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William J. Cahill, Jr.
Vice President

Consolidated Edison Company of New York, Inc.
4 Irving Place, New York, N Y 10003
Telephone (212) 460-3819

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Mr. James P. O'Reilly, Director
Region I
Office of Inspection and Enforcement
U.S. Nuclear Regulatory Commission
631 Park Avenue
King of Prussia, Pennsylvania 19406

Dear Mr. O'Reilly

Per your request, enclosed is a detailed technical report concerning the Westinghouse replacement of the fixed in-core detectors on May 4, 1976 at Indian Point Unit No. 2.

Should you have any questions or wish to discuss this matter further, please call me.

Very truly yours

William J. Cahill, Jr.
Vice President

TECHNICAL REPORT OF

EXTREMITY EXPOSURE INCIDENT DURING FIXED

THIMBLE REMOVAL PROCESS

BACKGROUND

One of the projects undertaken during the Spring 1976 Unit No. 2 Refueling Outage was to remove eight fixed in-core detectors (Note 1) of which four were to be replaced with self-powered fixed in-core detectors. This work was being done by Westinghouse Corporation personnel following Westinghouse Procedure MRS2.3.1, IPP-1 "Removal and Replacement of Bottom Mounted Instrumentation Thimbles" and was being controlled under Radiation Work Permit No. 456. Briefly, this procedure calls for complete removal of the detector thimbles (Note 2) from the top of the reactor. The thimble would then be cut into pieces starting at the "cold" (non-radioactive) end. When the cutting operation reached the "hot" (radioactive) end of the thimble, these pieces would be stored in a basket on the reactor cavity floor for later removal to, and storage in, the spent fuel pool. The entire operation was designed to be performed under water with only pieces cut from the cold end being removed from the water for disposal. This procedure had been successfully carried out for three thimbles. The incident in question occurred during removal of the fourth thimble.

DESCRIPTION OF INCIDENT

At approximately 0200 hours on Monday, May 24, 1976, work commenced on removal of the fourth fixed in-core detector thimble. The work crew had successfully withdrawn about 10-12 feet of the thimble. When they attempted to attach the gripper tool the second time to continue the withdrawal process, a seal on the hydraulic ram on the gripper tool failed making this tool inoperative. Not having a replacement gripper tool, the decision was made, by Westinghouse personnel, to use the hydraulic underwater cutter to extract the thimble. This decision was made by Mr. J. Headden in consultation with the Westinghouse project coordinator. According to Mr. Headden, previous experience had shown that the pneumatic vice grips were not capable of gripping the thimble with enough force to prevent it from slipping. The decision was also made, again by Westinghouse personnel to deviate from procedure and start the cutting operation at the "hot" end of the thimble.

1. Calculation of Gamma Exposure

The gamma dose to the hand was calculated assuming a line source of radiation due to neutron activation of the stainless steel thimble. Due to the small source-to-detector distance relative to the mean free path of the photons in air, the equation for gamma exposure rate from a line source becomes:

$$D(l, R) = \frac{K S_L \arctan l/2R}{2\pi R}$$

Where:
- D = exposure rate (R/hr)
- l = length of source (cm)
- R = perpendicular source-to-detector distance (cm)
- K = photon flux-to-dose conversion factor ((R/hr/(γ/cm -sec))
- S_L = source density (γ/cm-sec)

To estimate the contact exposure rate requires the calculation of exposure rates at various distances and extrapolation back to R=0. The results of this calculation as performed by Nuclear Engineering are shown as curve "a" in Figure 1.

Extrapolation yields about 3150 R/hr on contact, 54 days after shutdown. For a 10 second exposure, the dose would thus be about 8.8 Rem.

2. Experimental Determination of Gamma Exposure

An experiment was conducted to measure, as directly as possible, the exposure rate from a thimble. The procedure followed was to extract a thimble from the bottom of the reactor vessel and measure the exposure rate on contact (Note 3) with the stainless steel conduit which is 1/4" thick and in contact with the thimble. The thimble in fuel element J-1 was selected for this experiment due to its accessibility and in order to keep radiation exposures during the experiment to a minimum. Exposure rate measurements were made using a teletector (side window G.M. tube, 1" in diameter, on an extendable probe) and three 0-200 rem self-reading pocket dosimeters. These instruments were placed in contact with the thimble and the thimble was withdrawn so that measurements were made two feet into the "hot area" of the thimble. The thimble was left out for two minutes and then reinserted into the reactor vessel. The teletector was read while the thimble was withdrawn. It should be noted that the thimble touched by Mr. Headden was in fuel element E-11 which had a higher burn-up than element J-1. Correction for differences in activation products as a result of the different burn-ups is shown below. Also shown below is the adjustment to the measured exposure rate due to attenuation in the stainless steel conduit. The experimental measurements obtained are presented below.

