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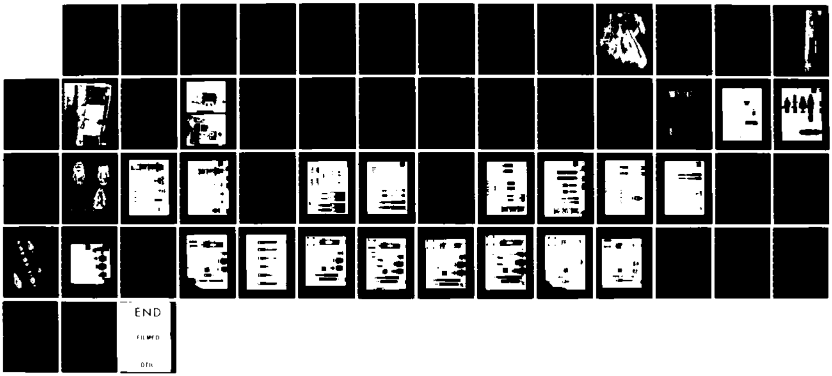

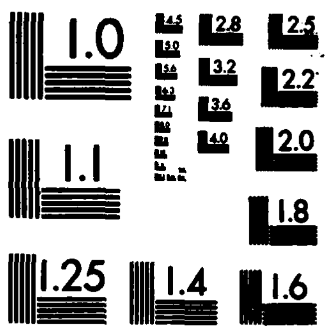

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AMMRC MOBILE ACCELERATOR NEUTRON RADIOGRAPHY SYSTEM OPERATIONS AT U.S. ARMY YUMA PROVING GROUND

Interim Technical Report
Report No. 3-41000/4R-110

Contract DAAG46-78-C-0007

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Prepared for

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Watertown, Massachusetts

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ABSTRACT

The mobile neutron radiography system designed and fabricated for the Army Materials and Mechanics Research Center by Vought Corporation was transported to U.S. Army Yuma Proving Ground (YPG) for exploratory evaluation by YPG radiography personnel. Objectives of the field operations were to demonstrate applicability of neutron radiography for inspection of specific Army ordnance items, to provide Army personnel with on-site experience and a data base for defining future neutron radiography and facility requirements, and to evaluate the reliability of this new type of mobile neutron radiography system in a non-laboratory or field environment. Neutron radiographs were compared with X-ray radiographs of the test items. Areas were noted where only the neutron images yielded useful NDI information, and others noted where X-ray is needed. The complementary nature of the results from the two radiographic techniques was well illustrated. Several neutron converter/film combinations were utilized during the operations to determine the optimum combination for producing good images in reasonable exposure times, using a relatively low-flux system. The system operated reliably during the six weeks period in the non-laboratory environment, and safety of operation of the mobile inspection unit was demonstrated.

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1.0 INTRODUCTION

The concept of a mobile on-off neutron radiography system, with potential for development into a transportable system suitable for operation in a depot environment, was conceived and demonstrated by Vought Corporation in the late seventies. This work, performed by Vought Advanced Technology Center on an in-house program, included the design and implementation of a test-bed laboratory system and the experimental determination of critical design parameters involved in the development of an inspection head for field use. The present contract encompasses the detail design, fabrication, and validation testing of an engineering model based on the earlier Vought work. The program objective is to provide the Army Materials and Mechanics Research Center with a hardware system capable of laboratory and limited field operations. This will provide the Army with the capability of mobile on-off neutron radiography for further studies of its application to many of the Army's current and future inspection problems.

The third phase of this program, the validation or evaluation phase, has been completed. This phase has included system demonstrations and neutron radiographic inspection of Army and Air Force aircraft structural specimens, both in the Vought Laboratories and during operations in which the system was transported off-site to Army and Air Force test and maintenance facilities, respectively.

This interim report covers the work performed at the U.S. Army Yuma Proving Ground (YPG) during a six-week program of system demonstration and evaluation. It is emphasized here that the AMMRC system was designed and intended for use in a laboratory or exploratory mode, as the first major step toward the development of a production inspection system. The current system represents the state-of-the-art in mobile on-off neutron radiography technology, being the first operating mobile system using an accelerator source of neutrons.

The operations at the Army Yuma Proving Ground were undertaken and carried out with the following objectives in mind:

(1) Evaluating the applicability of neutron radiography for solving inspection problems associated with specific Army ordnance devices and assessing its potential use for batch lot inspection.

(2) Assessing the radiation environment during operation of a system of the AMMRC type and evaluation of radiation safety operating procedures.

(3) Evaluating the performance parameters and reliability of the system in an environment external to the laboratory.

(4) Providing neutron radiography experience in the YPG environment to serve as a basis for defining future YPG N-Ray system requirements and formulating the specifications for an inspection system at YPG.

2.0 EQUIPMENT AND OPERATIONAL PROCEDURES

2.1 EQUIPMENT

The AMMRC mobile neutron radiography system, subject of the work reported here, is shown in the photograph of Figure 1. The system is comprised of a sealed-tube neutron generator system which serves as the source of primary neutrons, a moderator-collimator assembly, and a positioning vehicle. The relation of the neutron generator to the total system is shown in the block diagram of Figure 2. The fast neutrons generated in the target of the accelerator tube by means of the D-T reaction are monoenergetic, having an energy of approximately 14 MeV. These neutrons are slowed down to thermal energies (0.025 eV) in a moderating material which surrounds the target, and a thermal neutron beam for radiography is provided by a collimator inserted into the moderating medium.

The neutron source for the radiography system consists of a sealed neutron generator tube, high voltage DC power supply, a cooling unit, and remote control console unit. This is shown schematically in the block diagram of Figure 3. The system is typically operated at 180 Kv and 4 ma ion current. The H.V. power supply provides both ion source high voltage and the ion accelerating voltage. A cooling unit circulates liquid coolants through separate closed-loop circuits for ion source and target cooling. Temperature of the target coolant is maintained at approximately 40°F or below during operation. Total power consumption of the neutron generator system, including the cooling unit, is approximately 7 Kva.

Neutron imaging during the series of radiographic runs was primarily by neutron converter screen/film combination. Both industrial and medical X-ray film were utilized during the course of the tests. During the last week of operations, a near-real-time neutron/X-ray imager developed by Vought specifically for operating compatibly with the AMMRC radiography system was shipped to YPG for demonstration and evaluation.

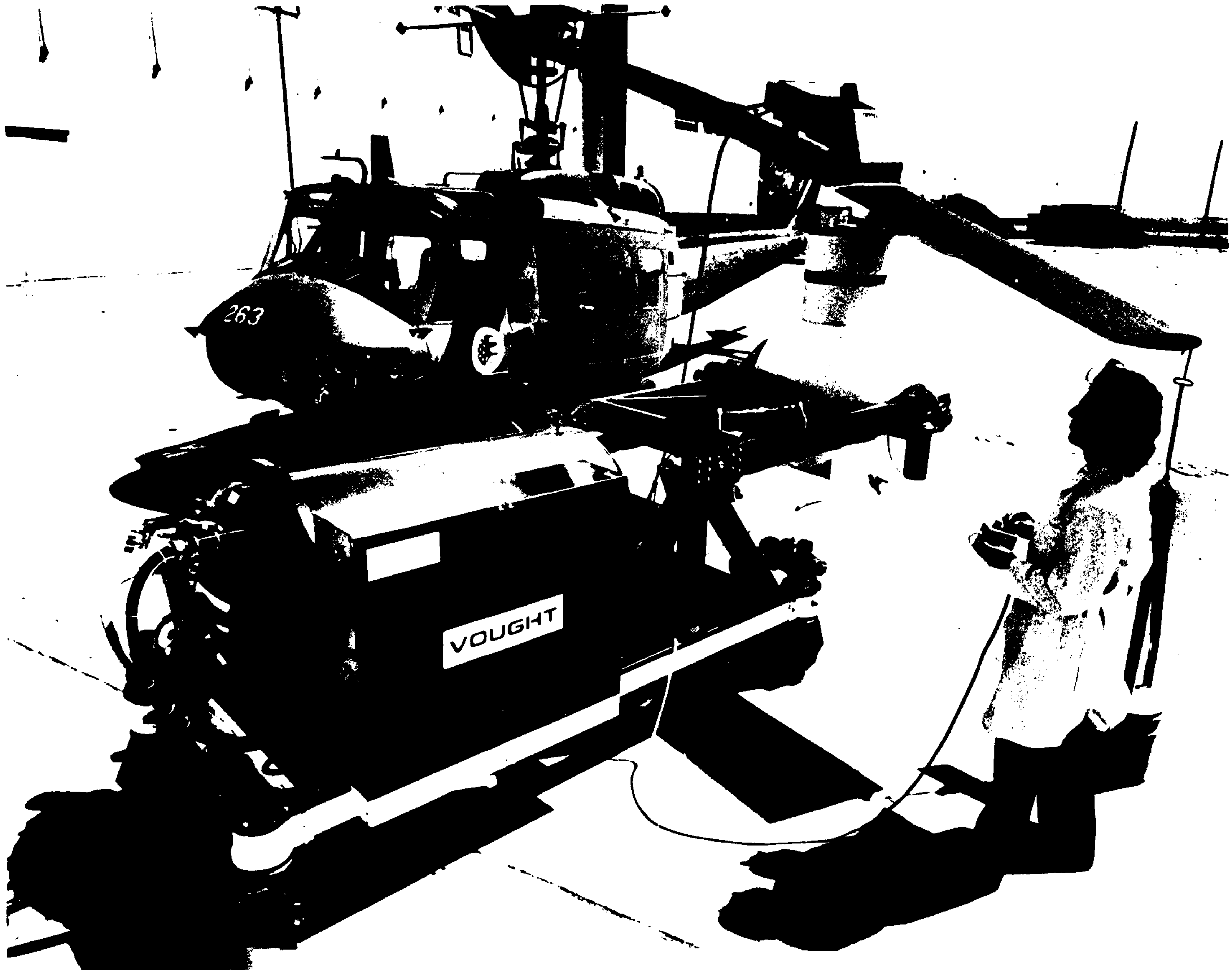


Figure 1. AMMRC Mobile Accelerator Neutron Radiography System

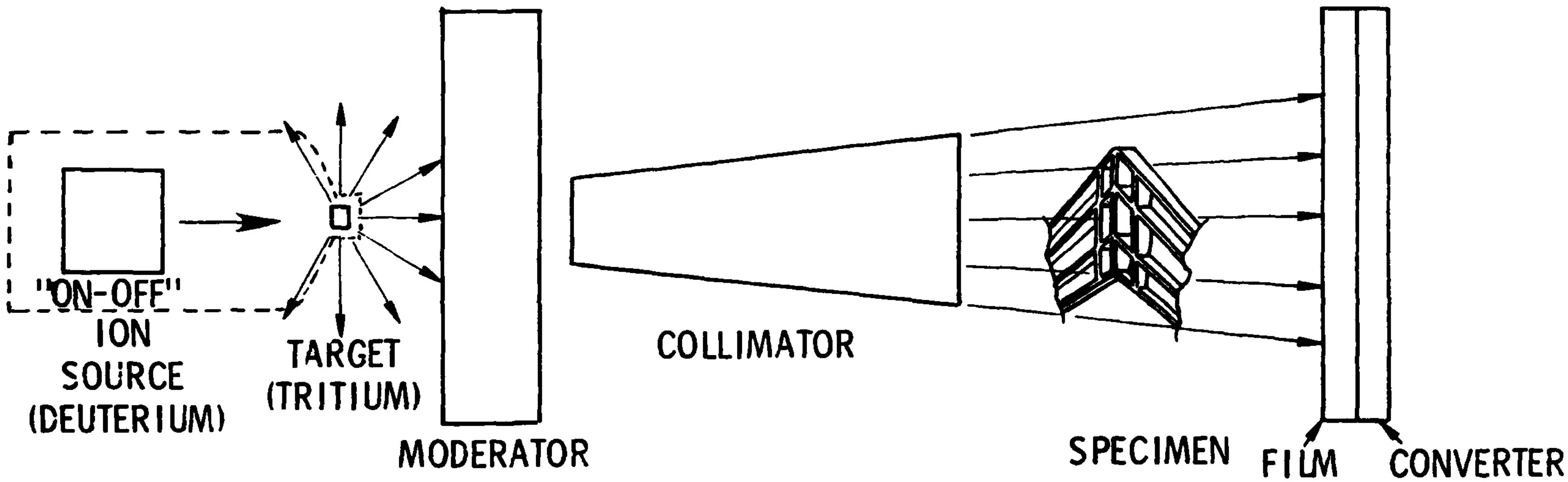


Figure 2. Schematic Representation of Sealed-Tube Neutron Generator Radiography System

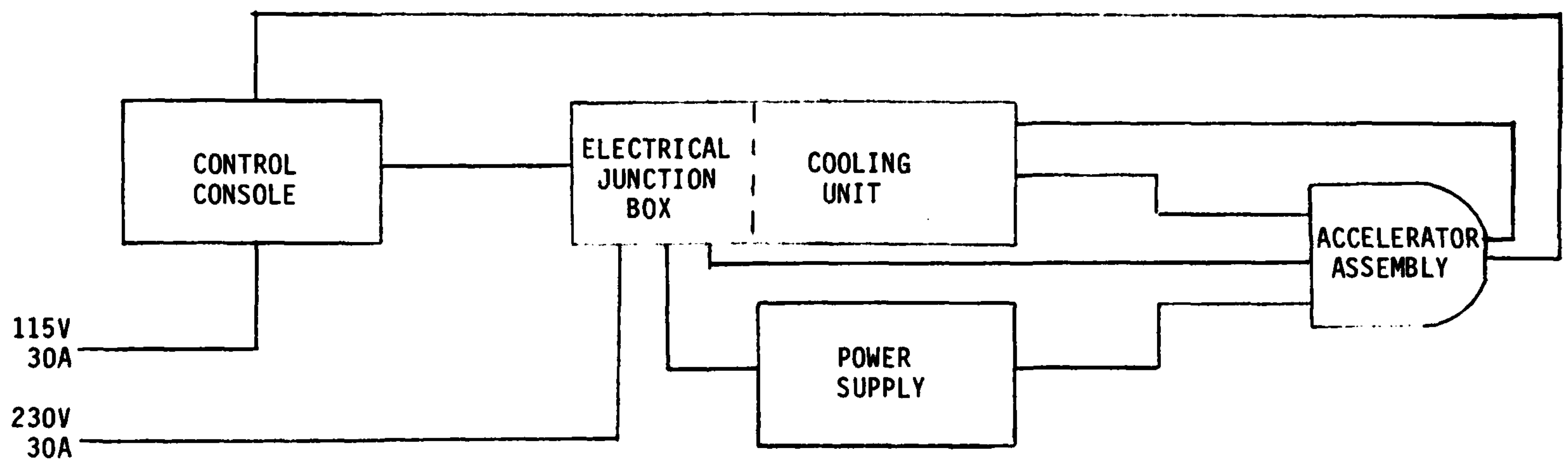


Figure 3. Block Diagram of Fast Neutron Generator

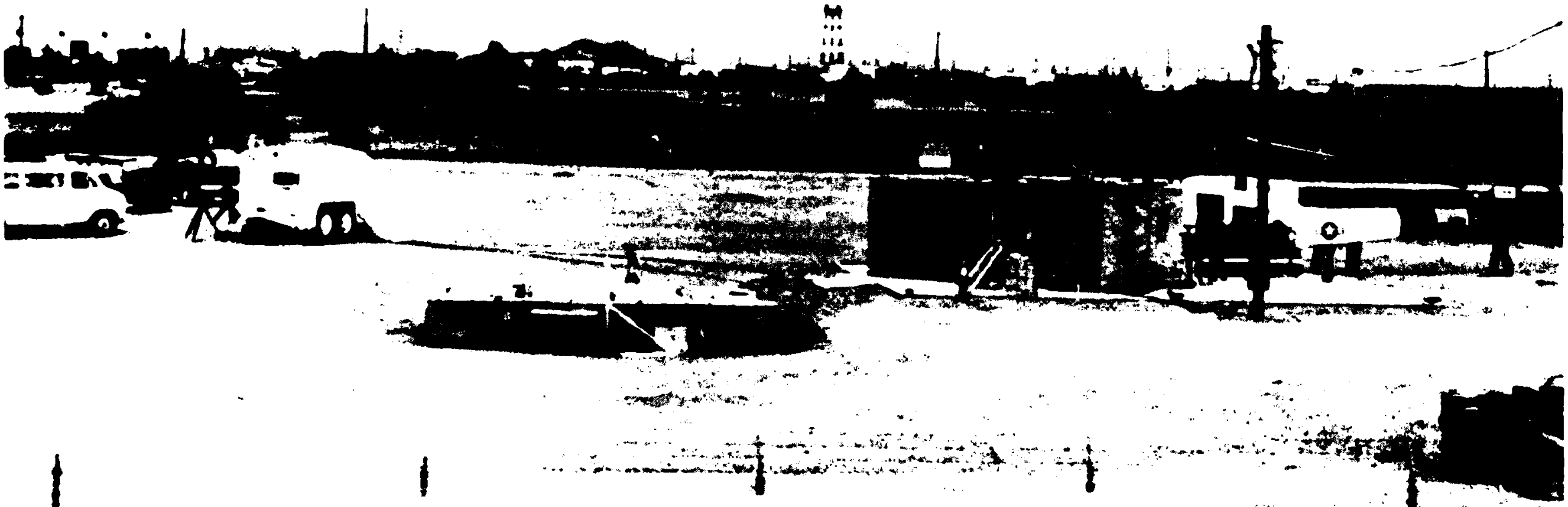


Figure 4. Site of Mobile Neutron System Neutron Radiography Operations – U.S. Army Yuma Proving Ground

2.2 FACILITIES

Neutron radiography operations were performed in an area adjacent to the USAYPG X-ray facility, within the X-ray compound. Minimum radiation shielding requirements for the neutron operations were specified by Vought, and in advance of the testing program, a concrete pad and concrete-block and paraffin shielding for the accelerator, and appropriate boundary fences were erected by USAYPG personnel to provide for area control and personnel safety during operations. A weatherproof trailer van was also provided as a remote operator control center. The adjacent X-Ray facilities were made available on a continuous basis for film processing and interpretation, and office and other needed support. An overview of the site of operation is shown in Figure 4. The concrete-block structure used for radiation shielding is shown in detail in Figure 5. Blocks were stacked in a staggered fashion to prevent radiation streaming through the cracks. A schematic diagram of the shielding is given in Figure 6. The control van is shown in Figure 7.

