
Normalized 12,169
Random 430
11,739 ± 112
Run #409,410. 11 Jan. 1968
\( \frac{1}{3} \text{ NaI spectrum of } ^{198}\text{Au} \) in coincidence with L x rays at 180°. Composite of four 200 minute measurements alternated with 90° coincidence measurements. Dist: \( \frac{1}{3} \text{ NaI}=7 \text{ cm}, \frac{1}{8} \text{ NaI}=7 \text{ cm}. \)

Counts in gate: Total = 128,275,
Standard = 126,917,
Stand./Avg. = 0.9894

Counts

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67-keV K x-ray
Singles counts
Before: Total = 140,284
After: Total = 140,462
Ratio = 1.0027

Gross Cts.
Normalized
Random
Run #409,410, 11 Jan., 1968
1/4 NaI spectrum of 195 Au in coincidence with L x-rays at 90°; Composite of four 200 minute measurements alternated with 180° coincidence measurements. Dist: 1/4 NaI = 7 cm, 1/8 NaI = 7 cm.

Counts in gate: Total = 126,917, Standard = 126,917.

Gross Cts. 24,898
Normalized 24,898
Random 372

= 24,526 ± 160
APPENDIX E.

Mercury 203 x ray-x ray work sheets. Coincidence spectra and coincidence and singles data from the 1/4-inch sodium iodide detector (normal) and the 1/8-inch sodium iodide detector (gating).

Plates LXXXI-XCIV.
Run #: 409,440, 5 July 1968
\( \frac{1}{3} \) NaI spectrum of 203Hg in coincidence with L x-rays at 180°, 800 minutes. Dist: \( \frac{1}{3} \) NaI—9 cm, \( \frac{1}{8} \) NaI—9 cm.

Counts in gate: Before—6,488, After—6,478, Standard—6,511.5
Stand./Avg. = 1.0044

---

10-keV L x-ray
Singles counts
Before 7,810
After 7,388.5
Stand. 7,810
Ratio 0.9864

73-keV K x-ray
Singles counts
Before 16,269
After 16,332
Stand. 16,720.5
Ratio 1.0258

---

Gross Cts. 1,281
Background 600
Net Counts 681
Normalized 675
Random 64

611 ± 37

---

Gross Cts. 13,140
Background 500
Net Counts 12,640
Normalized 13,023
Random 143

12,880 ± 115

---

PLATE LXXXI
Run #: 409,440. 6 July 1968
1/8" NaI spectrum of 203Hg in coincidence with L x ray at 90°, 800 minutes. Dist: 1/8" NaI--9 cm., 1/8" NaI--9 cm.

Counts in gate: Before--6,649, After--6,374, Standard--6,511.5

Stand./Avg.=1.0000

Gross Cts. 1,352
Background 600
Net Counts 752
Normalized 752
Random 64
668 ± 38

Gross Cts. 12,937
Background 500
Net Counts 12,437
Normalized 12,437
Random 143
12,294 ± 114
COUNTS

---

Run # 409,441, 10 July 1968

2# NaI spectrum of 203Hg in coincidence with K x rays at
180°, 800 minutes. Dist: 1# NaI=8.5 cm, 1/8# NaI=6 cm.

Counts in gate: Before--11,196, After--10,673, Standard--10,812
Stand./Avg.--0.9888

---

10-keV L x-ray
Singles Counts
Before 7,713
After 7,499
Stand. 7,185
Ratio 0.9446

73-keV K x-ray
Singles Counts
Before 18,615
After 18,478
Stand. 17,487.5
Ratio 0.9429

---

Background 170 Cts/Chan

Gross Cts. 10,975
Background 850
Net Counts 10,125
Normalized 9,457
Random 109

9,348 ± 105

Gross Cts. 4,175
Background 280
Net Counts 3,895
Normalized 3,631
Random 266

3,365 ± 67

Background 28 Cts/Chan

---

PLATE LXXXIII
Run #409441, 9 July 1968

3rd NaI spectrum of 203Hg in coincidence with K x rays at 90°, 800 minutes. Dist: 3rd NaI-8.5 cm, 1/6th NaI-8 cm.

