SSC-104

DEVELOPMENT OF FILMLESS TECHNIQUE FOR RECORDING DEFECTS IN SHIP WELDS

by

J. I. Bujes

SHIP STRUCTURE COMMITTEE

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SHIP STRUCTURE COMMITTEE

U. S. COAST GUARD HEADQUARTERS

WASHINGTON 25, D. C.

February 25, 1957

Dear Sir:

As part of its research program to improve the hull structures of ships, the Ship Structure Committee is sponsoring at the Naval Ordnance Test Station a project to develop filmless methods for detecting flaws in ship welds. Herewith is the First Progress Report, SSC-104, of this project, entitled "Development of Filmless Technique for Recording Defects in Ship Welds", by J. I. Bujes.

This project is being conducted under the guidance of the Flaw Detection Advisory Group under the Ship Structure Subcommittee.

Please submit any comments that you may have to the Secretary, Ship Structure Committee.

This report is being distributed to individuals and groups associated with and interested in the work of the Ship Structure Committee.

Yours sincerely,

K. K. Cowart
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure
Committee

Serial No. SSC-104

First Progress Report
of
Project SR-140

to the

Ship Structure Committee

on

DEVELOPMENT OF FILMLESS TECHNIQUE FOR
RECORDING DEFECTS IN SHIP WELDS

by

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China Lake, California

Under

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DEVELOPMENT OF FILMLESS TECHNIQUE FOR RECORDING DEFECTS IN SHIP WELDS

HISTORICAL

The November 1952 Defense Conference on Nondestructive Testing considered the problem of flaw detection in ship structures, particularly in type T-2 tankers. An investigation of failures in type T-2 tankers indicated that some of the failures were initiated by flaws in some of the welds in the midship structure. It was indicated then that a number of World War II tankers, while undergoing conversion or repairs, had been subjected to radiographic inspection which served as a guide in the elimination of defective welds and improvement of the quality of new welding being performed. A similar approach has been used in connection with new construction. It was pointed out that conventional radiography, even if applied to selected sensitive locations in the midship structure, is costly and time consuming and that economies in both factors would contribute toward the general acceptance of flaw detection by the shipbuilding industry.

With the above as a basis, the U. S. Naval Ordnance Test Station investigated informally the feasibility of a direct-reading or filmless technique in radiography using a 300 mC Cobalt-60 source and a Geiger counter as a detector on a 1-in. thick steel welded test plate furnished by the Long Beach Naval Shipyard. A sketch and a radiograph of the welded test plate are shown in Figs. 1 and 2, respectively.

1 FAIR WELD A	2"
2 SLUG B	2"
3 FAIR WELD	1½"
4 LACK PENETRATION C	1½"
5 LACK FUSION D	1½"
6 FAIR WELD	1½"

10"

WELDING TEST PLATE

WITH INTENTIONAL DEFECTS.

NP/45 L017078   NOTS CHINA LAKE, CALIFORNIA
FIGURE 1. WELDING TEST PLATE WITH INTENTIONAL DEFECTS.
12 MARCH 1956   UNCLASSIFIED

FIGURE 2. RADIOGRAPH OF TEST PLATE.
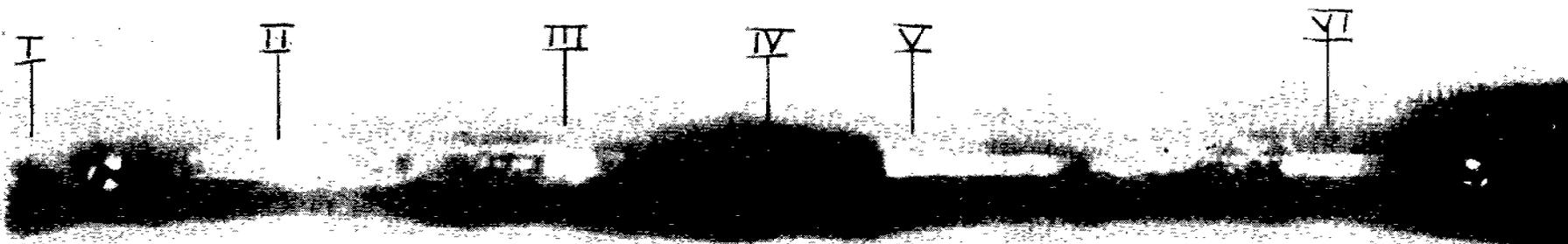
NP/45 L017077   NOTS CHINA LAKE, CALIFORNIA
FIGURE 2. RADIOGRAPH OF TEST PLATE.
15 MARCH 1956   UNCLASSIFIED

Lead sheet

Steel plate

Weld

Lead container

Geiger tube

Lead container

Radiation source
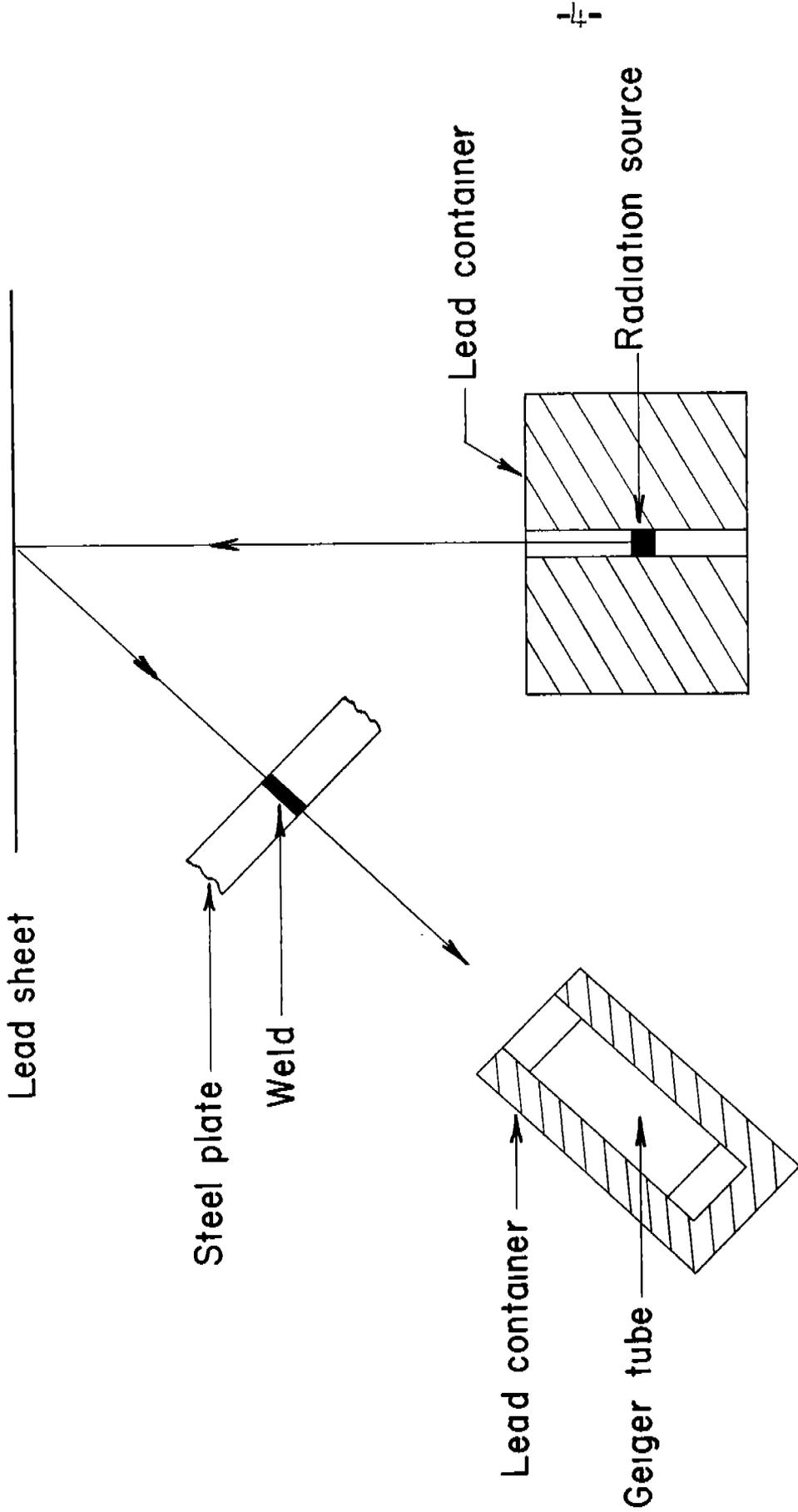
NP/45 LO19778   NOTS CHINA LAKE, CALIFORNIA
FIG. 2A SCHEMATIC ILLUSTRATION OF THE TEST ARRANGEMENT
FOR USE OF SCATTERED RADIATION OF LEAD.   UNCLASSIFIED
10 JULY 1956

The tests were based on transmitted radiation, and the time required for a preset number of counts on a Potter chronograph was a function of the radiation intensity passing through a specific area of the weld. The larger the void, the shorter the time indicated on the counter. These tests and results were incorporated in the NOTS Technical Memorandum No. 1760, "Study of Filmless Technique and Radiographic Method for Testing Welds in Butt Joints of Tankers T-2". A comparison of the densities of the test plate radiograph with the values read on the chronograph indicated a fair degree of correlation. The minimum void depth which was detected by the counter was 6 per cent of the 1-in. steel thickness. This method, as stated in the above memorandum, was based on a technique which required that the radiation source be placed on one side of the welded test plate and coordinated with the detector which was placed on the other side of the test plate. The memorandum also stated that preliminary tests indicated that it was feasible to place both the radiation source and the detector on the same side of the weld and to use a lead sheet radiation scatterer on the other side, as shown in Fig. 2(a).

