COPY NO. 15

TECHNICAL REPORT 4239

SCANNING GAMMA RAY DENSITOMETER SYSTEM FOR DETONATIONS

BY
W. E. VORECK
J. W. McCAHILL

SEPTEMBER 1971

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED.

PICATINNY ARSENAL
DOVER, NEW JERSEY

The findings in this report are not to be construed as an official Department of the Army position.

DISPOSITION

Destroy this report when it is no longer needed.
Do not return.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Picatinny Arsenal, Dover, N. J. 07801	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

SCANNING GAMMA RAY DENSITOMETER SYSTEM FOR DETONATORS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*
W. E. Voreck
J. W. Mc Cahill

6. REPORT DATE	7a. TOTAL NO. OF PAGES 33	7b. NO. OF REFS 2
8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. AMCMS Code 4810.16.2194 d.	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report 4239 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*	

10. DISTRIBUTION STATEMENT

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

The subject of this report is the description of a gamma ray scanning densitometer for measurement of height and density of the explosive increments in loaded detonators and delays. The 317 KEV gamma rays from an Ir^{192} source were collimated into a beam of 0.002 by 0.100 inch. A scanning system moved the detonators through this beam while the intensity of the transmitted radiation was recorded. On M-55 detonators (0.146 inch dia x 0.142 inch high), heights of explosive increments were measured to an accuracy of ±0.002 inch, and densities of lead azide were measured to ± 3%. With Ir^{192}, density measurements on NOL-130 were reproduced to ± 5%, and on RDX to ± 16%. Based on gamma ray absorption theory, it is known that accuracy of RDX measurements will be improved by use of a lower energy gamma ray source.

An improved instrument with both high and low energy sources has been designed and will be built for routine use at Picatinny Arsenal.

DD FORM 1 NOV 68 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Detonators						
Density						
Gamma ray absorption						
Gaging						

Technical Report 4239

SCANNING GAMMA RAY DENSITOMETER SYSTEM FOR DETONATORS

by

W. E. Voreck
J. W. Mc Cahill

September 1971

AMCMS Code 4810.16.2194

Explosives Laboratory
Feltman Research Laboratories
Picatinny Arsenal
Dover, N. J.

ACKNOWLEDGMENTS

This work was sponsored by the Picatinny Arsenal Quality Assurance Directorate, Ammunition Reliability Division. The assistance of Mr. Sam Helf was essential in the design and operation of the nuclear components. Mr. R. Cutler participated in making the required measurements and assisted in reduction of the data. Mr. M. R. Buchanan made and modified the scanning and collimation system. The encouragement and assistance of Mr. J. Hershkowitz, Chief, Applied Physics Branch, is gratefully acknowledged.

BLANK PAGE

TABLE OF CONTENTS

ABSTRACT

The subject of this report is the description of a gamma ray scanning densitometer for measurement of height and density of the explosive increments in loaded detonators and delays. The 317 KEV gamma rays from an Ir^{192} source were collimated into a beam of 0.002 by 0.100 inch. A scanning system moved the detonators through this beam while the intensity of the transmitted radiation was recorded. On M-55 detonators (0.146 inch dia x 0.142 inch high), heights of explosive increments were measured to an accuracy of ±0.002 inch, and densities of lead azide were measured to ± 3%. With Ir^{192}, density measurements on NOL-130 were reproduced to ± 5%, and on RDX to ± 16%. Based on gamma ray absorption theory, it is known that accuracy of RDX measurements will be improved by use of a lower energy gamma ray source.

An improved instrument with both high and low energy sources has been designed and will be built for routine use at Picatinny Arsenal.

INTRODUCTION

Two of the most important parameters determining detonator performance are the density and height of the explosive increments. Typical detonators have three increments: an ignition mix (such as NOL-130), a booster (such as lead azide), and an output charge (such as RDX). Particularly in small detonators each increment is close to its critical density and height, and so relatively small variations can result in great changes in performance. Therefore, the scanning gamma ray densitometer described in this report was developed for studies on effects of dimension and density on performance, and also for possible use as a routine quality control test within the operation of mass production lines.

A gamma ray densitometer is capable of obtaining information on the density and height of explosive increments in a detonator or delay rapidly and accurately. Although X-ray photographs could determine column height and density, it is difficult to obtain accurate measurements in this manner, since the X-ray beam is not parallel or monochromatic, and large quantities of reject detonators could be produced during the time from when the picture was taken until the film could be developed and interpreted.

The preliminary work was done largely by hand; however, an automated scanner could be constructed, based on the same technique, to quickly check representative samples from each loading machine. By promptly detecting any out-of-specification production and indicating what corrections should be made, average quality of production would be increased and production of rejects reduced.

DESIGN

The basic relationship governing absorption of gamma or X-rays in matter (Ref 1) is as follows:

$$\frac{I}{I_o} = e^{-K\rho x}$$

where I_o = intensity of the entering radiation

I = intensity of exiting radiation

x = thickness, cm

ρ = density, g/cc

K = mass absorption coefficient, cm^2/g

The mass absorption coefficient K is a function of the gamma ray wavelength and atomic number of the elements in the sample. The following formula approximates this relationship for wavelengths up to the K band absorption edge (down to 87 KEV for lead):

$$K = (2.25 \times 10^{-20} Z^4 \lambda^3 + b) \frac{N_o}{A}$$

where A = atomic weight, grams/mol

N_o = number of atoms/mol = 6.023×10^{23}

N_o/A = number of atoms per gram

Z = atomic number

λ = wavelength, $\mathring{A}$

b = a constant for each element

As shown above, K depends on gamma energy. Although published K values plotted against λ^3 are not completely linear. Still, this relationship was good enough to provide accurate interpolations to 317 KEV using reported (Ref 2) values above and below this energy level.

As shown in the preceding equation, K is different for each wavelength. Therefore, for accurate density measurement it is necessary to measure absorption at as nearly a single wavelength as possible. It also is necessary to have a constant intensity scanning beam (I_o) during the measurement period. These requirements are most easily met by use of a radioactive isotope source having a reasonably long half life. Although the choice of gamma ray wavelength or energy is restricted to the available isotopes, the selection must be guided by the fact that the maximum rate of change of intensity with density is produced when $K\rho x = 1$. This requirement was obtained by first differentiating the basic absorption equation with respect to a change in density, and then setting the further derivative equal to zero

$$\frac{d}{d\rho}\left(\frac{I}{I_o}\right) = -K\,xe^{-K\rho x}, \quad \frac{d}{dK}\left[\frac{d\frac{I}{I_o}}{d\rho}\right] = -xe^{-K\rho x} + Kx^2\rho e^{-K\rho x} = o$$

from which: $K\rho x = 1$

In a M-55 detonator, the density of the lead azide layer is about 3.43 g/cc, and the equivalent thickness after correcting for curvature and cup wall thickness is 0.3024 cm. Using the above relationships, the optimum gamma ray energy would be 220 KEV. Higher energies would be desirable for larger detonators, and lower ones for lower density components such as RDX.

An Ir^{192} source with an energy peak at 317 KEV was the available source closest to the desired energy and was therefore used for the measurements described. It was used in the form of a 1 mm x 1 mm foil mounted within a 1/4" outside diameter stainless steel tube (see Fig 1). The energy spectrum of Ir^{192} is shown in Figure 2. Major peaks in energy occur at 66, 317, 468, and 613 KEV, with the most intense one at 317 KEV. Discriminators were set to count only the 317 KEV peak in this work. Also shown is the spectrum obtained with the source 1/8" above the slit. Due to energy losses from Compton scattering passing through the lead, the 317 KEV energy was shifted below the counting range, and the 468 KEV peak was not degraded into it, this resulted in a "window" of relatively low background, as shown at the right of Figure 2. Because of the relatively thin layer of lead azide in the detonators, Compton scattering was not significant when absorption measurements were being made with the direct beam.