2.3 SAFETY OPERATIONS

2.3.1 Transportation of Equipment

In advance of the planned off-site neutron radiography operation, NRC Form 241 describing the activities to be conducted at YPG was filed and accepted by the area office of the Nuclear Regulatory Commission. An environmental impact statement, prepared earlier by AMMRC personnel was accepted by the area Environmental Protection Agency. The Department of Transportation, the Texas State Department of Health, and the state of Arizona - Bureau of Radiological Health were advised, and the Vought radiation safety plan for the Yuma Operation was forwarded in advance to the YPG safety office for approval.

Shipment of the AMMRC neutron radiography system and the necessary support equipment for these operations was by Vought Corporation truck. To assure meeting the available schedule window and to reduce risk of undue

Figure [illegible]. Concrete Shielding Structure for Neutron Radiography Operations

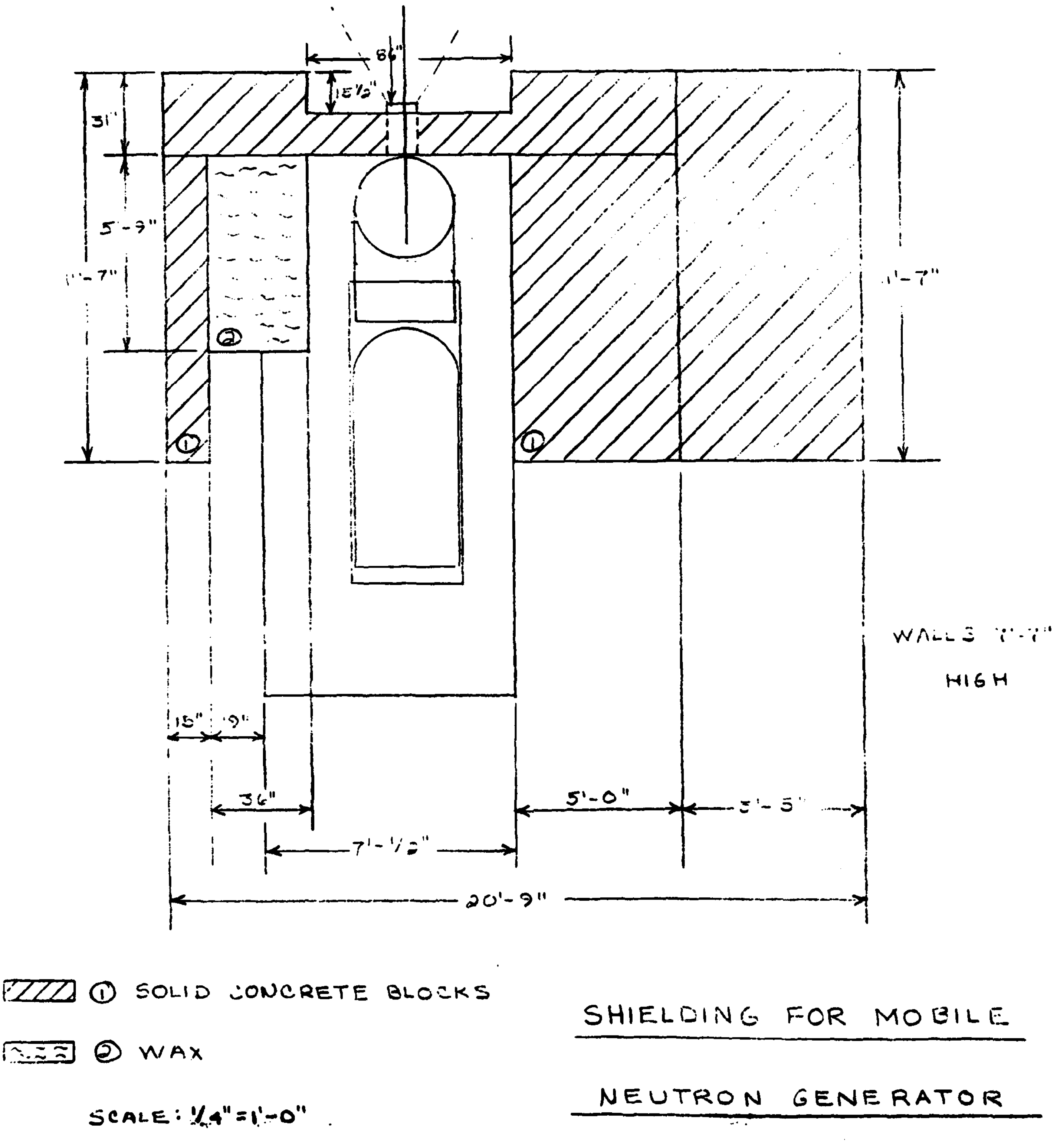


Figure 6. Schematic Diagram of Radiation Shielding for Neutron Radiography Operations

Figure 7a. Control Van for Neutron Radiography Operations

Figure 7b. Interior of Control Van Showing Operating Console and Area Monitoring Equipment

delays on this shipment of the new type radiography system, the Vought Radiological Safety Officer accompanied the truck and carried the necessary materials license and permit.

Pressure of the sulfur hexafluoride electrical insulating gas in the accelerator head was lowered from 60 to 30 psi per DOT requirements and the power supply tank was used as a gas reservoir. Both the initial trip to YPG and the return trip were without event.

2.3.2 System Set-up and Safety Survey

Army authorization to operate the radiation-producing device at USAYPG was granted under DARCOM Permit No. P42-81-01. Upon arrival at YPG the equipment was off-loaded by YPG personnel and radiation wipe tests were made. The equipment was subsequently transported by flat bed truck to the site of operation adjacent to the radiography laboratory. Access to the neutron area was limited by a chain link fence with locked gates. Wipe tests made by the YPG and Vought radiation safety officers were transported by YPG driver and Vought RSO to the University of Arizona in Tuscon for analysis. These tests proved negative and approval was given by phone to begin energizing the system. On site to monitor the initial radiation runs were two representatives from the U.S. Army Environmental Hygiene Agency (USAEHA), Aberdeen Proving Ground, MD, Maj. E. Potter and Capt. W. Curling. A preliminary meeting was held by Maj. Potter and Cpt. Curling, E. Matzkanin (USAYPG RPO) and F. J. Horak (Vought RSO) to discuss the safety operating procedure for the radiography site. A system check-out run was made which provided a preliminary radiation survey and an initial radiograph, verifying functional operation of the system after shipment. Radiation levels were monitored and recorded by DARCOM and Vought Corporation Radiation Safety Officer. The concrete and paraffin shielding, as well as distance, provided excellent biological protection, which lowered the control room radiation to well below acceptable levels.

2.3.3 Area Control

Admittance to the area was controlled by the operator inside the compound. In addition to the area control fence, a high-radiation perimeter was established inside the compound and roped and placarded to comply with 10 CFR, part 20.

2.3.4 Dosimetry/Personnel Monitoring

Project personnel and visitors were monitored by radiation film badges (Landauer Type III) during the operation. In addition, dosimeters were placed in the control van and on the outside of the trailer. During the six-week operation there were no significant radiation exposures to personnel. Successful operation was due to the complete support and cooperation of USAYPG personnel and to close adherence to the radiation safety operation plan. The tests were concluded without event. Post-operation wipe tests of the system, analyzed in Tuscon, were negative and the equipment was transported back to Vought-Dallas.

2.4 RADIATION SURVEY

The results of the radiation measurements of neutron and gamma dose equivalent rates around the controlled area fence line and control van are given in Section 3.0.

2.5 RADIOGRAPHY OPERATIONS

2.5.1 Radiography Specimens

All specimens were provided by YPG technical personnel. Effort was concentrated on the application of neutron radiographic inspection to specific artillery or ordnance fuze devices. Accurate determination of the position of igniter components is needed to ascertain any condition which could result in premature arming of the devices. Other specimens included small arms ammunition, training simulators, and various detonators. Handling of all ordnance items, including mounting and set-ups for radiography, was carried out by USAYPG personnel.

2.5.2 Film Imaging

The choice of converter/film combinations for demonstrating and evaluating this system in the YPG environment was based on a rationale which is a departure from the approach followed in the earlier days of demonstrating small-source neutron radiography when potential applications of the technique were first being explored. Rather than producing the bulk of the radiographs with the maximum resolution using gadolinium foil converter with M or R film without regard to exposure times required, converter/film combinations were chosen for most of the radiographs so as to maximize the speed, consistent with image quality sufficient to see the defect(s) or anomalies on the radiograph. Thus only a few of the radiographs were produced using gadolinium screen in combination with the slower industrial X-ray film, these being run to illustrate the resolution available by longer exposures or by increasing the neutron flux from the source, if required for specific applications. The majority of radiography runs were made using a fast, high-contrast Vought experimental converter screen, designated DC, or a medical screen, Kodak Lanex, in combination with industrial or medical X-ray film, including Kodak Types AA and SB or DuPont NDT -45, 55, 65, 70 or 91. Conventional aluminum vacuum cassettes, fabricated under this contract, were used for all neutron radiography exposures, to maintain contact between film and converter screen. Screens and film were 14" x 17" in size for all exposures.

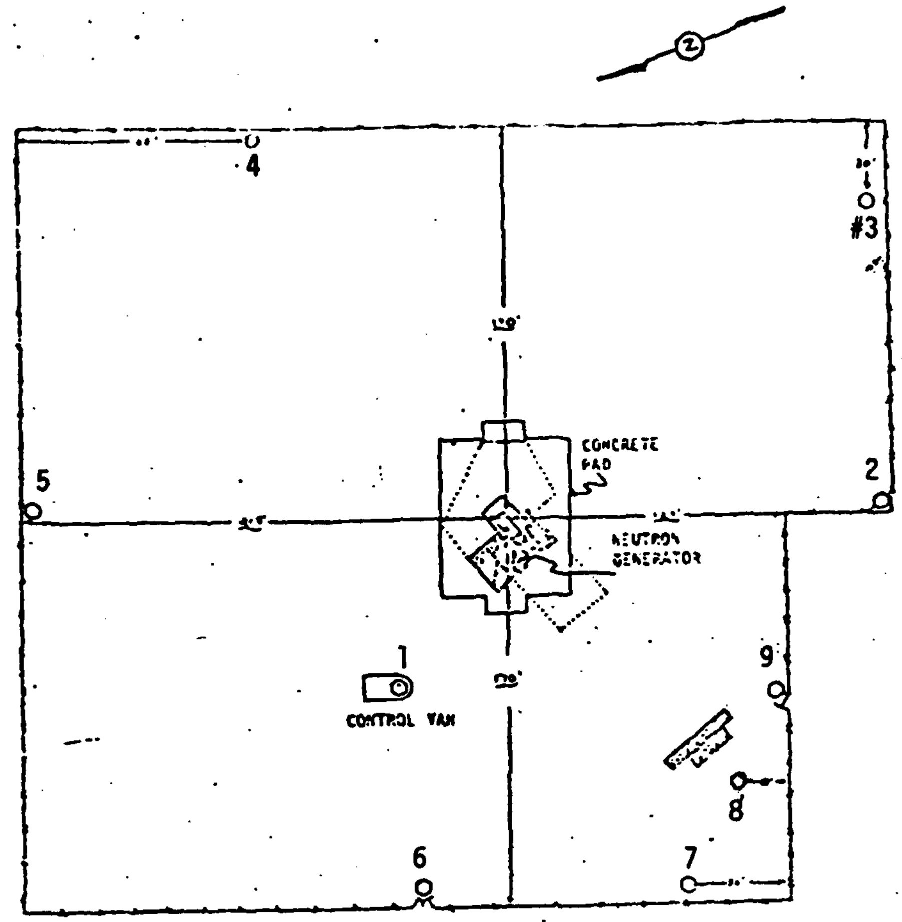
3.0 RESULTS

3.1 RADIATION ENVIRONMENT

Radiation levels for neutrons and X/Gammas outside the controlled area and within the control station during radiography operations were substantially lower than values acceptable by Regulation 10 CFR. Figure 8 shows the results of dose rate measurements at various locations around the perimeter of the controlled area, and at the control van. Dose rates measured deep inside the controlled area, in the immediate vicinity of the neutron radiography source, are shown in Figure 9.

3.2 SYSTEM RELIABILITY

During the six weeks duration of the neutron radiography operations at USAYPG, the system was operated daily for a minimum of 8 hours each day. In one long-duration test the system was run continuously for 21 hours. Ambient temperature during operation outdoors varied between 54 and 95 degree F. During the six-week period only two malfunctions occurred, which were considered as normal wear and were not attributed to the non-laboratory environment. The first was a failure, on the 18th day of testing, in the starting relay and capacitor associated with the cooling system water circulation motor. After replacement of these minor components the coolant temperature remained at the desired 38 to 39 degree F throughout the testing period. The second malfunction occurred during the 23rd day, and was due to voltage breakdown in one of the high voltage cables (extractor) near its feed-through from the power supply housing. After the damaged portion of the cable was removed and the cable re-installed, the system functioned reliab'y, through the remainder of the operations.