In October 1953 Noah A. Kahn, Chairman of the Advisory Group on Flaw Detection of the Ship Structure Committee, examined the experimental arrangement and reviewed the preliminary test data. On the basis of the Advisory Group's recommendation, the Bureau of Ships established a research project at the Station

in June 1954 to "Provide professional and technical services,
labor, materials, equipment and overhead for the development of
filmless techniques recording defects in ship welds by applica-
tion of available radioisotopes as radiation sources. Until
the sensitivity of the test method is specified by the Bureau
of Ships, weld test plates as supplied by the Naval Shipyard,
Long Beach, California, will be acknowledged as a basis for
evaluation".

PRELIMINARY INVESTIGATION

All the following experiments were conducted with a steel
plate as a scatterer instead of the originally adopted lead
sheet because the yield of the former was higher. Without go-
ing into detailed explanation, it is assumed that lead, being
of higher periodic system number than steel, absorbs more of
the primary radiation before it reappears as Compton scattered
radiation. As a further justification for this assumption, a
higher yield is observed with a 1-in. thick scattering steel
plate rather than with a 1/4-in. plate. The corresponding
values will be reported later in this report.

In place of the original Geiger tube which had been used
with a Potter chronograph in the early experiment, a scintil-
lator of the Nuclear Research and Development Company, St.
Louis, Missouri, was applied with a ratemeter. (See Figs. 3
and 4.)
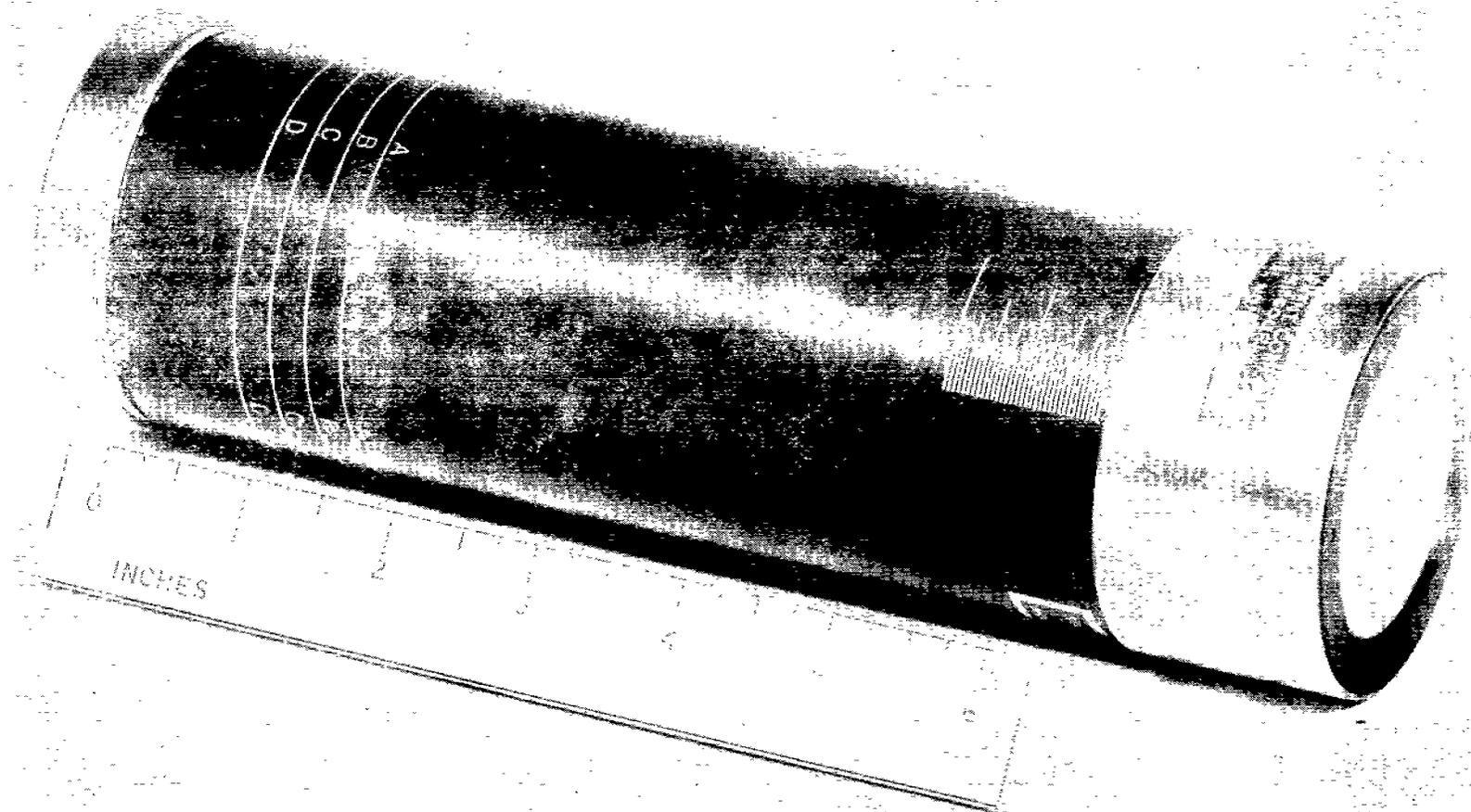
NP/45 L017193   NOTS CHINA LAKE, CALIFORNIA
FIGURE 3. SCINTILLATOR, NRD.
15 MARCH 1956   UNCLASSIFIED.

NP/45 L017192   NOTS CHINA LAKE, CALIFORNIA
FIGURE 4. NRD RATEMETER. 3/4 VIEW.
15 MARCH 1956   UNCLASSIFIED

As shown in Fig. 3, the scintillator was over 7 in. long and 2 in. in diameter. Even though the results with the scintillator when used with a Cobalt-60 isotope of about 200 mC were satisfactory for laboratory use, it was realized that the bulkiness of the scintillator would restrict the field application of the method under discussion. The excessive dimension of the "window" appeared particularly prohibitive when considering the simultaneous use of two detectors which would be connected electrically in a bridge circuit for greater accuracy and precision. For such use, a North American Philips Corporation scintillator with a diameter of about 1 in. was purchased; it will be discussed in detail later.

RECENT INVESTIGATION

General.

Even though only radioisotopes are mentioned as radiation sources in the project assignment, the investigation was extended to include X rays since a higher radiation intensity was expected from the 250 kvp X-ray equipment than from the available weak gamma source of 150 mC. The detectors used in these tests were as follows: a scintillator, an industrial Geiger counter (radiation monitor), and cadmium sulfide and cadmium selenide crystals.

X rays.

GEIGER COUNTER. The diagrammatic arrangement of the Geiger counter and X-ray source is shown in Fig. 5. In this arrangement the X-ray equipment was operated at 250 kvp and about 4.3 ma.

The Geiger counter was a commercial radiation monitor with an inside silver coated glass tube. The readings of the Geiger tube with 1/2-in. steel in front of the tube were 1.05 mr/hr; with an additional 0.094 in. of steel, 0.95 mr/hr; and when scatterer C was removed, the readings were 0.3 mr/hr, representing the "noise".