Counts in gate: Before--10,725, After--10,899, Standard--10,812

Stand./Avg.--1,0000

Gross Cts.
Before 7,303
After 7,067
Stand. 7,185
Ratio 1.0000

73-keV K x-ray
Singles counts
Before 17,464
After 17,511
Stand. 17,487.5
Ratio 1.0000

10-keV L x-ray
Singles counts
Before 7,067
After 7,303
Stand. 7,185
Ratio 1.0000

Channel No. 10 20 30 40 50 60

Plate LXXXIV

102 103

Counts

Bkgnd 170 Cts/Chan

Gross Cts.
9,878
850
9,028
9,028
109

Random

8,917±100

Bkgnd 28 Cts/Chan

Gross Cts.
4,027
280
3,747
3,747
266

Bkgnd 28 Cts/Chan

Counts

PLATE LXXXIV

179
Run #409#441. 10 JULY 1968
1/4 NaI spectrum of 203Hg in
coincidence with L x rays at
180°, 800 minutes. Dist: 1/4
NaI -- 8.5 cm, 1/8 NaI -- 8 cm.

Counts in gate: Before--7,480,
After--7,087, Standard--7,308.5
Stand./Avg.--1.0034

--- Runs Ends ---
Run # 409,441.  9 July 1968
3\textsuperscript{1/2} Nal spectrum of \textsuperscript{203}Hg in coincidence with L x rays at 90\degree, 800 minutes. Dist: 1" Nai--8.5 cm, 1/8" NaI--8 cm.

Counts in gate: Before--7,376, After--7,241, Standard--7,308.5
Standard/Avg.--1,0000

10-keV L x-ray
Singles counts
Before 7,303
After 7,067
Standard 7,185
Ratio 1.0000

73-keV K x-ray
Singles counts
Before 17,511
After 17,464
Standard 17,487.5
Ratio 1.0000

Background 120 Cts/Chan

Background 52 Cts/Chan

Gross Cts. 1,799
Background 600
Net Cts. 1,199
Normalized 1,199
Random 72
\frac{1,127 \pm 43}{1,127 \pm 43}

Gross Cts. 15,853
Background 520
Net Cts. 15,333
Normalized 15,333
Random 175
\frac{15,158 \pm 127}{15,158 \pm 127}

PLATE LXXXVI
Counts

10-keV L x-ray
Singles Counts
Before 7,215
After 7,358
Stand. 7,375.5
Ratio 1.0122

73-keV K x-ray
Singles Counts
Before 18,533
After 18,220
Stand. 17,598.5
Ratio 0.9549

Run # 409,442. 11 July 1968
\^NaI spectrum of 203Hg in
coincidence with K x rays at
180°, 800 minutes. Dist: \^NaI--8.5 cm, 1/8\^NaI--8 cm.

Counts in gate: Before--11,523,
After--11,052, Standard--11,351
Stand./Avg. = 1.0056

PLATE LXXXVII
10-keV L x ray
Singles Counts
Before 7,280
After 7,471
Stand. 7,375.5
Ratio 1.0000

73-keV K x ray
Singles Counts
Before 17,477
After 17,620
Stand. 17,598.5
Ratio 1.0000

Counts in gate: Before—11,230
After—11,472, Standard—11,351
Stand./Avg.—1.0000

Run #409442. 12 July 1968
4" NaI spectrum of 203Hg in coincidence with K x rays at 90°, 800 minutes. Dist: 4"
NaI—8.5 cm, 1/8\" NaI—8 cm.

Gross Cts. 11,762
Background 900
Net Counts 10,862
Normalized 10,862
Random 111
10,751 ± 109

Gross Cts. 4,463
Background 250
Net Counts 4,213
Normalized 4,213
Random 268
3,945 ± 69

Bkgnd 180 Cts/Chan

Bkgnd 25 Cts/Chan
10-keV L X-ray
Singles Counts
Before 7,215
After 7,358
Stand. 7,375.5
Ratio 1.0122

73-keV K X-ray
Singles Counts
Before 18,533
After 18,220
Stand. 17,598.5
Ratio 0.9549

Counts in gate: Before — 7,370,
After — 7,264, Standard — 7,560
Stand./Avg. = 1.0332

Run # 409,442, 11 July 1968
3° NaI spectrum of 203Hg in
coincidence with L X rays at
180°, 800 minutes. Dist: ½
NaI—8.5 cm, 1/8° NaI—6 crn.

Background 140 Cts/Chan

Background 65 Cts/Chan

Gross Cts. 1,852
Background 700
Net Counts 1,152
Normalized 1,205
Random 73

Gross Cts. 18,608
Background 650
Net Counts 18,158
Normalized 17,916
Random 176

1,132 ± 44
17,740 ± 138
Run #409,442, 12 July 1968
\( \frac{1}{2} \) NaI spectrum of \(^{203}\text{Hg}\) in coincidence with L x rays at 90°, 800 minutes. Dist: \( \frac{1}{2} \) NaI=8.5 cm, 1/8" NaI=8 cm.