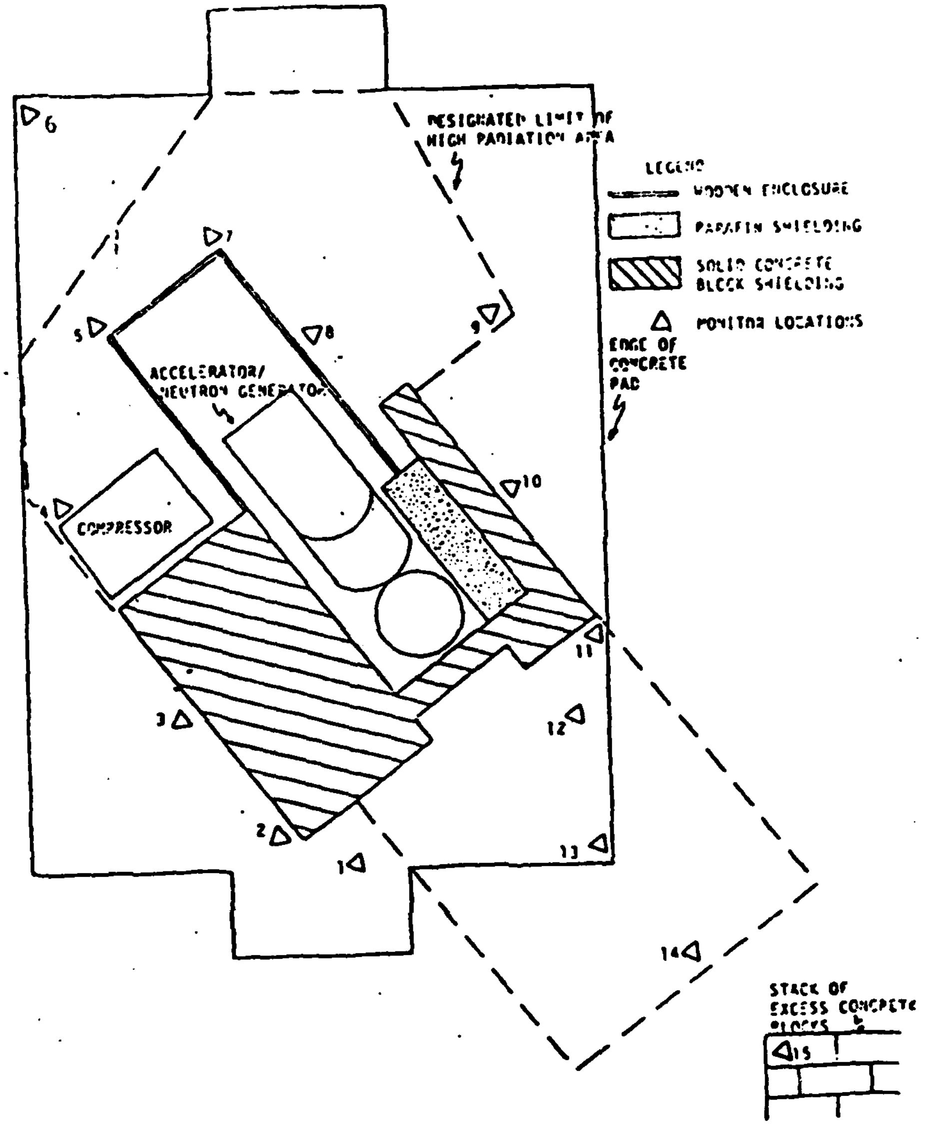


SYMBOLS:

- Fence Line
- Gate
- Solid Concrete Block (shielding)
- Parafin (shielding)
- Designated Limit Of High Radiation Area
- Radiation Measurement Point

LOCATION	DOSE EQUIVALENT RATES (mRem/hr) NEUTRON	GAMMA
#1	0.56	0.10
#2	0.25	0.13
#3	0.21	0.05
#4	0.34	0.05
#5	0.24	0.05
#6	0.27	0.05
#7	0.72	0.20
#8	0.25	0.07
#9	0.54	0.30

Figure 8. Dose Rate Measurements at Various Locations Around Perimeter of Controlled Area



DOSE EQUIVALENT RATES (mRem/hr)

LOCATION	NEUTRON	GAMMA
#1	31	5.0
#2	2.2	0.2
#3	0.48	<0.1
#4	4.8	8.0
#5	24	10
#6	9.7	1.5
#7	89	10
#8	126	27
#9	7.2	1.5
#10	6.8	1.0
#11	4.8	1.0
#12	63	8.0
#13	133	20
#14	8.5	3.5
#15	15	4.0

Figure 9. Dose Rate Measurements in Vicinity of Neutron Generator Radiography Source, Inside Controlled Area

3.3 NEUTRON OUTPUT

The neutron tube utilized in this study was the original tube, incorpoated in the neutron generator system as purchased. Fast neutron yield from this tube was initially 9 x 10^{10} n/sec. Prior to the USAYPG operations the tube had operated for approximately 350 hours without significant reduction in output. This is in excess of the guaranteed lifetime of 200 hours operation above 50% of initial yield. However during the course of this study it was determined that the output had dropped substantially, to 1/3 to 1/4 of the normal output. Consequently, the exposure times observed in the radiography and given in Section 3.4 are 3 to 4 times longer than typically obtained with this type tube with normal output during the first few hundred hours' operation.

3.4 RADIOGRAPHIC RESULTS

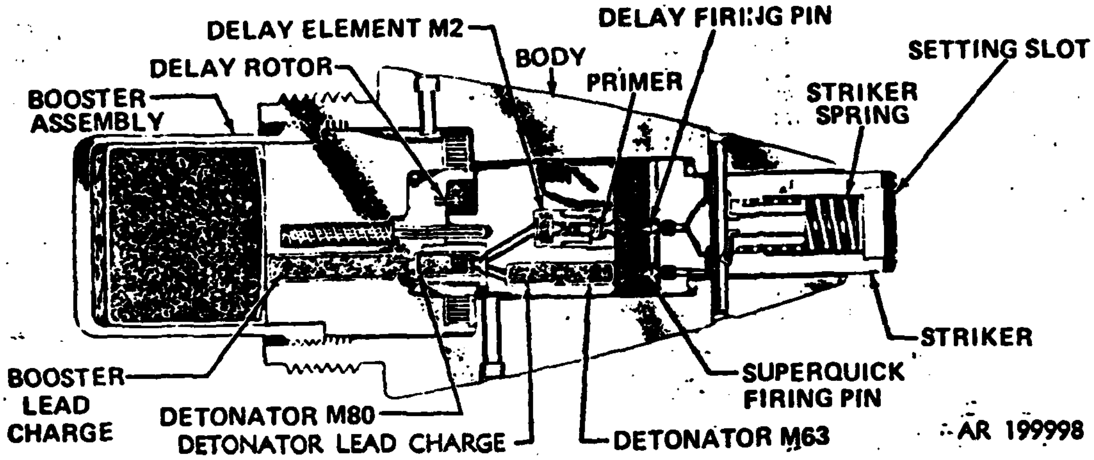
Eighty neutron radiographs were produced during the period at USAYPG. The L/D ratio for this set of exposures ranged from 12 to 36. Prior to each run, YPG personnel inspected the test items by X-ray radiography to allow comparison of the two radiographic techniques for these items. Each radiograph was interpreted before making the next exposure and parameters adjusted as needed for optimization.

A series of neutron radiographs produced during this study is presented in this section. In several cases the corresponding X-ray radiographs are shown, for representative comparisons. In those cases, discussion of the X-ray precedes the comments on the corresponding neutron radiograph.

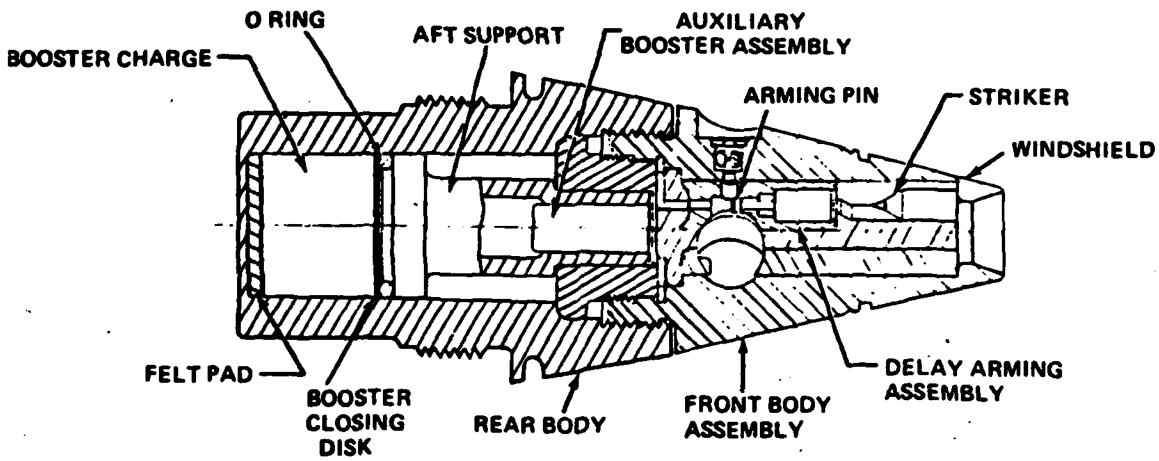
3.4.1 Interpretation and Discussion of Radiographs

Figures 10X and 10N are X-ray and neutron radiographs, respectively, of five ordnance fuzes. Cross section illustrations of three of these devices are given in Figure 10. The X-ray image (Figure 10X) shows good detail of metal parts in most cases and good detail of some sub-assemblies, but little or no imaging of explosive charges. For example the X-ray image of the M524

M524



M567



M557

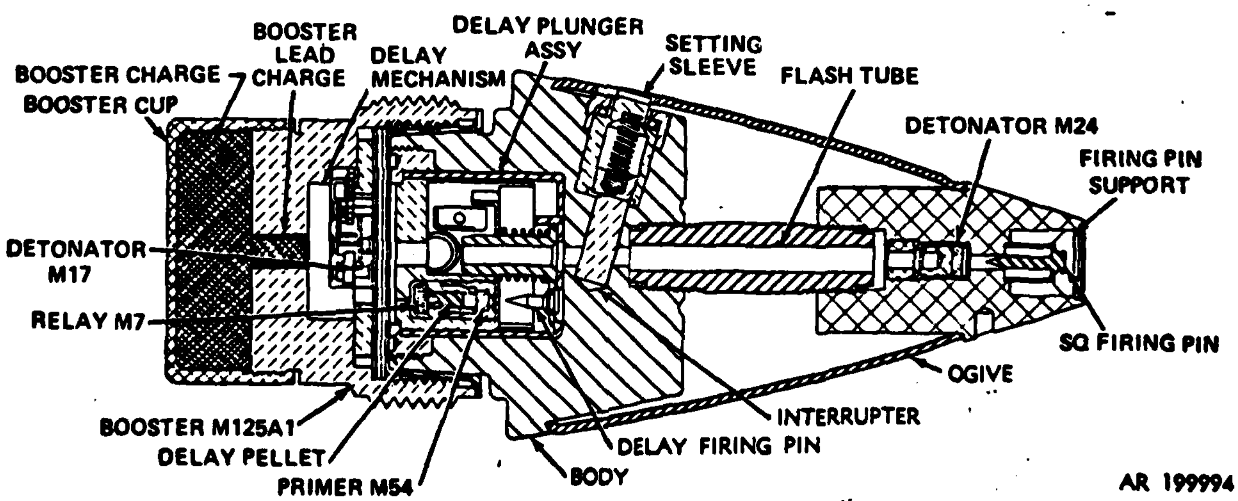


Figure 10. Cross Section Diagrams of M524, M567, and M557 Point Detonating Fuzes

Figure 10X. X-Ray Radi^graph of M524 Fuze (Top, Right), M567 Fuze (2nd from top on right), M557 Fuze , 3rd from top, right), M728 Proximity Fuze (Bottom, right), M432 Rocket Fuze (Bottom, left).

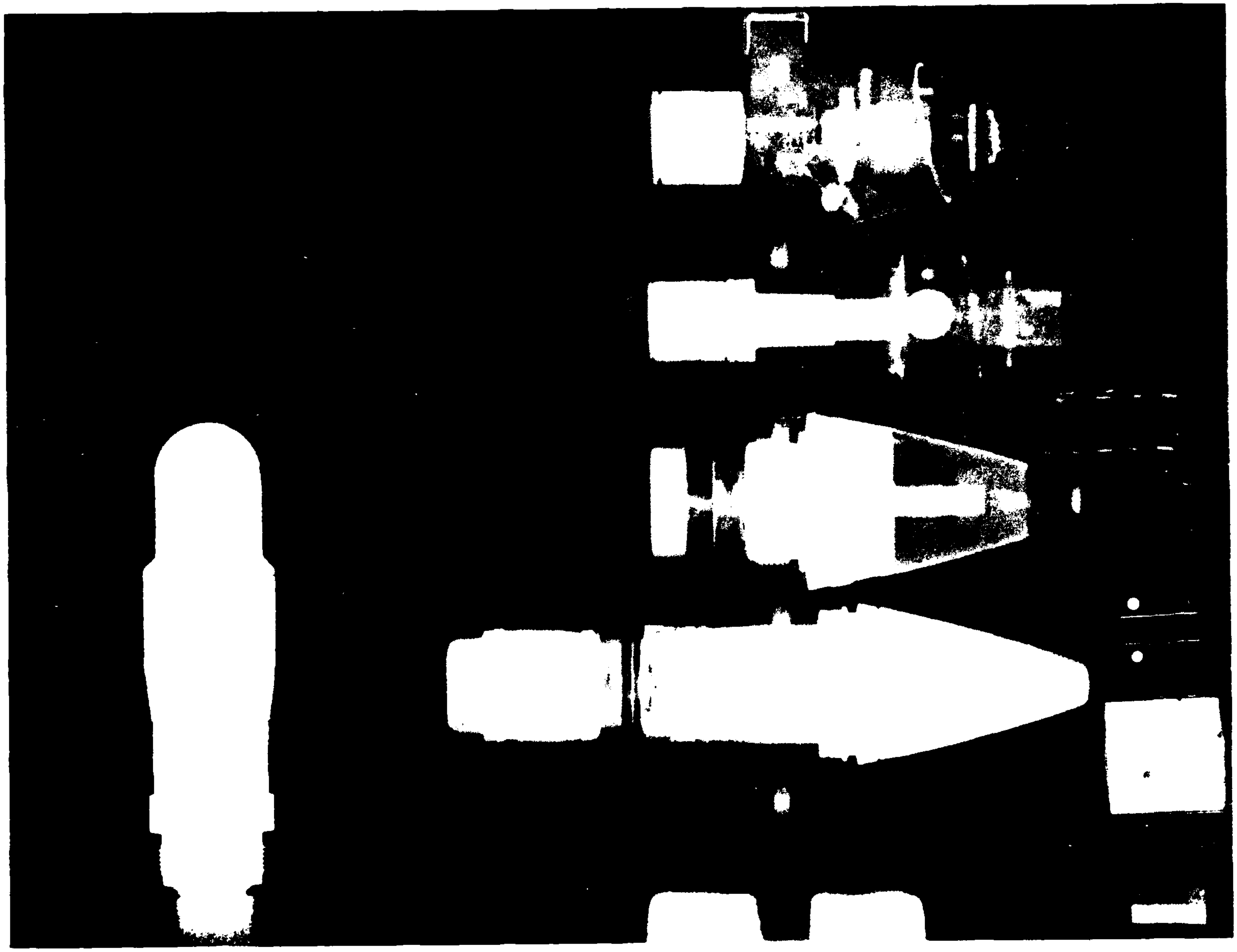
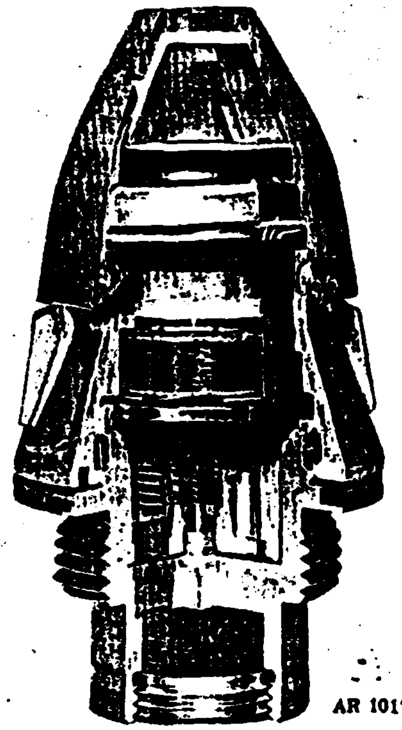
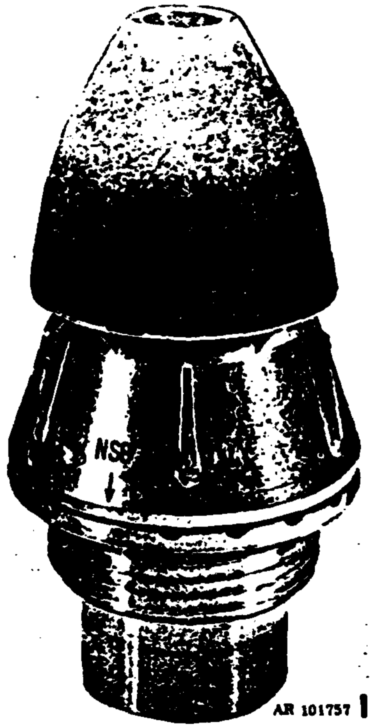


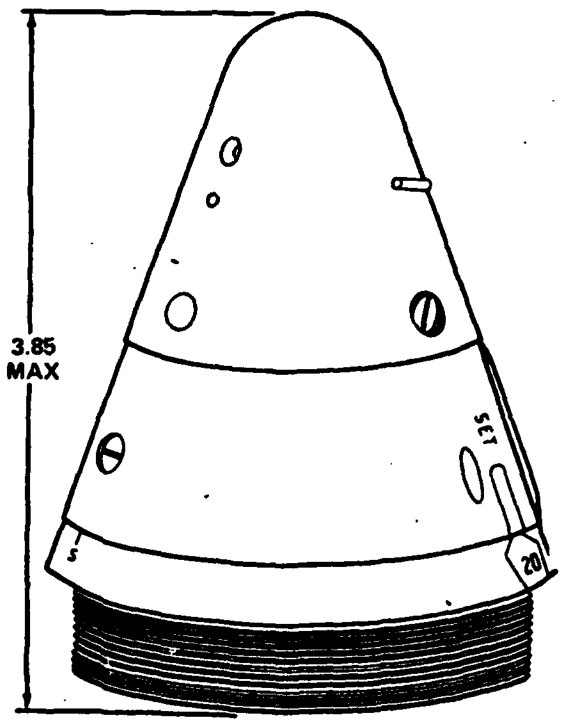
Figure 10N. Neutron Radiograph of M524 Fuze (Top, Right), M567 Fuze (2nd from top on right), M557 Fuze (3rd from top, right), M728 Proximity Fuze (Bottom, right), M432 Rocket Fuze (Bottom, left) fuze shows the safety/arming device in good detail but no image of the explosive. Likewise, this X-ray image of the M567 fuze shows the delay arming assembly and pin but does not image the explosive. On the M557 fuze the X-ray shows good detail of the flash tube, setting sleeve, delay mechanism, and detonator, but shows very little detail of the delay plunger assembly. The X-ray image of the M728 proximity fuze shows no detail of the electonics in the windshield area, good detail of the battery plates and electronics, marginal detail of the S&A position, and no image of the detonator. The M432 rocket fuze shows safe positioning of the S&A, but no image of the detonators.