The reason for using only 1/2-in. steel instead of the required 1 in. was that the radiation beam was passing the Geiger tube axially, and there was a heavy aluminum button on the front end of the protecting metal sleeve. Furthermore, the distance of the X-ray focus to the Geiger tube was relatively high (52 in.). In the course of discussion it will be shown that the differential response of the detector to the thickness of the "void" alone determines the sensitivity and accuracy of the test method.

Returning to the two corresponding values of 1.05 and 0.95 mr/hr for 0.500-in. and 0.594-in. steel, the difference of 0.1 mr/hr is significant. By application of an "electric vernier" this relatively small difference can be adequately enlarged and used as thickness gage for detecting minimum flaws in welds equivalent to 6 per cent of the total steel thickness of 1 in.

Diagrammatic Arrangement of Geiger Counter and X-ray Source
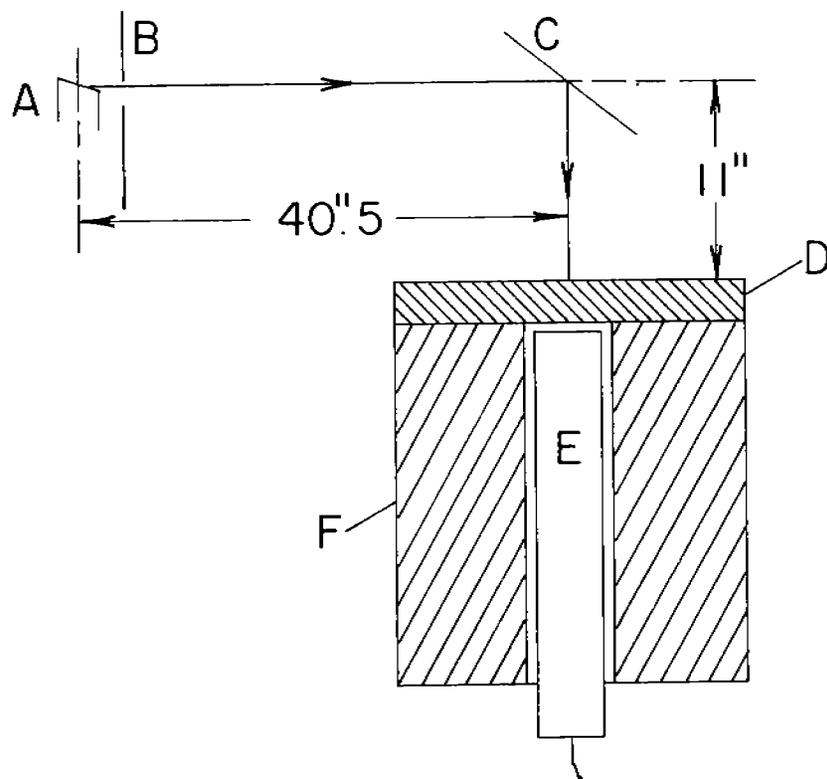
A _ X-Ray tube target
B _ Lead collimator
C _ $\frac{1}{4}$" steel plate scatterer
D _ $\frac{1}{2}$" steel plate
E _ Geiger tube
F _ Lead container

40".5

11"

CRYSTALS. The same X-ray machine was applied in testing cadmium sulfide or cadmium selenide crystals as detectors. The application of those crystals as detectors of any electromagnetic radiation, such as X rays, gamma rays, visible, infrared or ultraviolet light, is possible because of their photoelectrical properties. The conductivity and resistance of a crystal is a function of the intensity and wave length of radiation which falls upon the crystal. Thus, the crystal has the highest resistance when no radiation falls upon it, and diminishing resistance as the radiation increases.

At present, the crystals have to be selected from a large number for their sensitivity to X rays and gamma rays. From about 70 crystals tested, only 12 were found to be sensitive to X rays, and some of these were particularly sensitive to gamma rays.

The circuitry as shown in Fig. 6 is very simple. Several 45-volt dry cells connected in series are sufficient to originate a photocurrent through the crystal when affected by X rays or gamma rays. Unfortunately, the current is very low and a very sensitive microammeter is required. So far, the most useful instrument for this purpose is the RCA ultra-sensitive microammeter, Type WV-84A. The highest sensitivity of the instrument is 0.01 μA for 50 divisions so that 0.0001 μA may still be read.

Circuit Diagram of Cadmium Sulfide or Selenide Crystal
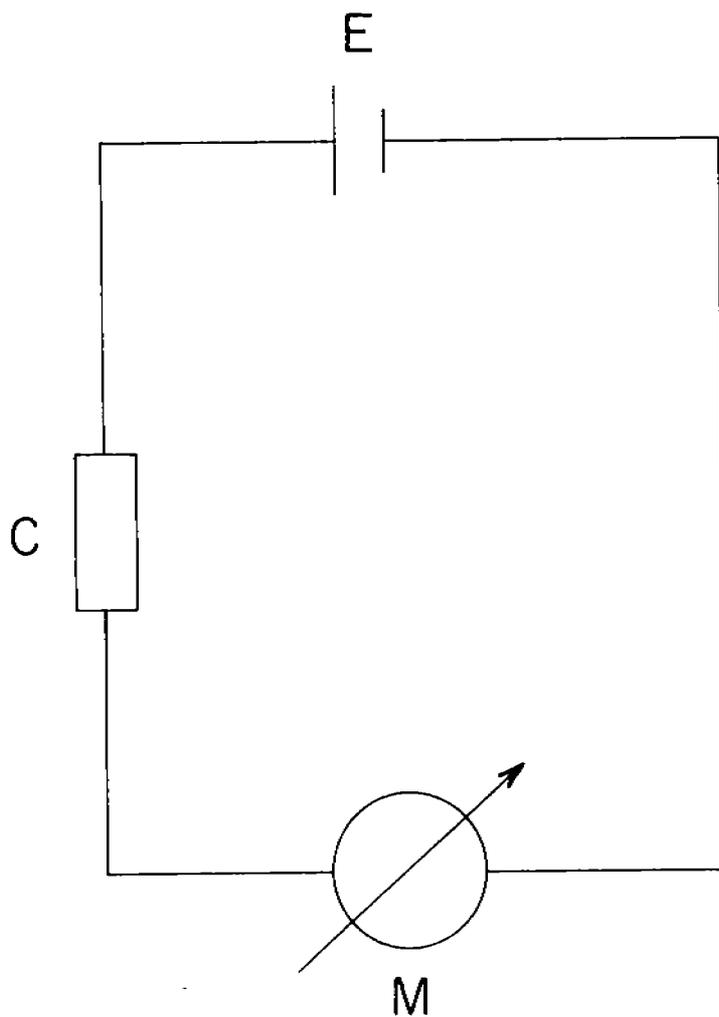
E _ Battery
C _ Crystal
M _ Microammeter

The diagrammatic arrangement of the cadmium sulfide or cadmium selenide crystals in connection with X radiation is shown in Fig. 7.

Because the relationship of flaw thickness to microammeter readings is linear, even 1 per cent "voids" can be determined according to Fig. 8. Since one division on the abscissa indicates 0.002-in. steel and 1 per cent is 0.0025 in., this abscissa value corresponds to about one division (0.0001 μA) on the ordinate scale.

The applied battery voltage of 90 volts consisted of two 45-volt cells connected in series.

Even though the sensitivity of the method is satisfactory, the time required for reaching the instrument equilibrium was one minute because of the very small photoconductive current.

In this connection, a new device called an "electric vernier" (Fig. 9) should be mentioned as it might shorten the reading time. Its use was suggested some years ago by H. L. Ellsworth, Clinton, New Jersey.