To obtain the desired spatial resolution, a lead collimator with a 0.002" high, 0.10" wide slit, and a scanning system was built as shown in Figure 1. This allowed the source to be raised into position for measurement, or stored in its shipping pig when not in use. The scanning motor turned at such a rate that 1/32" (0.03125") was traversed each minute; other scanning speeds could be used as required to obtain the desired counts/inch.

The collimator design is a compromise between having a large enough thickness of lead to block the radiation not passing through the sample, and positioning the sample close enough to the source to obtain a reasonable counting rate. With the 6" collimator length used, a counting ratio of 5/1 was obtained for a copper sample compared to background. Before scanning a detonator, correct positioning of the source was obtained by maximizing the transmitted gamma beam with the ratemeter. The proper positioning of the source is of prime importance to avoid longer counting times as well as spectrum distorting effects from the decreased ratio of primary beam to background intensity. An adjustable screw and lock nut are used to hold the source in proper position during scanning.

To improve accuracy, the background during measurements was calculated from counting rates on copper and aluminum standards with the beam in measuring position. Under these conditions, background was about 15% of the sample rate. A permanent record of the rates during detonator scans was made with a strip chart recorder connected to an Ortec Model 441 ratemeter; a more accurate record was also made of the counts per unit time with a Franklin printer attached to the multichannel analyzer.

The scintillation detector tried at first was a 1" diameter x 1" long thallium-activated sodium iodide crystal counting the full energy spectrum of Ir^{192}; however, accurate measurements could not be obtained. Therefore this was replaced by a 2" diameter x 2" long thallium-activated cesium iodide crystal, which was more sensitive and allowed better resolution of energy peaks. Using this detector, background was minimized and satisfactory measurements were obtained by using a pulse height discriminator to count only the pulses in the range from 240 to 400 KEV, which included the iridium 317 KEV peak.

A Northern Scientific Co. Model 610, 1024 channel analyzer operated in the multiscaler mode was used as the amplifier, discriminator, and scaler to measure the intensity of the gamma rays after passing through the samples. To achieve statistically accurate results, it was necessary to accumulate at least 10^4 counts per channel. Originally the maximum counting time per channel in the multichannel analyzer was only one second. As the source decayed, this was increased to 5 seconds, and finally a single channel analyzer was used, with a timer range of up to 10^4 minutes.

A second higher intensity 2 Curie Ir^{192} source was obtained which increased the counting rate so that the multichannel analyzer and printer could be used to obtain data on an M-55 detonator in about 5 minutes. Best results were obtained when the counting time of the multichannel analyzer was extended to 5 seconds by use of a crystal-controlled external timer, the Tektronix 184 Time Mark Generator.

MATERIALS MEASURED

Of the eight materials studied, only aluminum and copper were solids at their crystal density. Solid aluminum and the empty aluminum cup had different counting rates, and a K value for aluminum was obtained from these measurements. However reproducibility was poor, and results did not agree with standard values (Ref 2). This is attributed to the fact that at 317 KEV the aluminum does not absorb many gamma rays, and therefore $K\rho x$ was not close enough to 1.0 to produce accurate results.

All remaining materials were explosives in pressed powder form. Three of these were individual compounds (lead azide, RDX, and tetryl). The other two were mixtures, stab mix NOL-130, and the output mix composition shown in Table 1.

CALCULATIONS

In order to use the basic equation $\frac{I}{I_o} = e^{-K\rho x}$, it is necessary to introduce a correction for background scattered radiation which does not pass through the sample, as shown in Figure 3. If this is taken into account the equation becomes:

$$\frac{I-I_b}{I_o-I_b} = e^{-K\rho x}.$$

Since the explosive samples were encased in aluminum cups, it also was necessary to correct for the amount of radiation absorbed by the cup. Mathematically:

$$\frac{I-I_b}{I_{ec}-I_b} = e^{-K\rho x}.$$

where I_b = background radiation, I_{ec} = intensity after passing through an empty cup. While it was possible to measure I_{ec} directly, the difference between I_{ec} and I_o often was so small as to be indistinguishable on the ratemeter, and so the calculated ratio of $\frac{I_{ec}}{I_o}$ was used for the aluminum in the cup. Since copper has about the same absorption as lead azide, and aluminum has about the same absorption as RDX, they were chosen as references to allow corrections to be made for decay of the source, changes in the source location, and background radiation.

Assuming absorption from a monochromatic source of 317 KEV gamma rays, the mass absorption coefficients of copper and aluminum were obtained by interpolation from the published (Ref 2) values, this assumption is reasonably correct because only the narrow band of energies between 240 and 400 KEV were counted. The background cannot be measured directly with the source in place; however, calculation of I_b and $I_{ec} - I_b$ can be made since the dimensions of the aluminum and copper samples, their densities, and their mass absorption coefficients are known. For example, the following calculation was made for the M-55 detonator with the dimensions and gamma intensities shown in Figure 3:

Interpolation of published K values to 317 KEV was made assuming a linear relationship between λ^3 and K over the range from 307 to 409 KEV. The interpolated values for copper and aluminum were:

$$K_{Cu} = 0.12178$$

$$K_{Al} = 0.010305$$

The basic relationship for absorption of gamma rays in thin samples is:

$$\frac{I_s - I_b}{I_o - I_b} = e^{-K\rho x}$$

where I_s = intensity measured with sample in beam

I_o = intensity of direct beam without sample

I_b = background intensity which reaches detector without passing through sample

Using the known constants for M-55 detonators from Figure 3 in the above equation:

$$\frac{I_{Al} - I_b}{I_o - I_b} = A = 0.9086$$

$$\frac{I_{ec} - I_b}{I_o - I_b} = B = 0.9930$$

$$\frac{I_{Cu} - I_b}{I_o - I_b} = C = 0.6903$$

From these relationships:

$$\frac{I_{Cu} - I_b}{I_{Al} - I_b} = D = 0.7597$$

where subscripts refer to the material placed in the gamma beam:

Cu = Copper
Al = Aluminum

ec = Empty aluminum cup

Since I_{Al}, I_{Cu}, and I_s are recorded for each sample, the above equations can be rearranged to obtain the following:

$$I_b = I_{Cu} - \frac{D}{1 - D} (I_{Al} - I_{Cu}) = I_{Cu} - 3.1618 (I_{Al} - I_{Cu})$$

$$I_{ec} - I_b = \frac{B}{(1 - D) A} (I_{Al} - I_{Cu}) = 4.5481 (I_{Al} - I_{Cu})$$

This method of obtaining I_b is more accurate than the approximate value obtained when the source is 1/8" above the collimator slit, since the reflections around the sample are not the same when the rays arrive by a different path. These constants apply only for the M-55 detonator dimensions. Different constants could be obtained for other detonator dimensions, using the same equations.