The neutron radiograph (Figure 10N) on the other hand, clearly images, reading from right to left on the M524 fuze (which is the first device beginning at top right in the radiograph), the primer, the M63 detonator, the M2 delay element, the detonator lead charge, the M80 detonator, the booster lead charge and booster assembly. On the M567 fuze (second from top, on right) the metal parts and arming mechanism are not imaged well with neutrons, as would be expected; however, the auxiliary booster assembly, the O-Ring, and booster charge and felt pad are clearly imaged. The M557 fuze, (third from top, on right) had a high attenuation for thermal neutrons throughout the fuze body, and hence details within the body are not imaged. However, the booster charge at the base of the fuze is clearly imaged. The other two devices, the M728 fuze and M432 rocket fuze, do not lend themselves to inspection by thermal neutrons because of the synthetic materials used in the windshield, the plastic material encasing the elctronics in the nose cones, and the cadmium plating over most of the metal casing. Exposure parameters used in this neutron radiograph were: Film Kodak SB; converter-Lanex Fine; L/D = 36; Exposure-80 minutes (20 to 30 min. with normal output).

Figure 11 is an illustration of additional types of fuzes which, along with others, are the specimens for radiographs 11X and 11N. From left to right in the radiographs are: M734 fuze, M567 fuze, 2.75 rocket fuze, M84 fuze, and a special three-fuze assembly. Again, the X-ray, Figure 11X shows good images of the S&A's. However, no explosive charges are imaged and there is a lack of penetration of the lowest fuze in the three-fuze assembly.







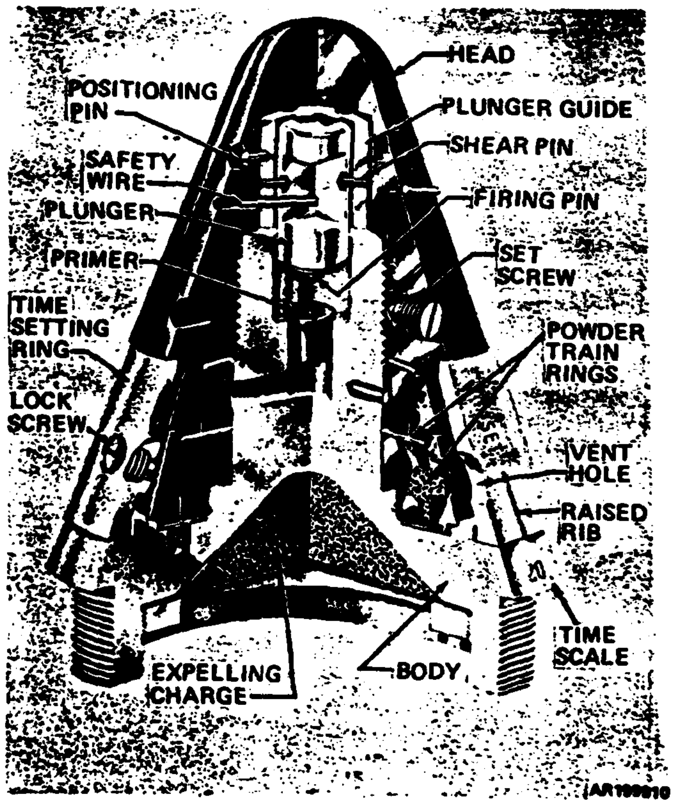


Figure 11. Diagrams of M734 Fuze (Top) and M84 Fuze (Bottom)

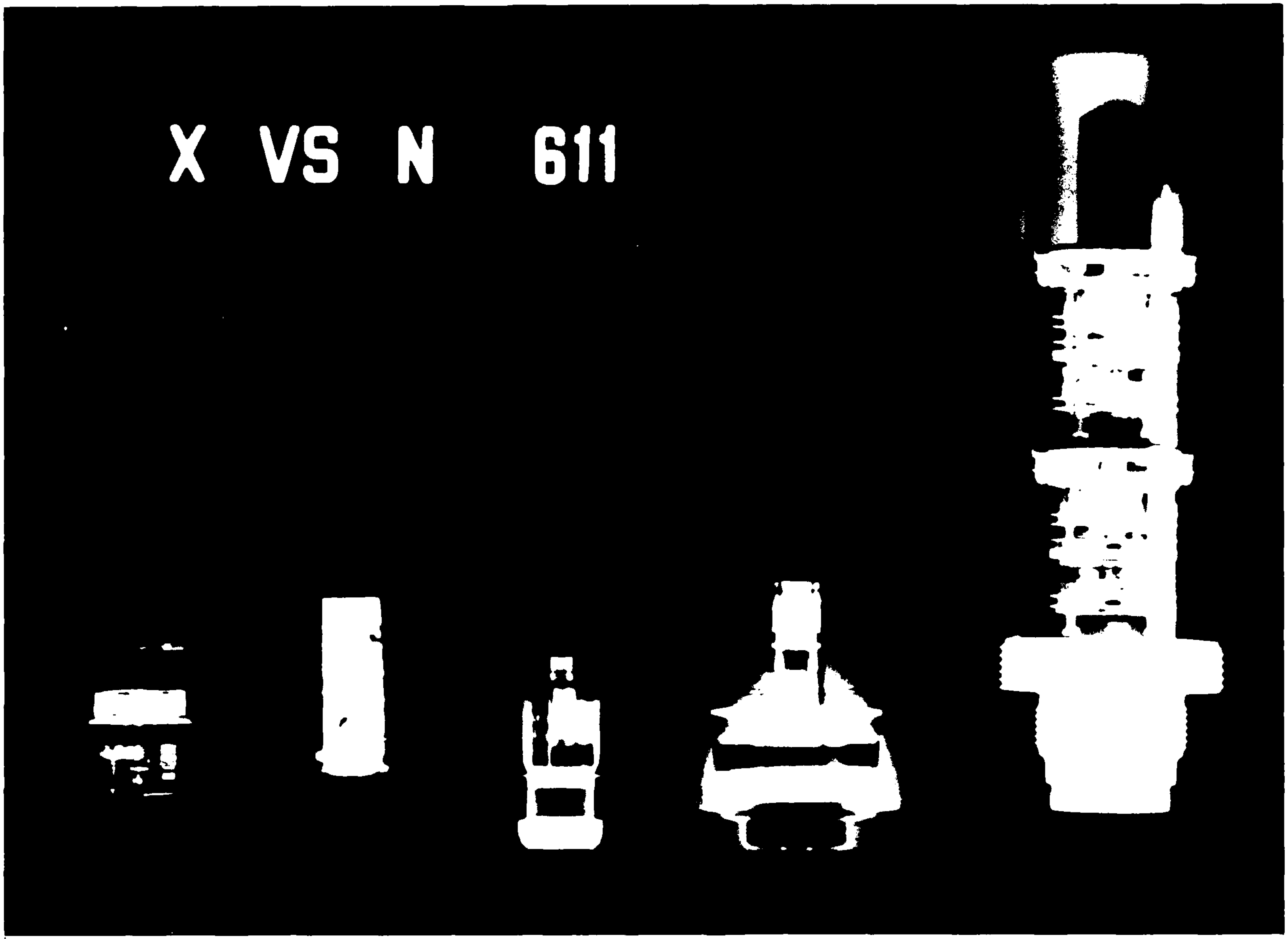


Figure 11X. X-Ray Radiograph of (Left to right) M734 Fuze, M567 Fuze, 2.75 Rocket Fuze, M84 Fuze, and a Special Three-Fuze Assembly

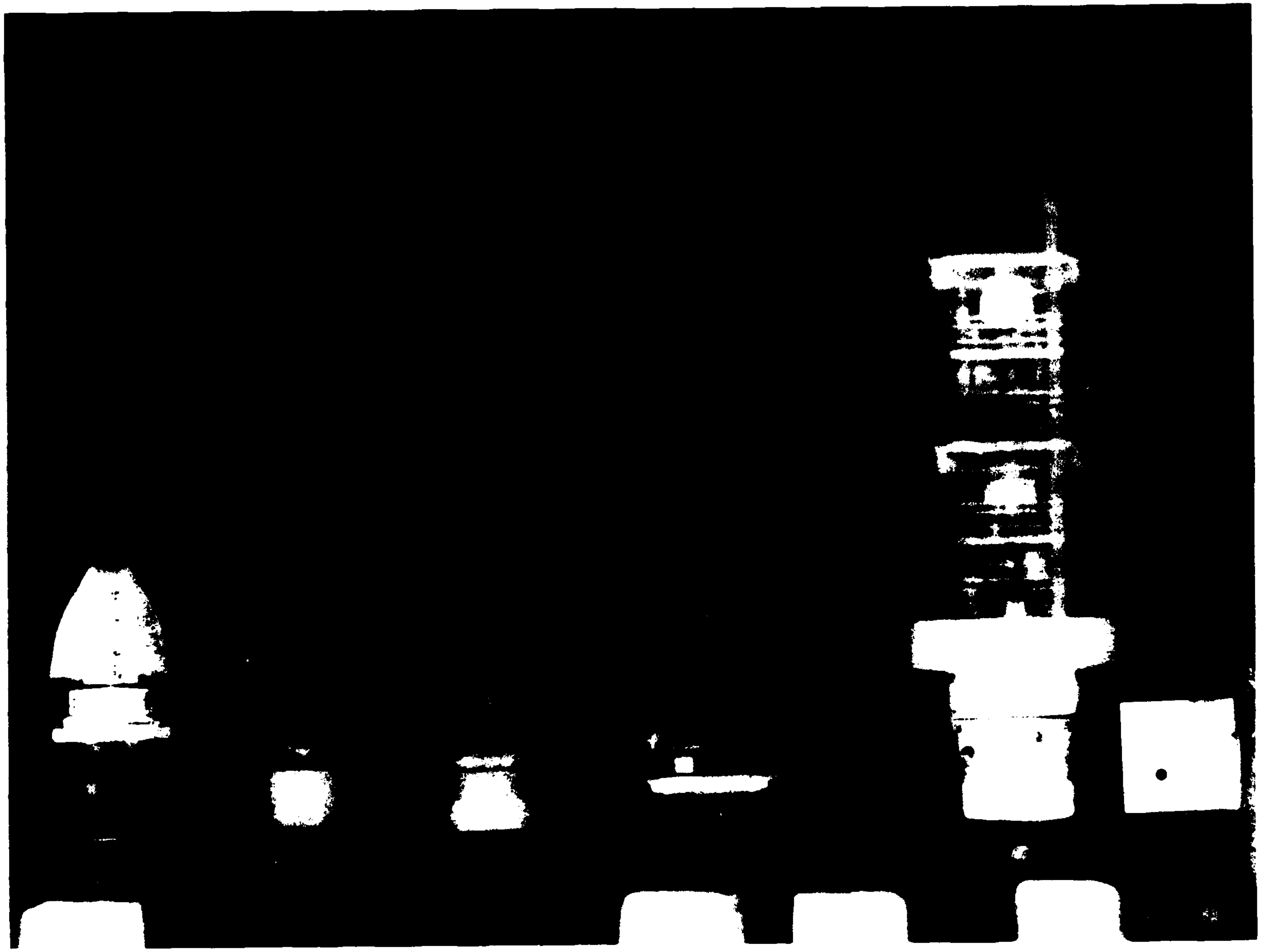


Figure 11N. Neutron Radiograph of (Left to right) M734 Fuze, M567 Fuze, 2.75 Rocket Fuze, M84 Fuze, and a Special Three-Fuze Assembly

In the neutron radiograph, Figure 11N, there is some improvement over the X-ray in the detail of the turbine alternator of the M734 fuze (first device on left). The detonator of this device is clearly shown, and the booster cup below the detonator is clearly empty. The M567 fuze image is almost identical to that of Figure 10N. In the 2.75 fuze, good images of the detonator are obtained, and the presence of a booster charge is apparent. The M84 shows good detail on powder train rings and detonators not imaged well with X-ray. The three-fuze stack neutron image shows for the most part the same data as the X-ray. Exposure parameters were the same as for Figure 10N.

Items appearing in the radiographs of Figures 12X and 12N, reading from left to right, bottom are: 30 mm APDS-T projectiles (2 ea), 25 mm 792 projectiles (2 ea), 12 gauge shotgun shells (3 ea), 45 caliber ball ammunition (right center of radiograph, 3 ea). From left to right, top are: 38 caliber specials (3 ea) and 7.62 tracer ammunition (2 clips, one of 5 each and one of 4 each).

The X-ray images the fuzes in the 30 mm APDS-T projectiles but shows little definition of the case charges, the projectile body charges, and the fuze detonators. In the 25 mm 792 projectiles the X-ray images the projectile body and provides a good image of the case charge except at the lower end of the case, where the firing pin/detonator, which also is not imaged, is located. The X-ray image of the 12-gauge shells show good definition of the cartridge base and minimal detail in the shell area. Similarly, the other small ammunition show little or no definition of the case charges.

In the neutron radiograph, Figure 12N, much better detail of the case charges are shown for both the 30 mm and 25 mm projectiles. The neutron image of the 25 mm projectile shows the outer body component, while the X-ray shows the inner body core. The image of the 12-gauge shotgun shells shows better ball definition than the X-ray, with lesser definition of the cases. The neutron images of the 45 caliber ammunition, the 38 caliber specials, and the 7.62 tracer all show good definition of the case charges. Exposure parameters are the same as for the preceeding two neutron radiographs.