The essential part of the device is a counter-EMF which balances the instrument B to zero at a certain reading of instrument A. Instrument A was the RCA microammeter with a 50-division scale, and instrument B was the 20 microamperes full-scale meter with a 50-division scale. Incidentally, the high sensitivity of the RCA meter is obtained by a two-stage amplification inside

17".5

3"

A

B

C

E

D

A – X-Ray tube target
B – Steel plate scatterer
C – Lead container
D – Crystal
E – $\frac{1}{4}$" steel plate absorber
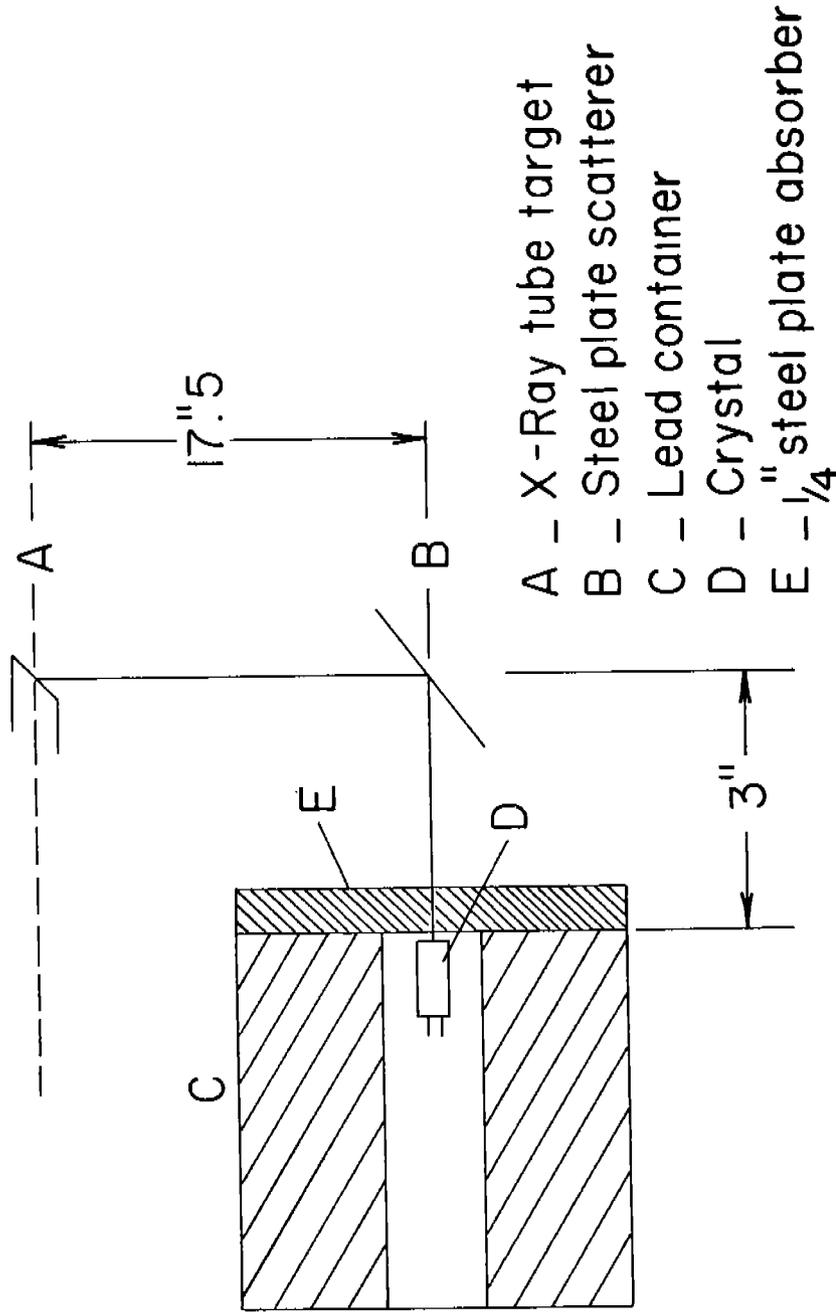
Diagrammatic Arrangement of Cadmium Sulfide or Selenide Crystal

NP/45 L017079   NOTS CHINA LAKE, CALIFORNIA
FIGURE 7. DIAGRAMMATIC ARRANGEMENT OF CADMIUM SULFIDE
OR SELENIDE CRYSTAL.
13 MARCH 1956   UNCLASSIFIED

Typical Example of RCA-Meter Readings in
the CdS or CdSe Crystal Circuit

Steel Absorber, Inch		μA	After Reduction of "Noise"
No scatterer	.25	.0054	
With scatterer	.25	.0093 - .0094 (fluctuates)	.004
"	.281	.0084 - .0085 (fluctuates)	.003
"	.312	.0079	.0025
"	.344	.0072	.0018

Transmitted Radiation, μA

Steel Thickness, inch
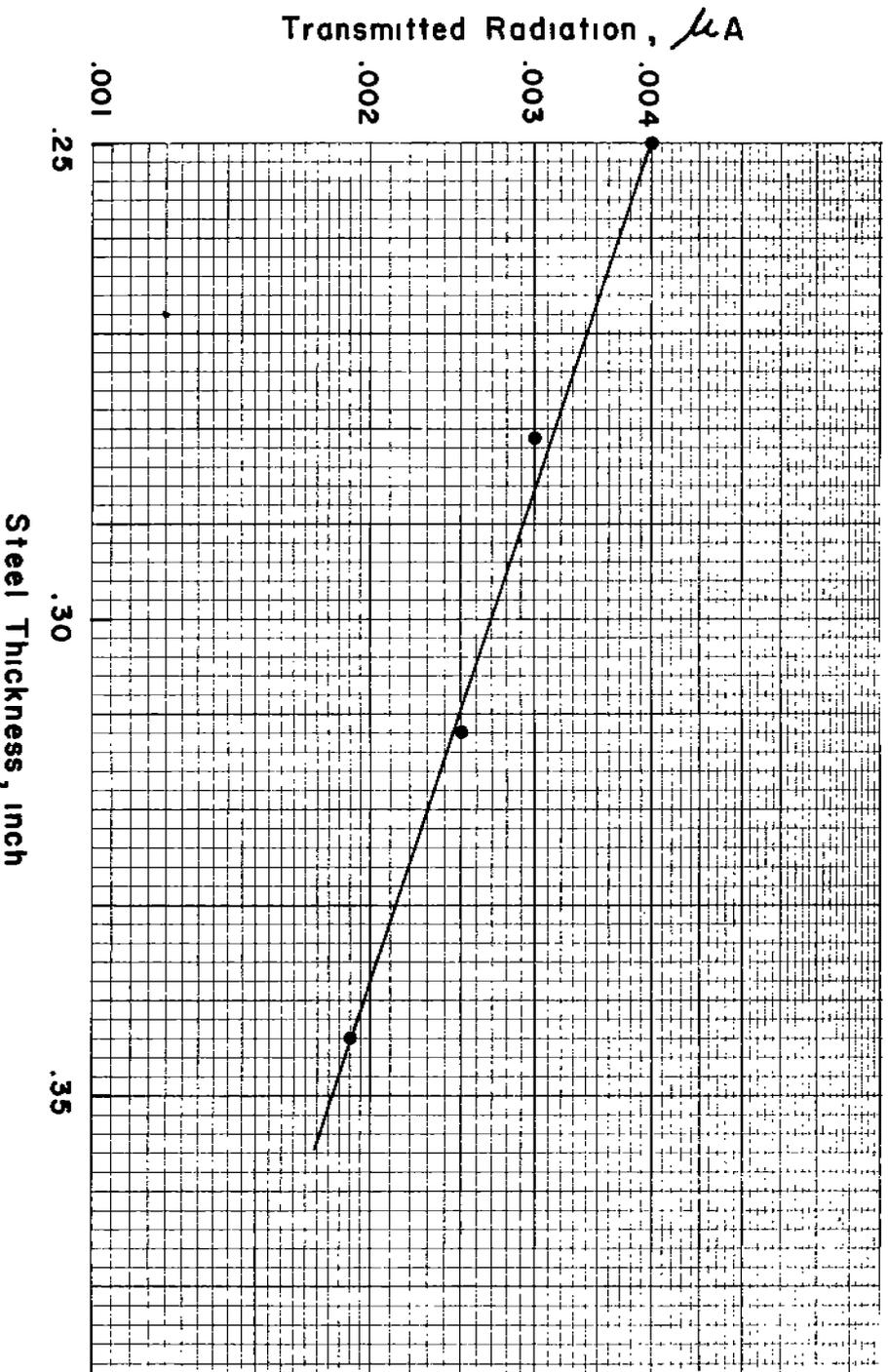
NP/45 L017189
FIGURE 8. TYPICAL EXAMPLE OF RCA-METER READINGS IN THE
CdS OR CdSe CRYSTAL CIRCUIT.
14 MARCH 1956