RESULTS

The procedure used was to place a copper standard next to the RDX, and an aluminum standard next to the NOL-130 and then scan the detonator and the two standards consecutively. The counts per unit time were recorded on a printed tape as the beam scanned the detonator, and then the density was calculated by rearranging the absorption equation to the form:

$$\rho s = \frac{-I}{K_s x_s} \ln \left[\frac{I_s - I_b}{I_{ec} - I_b} \right] = \frac{-I}{K_s x_s} \ln \left[\frac{I_s - I_{Cu}}{4.5481 (I_{Al} - I_{Cu})} + 0.6952 \right]$$

where:

ρs = density of the explosive scanned, g/cc

K_s = mass absorption coefficient of the explosive, cm^2/g

x_s = average thickness of the explosive = 0.3024 cm in M-55 cups

I_s = average counts per second measured with the sample in the beam

The values of the mass absorption coefficient, K, for the explosives were determined by scanning at least six samples of known density of each of the materials of interest. These results are shown in Figure 4. The measured values of K are lower than the calculated values because the gamma rays are not truly monochromatic and because some of the higher energy rays may be degraded down into the measuring range as they pass through the sample. The values of $K\rho x$ also are calculated to indicate the relative accuracy of density measurement that would be expected with 317 KEV for these materials. As can be seen, a lower energy gamma source will be needed for accurate measurements on tetryl and RDX. It must be remembered that some of the variations are due to errors in measuring the standard densities. These were determined by weighing the samples to ± 0.0002 g and measuring their diameter and height to ±0.0002"after pressing into M-55 cups. Because the samples were so small, weighing and measuring errors could account for ± 1% and cannot be ignored. This is shown by the increase in precision obtained with duplicate measurements on the same samples marked with an asterisk in Table 2.

A sketch of a M-55 detonator is shown in Figure 5 and typical scans of M-55 detonators are shown in Figure 6. The distance between interfaces were read from these Ortec 441 rate meter plots while the densities were calculated from the printed counts. A series of eight measurements was made on one M-55 detonator, and of four on another to determine the reproducibility of the measurement system. These results are shown in Table 2.

As can be seen from these results, interface locations can be measured to an accuracy of ± 0.002", and densities to a precision of ± 0.2 g/cc for lead azide and NOL-130. The differences in measured increment heights were caused by (1) sample rotation, (2) hysteresis of the recording system, (3) width of the slit, and (4) the statistical uncertainty of the nuclear counting. In the present scanner, samples could rotate, particularly while moving down, because they are moved through the gamma ray beam by being pushed by the rotating end of a threaded rod screwed through a fixed nut. Variations near the upper sides of interfaces are caused by sample rotation because of uneven amounts of "upstand" in loading. Upstand is defined as the small quantity of explosive extruded or trapped in the clearance between the punch and the cup which is left extending above the face produced by the flat end of the punch.

Results of the measurements on 100 typical M-55 detonators from the production plants are shown in Figure 7. Variations in density generally have a normal statistical distribution. Variations in column heights show the contributions of several different loading machines to the lots. This is to be expected, since loading pressures rather than column heights, for NOL-130 and lead azide are controlled and quantity of fill varies. Density data on RDX are too inaccurate to draw any significant conclusions, as previously discussed.

The effect of pressure variations on density of the explosive increments in M-55 detonators was obtained during preparation of the standard samples listed in Table 2 and is shown in Figure 8. Although the densities of NOL-130 and lead azide in M-55 detonators were higher for the same pressure because column heights were smaller, the relatively large changes in density with pressure for NOL-130 and lead azide emphasize the importance of accurate control of pressure and density measurements on these key components.

X-ray pictures of the same M-55 detonators whose scans are shown in Table 4 were made with a 150 KEV tube, and typical ones are shown for comparison in Figure 9. As can be seen from this figure, the interfaces between NOL-130 and azide cannot be discerned, and the RDX interfaces cannot be determined as accurately as with the scanner.

FUTURE PLANS

Mass absorption coefficients will be measured on the components in other detonators and fuzes, and scans made on them. The XM-53 delay is of particular interest due to a current problem in controlling its reliability. Preliminary data show that the interfaces between the three delay increments as well as their density gradients, can be determined, as shown in Figure 10.

An improved density scanner for routine measurements is being designed by the Loading Division of the Industrial Services Directorate, Picatinny Arsenal (see Fig 11). The following improvements over the current scanner were incorporated:

1. A depleted uranium instead of lead collimator is used to increase signal-to-background ratio due to its higher density (19.0 vs 11.3).

2. Slit is adjustable for both width and thickness to optimize dimensions for each type of detonator. A narrower slit will improve length resolution, but decrease counting rates and reduce accuracy of density measurements.

3. Slit is vertical to prevent sagging due to its weight.

4. Sample insertion and removal is facilitated by permitting horizontal movement.

5. A line source (foil or wire) is being provided to make use of a larger fraction of the available flux.

6. By preventing sample rotation, accuracy of height measurements will be improved when interfaces are not horizontal.

7. Scans will be made in opposite directions and averaged to compensate for hysteresis in the recording system.

8. Because of the wide range of densities of interest, an additional isotope source is needed to improve accuracy. For RDX and tetryl, a lower intensity source such as Co^{57}, which produces 14 KEV and 122 KEV gamma rays and has a half life of 270 days,

appears to be the least expensive. Other isotopes that may be of interest in subsequent work are Cd^{109} (22 KEV), Se^{75} (130, 270, and 402 KEV), and Cs^{137} (32 and 66 KEV).

CONCLUSIONS

This study has shown that it is possible to establish a gamma ray density scanning system which will determine densities within ± 3% if the gamma energy is within 30% of optimum and a single energy peak is counted. A collimator only 0.002" wide, which allows heights of explosive increments to be measured to an accuracy of 0.002", also was designed and constructed. This study was conducted using the 317 KEV gamma rays from an Ir^{192} source, which is accurate only for explosives containing lead; however, it provides the justification for procurement of an additional source more nearly optimized for lower density components such as RDX, and design of an improved scanning system adapted to routine measurement and control applications.

REFERENCES

1. Richtmyer, F. K. and Kennard, E. H., "Introduction to Modern Physics", McGraw Hill, New York, N. Y. 1947, pp 501-505

2. Weast, R. C., "Handbook of Chemistry and Physics," 47th edition, Chemical Rubber Co., Cleveland, Ohio, 1966

TABLE 1

NOL-130 stab mix

Lead styphnate (basic)	40%
Lead azide (dextrinated)	20%
Barium nitrate	20%
Antimony sulfide (Sb_2S_3)	15%
Tetracene	5%

Output mix for Xm53 delay

Lead styphnate (basic)	40%
Lead oxide	44%
Silicone	11%
Nitrocellulose/ethyl centralite	5%

TABLE 2

Reproducibility of density scans on M-55 detonator

Lot LS 167-5

Scan Direction	NOL-130 Height mils	NOL-130 Density g/cc	Interface Length mils	Interface Shape	Lead Azide Height mils	Lead Azide Density g/cc	Interface Length mils	RDX Height mils	RDX Density g/cc	Total Height mils
Down	18.1	3.672	13.7	Fair	62.5	3.453	3.1	56.9	1.453	137.5
Down	18.8	3.310	13.7	Sharp	62.5	3.322	3.8	57.5	1.484	138.8
Down	18.8	3.340	10.0	Fair	63.7	3.481	3.1	56.9	1.889	139.4
Down	17.5	3.249	14.4	Fair	63.7	3.471	1.9	56.9	1.772	138.1
Up	19.4	3.473	8.7	Sharp	63.1	3.474	3.1	56.9	2.181	139.4
Up	18.8	3.408	11.9	Sharp	62.5	3.346	3.8	58.1	1.998	139.4
Up	17.5	3.531	6.2	Sharp	65.0	3.367	1.9	57.5	1.950	140.0
Up	18.8	3.391	3.7	Sharp	63.1	3.369	3.8	58.1	1.838	140.0
Avg down	18.3		13.0		63.1		3.0	57.0		138.4
Avg up	18.6		7.6		63.4		3.2	57.6		139.7
Avg	18.5	3.422	10.3		63.3	3.410	3.1	57.4	1.821	139.1
Std deviation	0.64	0.126	3.63		0.81	0.061	0.74	0.53	0.233	0.83