Counts in gate: Before = 7,591, After = 7,539, Standard = 7,560.
Standard/Avg. = 1,0000

Counts:
- 10-keV L x ray: Before 7,280, After 7,471, Stand 7,375.5, Ratio 1.0000
- 73-keV K x ray: Before 17,477, After 17,620, Stand 17,598.5, Ratio 1.0000

Background 130 Cts/Chan

Gross Cts. = 1,979
Background = 650
Net Counts = 1,229
Normalized = 1,229
Random = 73

Gross Cts. = 17,698
Background = 700
Net Counts = 16,998
Normalized = 16,998
Random = 176

Background 70 Cts/Chan

Gross Cts. = 1,879
Background = 650
Net Counts = 1,229
Normalized = 1,229
Random = 73

Gross Cts. = 17,698
Background = 700
Net Counts = 16,998
Normalized = 16,998
Random = 176
**Run #409,443, 14 July 1968**

1/8 NaI spectrum of 203Hg in coincidence with K x rays at 180°, 800 minutes. Dist: 1/8 NaI—9 cm, 1/8 NaI—8 cm.

Counts in gate: Before—10,595
After—10,618
Standard—10,511
Stand./Avg.—0.9910

---

**10-keV L x-ray**

**Singles Counts**

**Before** 7,347

**After** 7,287

**Stand.** 7,203

**Ratio** 0.9844

**73-keV K x-ray**

**Singles Counts**

**Before** 17,552

**After** 17,395

**Stand.** 16,994.5

**Ratio** 0.9726

---

**Bkgnd 170 Cts/Chan**

**Gross Cts.** 11,276

**Background** 850

**Net Counts** 10,426

**Normalized** 10,171

**Random** 104

**10,067 ± 107**

---

**Bkgnd 28 Cts/Chan**

**Gross Cts.** 4,365

**Background** 280

**Net Counts** 4,085

**Normalized** 3,937

**Random** 200

**3,737 ± 68**

---

**PLATE XCI**
Counts in gate: Before -- 10,548
After -- 10,474, Standard -- 10,511
Stand./Avg. -- 1.0000

Run #409443, 13 July 1968
\( \frac{1}{8} \) NaI spectrum of 203Hg in coincidence with K x-rays at 90°, 800 minutes. Dist: \( \frac{1}{4} \) NaI--9 cm, 1/8 NaI--8 cm.

Counts in gate:
- Before: 10,548
- After: 10,474
- Standard: 10,511
- Stand./Avg.: 1.0000

Gross Cts. 10,515
Background 800
Net Counts 9,715
Normalized 9,715
Random 104
9,611 ± 103

Gross Cts. 4,111
Background 300
Net Counts 3,811
Normalized 3,811
Random 200
3,611 ± 66

Background 30 Cts/Chan
Run # 409,443, 14 July 1968
1/4 NaI spectrum of 203Hg in coincidence with L x rays at 180°, 800 minutes, Dist: 1/4 NaI--9 cm, 1/8 NaI--8 cm.

Counts in gate: Before--7,154
After--7,128, Standard--7,049
Stand./Avg. -- 0.9871

Gross Cts., 1,735
Background, 750
Net Counts, 985
Normalized, 957
Random, 76

881 ± 43

Gross Cts., 18,051
Background, 700
Net Counts, 17,351
Normalized, 16,659
Random, 127
16,532 ± 135

PLATE XCIII
Counts in gate: Before -- 7,130
After -- 6,968, Standard -- 7,049
Stand./Avg. -- 1,0000

Run \# 409,443, 13 July 1968
1/4 NaI spectrum of 203Hg in
coincidence with L x rays at
90°, 800 minutes, Dist: 1°
NaI = 9 cm, 1/8 NaI = 8 cm.

Counts in gate: Before -- 7,130
After -- 6,968, Standard -- 7,049
Stand./Avg. -- 1,0000

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<tr>
<th>10-keV L x-ray</th>
<th>73-keV K x-ray</th>
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<tbody>
<tr>
<td>Singles counts</td>
<td>Singles counts</td>
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<tr>
<td>Before 7,108</td>
<td>Before 17,054</td>
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<td>After 7,298</td>
<td>After 16,935</td>
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<tr>
<td>Stand. 7,203</td>
<td>Stand. 16,994.5</td>
</tr>
<tr>
<td>Ratio 1,0000</td>
<td>Ratio 1,0000</td>
</tr>
</tbody>
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Gross Cts. 1,669
Background 750
Net Counts 919
Normalized 919
Random 76

Bkgd 150 Cts/Chan

Gross Cts. 16,855
Background 700
Net Counts 16,155
Normalized 16,155
Random 127

Bkgd 70 Cts/Chan

843 ± 42
16,028 ± 130

PLATE XCIV
BIBLIOGRAPHY