Experimental Results

Measured Exposure Rate:

Teletector	-	400 R/hr at 2.9 inches from conduit
Dosimeter 1	-	20 rem/2 minutes = 600 rem/hr at 2.95 inches from conduit
Dosimeter 2	-	18 rem/2 minutes = 540 rem/hr at 3.35 inches from conduit
Dosimeter 3	-	20 rem/2 minutes = 600 rem/hr at 3.70 inches from conduit

Assume 600 rem/hr at 3.35 inches for composite dosimeter reading.

Corrective Factor for Burn-up Difference:

Element	Burn-up, MW days/Metric Ton Uranium
E-11	18,340
J-1	12,687

Calculated Correction Factor - 1.8 (from Nuclear Engineering).

Attenuation Through Conduit:

To calculate the attenuation correction factor the following equation is used:

$$I = I_0 e^{-\mu x}$$

Where:
- I = measured exposure rate
- I_o = unattenuated exposure rate
- μ = linear absorption coefficient, cm^{-1}
- x = thickness of conduit - 0.635 cm

Then:

$$I_0 = \frac{I}{e^{-\mu x}}$$

For a gamma energy of 0.51 MeV(Note 4), $\mu = 0.82\ cm^{-1}$

$$I_0 = I/0.596$$

According to Mr. Headden, he used the hydraulic cutting tool to grip the thimble, which was extended upward such that the end was about at the reactor vessel flange level, and pulled it upward until it was about two feet below the surface of the cavity water. He then bridged east as far as possible which caused more thimble to be extracted from the vessel conduit. The pneumatic vice grips were then attached to the portion above the cutter and a piece 9-10 feet in length cut off and disposed of in the trash basket located in the reactor cavity floor. Mr. Headden then bridged west over the core in an attempt to regrip the thimble. In order to extract more of the thimble, it was necessary to get it in the fully vertical position. Using the vice grips, the thimble was being moved towards the vertical position when about two feet of the end broke water. At this time, two events occurred virtually simultaneously. The first was immediate notification by the on-the-job H.P. Technician (Mr B. Jackson) to get the thimble back underwater. Mr. Jackson was standing on the bridge about 7.5 feet from the exposed thimble. At this position his "cutie pie" survey meter read approximately 25 R/hr. The second was that the thimble started slipping from the vice grips. At this point, to prevent the thimble from slipping out of reach, Mr. Headden grabbed it about a foot from the end and looped it back under water. It was estimated that the thimble was above water for approximately 20 seconds and that Mr. Headden handled it for approximately 10 seconds. With the thimble back under water and once more held securely, Mr. Headden read his 0-200 and 0-500 mrem self-reading pocket dosimeters, both of which were off-scale. Mr. Jackson's dosimeter read 175 mrem, while Messrs. W. Masterlee (Westinghouse) and R. Orzo (Unit 2 Watch Foreman) had dosimeter readings of 220 mrem and 300 mrem respectively. These latter two individuals were also on the bridge assisting in the operation. Mr. Headden's photographic film badge was immediately sent for processing and showed an exposure of 1360 mrem whole body, of which approximately 900 mrem was attributed to this incident.

EXTREMITY EXPOSURE

Due to the fact that the Westinghouse procedure called for all work to be done under a minimum of six (6) feet of water, no extremity monitoring was provided to the individual performing the work.

As a result, there is no direct measurement of the extremity exposure received by Mr. Headden while his hand was in contact with the thimble. Two methods were employed in order to determine Mr. Headden's hand exposure: calculation and experimentation.

Correcting for difference in burn-up and attenuation:

Teletector: $\left(\frac{400}{0.596}\right)1.8 = 1200$ R/hr (Point 3, Figure 1, Curve b)

Dosimeter: $\left(\frac{600}{0.596}\right)1.8 = 1800$ R/hr (Point 4, Figure 1, Curve b)

2. Measured Gamma Extremity Exposure

In addition to points 3 and 4 on curve b of Figure 1, described above, the following data were plotted:

Point 1 - Cutie Pie reading of 25 R/hr at 7.5 feet
Point 2 - Film Badge reading of 900 mrem/20 seconds (162 rem/hr) at 2 feet.