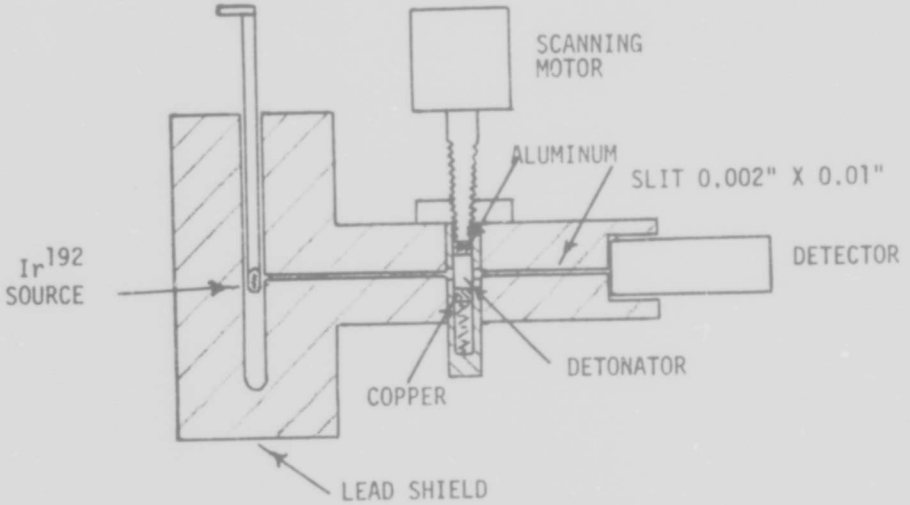
Lot IOP 52.6

Up	20.8[a]	3.415	8.0	57.3[a]	3.216	2.0	57.3[a]	1.846	135.1[a]
Down	20.6	3.440	12.4	56.9	3.230	6.2	60.0	1.840	137.5
Up	20.8[a]	3.496	8.0	57.3[a]	3.227	3.0	57.3[a]	1.633	135.1[a]
Down	21.2	3.406	12.4	55.6	3.294	3.1	60.6	1.952	137.5
Avg	20.8	3.439	10.2	56.7	3.242	3.6	60.0	1.818	136.4
Std deviation	.25	0.040		0.80	0.035		1.75	0.133	1.21

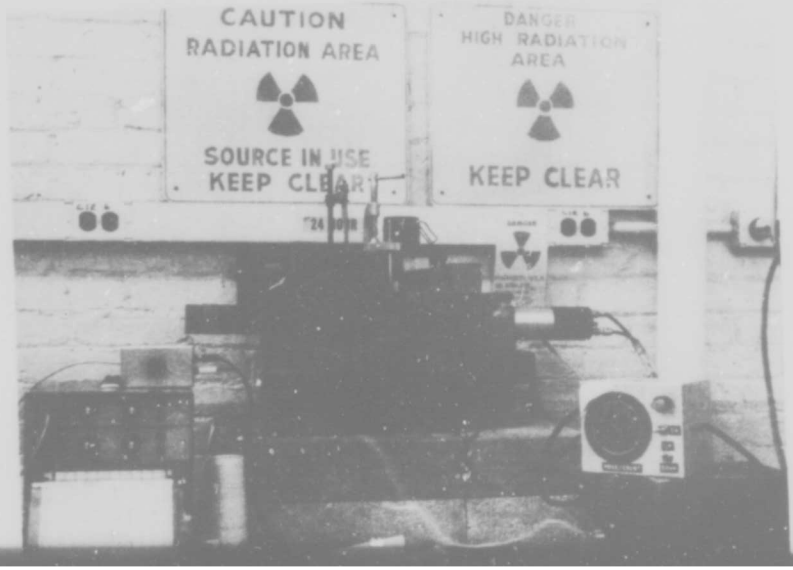
Accuracy of height measurements Lot LS 137-5
Combining all four increments
Average standard deviation = 0.713 mil
95% confidence limits = ±1.43 mil

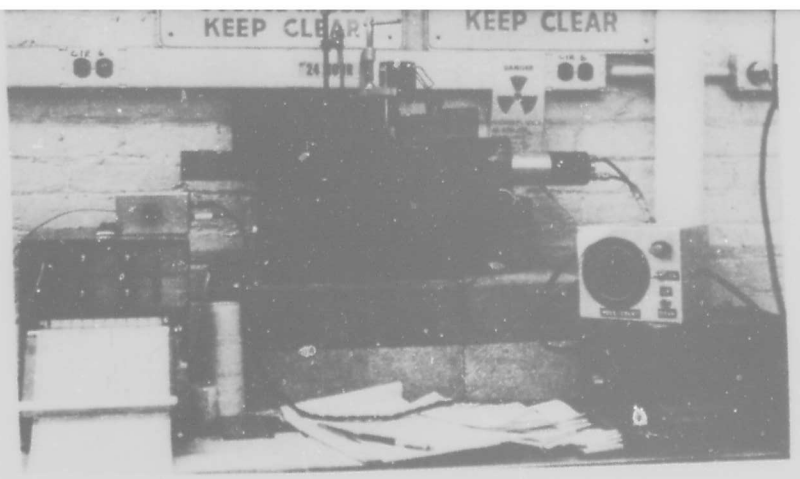
Accuracy of density measurements
NOL-130 95% confidence limit = .19 g/cc or ±5.4%
Lead azide 95% confidence limit = .10 g/cc or ±3.0%
RDX 95% confidence limit = .38 g/cc or ±20%

[a]Data from printer, analog recorder not working, 2.6 mil steps increased interface location errors, so IOP 52-6 was not used to calculate accuracy of length measurements