NOTS CHINA LAKE, CALIFORNIA

UNCLASSIFIED
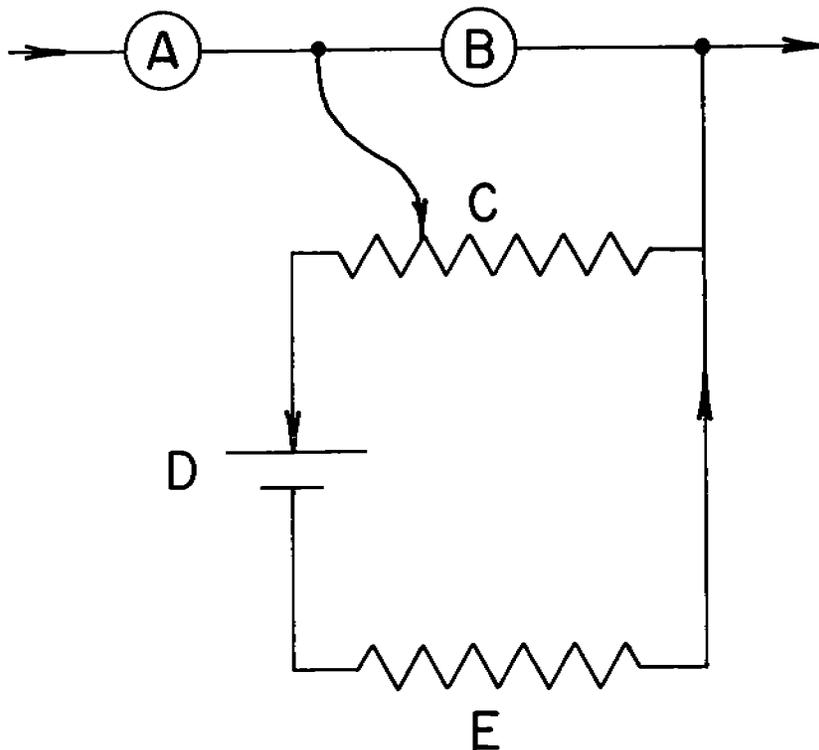
A _ Original microammeter

B _ Microammeter of higher sensitivity

C _ Potentiometer

D _ 1.5 v - dry cell

E _ Ballast resistance

Electric Vernier

the meter. By application of the "electric vernier," it was possible to read a difference of 0.009 μA, corresponding to 4 1/2 full divisions of instrument A, and to 22 1/2 full divisions of instrument B.

Because the sweep of instrument B is five times larger than instrument A, perhaps it might be possible to reduce the reading time by utilizing only a part of the current rise. This investigation has not been performed as yet.

It is also noteworthy that the RCA meter can be zeroed on any point of the scale; therefore, it is possible to put the "noise" value on zero and read only the actual absorption differences in the specimen.

By application of the above figures it was possible to determine the extent of the modification of the primary X radiation by scattering, which is the basis of the method under discussion. Equation 2 (Fig. 10) indicates that the ratio of the two radiations passing through the test object with and without a void determines the sensitivity of the test method. In other words, the higher sensitivity is obtained when the ratio of the two corresponding microammeter readings is larger. The efficiency of converting 250 kvp emitted from the target to the scattered radiation absorbed in 1/2-in. steel was computed to be about 0.03 per cent. (See Appendix.)

RECONCILIATION OF THEORY AND PRACTICE
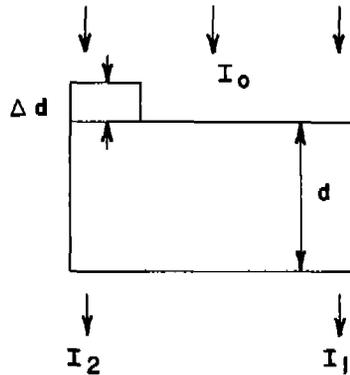
$I_1 = I_0 e^{-\mu d}$ (1)   Lambert's absorption equation

$\dfrac{I_1}{I_2} = e^{-\mu \Delta d}$ (2)

I_0 = primary radiation

I_1, I_2 = transmitted radiations

$I_1 = I_{.25} = .04 \mu A$

μ = X-ray coefficient

$I_2 = I_{.281} = .03 \mu A$

d = thickness of the absorbent

$I_3 = I_{.314} = .025 \mu A$

Δd = additional thickness

$I_4 = I_{.344} = .018 \mu A$

By log of eq. (2), and substituting the proper values for I_2, I_3, and I_4, an average μ was obtained as 3.16.

Since $\mu = \dfrac{\mu}{\rho} \cdot \rho$ where ρ = density of steel = 7.86

$\dfrac{\mu}{\rho}$ was computed to 0.403 which corresponds to λ = .126 $\overset{o}{A}$

From the Einstein-Planck equation   kv = $\dfrac{12.4}{.126}$ = 99

Assuming that 250 kvp of a self-rectified X-ray equipment is about 125 kv_{eff}, its λ = .10 $\overset{o}{A}$ which by scattering was increased to .126 making a difference of .026 λ

This reconciles the Compton equation:

     $\delta \lambda$ = .024 (1 - cos ϕ) Ångstrom

     $\delta \lambda$ (for ϕ = 90°) = .024

Under consideration of many uncertain factors, the agreement of 8% between theory and practice is acceptable.

Gamma Radiation.

Since the final goal of this project is the application of
an isotope as radiation source, it was necessary to investigate
the crystals, a scintillator, and a Geiger tube as detectors
of gamma radiation transmitted through a 1-in. steel plate.
The activity of the Cobalt-60 isotope was approximately 150 mC,
and the average energy level about 1.2 Mev. Because of the
higher energy as compared with the 125 kv_{eff} X radiation, a 1-in.
thick steel plate could be successfully used as an absorber.

CRYSTALS. The diagrammatic arrangement of the crystal used
with gamma radiation is shown in Fig. 11. As mentioned before,
the crystal sensitivity to X rays differs from that to gamma rays.
The most sensitive crystal was selected for the following tests
for which the RCA microammeter was again used as an indicator.
The readings were:

Scattered radiation transmitted through 1-in. steel   .0099 μA

Scattered radiation transmitted through 1.094-in. steel.0090 μA

Without scattering   .0079 μA

Four and one half divisions out of 50 correspond to absorption in
0.094 in. or, in other words, under assumption of linearity one
division represents the absorption in 0.023 in. of steel.

Applying the above-mentioned electric vernier and a 20-
microampere full-scale meter, 0.01-in. steel thickness difference
or 1 per cent of a 1-in. thick steel plate would be indicated by
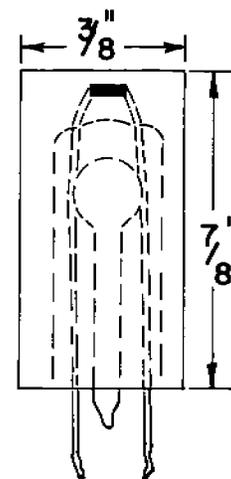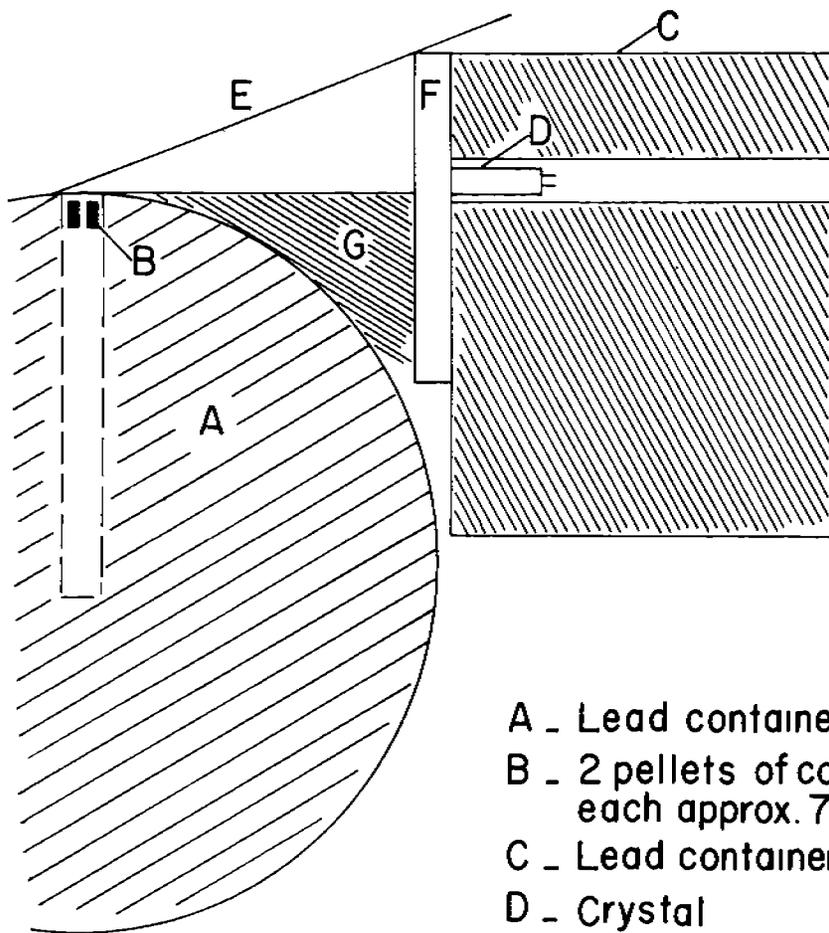
Dimension Sketch
of C_dS or C_dS_e
Crystal

A _ Lead container
B _ 2 pellets of cobalt 60,
    each approx. 75 mc
C _ Lead container
D _ Crystal
E _ Steel plate scatterer
F _ 1" steel plate absorber
G _ Lead

Diagrammatic Arrangement of C_dS or C_dS_e in connection with Gamma
Radiation

NP/45 L017186   NOTS CHINA LAKE, CALIFORNIA
FIGURE 11. DIAGRAMMATIC ARRANGEMENT OF CdS OR CdSe IN
CONNECTION WITH GAMMA RADIATION.
14 MARCH 1956   UNCLASSIFIED

2.5 divisions on a 50-division scale. Also here individual readings required about 1 minute in order to obtain an accurate reading.