Extrapolating curve b to zero yields a measured gamma extremity dose of from 1700-2700 R/hr, the measured gamma exposure to the hand was found to be:

$$2700 \text{ R/hr} \times \frac{1}{3600 \frac{\text{sec}}{\text{hr}}} \times 10 \text{ sec} = 7.5 \text{ Rem (Note 5)}$$

3. Estimation of beta exposure

To estimate the amount of beta exposure, the first step was to determine the attenuation due to the heavy plastic cotton lined work glove worn by Mr. Headden. To accomplish this, an experiment was conducted in which the attenuation of the betas emitted by Cl-36 was measured. Cl-36 was selected because it best approximated the energy spectra of the beta radiation emitted by the activation products in the stainless steel. The beta emitting activation products in the stainless steel are Co-60 and Fe-59. The energy data, as taken from the Radiological Health Handbook, for the isotopes in question are as follows:

Isotopes	E, av, Mev	E, max, MeV
Fe-59	0.116	0.475
Co-60	0.094	0.314
Cl-36	0.252	0.714

An RM-14 count rate meter was used with an HP-210 GM pancake detector with the following results:

Unattenuated source count rate = 25,000 cpm
Attenuated source rate = 2,000 cpm

Attenuation factor = 12.5

Further, the density thickness of the work glove was measured to be 88.3 mg/cm^2 which requires a beta energy of at least 0.34 MeV for penetration. Therefore, the dominant beta particles from the Co-60 are absorbed. Therefore, calculation of beta dose was based only on the beta particles emitted by the Fe-59.

Fifty-four days after reactor shutdown, based on a thermal neutron flux of 10^{14} n/cm^2- sec and a fast neutron flux of 4 x 10^{14} n/cm^2-sec, the Fe-59 emits 5.2 x 10^9 betas per unit length of the thimble (cm) per second.

Thickness of the thimble wall	= 0.31 cm
Outside diameter of the thimble	= 0.98 cm

Assuming a self absorbing infinite slab of uniform source density, the beta flux was calculated to be about 10^7 β/ cm^2-sec.

The unattenuated beta dose rate to the skin was then calculated to be 2400 R/hr using flux to dose conversion factors from the Engineering Compendium.

The dose to the skin was thus about 0.5 Rad in 10 seconds using the glove attenuation factor of 12.5.

4. Medical Follow-Up and Evaluation

Westinghouse Corporation medical personnel have been observing Mr. Headden on virtually a daily basis in addition to performing blood platelet and chromosome studies. Mr. Headden had been advised to keep his hands out of any solvents or other materials which might produce reddening of the skin. As of five weeks after the incident, Mr. Headden's hand had shown no indication of any radiation exposure. Further the findings from the blood platelet and blood tissue chromosome studies have been reported by Westinghouse as being normal.

Summary and Conclusions

On May 24, 1976, Mr. J. Headden of the Westinghouse Corporation physically touched the activated zone of a fixed in-core detector thimble while in the process of removing said thimble from the reactor vessel. As the procedure called for maintaining a minimum of six feet of water between the thimble and the worker, Mr. Headden was not provided with any extremity monitoring devices and thus a series of experiments and calculations were performed to determine the exposure received by Mr. Headden's hand.

In calculating the results of the experimental data to arrive at the hand exposure, the following assumptions were made:

Gamma Exposure:

1. Highest measured exposure rate was used.

2. Dose buildup in the conduit was neglected. (Neglecting the buildup has the direct effect of increasing the exposure rate attributed to the thimble).

3. In calculating the linear absorption coefficient the energy of the Co-58 positron annihilation photons (0.511 MeV) was used as opposed to the more predominant energy of 0.81 MeV. This decreased the term, $e^{-\mu x}$, thereby increasing the exposure attributed to the thimble.

Beta Exposure:

1. The energy spectrum for the Cl-36 used in determining the attenuation of the work gloves is higher than 99+% of the beta energies being emitted by the thimble activation products. This results in a lower attenuation factor and a higher calculated beta exposure.

2. It was assumed that all the beta particles due to the decay of the Fe-59 are uniformly distributed through the thimble and are emitted in the direction of the hand.

3. It was assumed that all the beta energy was deposited on the surface of the skin.

4. It was assumed that all of the 0.475 MeV beta particles are emitted with the maximum energy of 0.475 MeV and that the energy spectra of those betas penetrating the glove is not changed (degraded).

On the basis of these assumptions, it has been determined that Mr. Headden's hand received the following exposure:

Gamma to the hand - 7½-9 rems
Beta to the skin of the hand - 0.5 rad

Using even these highly conservative exposure values, one would not expect to see any physical effects from the exposure. This, in fact, has been borne out by observation and blood platelet and chromosome studies by Westinghouse medical personnel who have reported no reddening of the skin of Mr. Headden's hand and normal findings with respect to the blood platelet and chromosome study.