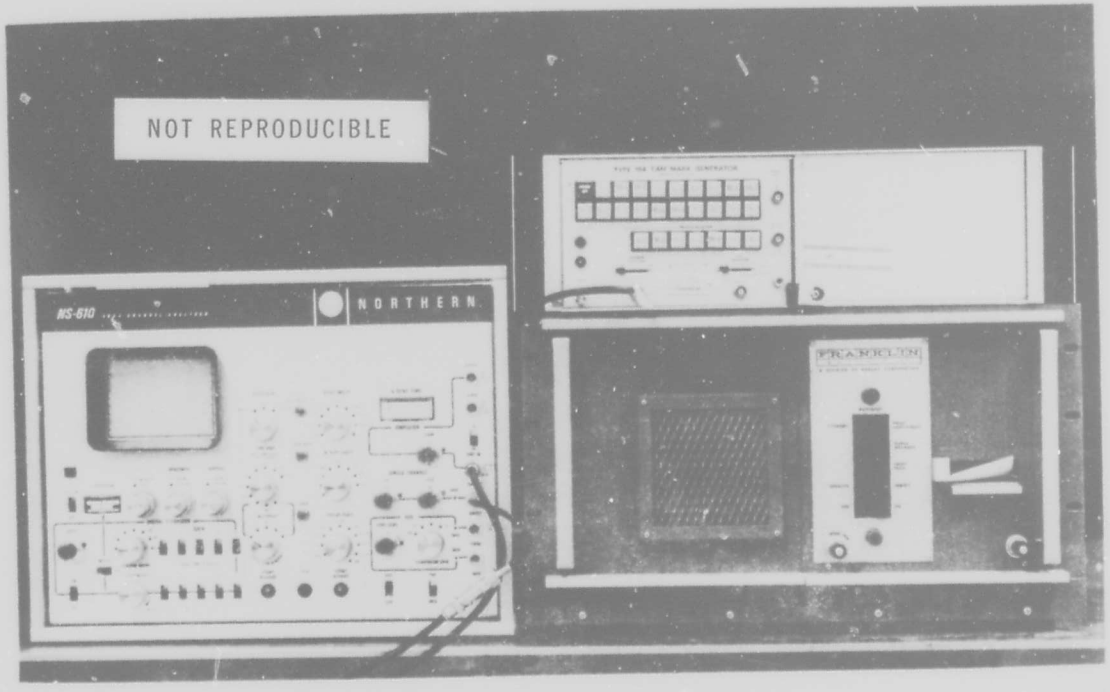


Cross Section





Shielding



Instrumentation

Fig 1 Gamma ray density scanner

BLANK PAGE

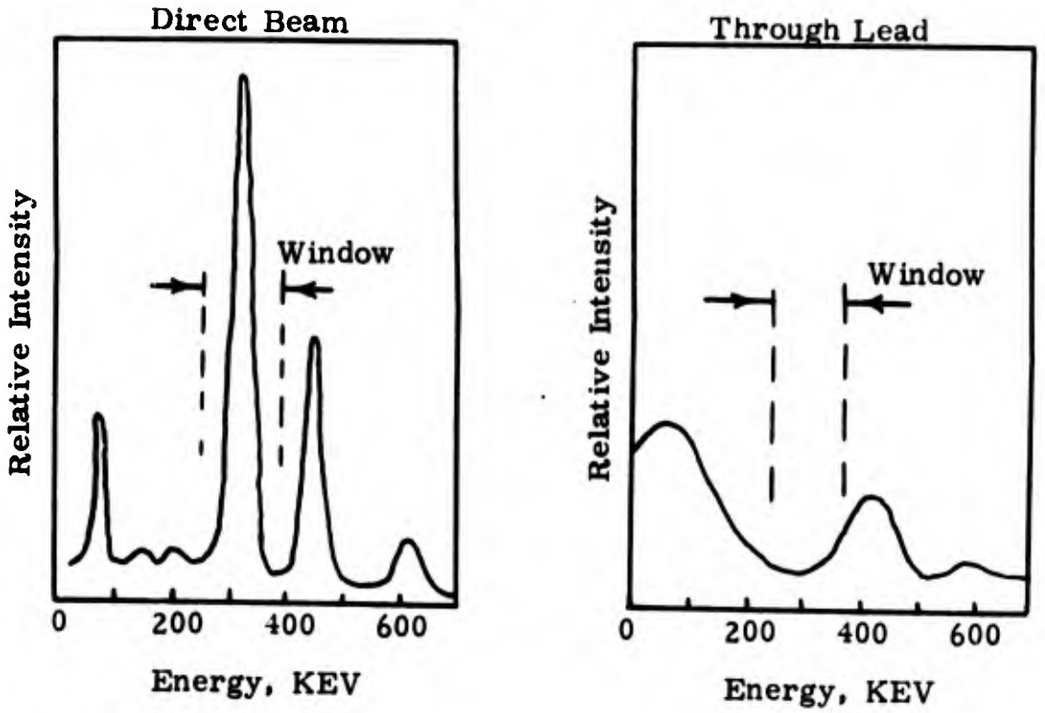
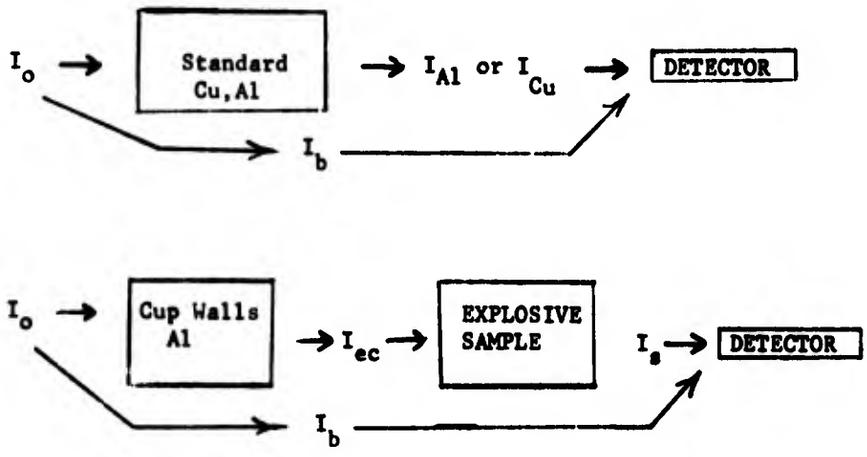
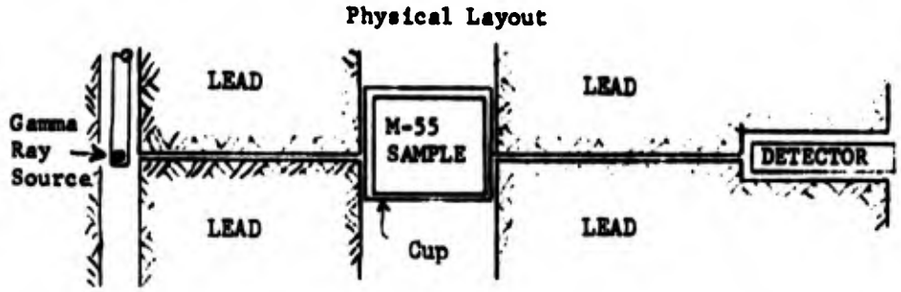


Fig 2 Ir^{192} gamma spectrum





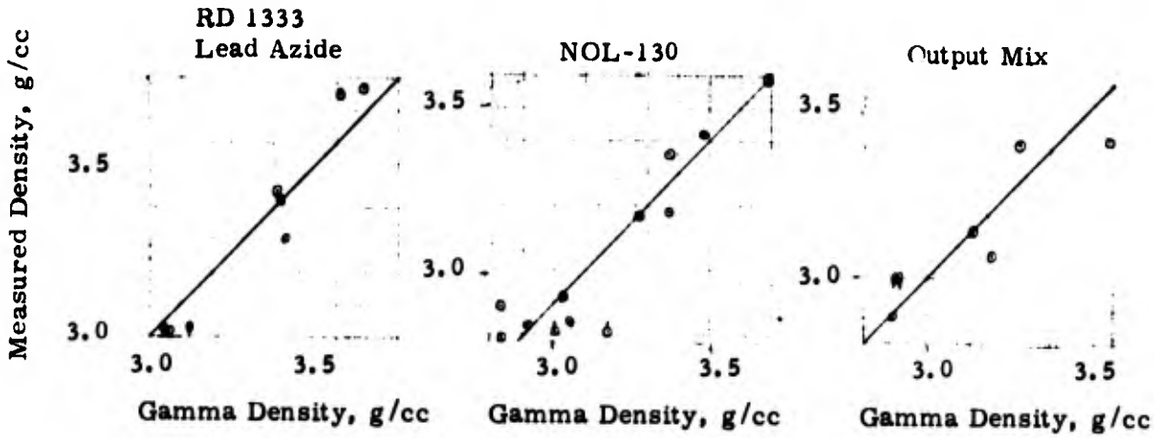
Scattered radiation not passing through sample = I_b