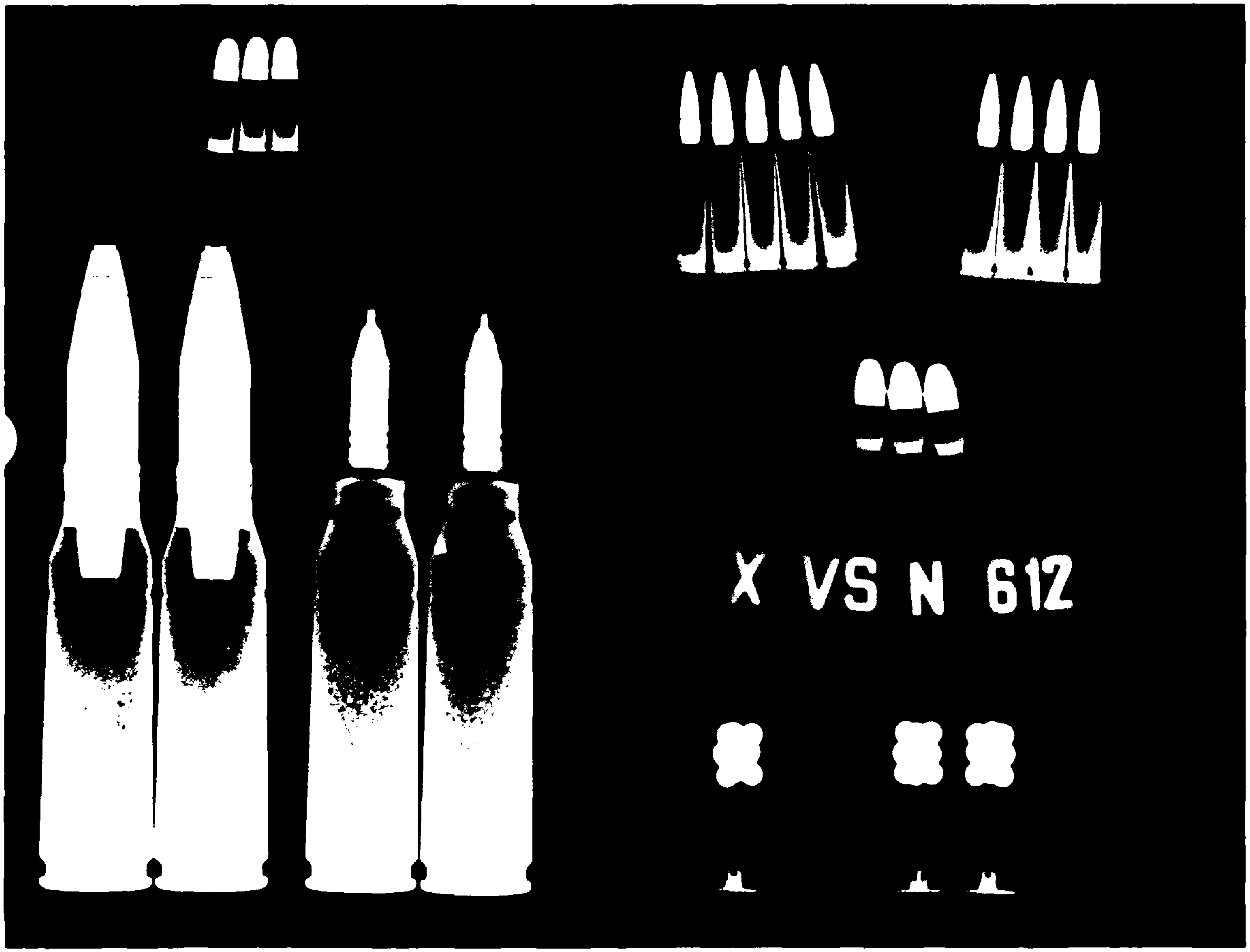


Figure 12X. X-Ray Radiograph, Reading from left to right, bottom, 30 mm APDS-T Projectiles (2 ea); 25 mm 792 Projectiles (2 ea), 12-Gauge Shotgun Shells (3 ea); from left to right top, 38 Caliber Specials (3 ea) and 7.62 Tracer Ammunition (5 ea and 4 ea)

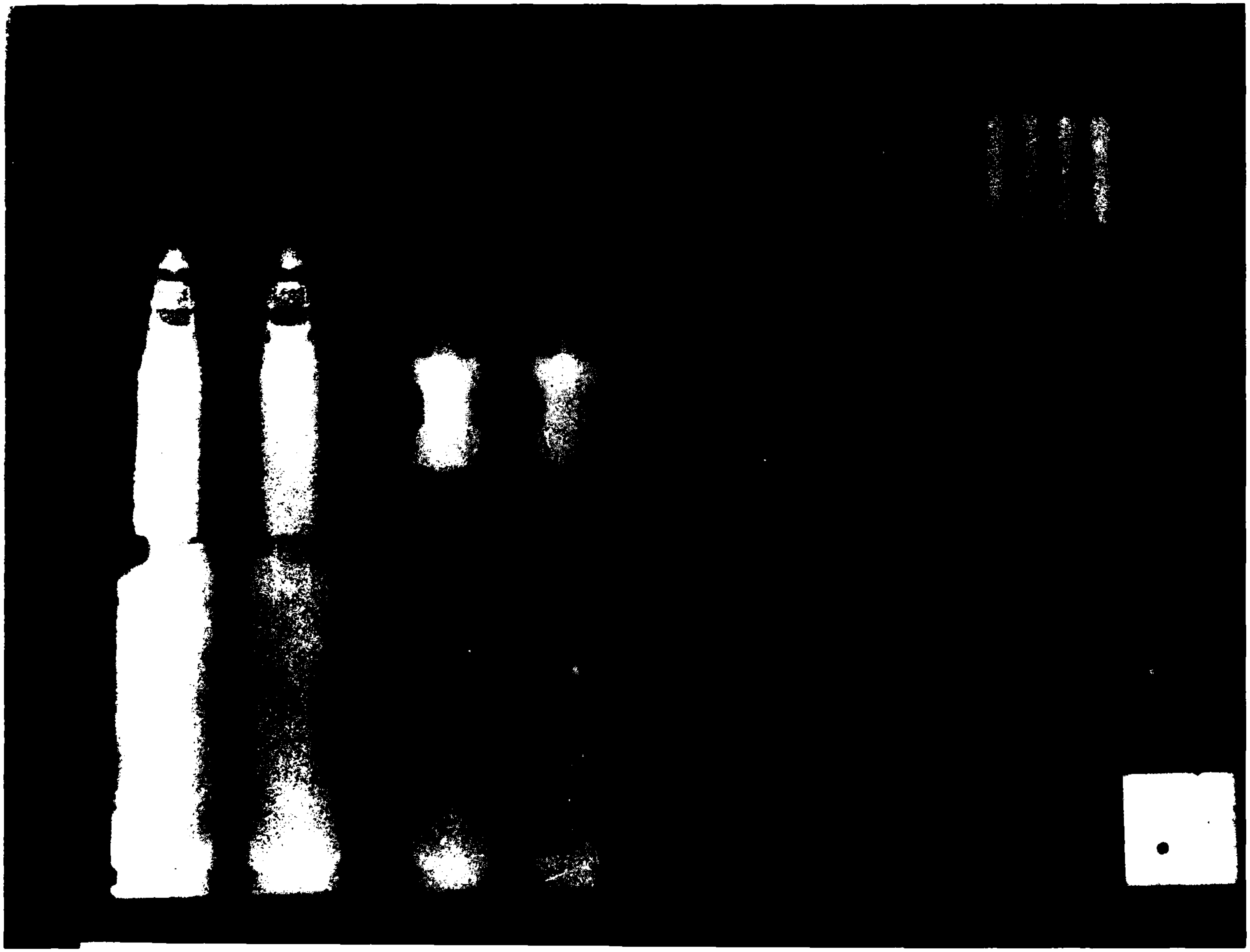


Figure 12N. Neutron Radiograph, Reading from left to right, bottom, 30 mm APDS-T Projectiles (2 ea); 25 mm 792 Projectiles (2 ea), 12-Gauge Shotgun Shells (3 ea); from left to right top, 38 Caliber Specials (3 ea) and 7.62 Tracer Ammunition (5 ea and 4 ea)

Radiographs of another group of items are shown in Figures 13X and 13N. These items are, left to right: three element fuze assembly, 20 mm M56A4 HEI projectile, (2 ea), 30 mm M552 projectile with XM579E2 fuze (2 ea), 25 mm HEI-T XM792 projectile with a PD M714E5 fuze. At top, center are 9 mm ball projectiles (4 each).

In the three element fuze assembly the X-ray, Figure 13X shows good detail of the metal parts and S&A device but no image of the detonators. The X-ray image of the 20 mm M56A4 HEI projectile shows some detail of both the case charge and the HE body charge. The 30 mm M552 projectile with XM579E2 fuze and 25 mm HEI-T, XM792 w/PD M71435 fuze images show fair definition of the case charge flash element, good body definition and good definition of fuze metal parts but no image of fuze detonators and very little case charge definition. Likewise, the X-ray images show no image of the case charge in the 9 mm projectile shells.

In the neutron radiograph, Figure 13N, of the three-element fuze, although the detail is less sharp than the X-ray, it is seen that some of the components which are masked by intervening structure in the X-ray are visible in the neutron radiograph. In the 20 mm M56A4HEI projectile the case charge is clearly imaged, with much less definition of the body charge. The 30 mm M552 image shows fair definition of the case charge and good fuze detonator imaging. The 25 mm HEI-T projectile image shows fair definition of the flash tube, good image of the case charge, and minimal imaging of the body charge. As in other devices, the fuze detonators are clearly imaged. In the 9 mm projectile the case charges are well defined. Exposure parameters were the same as for the three preceeding neutron radiographs.

The items shown in the radiographs of Figures 14X and 14N are, left to right, S&A from a M718 mine (on N-Radiograph only), 2.75 rocket fuze, 20 mm XM599 projectiles (2 each), and at the top of the radiographs, 7.62 mm projectiles (10 each).

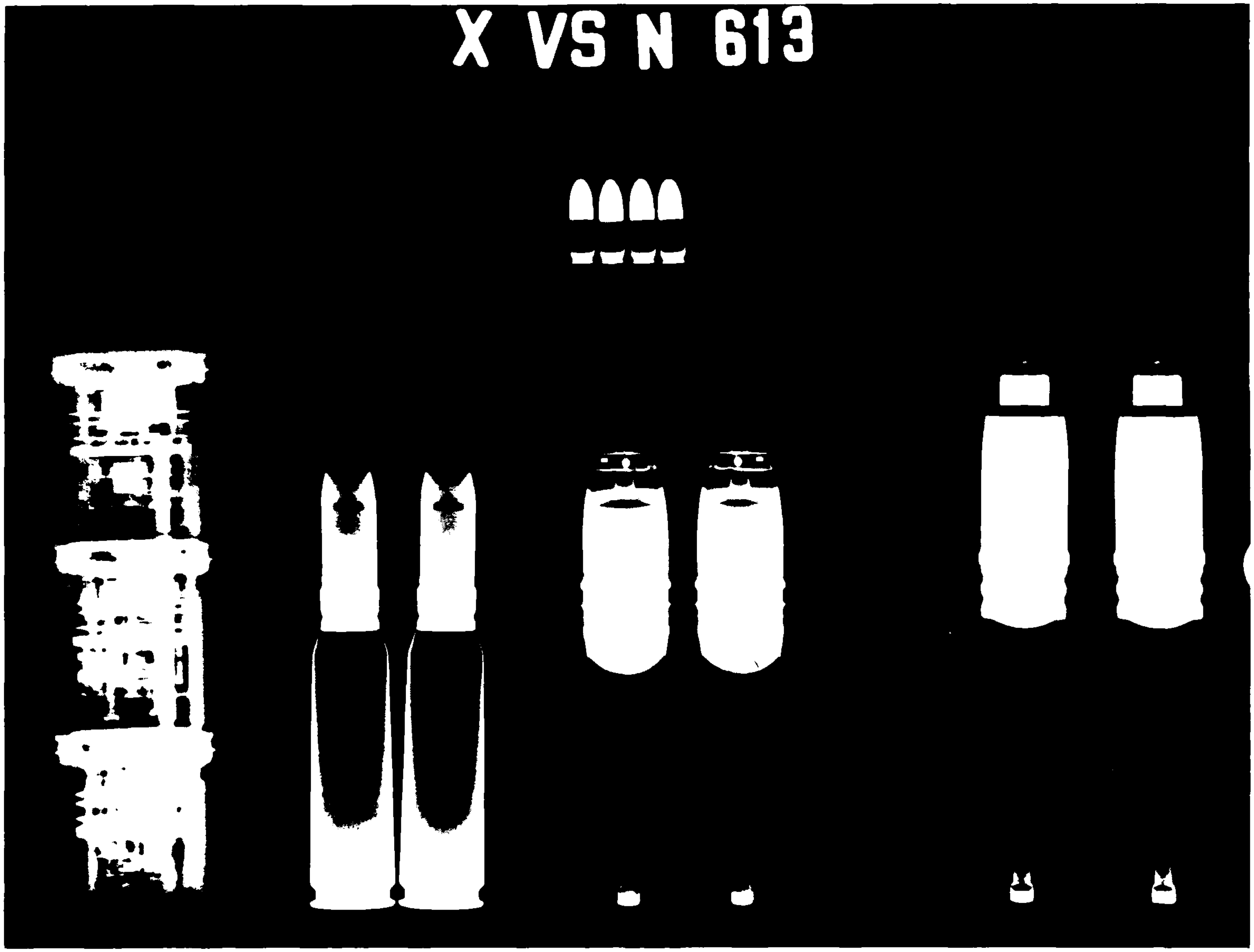


Figure 13X. X-Ray Radiograph, Left to Right, of Three-Element Fuze Assembly, 20 mm M56A4 HEI Projectile (2 ea), 30 mm M552 Projectile with XM579E2 Fuze (2 ea), 25 mm HEI-T XM 792 Projectile with a PDM714E5 Fuze, Top Center: 9 mm Ball Projectile (4 ea)

Figure 13N. Neutron Radiograph, Left to Right, of Three-Element Fuze Assembly, 20 mm M564A HEI Projectile (2 ea), 30 mm M552 Projectile with XM579E2 Fuze (2 ea), 25 mm HEI-T XM 792 Projectile with a PDM714E5 Fuze, Top Center: 9 mm Ball Projectile (4 ea)

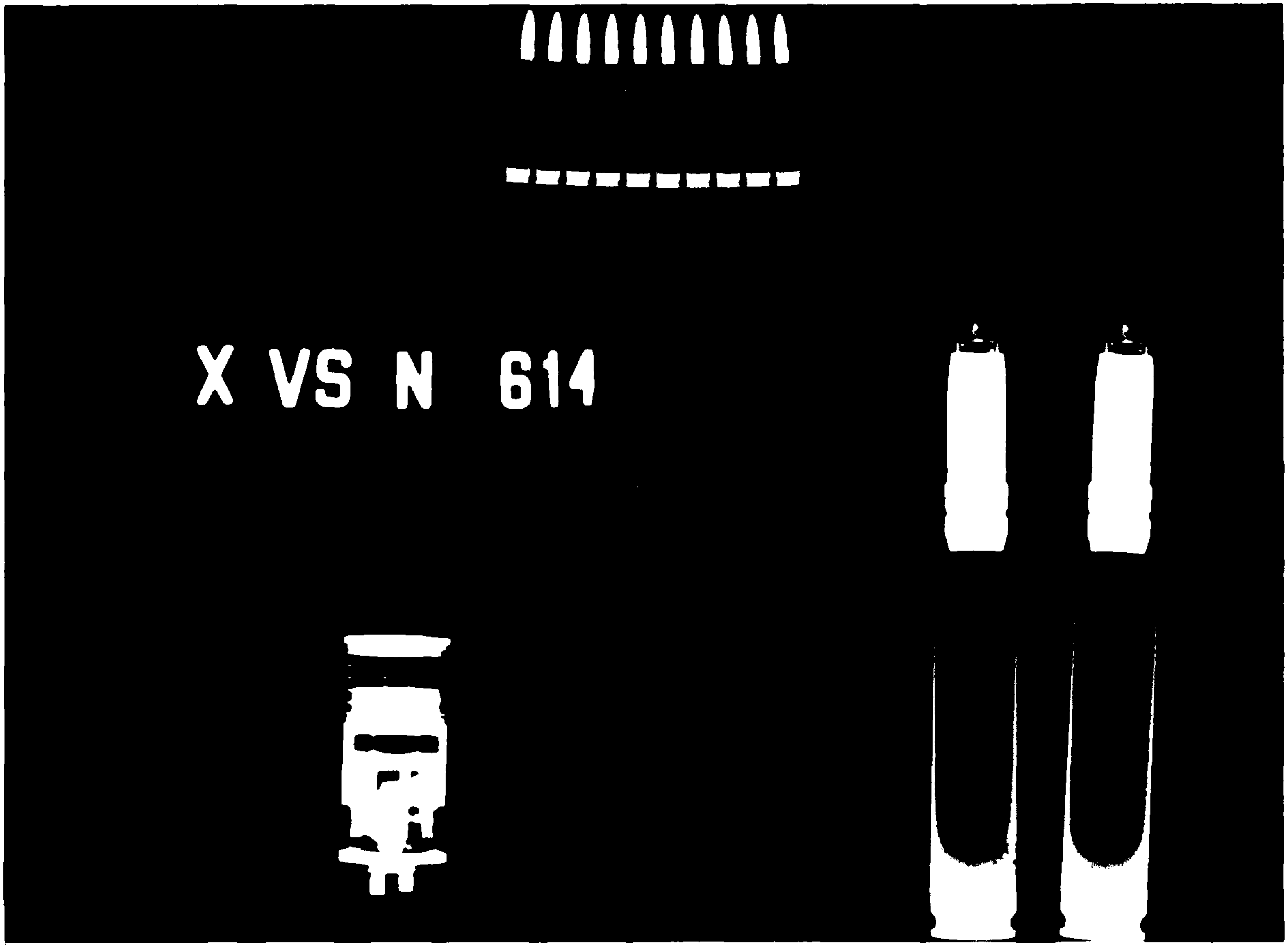


Figure 14X. X-Ray Radiograph of, Left to Right, 2.75 Rocket Fuze, 20 mm XM 599 Projectile (2 ea), and, at top, 7.62 mm Projectile (10 ea)