SCINTILLATOR. The Philips scintillator with a diameter of about 1 in. is shown in Fig. 12. The sodium iodide crystal is only 5/8 in. square and is about 1/8 in. thick. The built-in preamplifier in the effectively ventilated base of the scintillator is relatively small and will not interfere with the planned scanning by the scintillator above the weld; but if it should interfere, it could easily be separated from the scintillator.

The output of the scintillator was fed into an "EPUT" (event per unit time) scaler. The geometrical arrangement is shown in Fig. 13.

With 1100 volts applied to the photomultiplier tube, the exposure time per reading was 4 seconds. Table 1 shows the numerical results with only moderate protection of the scintillator from stray radiation; and Table 2 shows the numerical results with more protection. From the values for different "void" depths expressed in steel thicknesses, it is found that the relationship of "void" depth vs. counts is practically linear.

The figures in Table 2 are smaller than those in Table 1 because the scintillator was more effectively protected against stray radiation and the "noise" dropped from about 15,000 to 3,700 counts.
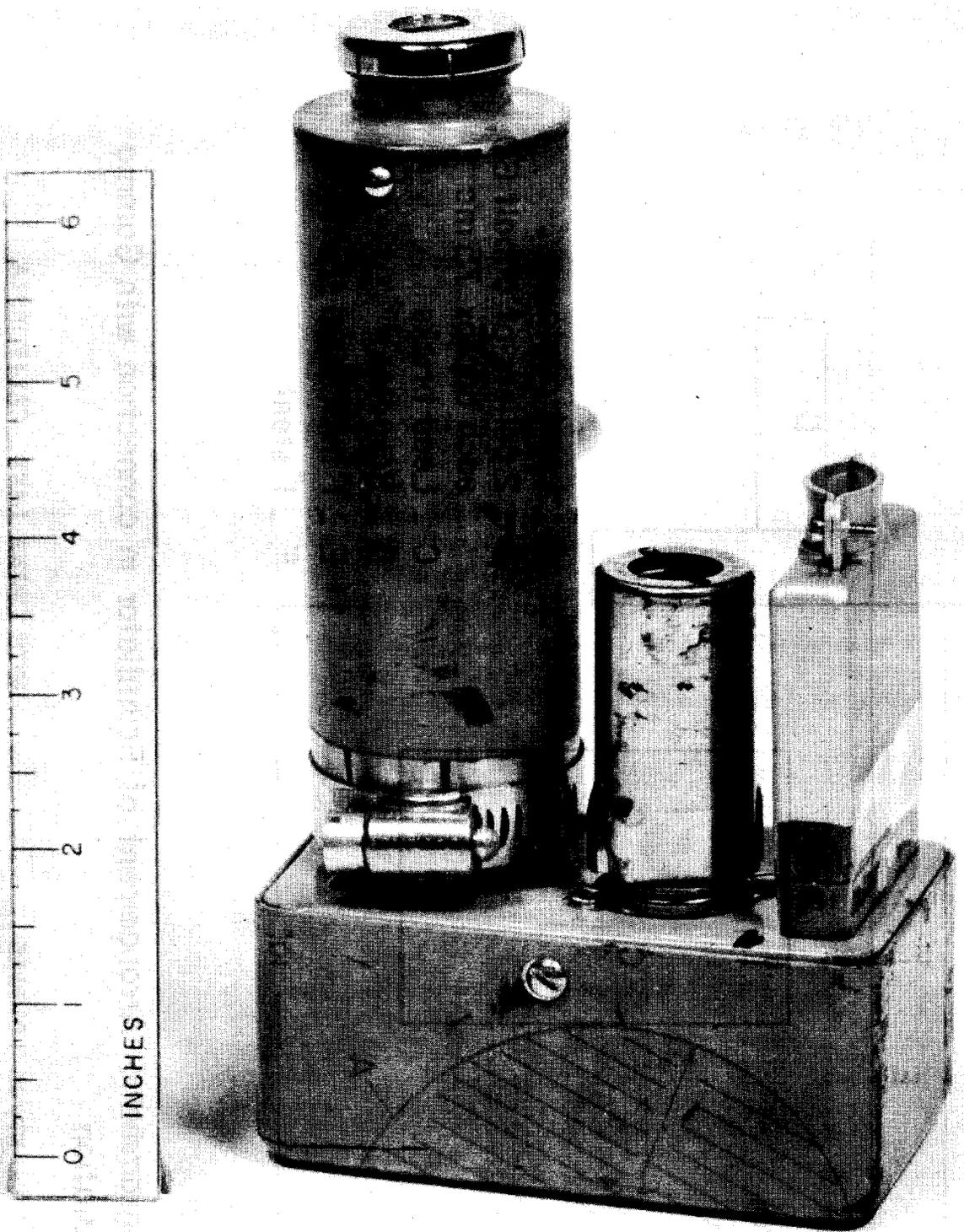
NP/45 L017191   NOTS CHINA LAKE, CALIFORNIA
FIGURE 12. SCINTILLATOR, PHILIPS.
15 MARCH 1956   UNCLASSIFIED
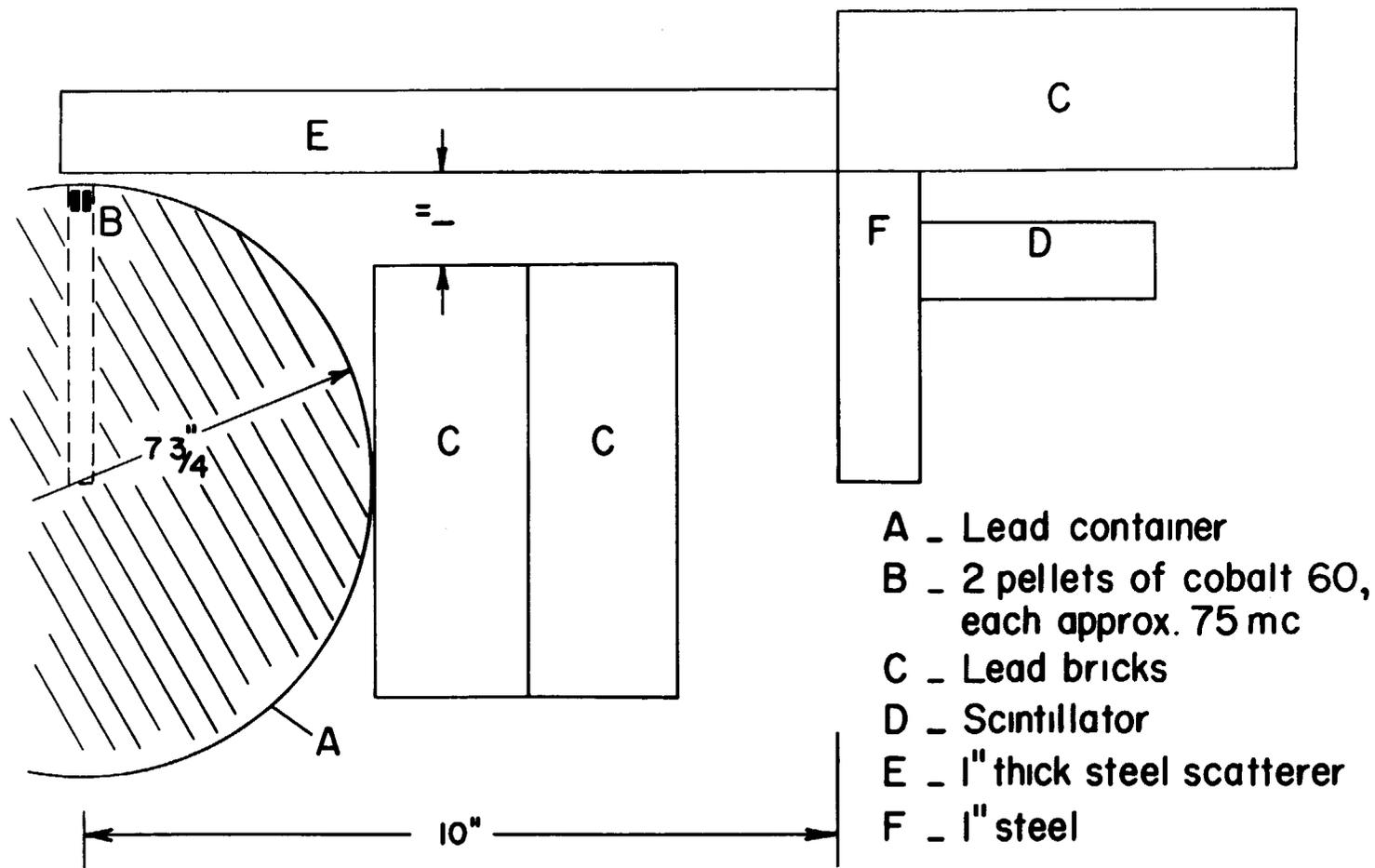
Diagrammatic Arrangement of Scintillator in connection with Gamma Radiation