Note:

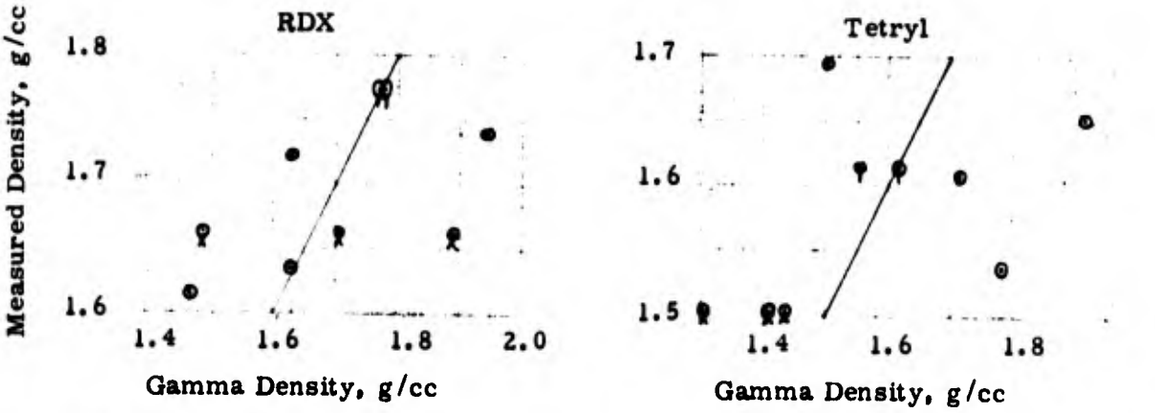
Measurements of the standards:

X_{Cu} = 0.3412 cm = 0.1467 inches
X_{Al} = 0.3444 cm = 0.1480 inches
ρ_{Cu} = 8.92 g/cc
ρ_{Al} = 2.70 g/cc
X_{ec} = 0.0254 cm = 0.010 inches = thickness of walls of cup

Fig 3 M-55 detonator gamma ray intensities used in calculations



95% C.L. on Density, %	2.9	4.3	3.3
Average K, cm^2/g	0.3351	0.2443	0.3047
$K\rho X$	0.369	0.261	0.320



95% C.L. on Density, %	10.9	11.4
Average K, cm^2/g	0.1016	0.1020
$K\rho X$	0.052	0.049