Notes:

1. "Detectors" are fission chambers inserted in the reactor core to monitor neutron flux.

2. "Thimbles" are the tubular housing which contained the fission detectors.

3. The edge of the teletector was in contact with the conduit. For actual distances from conduit to actual detectors see Figure 2.

4. The gamma energy of 0.51 MeV represents the gamma radiation emitted as a result of positron annihilation. This energy was used to conservatively calculate the linear absorption coefficient. Use of a higher gamma energy would increase $e^{-\mu x}$ and decrease Io.

5. This calculation ignores dose "build-up" in the conduit inclusion of which would result in a lower thimble contact dose rate.

FIGURE 1

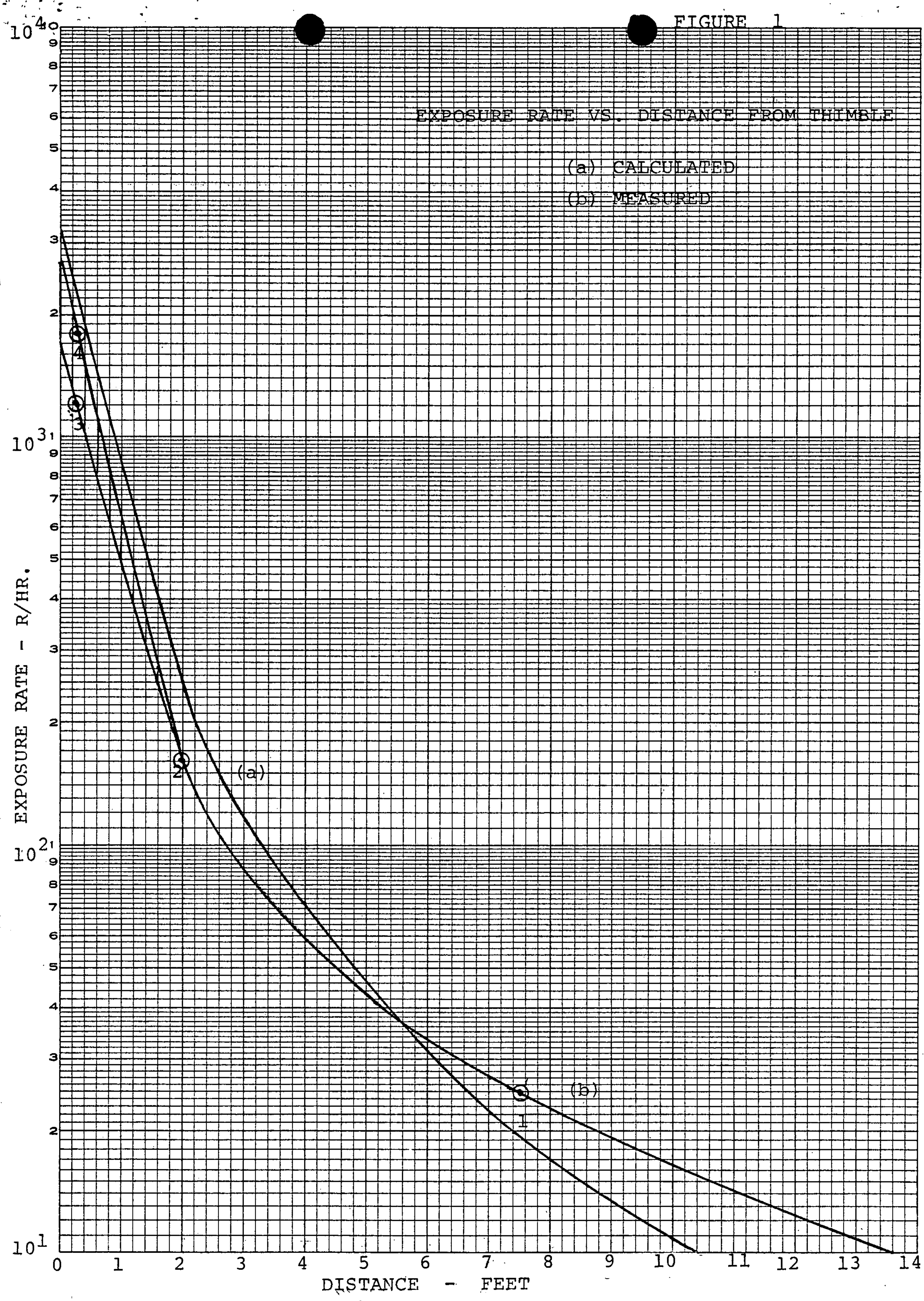
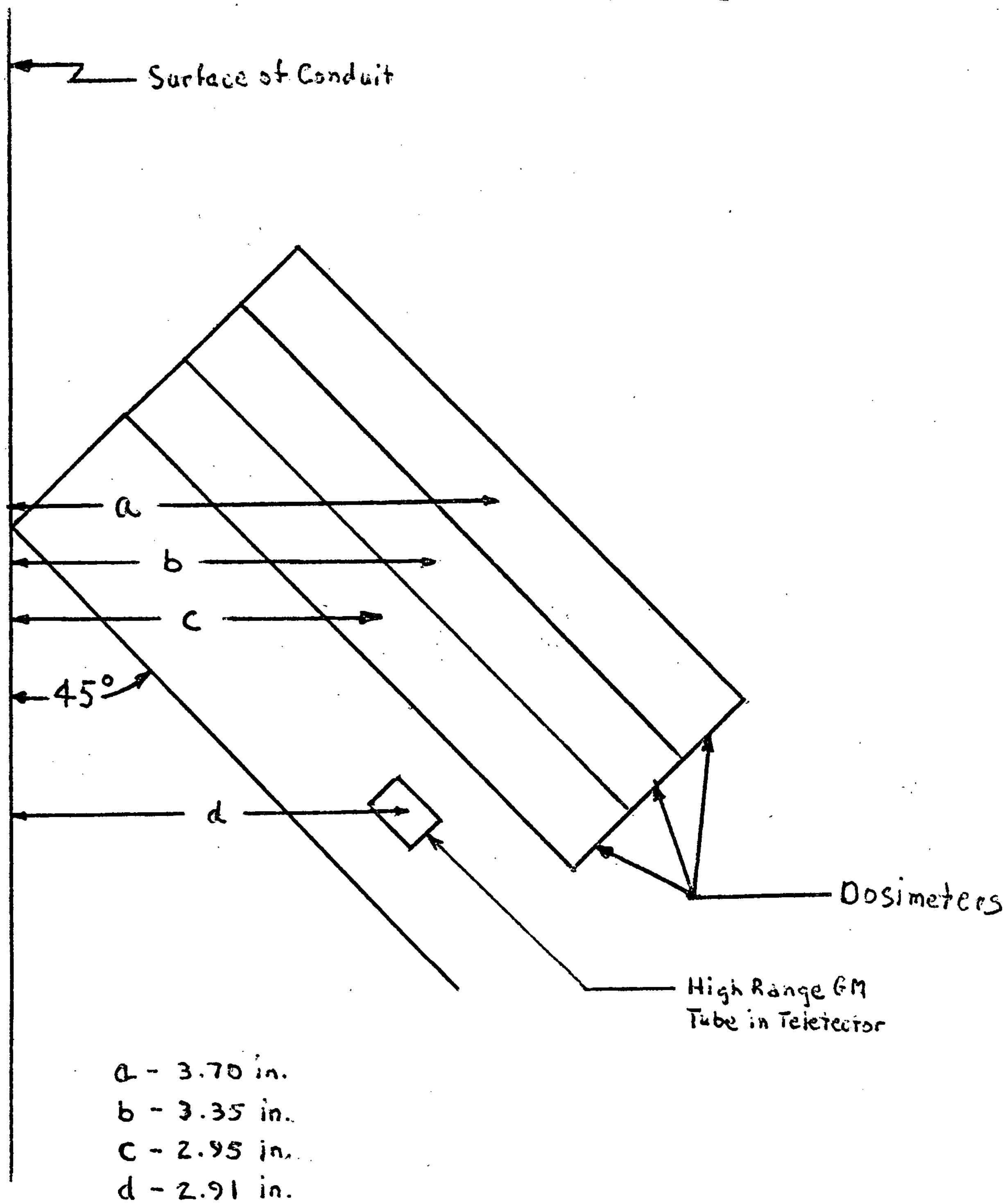

EXPOSURE RATE VS. DISTANCE FROM THIMBLE
(a) CALCULATED
(b) MEASURED
EXPOSURE RATE - R/HR.
DISTANCE - FEET
10^4
10^3
10^2
10^1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
(a)
(b)
1
2
3
4
NO. 341-L310 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
3 CYCLES X 10 DIVISIONS PER INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.

Figure 2



Experimental Set-Up for Measuring Conduit Surface Exposure Rate