A _ Lead container
B _ 2 pellets of cobalt 60, each approx. 75 mc
C _ Lead bricks
D _ Scintillator
E _ 1" thick steel scatterer
F _ 1" steel

TABLE 1. Scintillator

Typical scaler readings, each 4 seconds.

| Remarks | Steel Absorber | | | |
	1.0 in.	1.031 in.	1.062 in.	1.094 in.
With scatterer	38,773	38,225	37,276	36,763
	38,556	38,046	37,545	36,791
	38,554	37,847	37,688	36,815
	38,628	38,444	37,883	36,892
	38,402	38,228	37,483	36,652
Average	38,577	38,158	37,575	36,783
Repeated after about 5 minutes	38,191	37,948	37,260	
	38,786	38,175	37,121	
	38,217	38,362	37,266	
	38,475	37,682	36,934	
	38,587	37,775	37,184	
Average	38,441	37,988	37,175	
Without scatterer	15,396			15,105
	15,523			15,133
	15,357			15,001
	15,433			15,147
	15,439			15,217
Average	15,430*			15,121**

* represents the "noise"
** represents the "noise" reduced by 309 counts because of additional protection with 0.094-in. steel.

The 254-count difference in stray radiation in Table 2, which represents a partial protection from "noise", is only 10 per cent of the 2,486 counts corresponding to a 0.094-in. steel thickness difference and can be neglected.

On the basis of the evaluated standard deviation, the error level was computed as $(N - \sigma)/(N + \sigma)$ where N is the mean

TABLE 2. Scintillator

Typical scaler readings, each 4 seconds.

Remarks	Steel Absorber		
	1.0 in.	1.094 in.	1.0 in.
With scatterer	22,155	19,813	22,395
	22,452	19,939	22,480
	22,246	19,819	22,305
	22,124	19,882	22,084
	22,282	19,787	22,568
	22,704	19,650	22,311
	22,061	19,733	22,064
	22,168	19,942	22,039
	22,398	20,007	22,143
	22,583	19,562	22,173
Average	22,317	19,813	22,256
Mean value	22,317	19,813	22,256
Standard deviation	211.6	138.1	184.0
Minimum value	21,839	19,501	21,840
Maximum value	22,796	20,106	22,673
Without scatterer	4,312	4,125	
	4,266	3,994	
	4,300	3,965	
	4,251	4,061	
	4,210	3,918	
	4,353	4,208	
	4,301	4,002	
	4,334	4,028	
	4,377	4,048	
	4,236	4,017	
Average	4,294	4,040	

value of the number of counts in 4 seconds, and σ the standard deviation. This computed error level (confidence) for 1-in. steel absorber amounts to 0.981.

From the Counting Reference Chart (U. S. Atomic Energy Commission New York Operations), the counting error in counts per second at the prevailing conditions was found to be 95, which is 1.7 per cent. By increasing the average number of counts 16 times in 4 seconds, applying a 2,400-mC source instead of the presently used 150 mC, the error of 1.7 will be reduced 4 times to 0.43 per cent.

The ratio of counts from a 1-in. steel scatterer to counts from one only 1/4 in. thick was 16,117/11,728 = 1.37, which appears to prove the assumption made previously in this report that a thicker scatterer may yield a higher scatter effect.

Since a real void in a weld results in a higher number of counts in the transmitted radiation than does a sound weld, the scaler used with the scintillator could be designed as a "go, no-go" gage. A maximum number of counts representing an acceptable percentage of the weld thickness can be preset on the scaler; and when the counts are reached before the exposure time is passed, a signal would indicate a defective spot in the weld. Of course, the same effect can be obtained with a ratemeter.

GEIGER COUNTER. The Geiger counter used for the following, tests consisted of a thin steel tube of about 1 1/4-in. diameter and 4 in. long, adequately insulated from the centrally located rod anode. The "window" was of mica. The lifetime of this type of Geiger tube is given as "infinite" by the manufacturer.

Fig. 14 is a block diagram of the Geiger counter circuit, and
Fig. 15 shows a diagrammatic arrangement of the Geiger tube
when used with gamma radiation.

The scaler reading according to Table 3 indicates the
lesser sensitivity of the applied Geiger tube as compared with
the scintillator even though a single reading was taken in 10
seconds vs. 4 seconds with the scintillator. The ten readings
made without the use of a scatterer in Table 3 indicate the "noise".

TABLE 3. Geiger Counter

Typical scaler readings, each 10 seconds.

	Steel Absorber			
Remarks	1.0 in.	1.031 in.	1.062 in.	1.094 in.
With scatterer	8,767	8,684	8,586	8,535
	8,856	8,665	8,731	8,470
	8,902	8,586	8,630	8,355
	8,957	8,698	8,609	8,341
	8,918	8,807	8,617	8,483
	8,814	8,729	8,496	8,464
	8,833	8,846	8,627	8,458
	8,881	8,802	8,730	8,526
	8,664	8,722	8,715	8,573
	8,777	8,771	8,760	8,602
Average	8,837	8,761	8,650	8,481
Without scatterer	5,933			
	6,099			
	6,089			
	6,078			
	5,926			
	6,071			
	6,023			
	6,070			
	5,967			
	5,989			
Average	6,025			
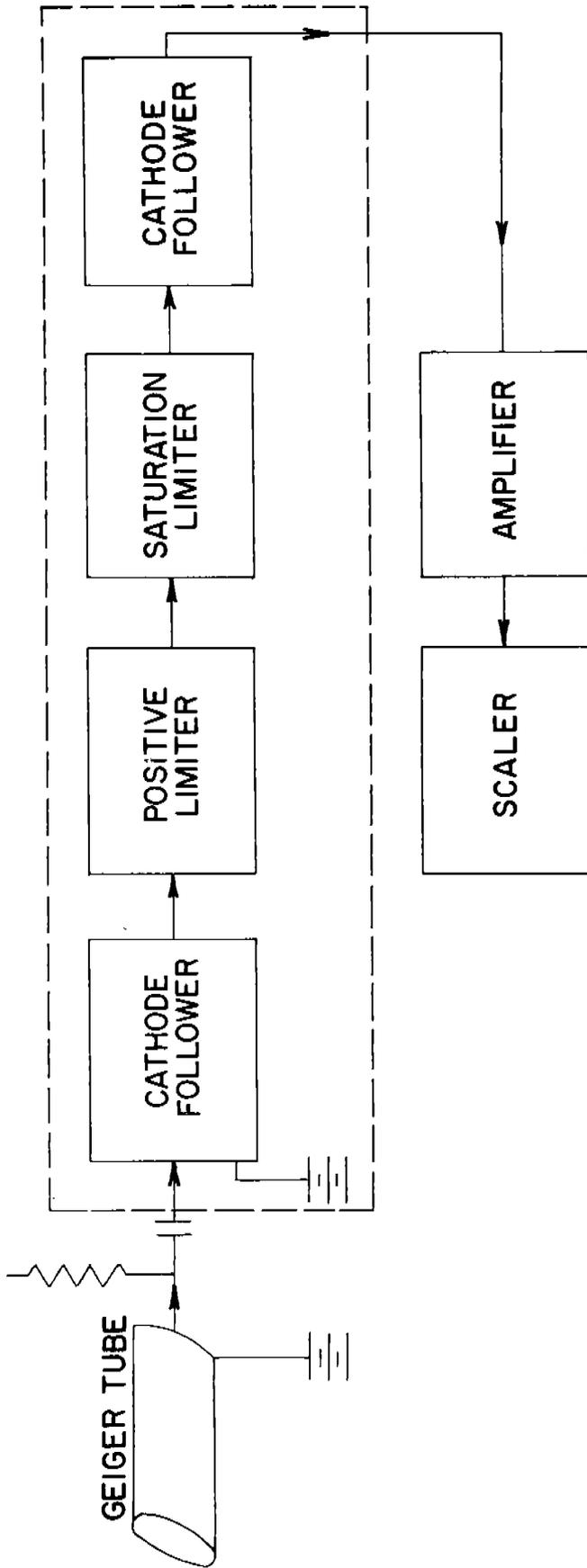
BLOCK DIAGRAM OF THE GEIGER COUNTER
CIRCUIT