Fig 4 Mass absorption coefficients and density measurements

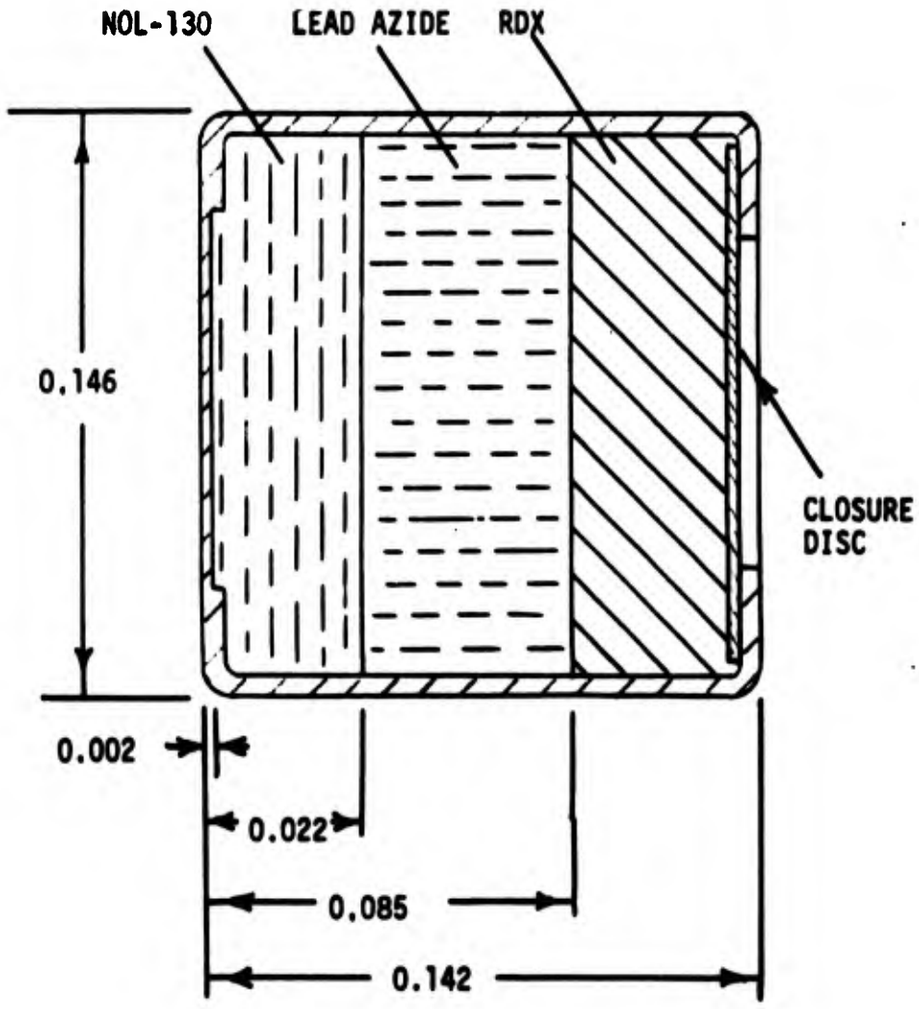


Fig 5 M55 Detonator

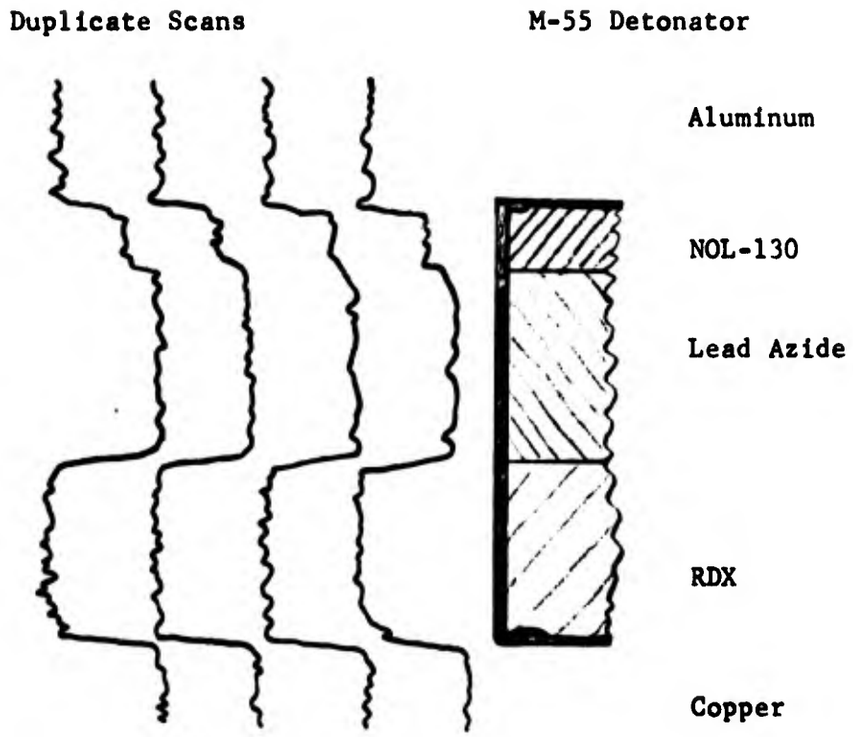


Fig 6 Typical densitometer scans on M55 detonator

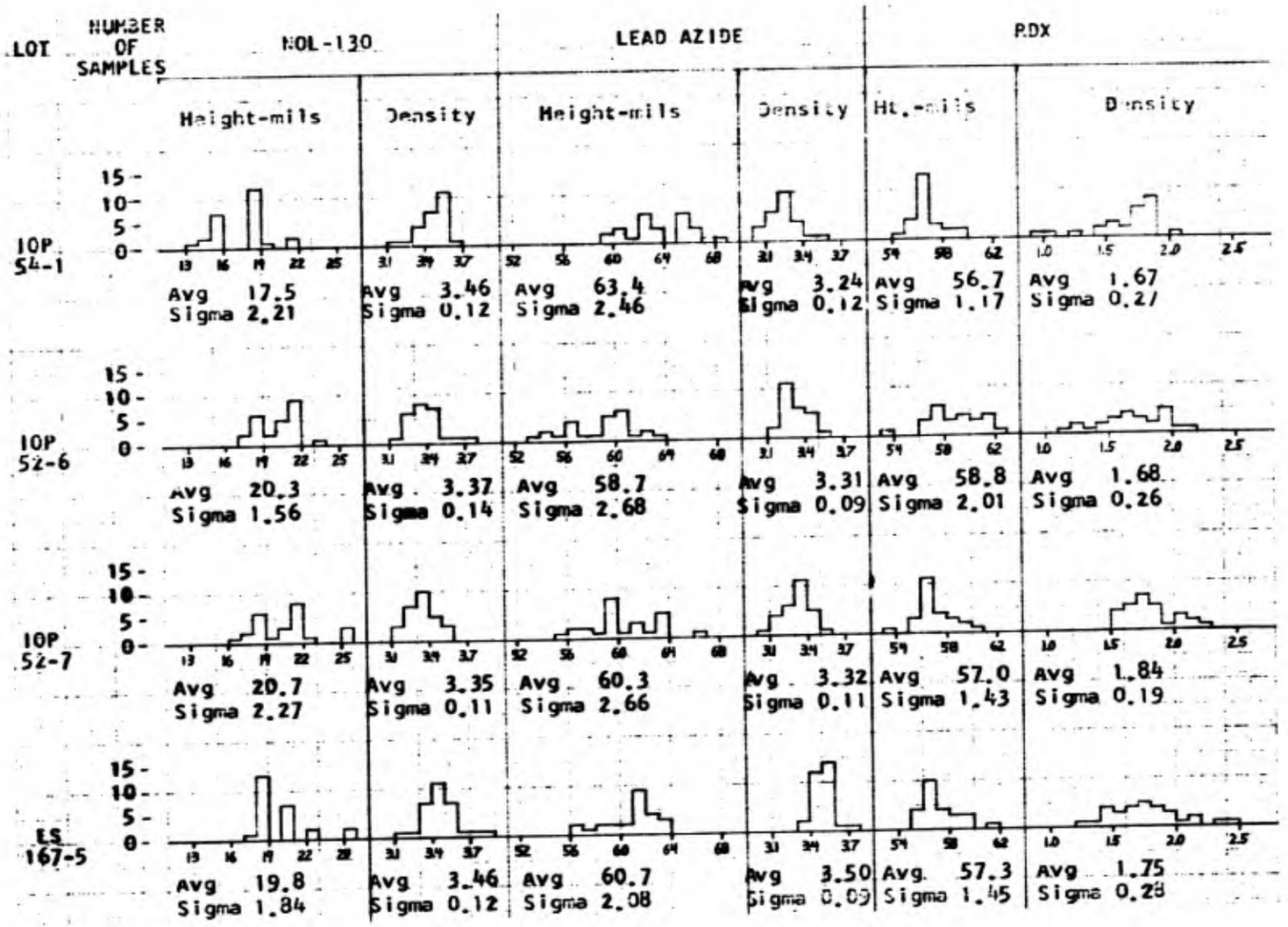
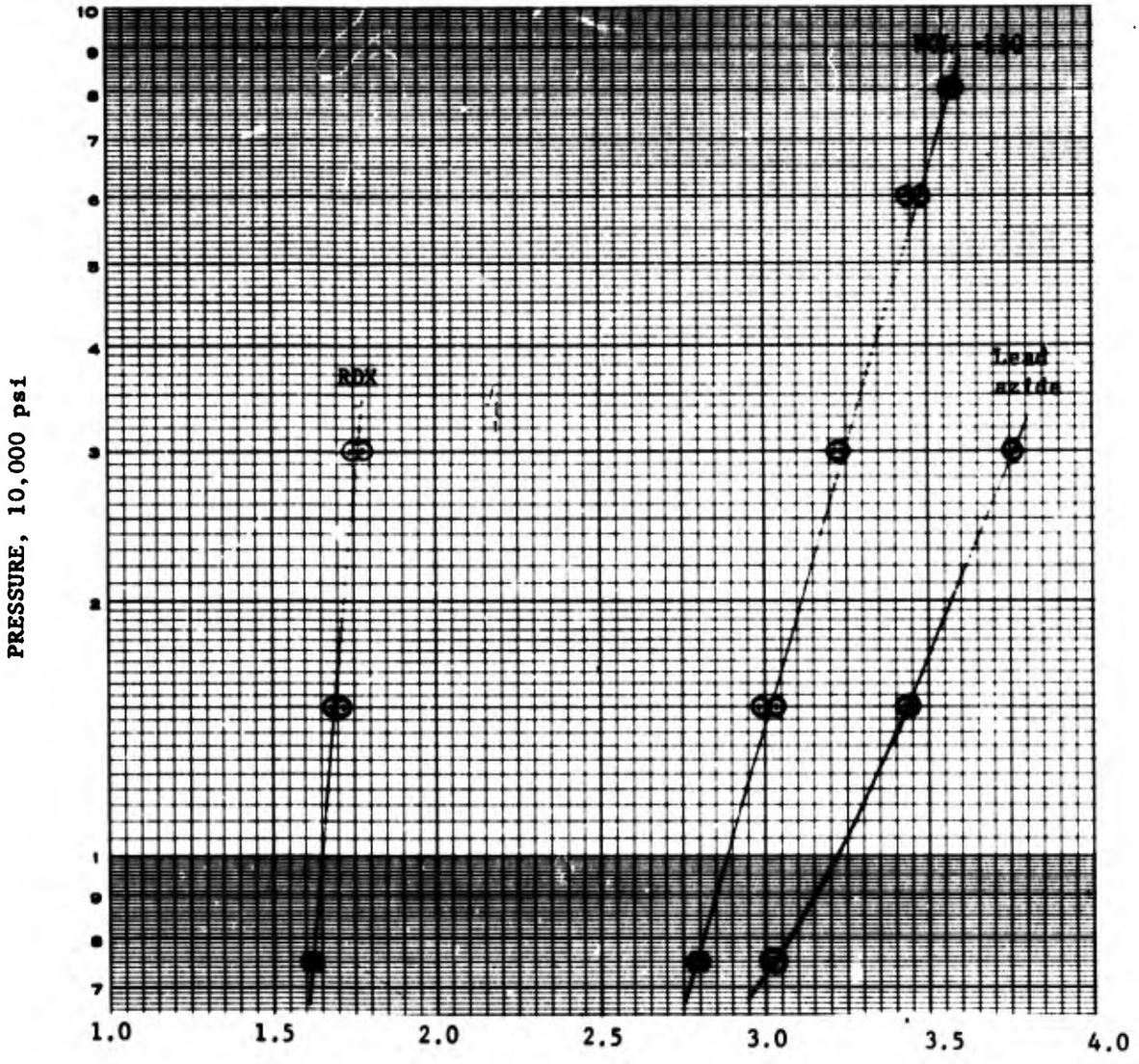