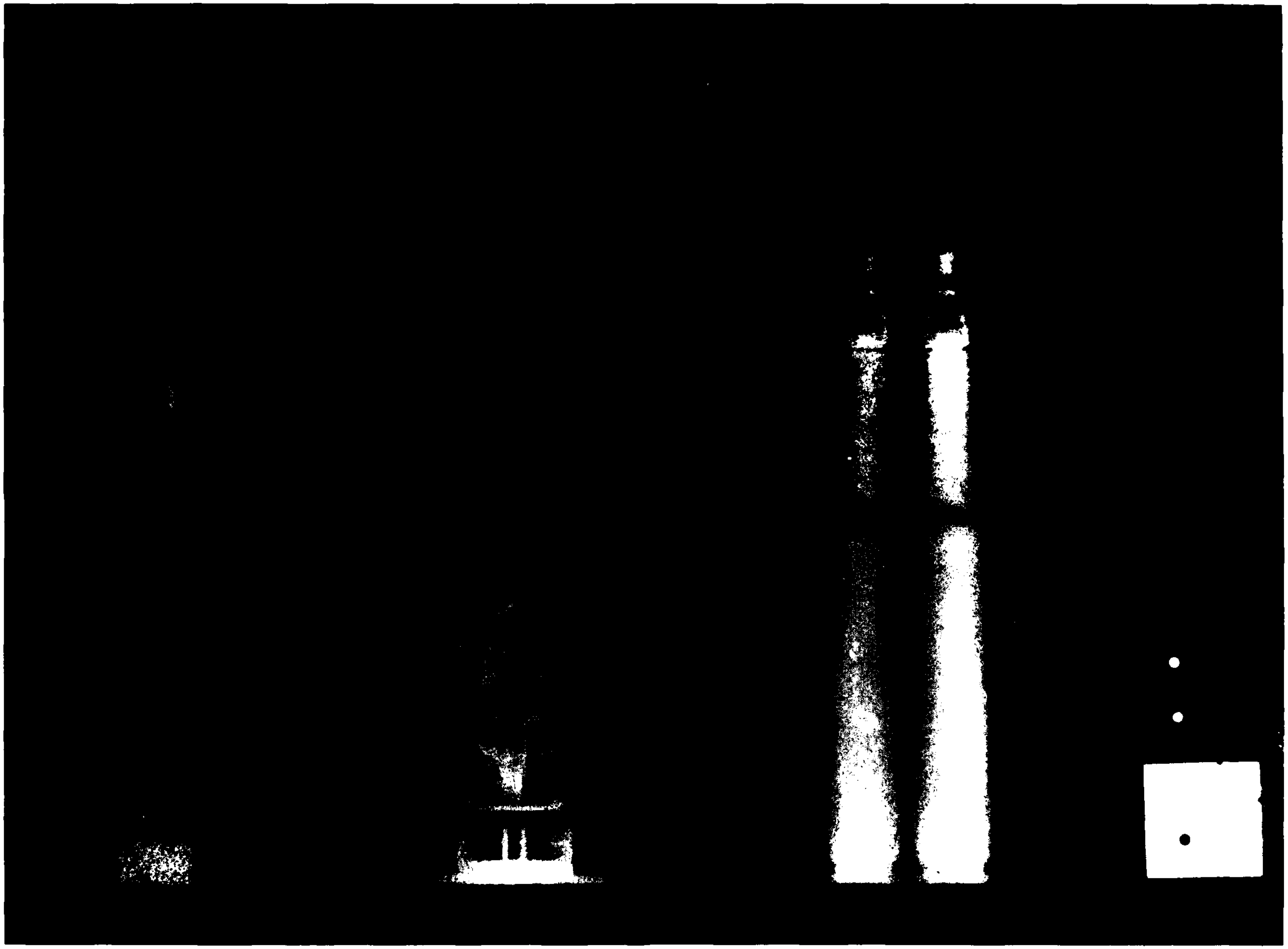


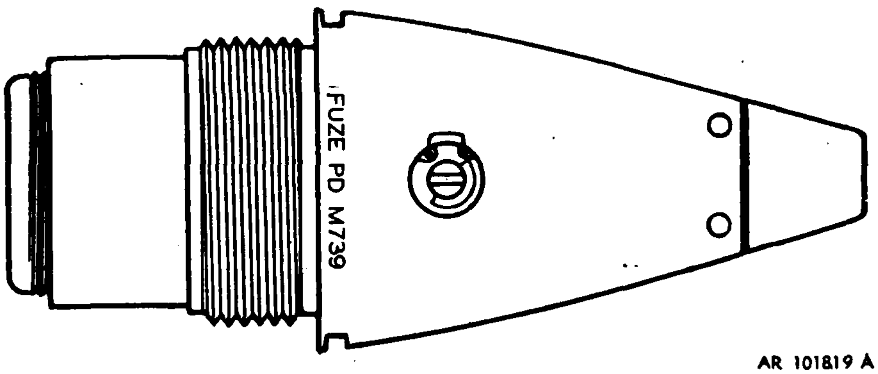
Figure 14N. Neutron Radiograph, reading left to right, of Safety and Arming (S&A) Device from a M718 Mine, 2.75 Rocket Fuze, 20 mm XM 599 Projectile (2 ea), and at top, 7.62 mm Projectile (10 ea)

On the X-ray, Figure 14X, in addition to the usually good definition of the metal parts and S&A device, it is seen that two fuze detonators below the fuze base ring of the 2.75 rocket fuze also are imaged. On the 20 mm XM 599 the X-ray does not image the case detonator. The projectile body and metal fuze parts show the usual good definition, and the usual lack of good definition of the case charge is apparent. The 7.62 projectile image shows only the case and shell projectile body.

On the neutron radiograph, Figure 14N, on the left, is an image of the S&A (2 ea) from a M718 mine (not on the X-ray). This image shows good definition of the S&A safety locks; the device was an inert fuze and hence no image of the detonators is present. On the 2.75 fuze, from the detail of the image it appears feasible to determine if the fuze was safe or armed, given the proper orientation of the device for radiography. Two explosive leads are imaged at the bottom of the fuze which did not show on the X-ray. On the 20 mm XM599 projectile the case detonator is not imaged, but the radiograph produced a good image of the case charge and a fair image of the fuze. A good image of the case charge of the 7 mm projectile resulted, with a fair image of the projectile body. Exposure parameters were the same as for the radiographs of Figures 10N through 13N.

Figures 15A and 15B are illustrations of two types of fuzes which appear in the neutron radiograph of Figure 15N. These items, which are common ordnance fuzes, are left to right, M739, M564, and M577 fuzes. Although the image is not as sharp as is possible, due to the low L/D (18) and a slight misalignment of the specimens (see Figure 16N for example), several components/parts are shown on the NR which would not be imaged on the X-rays. In the M739 such items are the O-rings on the setting sleeve assembly and the detonator in the delay assembly; in the M564, the M4 detonator in the nose (white area inside upper cavity, dead center), the M6 detonator just above the base flange, and the desiccant units just below the base flange fall into this category; in the M577 (image on the right) the detonator charge (dead center at the bottom of the fuze) is clearly defined. Exposure parameters for this radiograph were: Film-DuPont NDT 65; convertor-gadolinium, L/D=18; exposure time 3-1/2 hours (approximately 1 hour with normal tube output).

FUZE, POINT DETONATING: M739



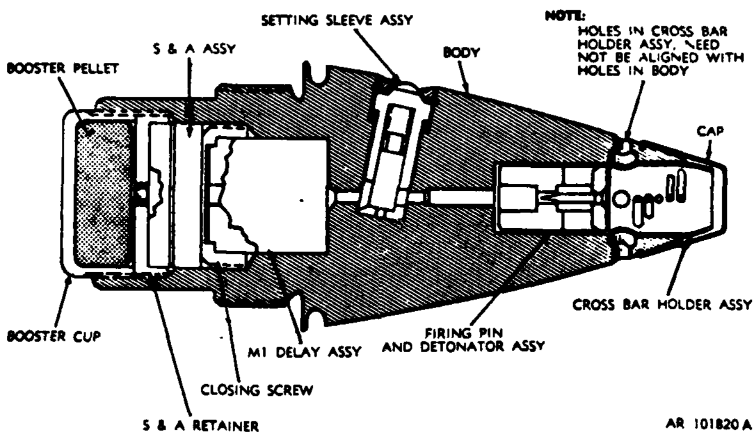


Figure 15A. Diagrams of M739 Point Detonating Fuze

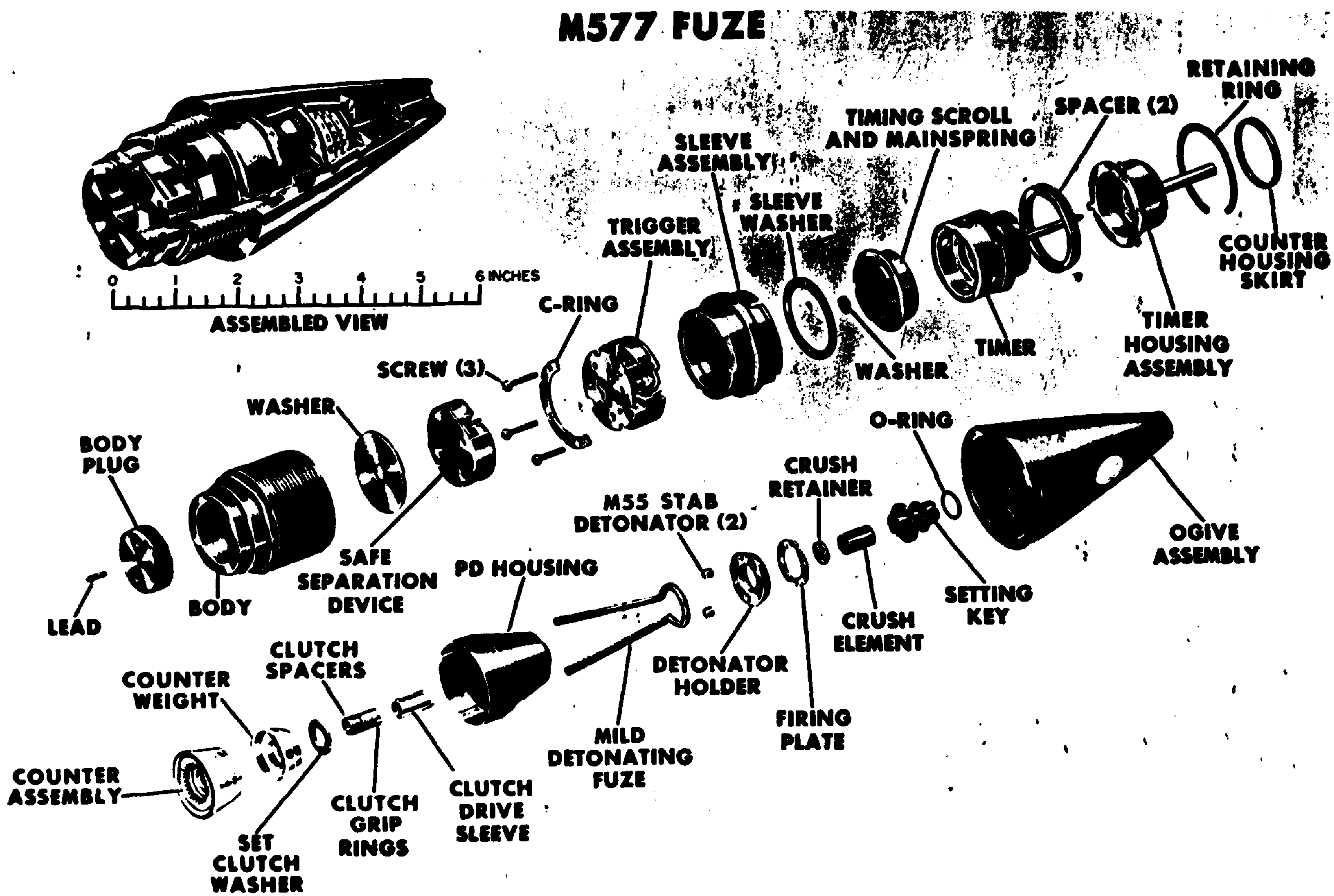


Figure 15B. Diagram Showing Components of M577 Fuze

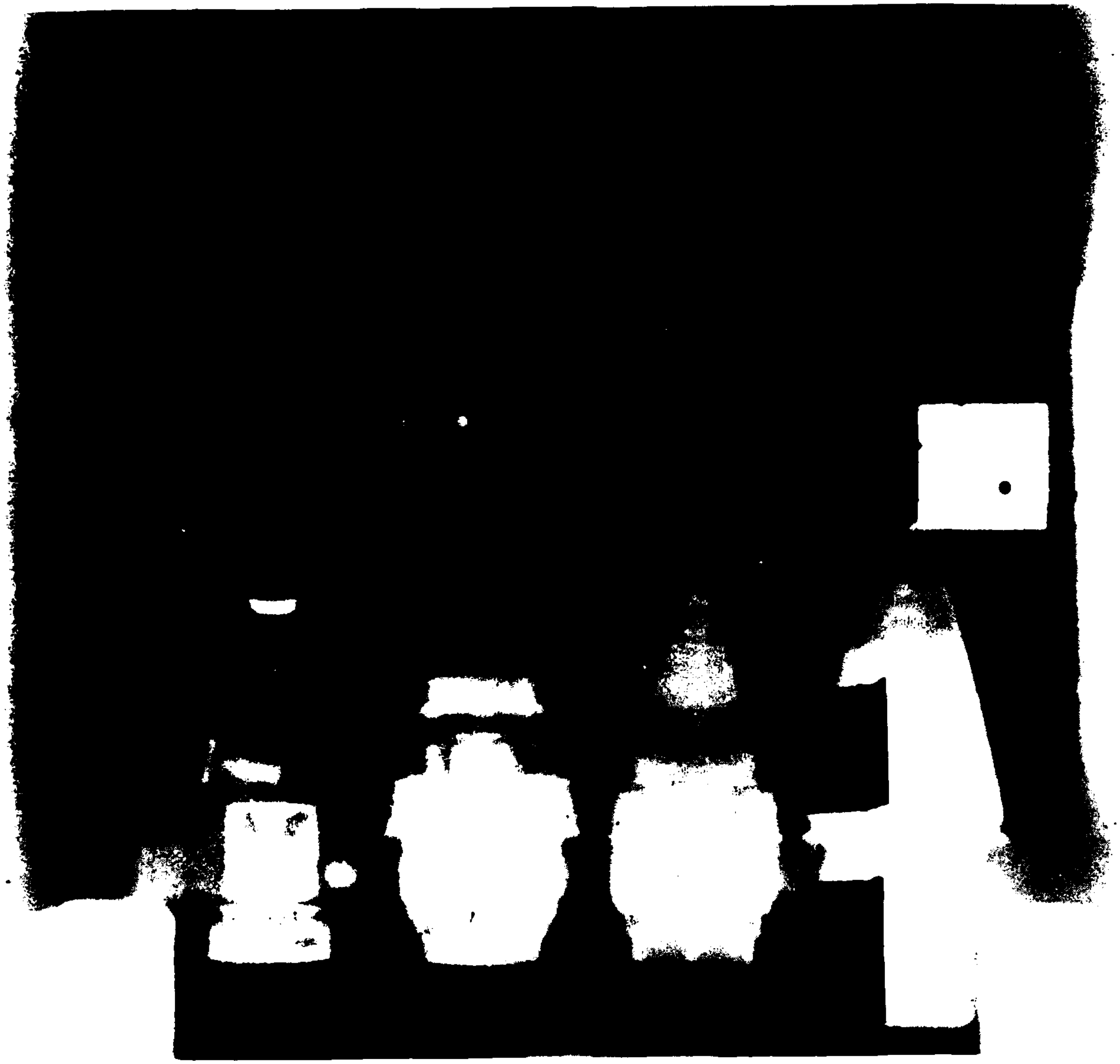


Figure 15N. Neutron Radiograph, Left to right, of M739, M564 and M577 Fuzes

The three fuzes shown in Figure 15N, along with some additional items, are the specimens shown in the neutron radiograph of Figure 16N. The additional specimens are: left, bottom -20 and 30 mm projectiles, right, bottom - M115A2 simulator, top-three different types of ignition cartridges for 81 mm mortars. The three fuzes are imaged with improved sharpness over the previous radiograph, due chiefly to doubling the L/D ratio 18 of the previous radiograph. On the M115A2 the explosive charge and the explosive lead including the whistler are imaged. On the 81 mm ignition cartridges at left and right top, the explosive charge is imaged with good definition. On the center ignition cartridge the cellulose nitrate charge which is clearly imaged (the upper section which appears almost white), is not imagable with conventional X-ray radiography. This radiograph was produced using the same exposure parameters as for Figures 10 through 14.