NP/45 L017187   NOTS CHINA LAKE, CALIFORNIA
FIGURE 14. BLOCK DIAGRAM OF THE GEIGER COUNTER CIRCUIT.
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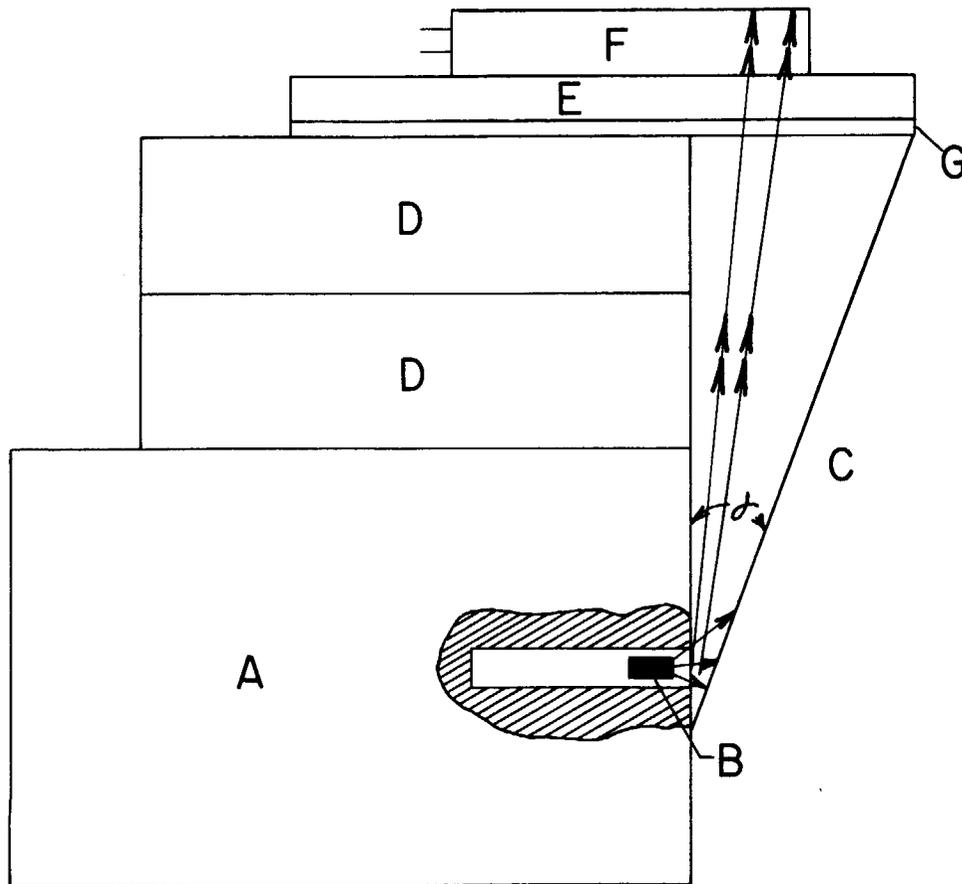
A – Lead container

B – 2 pellets cobalt 60, each approx. 150 mC

C – ¼" steel scatterer

D – Lead bricks, each 2" high

E – 1" steel

F – Geiger tube

G – Tunnel for inserting additional steel sheets

$\gamma = \sim 15°$

→ Primary, radiation

↠ Scattered radiation

Diagrammatic Arrangement of Geiger Tube in Connection with Gamma Radiation

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FIGURE 15. DIAGRAMMATIC ARRANGEMENT OF GEIGER TUBE IN
CONNECTION WITH GAMMA RADIATION.
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By subtraction of the "noise" from the average values, the actual transmitted radiation was computed and plotted vs. steel thickness ("void" depth) in Fig. 16.

Even though the relationship plots as a straight line on semilogarithmic paper for the "void" depths up to 0.094 in., it is to be considered that single readings were obtained in 10 seconds and an average of only 280 counts per second was available as compared with 4,500 counts with the scintillator. When using the Geiger counter, about 12,000 mC would be required for the same value of error, 0.3 per cent, which can be obtained when using a scintillator and 2,400 mC.

A radiation monitor calibrated in mr/hr was used to determine the efficiency of the conversion of the primary Cobalt-60 radiation into the scattered radiation. The monitor was placed in the same location as the Geiger tube and was affected by scattered radiation under identical conditions as the Geiger tube. By consideration of the measurement of the absorption in 1-in. steel and by computation, it was found that about 2.2 per cent of the Cobalt-60 radiation was converted into scattered radiation and affected the Geiger tube.

Also the wave length of the scattered radiation filtered by 1-in. steel was computed from the preceding experimental results. It was found to be about 590 kv which is about 50 per cent of the original average of 1,200 kv.

CONCLUSIONS AND FUTURE WORK

From the foregoing it is concluded that, at least at present, the scintillator is the most useful detector of gamma radiation. Its usefulness will be investigated in connection with a larger gamma ray source (at present about 2000 mC is available). New standard welded plates in preparation at the Philadelphia Naval Shipyard will be checked with one and two scintillators. The latter will be connected electrically in a bridge circuit, and one scintillator will be affected by the radiation transmitted through the weld, and the other through the adjacent base metal. The application of the ratemeter instead of the scaler will be investigated.

The crystals will be investigated for the effect of the 2000 mC Cobalt-60 gamma source and the application of the electric vernier.

After final selection of the detector, the activity of the Cobalt-60 isotope will be determined, and a prototype of the field instrument will be designed.

APPENDIX

EFFICIENCY OF CONVERTING PRIMARY X-RADIATION INTO SCATTERED COMPTON BEAM FOR TEST PURPOSES

The 250 kvp and 4.3 milliamperes applied to the self-rectified X-ray tube are equivalent to about 125 kv effective. Assuming the absorption of the primary radiation by oil and the wall of the plastic cone to be equivalent to about 0.5 mm copper, the roentgen output per minute per milliampere at 1 meter distance is 0.35.[1] The focal spot Geiger counter distance was 137 cm. The output of the primary unabsorbed radiation at the Geiger counter would be 0.83 r/min.

The wave length of the 125-kv radiation according to the Einstein-Planck equation ($\lambda = 12.4/kv$) is about 0.1 Å. From the mass absorption coefficient tables[2] on X rays and gamma rays for $\lambda = 0.1$ Å, μ/ρ was found to be 0.265, and assuming 7.86 as the density of steel, $\mu = 2.08$.

By application of the classical equation $e^{-\mu d} = I_1/I_2$ where $\mu = 2.08$, d = 1/2 inch, I_1 and I_2 are the primary and transmitted radiations respectively, I_1/I_2 was found to equal 0.072.

$$0.072 \times 0.83 = 0.06 \text{ r/min or } 3,600 \text{ mr/hr}$$

Since the scattered radiation transmitted through 1/2-in. steel was measured at approximately 1 mr/hr, the efficiency is $1/3600 \times 100 = 0.03\%$. This figure indicates only the order of magnitude; in fact, it should be higher because the radiation

was entering the counter axially and absorbed by a protective disc of aluminum of about 1/4-in. thickness.

REFERENCES

1. Crowther, J. A. Industrial Radiology. P. 198.
2. Handbook of Chemistry and Physics, 31st Ed.