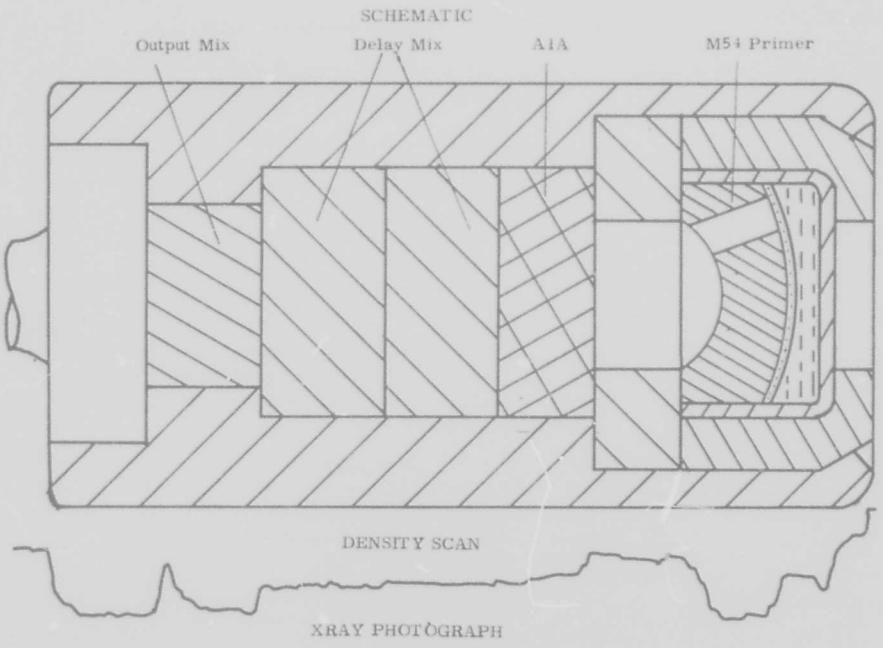
Fig 7 Summary of measurements of M55 detonator



RDX	$P = 0.00026e^{10.58d}$
NOL-130	$P = 3.679e^{2.794d}$
Lead Azide	$P = 8.748e^{2.166d}$

Fig 8 Density vs loading pressure in M55 detonator

Fig 9 Typical X-ray pictures of M55 detonators (taken with 150 KEV tube)



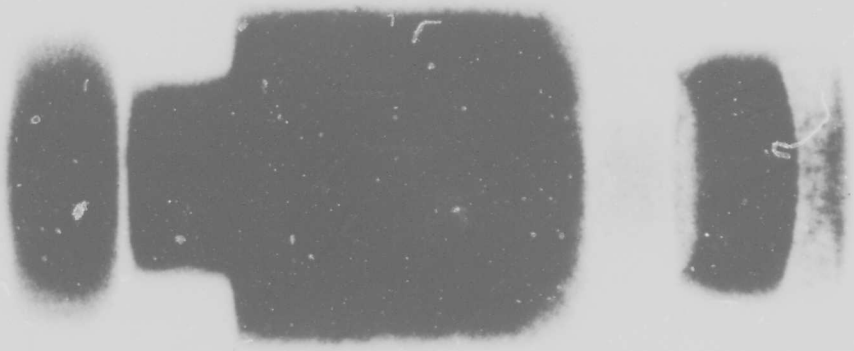


Fig 10 XM53 delay scan

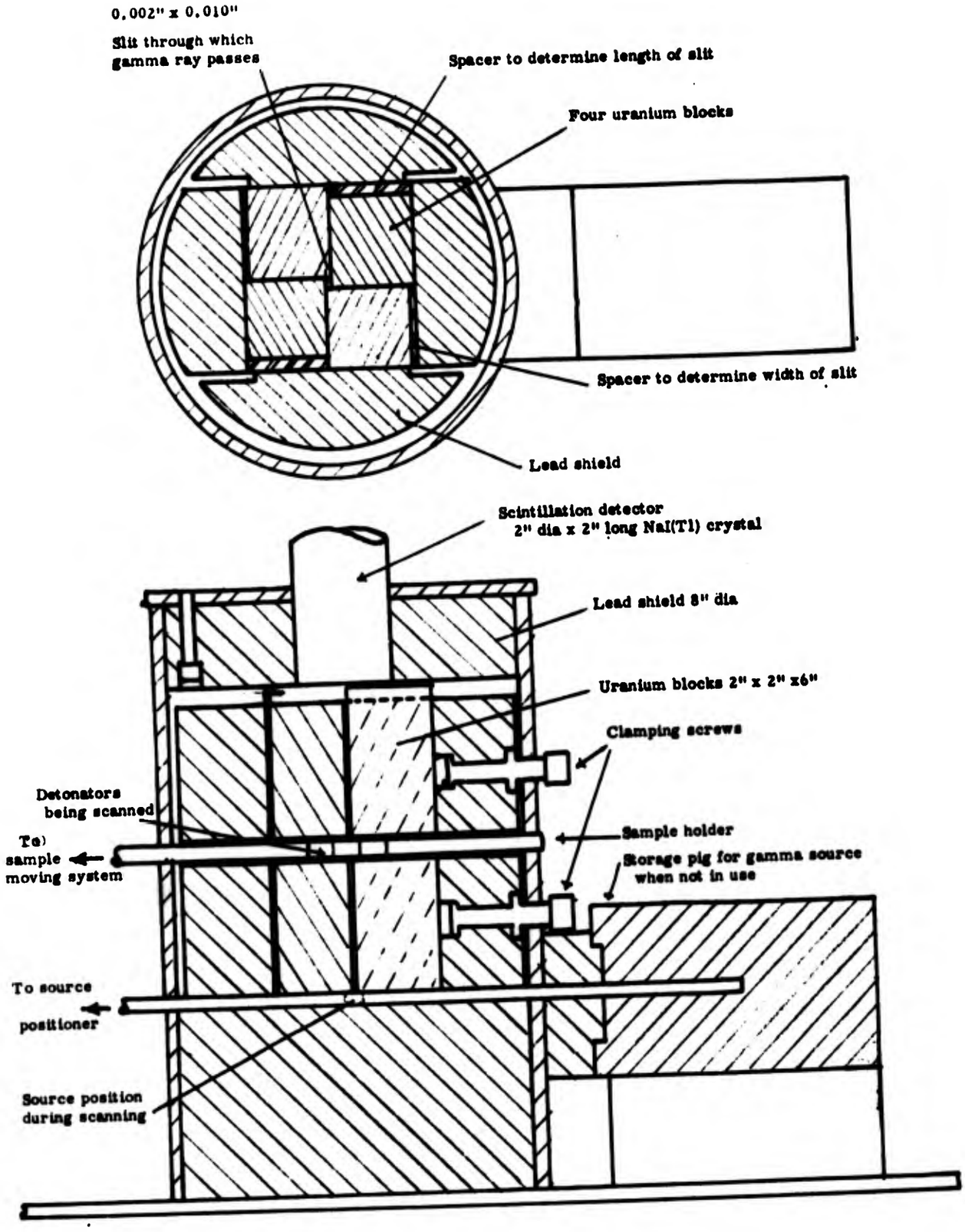


Fig 11 Improved gamma ray scanner system