The neutron radiograph presented in Figure 17N images a faulty condition in 30 mm XM789 projectiles which cannot be determined with X-ray inspection. Inside the flash tubes of the projectiles (bottom end) can be seen the independent flash elements. The positions of the elements along the projectile axes are seen to be random. This random positioning can result in an unacceptable "hang-fire" functioning. X-rays do not image the internal portions of the flash tube and hence, as mentioned above, cannot be used to detect this unsafe condition.

The next series of neutron radiographs, Figures 18N through 23N, are radiographs of the same group of specimens. Each radiograph was produced using a different film/converter screen combination, for comparison of results. All exposures in this group were run at L/D=36. The wide variation in film/screen combinations resulted in exposure times ranging from 15 minutes to 21-1/2 hours (5 minutes to 7 hours with normal tube output). The specimens are: left to right, top - various small caliber ammunition, 81 mm ignition cartridges (2 each); left to right, bottom - 81 mm mortar ignition cartridge, 30 mm projectile, 20 mm projectile, M577 fuze, M564 fuze, M739 fuze, M115A2 simulator; center - 81 mm cartridges (2 each). Other exposure details and discussion of these radiographs are given below:

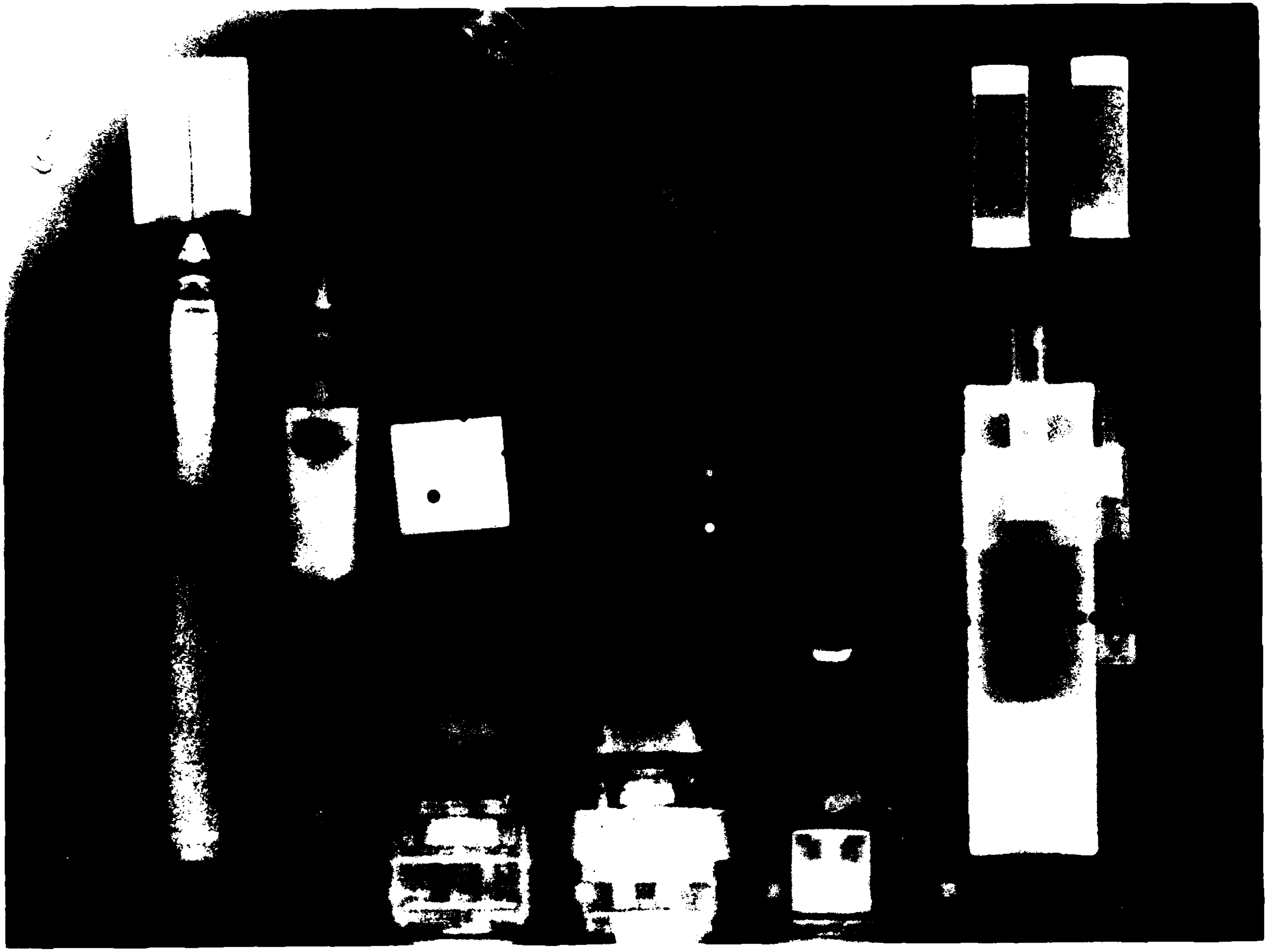


Figure 16N. Neutron Radiograph, Bottom Left to Right, of 20 and 30 mm Projectiles, M577 Fuze, M564 Fuze, M739 Fuze, M115A2 Simulator, and Top, Three Types of Ignition Cartridges for 81 mm Mortars

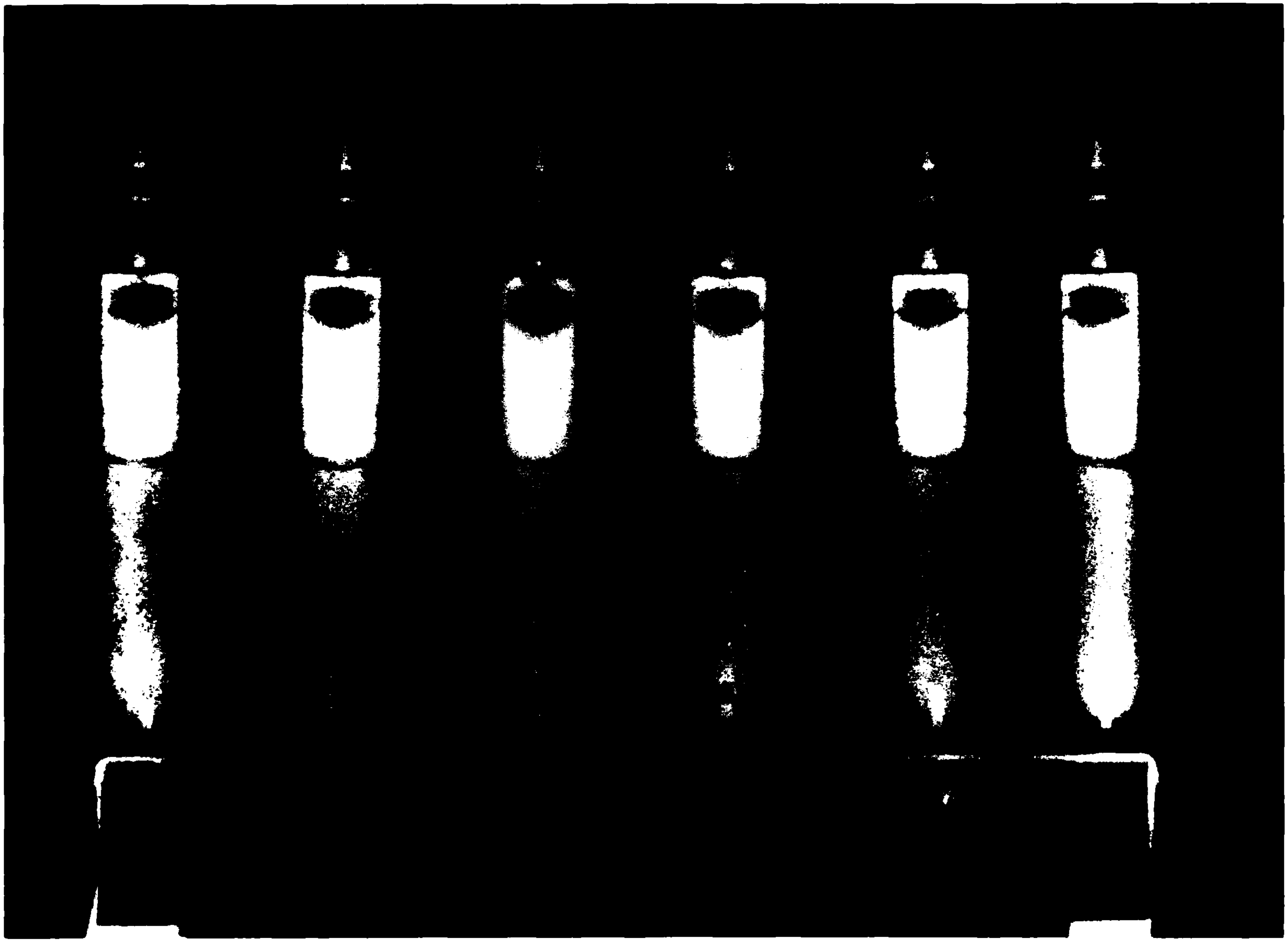


Figure 17N. Neutron Radiograph of 30 mm XM 789 Projectiles Showing Unacceptably Random Positions of the Flash Elements Along Projectile Axes (at Bottom End of Projectiles)

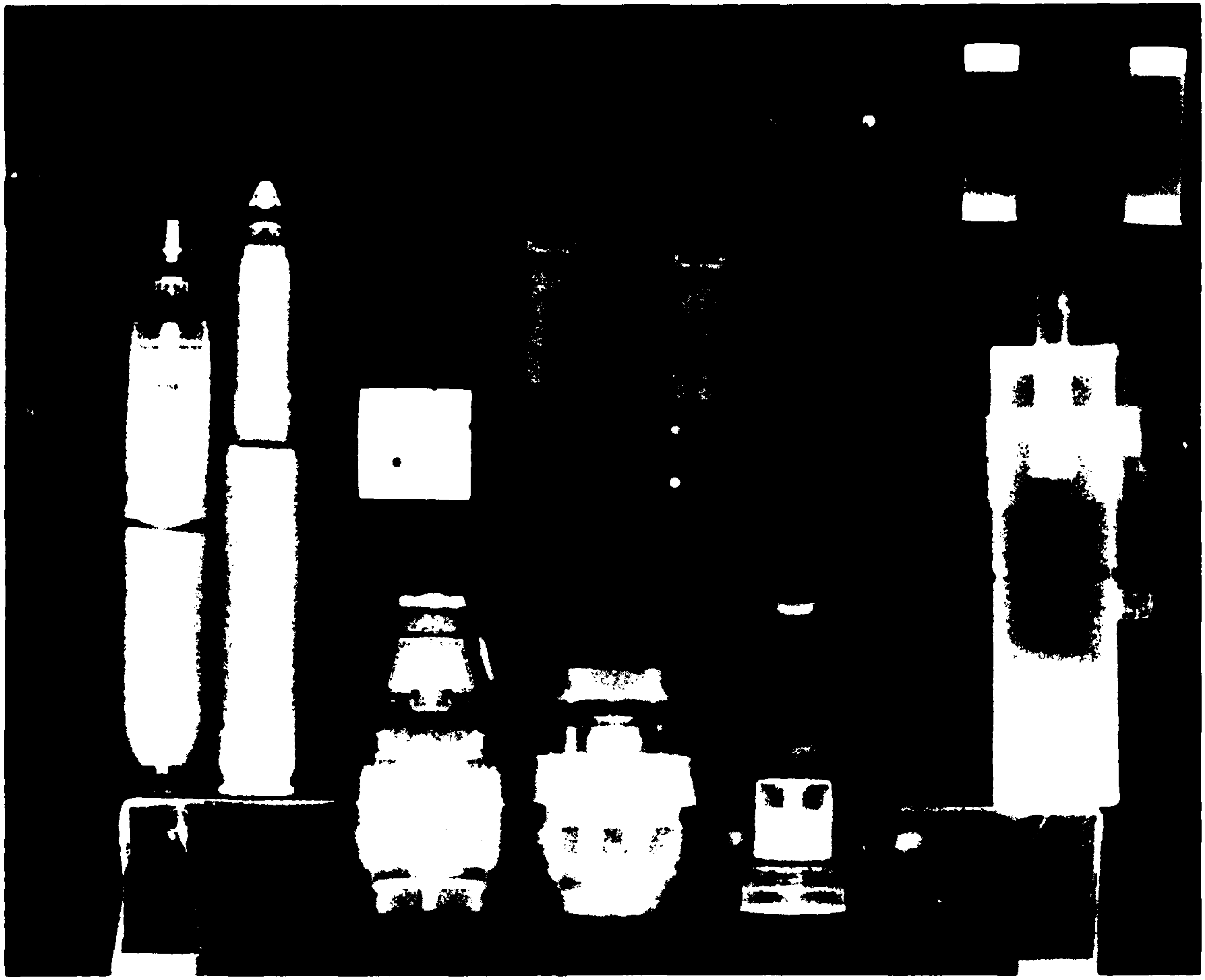


Figure 18N. Neutron Radiograph of Various Ordnance Devices (Items Appearing in Figures 10N through 17N). Film/Converter: DuPont NDT 91/Vought DC-4

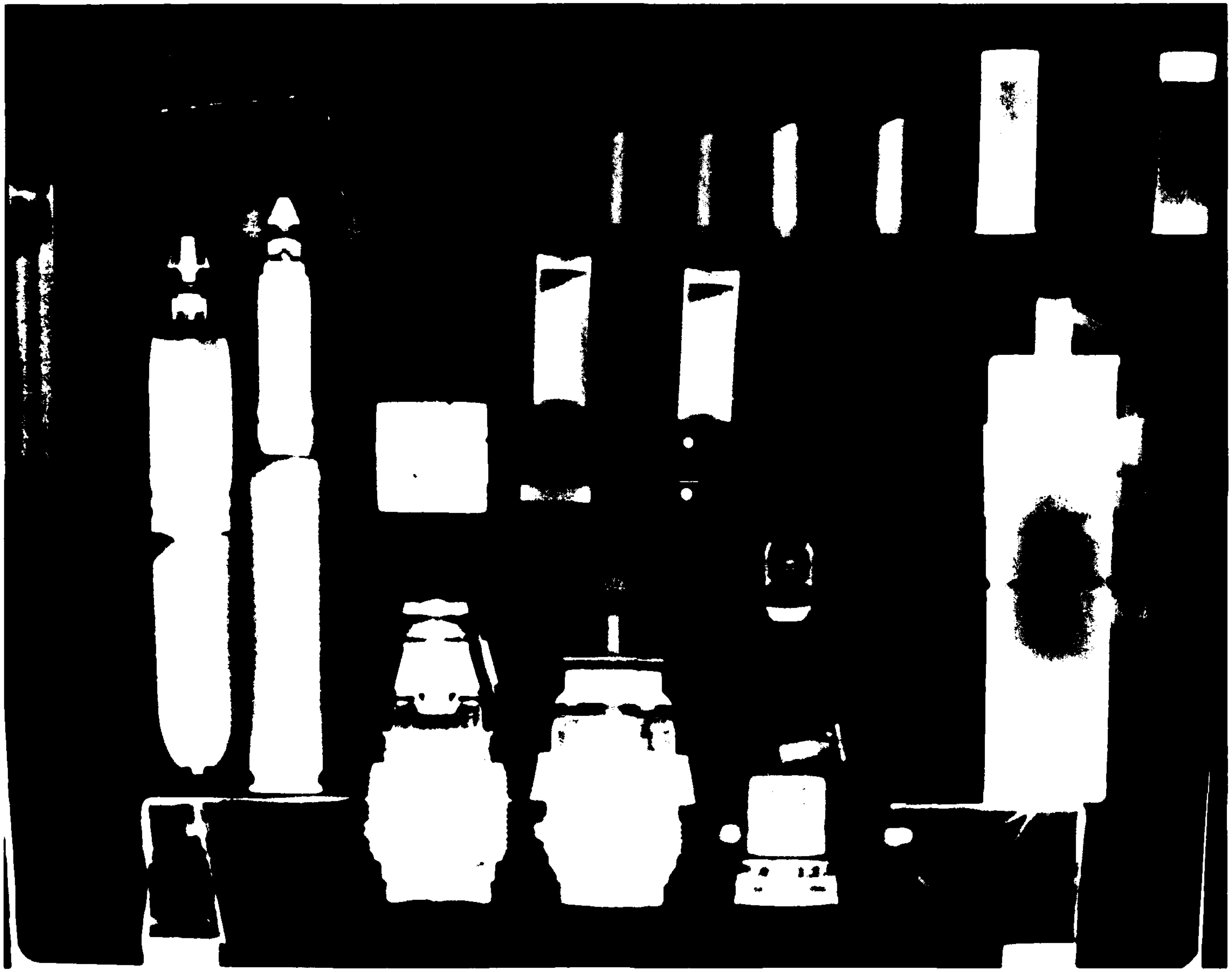


Figure 19N. Neutron Radiograph of Various Ordnance Devices (Items Appearing in Figures 10N through 17N). Film/Converter: DuPont NDT 75/Vought DC-4

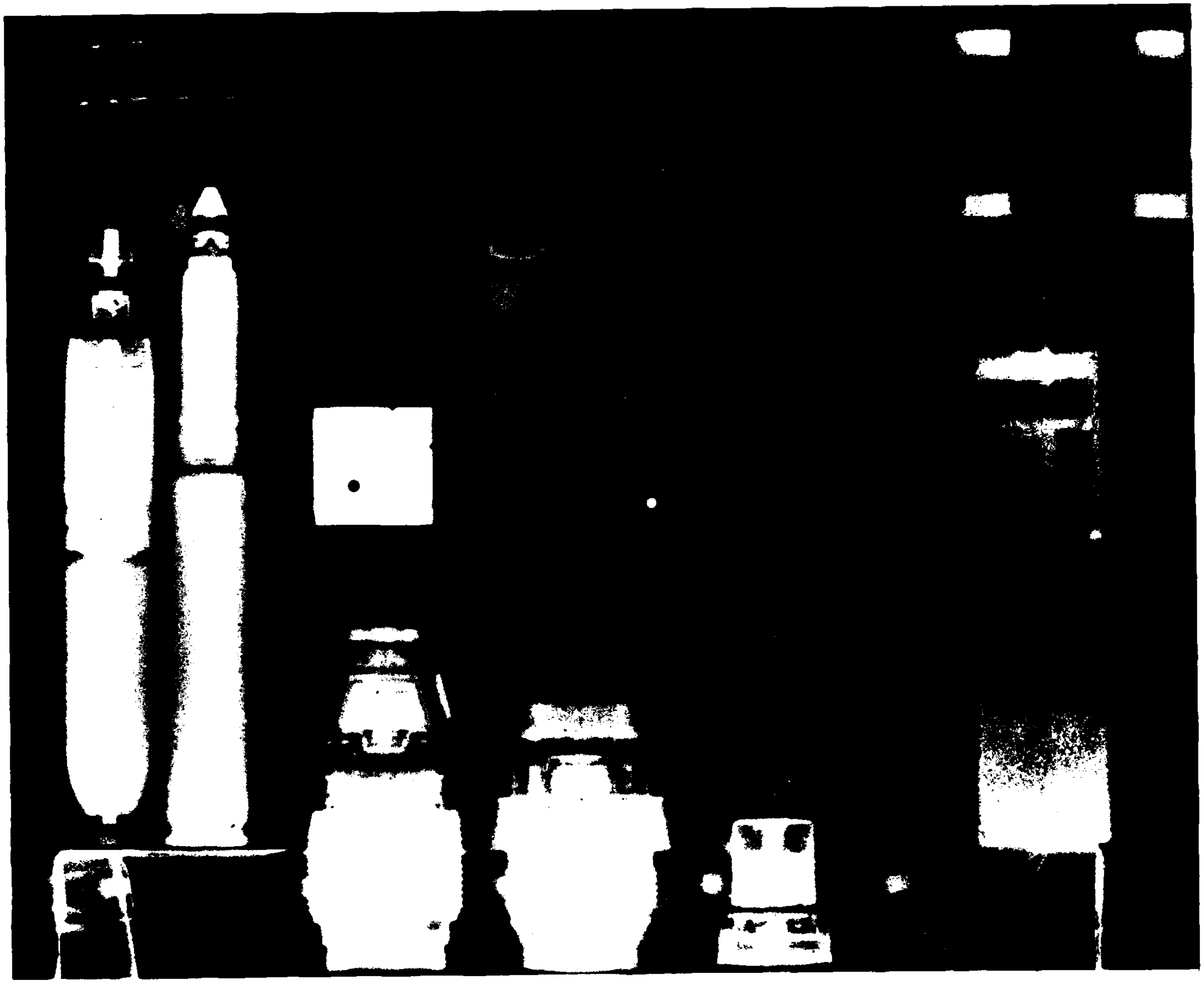


Figure 20N. Neutron Radiograph of Various Ordnance Devices (Items Appearing in Figures 10N through 17N). Film/Converter: DuPont NDT-65/Vought DC-4

Figure 21N. Neutron Radiograph of Various Ordnance Devices (Items Appearing in Figures 10N through 17N). Film/Converter: DuPont NDT 55/Vought DC-4

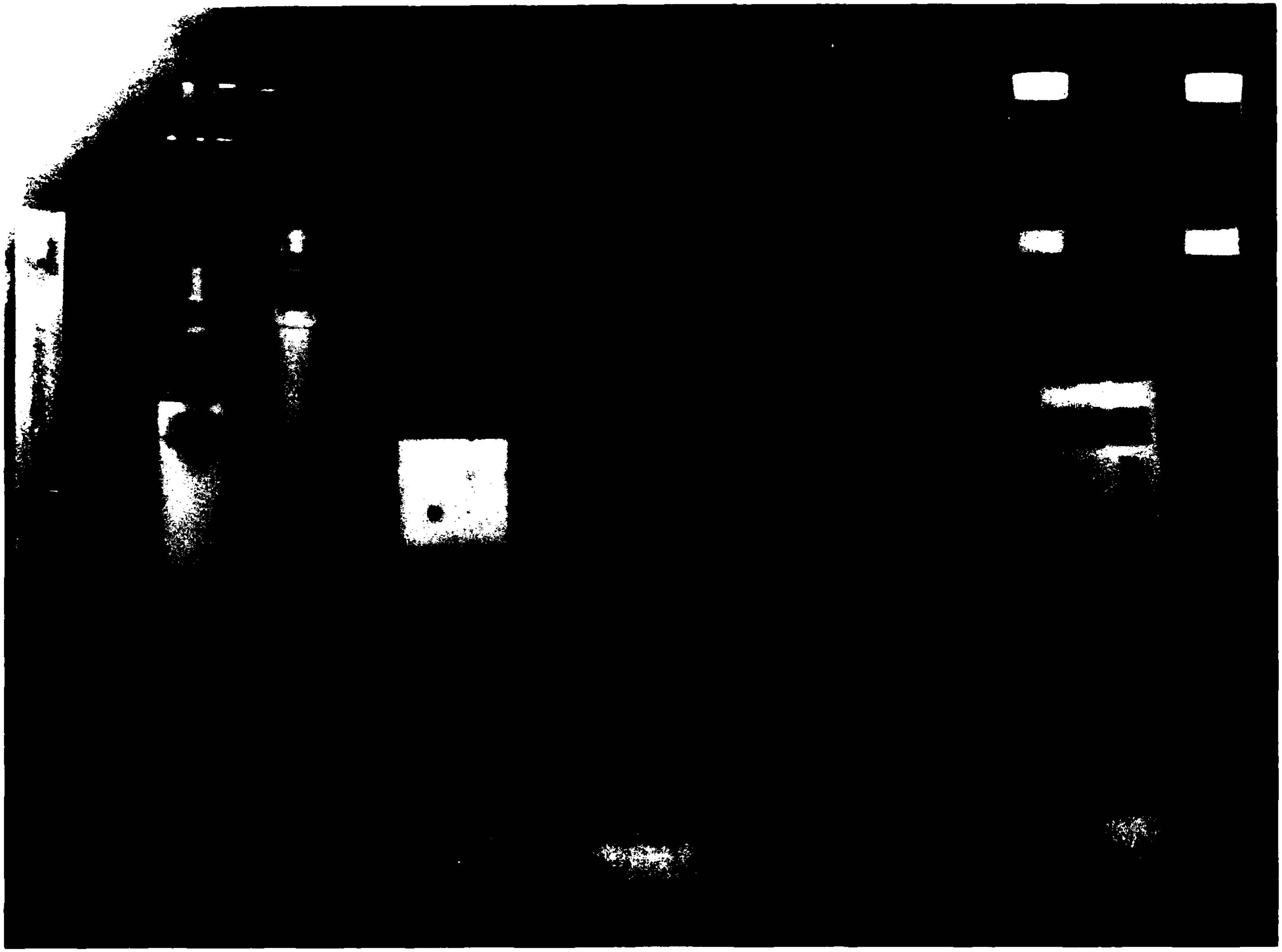


Figure 22N. Neutron Radiograph of Various Ordnance Devices (Items Appearing in Figures 10N through 17N). Kodak SB/Kodak Lanex Fine

Figure 23N. Neutron Radiograph of Various Ordnance Devices (Items Appearing in Figures 10N through 17N). Film/Converter: Kodak AA/ Gadolinium

Figure 18N : An example of results obtained with a very fast film/screen combination: DuPont NDT 91/Vought DC-4. Exposure time was 15 minutes (4 to 5 minutes with normal tube output), overall density 1.95. Although the very fast film produces a grainy picture, the high density and good contrast resulting from this film/screen combination provides radiographic information useful for many applications.

Figure 19N: Film/screen - DuPont NDT-75/Vought DC-4; exposure time - 2.5 hr (40 to 50 minutes with normal tube output); film density, 2.88. As seen by the radiograph, the NDT 75 is much slower when used with the DC-4 screen, but provides a high density, high contrast neutron image with significantly less grain than the NDT 91. This combination shows considerable potential for future use with mobile neutron radiography systems.

Figure 20N: DuPont NDT 65/Vought DC-4; exposure time 3 hours (45 minutes to 1 hour with normal tube output), film density 0.88. As seen in the radiograph, the NDT 65 film, used with this converter screen, affords only a slight gain in sharpness of detail over that of NDT 75, while resulting in substantially lower film density.

Figure 21N: DuPont NDT 55/Vought DC-4; exposure time 3 hours (45 minutes to 1 hour with normal tube output); film density 0.96. The radiographic result is seen to be similar to that of NDT 65, used with this converter screen. However the substantial increase in exposure time required to produce a given film density is not offset by the slight gain in image sharpness over the NDT 75 film, and hence does not appear to be as useful for mobile neutron radiography.

Figure 22N: Kodak SB/Lanex Fine; exposure time 3 hour (45 minutes to 1 hour, with normal tube output); film density 1.56. This combination yields good film density and sharpness of detail. Contrast is lower than with the DuPont/DC combinations.

Figure 23N: Kodak AA/Gadolinium; exposure time 21-1/2 hours (5-1/2 to 7 hours with normal tube output); film density, 1.27. This long exposure radiograph illustrates the resolution attainable with gadolinium foil as converter material. Although the resolution is appreciably better than many other types of converters, a comparison of this radiograph with the previous one, Figure 22, reveals that the results, in both resolution and contrast are not appreciably different. Thus the SB/Lanex combination approximates the AA/Gadolinium results and requires only 1/7 the exposure time.

From the radiographic exposure data accumulated during these operations a set of curves may be drawn comparing film density versus exposure times for various film/screen combinations, adjusted for normal output of the neutron generator tube. These comparisons are shown in Figure 24.

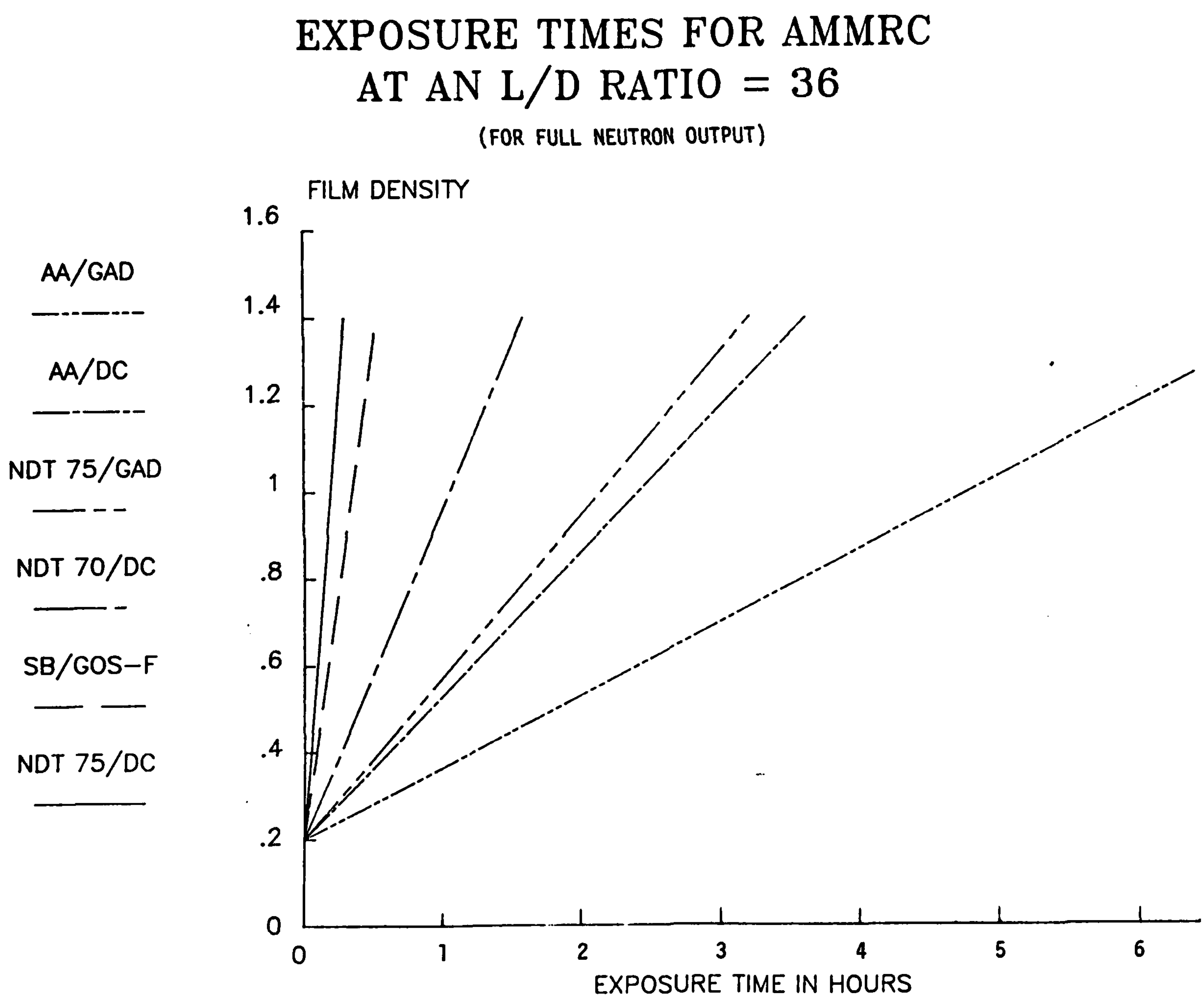


Figure 24. Comparison of Film Density-versus-Exposure Times for Various Film/Screen Combinations

4.0 CONCLUSIONS

From the results and experience gained during the USAYPG operations the project objectives were met.

Comparison of X-ray and neutron radiographic inspection results obtained in this study clearly indicates the applicability of neutron radiography for solving the inspection problem of imaging detonators, explosive charges, and other non-metal components not imaged by more conventional means in specific ordnance devices. The complementary nature of the NDE information provided by the two radiographic techniques was well demonstrated.

The radiation measurements made in assessing the radiation environment during operation of a mobile system of this type, and the experience gained in operational procedures demonstrated that a radiation-safe area of reasonable bounds can be maintained and safe operations carried out in a manner analagous to X-ray operations.

The performance and reliability of the neutron radiography system in an environment external to the laboratory were proven. Although the neutron output of the generator tube was significantly below its normal output, lifetime of this specific tube had already exceeded that expected before its output showed significant decline (~350 hours). The tube continued to operate reliably at the reduced output throughout the operations. The total system demonstrated good reliability. Only minor component failures such as a water pump relay and capacitor and a shorted high voltage cable occurred, being repaired with no downtime in regular shift operation.

From the comparisons of radiographic results from various film/screen combinations it is concluded that, for a mobile neutron radiography system, the fast combinations such as the SB/Lanex and the NDT 75/Vought DC closely approximate the results from AA/Gd in only a fraction of the exposure time required for the latter. Thus the former two combinations provide an excellent compromise in the image quality/exposure time trade-off, since the longer exposure times are impractical.

The operations at USAYPG provided Army personnel with valuable hands-on experience with neutron radiography in the YPG environment and a significant volume of data which should be extremely useful, as a basis for defining future neutron radiography requirements and specifications.

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