(2)

AD-A148 808

AD

AMMRC TR 84-39

MOBILE ACCELERATOR NEUTRON RADIOGRAPHY SYSTEM

OCTOBER 1984

W. E. DANCE, S. F. CAROLLO, AND H. M. BUMGARDNER
LTV AEROSPACE AND DEFENSE COMPANY
VOUGHT MISSILES AND ADVANCED PROGRAMS DIVISION
P. O. BOX 650003
DALLAS, TEXAS 75265-0003

FINAL REPORT

CONTRACT NO. DAAG46-78-C-0007

Approved for public release; distribution unlimited.

DTIC
ELECTE
DEC 26 1984
S D
E

PREPARED FOR

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
WATERTOWN, MASSACHUSETTS 02172

84 12 13 033

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AMMRC TR 84-39	2. GOVT ACCESSION NO. AD-A148 808	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MOBILE ACCELERATOR NEUTRON RADIOGRAPHY SYSTEM		5. TYPE OF REPORT & PERIOD COVERED Final Report - Feb 1978 thru Dec 83
		6. PERFORMING ORG. REPORT NUMBER 3-56000/4R-169
7. AUTHOR(s) W. [illegible], C. F. [illegible], [illegible] R. M. Bumgardner		8. CONTRACT OR GRANT NUMBER(s) DAAG46-78-C-0007
9. PERFORMING ORGANIZATION NAME AND ADDRESS LTV Aerospace and Defense Company P.O. Box 225907 Dallas, Texas 75265		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS D/A Project: M776350 AMCMS Code: 53970M6350
11. CONTROLLING OFFICE NAME AND ADDRESS Army Materials and Mechanics Research Center ATTN: AMXMR-K Watertown, Massachusetts 02172-0001		12. REPORT DATE October 1984
		13. NUMBER OF PAGES 149
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This project has been accomplished as part of the U.S. Army Materials Testing Technology Program, which has for its objective the timely establishment of testing techniques, procedures or prototype equipment (in mechanical, chemical, or nondestructive testing) to insure efficient inspection methods for materiel/material procured or maintained by AMC.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Neutron radiography	Lightweight materials
Nondestructive testing	Aircraft maintenance
Radiography	Corrosion

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(SEE REVERSE SIDE)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Block No. 20

ABSTRACT

The use of neutron radiography for the inspection and maintenance of large structures such as aircraft has been delayed by the absence of a mobile system particularly suited to the requirements of field use. This report describes the production, extensive field testing, evaluation and disposition of the first mobile neutron radiography system to satisfy the majority of requirements for field use. The system is based upon the concept of a mobile on-off neutron radiography system based on a sealed-tube ion accelerator as neutron source demonstrated earlier by the Vought Corporation. Primary features of the system are its self-propelled mobility, versatile positioning capability scaled to Army helicopter dimensions, an on-off beam capability, exposure capability measured in minutes, and suitability for AMMRC laboratory and field use. Included in the report are a description of all components of the system, an evaluation of the operation of the system, an evaluation of its radiographic capabilities, a description of installation elements for the AMMRC site, and recommendations for next-generation systems.

FOREWORD

This report was prepared by the LTV Aerospace and Defense Company Vought Missiles and Advanced Programs Division (formerly Vought Corporation Advanced Technology Center) for the U.S. Army Materials and Mechanics Research Center under Contract DAAG46-78-C-0007. The work was performed during the period from February 1978 to December 1983. Dr. John J. Antal at AMMRC was the program Technical Monitor and Dr. William E. Dance at LTV Aerospace and Defense was Principal Investigator.

The authors gratefully acknowledge the contributions made by many other personnel, without whose support the successful completion of the project would not have been possible. Special thanks are extended to Dr. John Antal for invaluable, continued technical and project management support, and to Mr. Paul Rolston, AMMRC, whose office provided funding, for his active interest and support throughout the program.

The authors wish to thank also Mr. James Moravec and his staff at U.S. Army Yuma Proving Ground for thorough and well-planned site preparation and total support provided during the operations at that facility. Likewise, the efforts of personnel at Sacramento Air Logistics Center, McClellan AFB, supporting the operations at that facility are greatly appreciated, especially the untiring efforts of Messrs. Don Johnson, Chuck McCranie, Francis Tripp, and Jim Ellison. The interest of Mr. Bernie Boisvert, Air Force Logistics Command, in this work and funding for the McClellan AFB operations through his office, with Lt. Tim Fotinos as project monitor, are gratefully acknowledged.

The contributions of Mr. Frank Horak, Vought Radiological Safety Officer, in supporting activities throughout the program were invaluable.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Cont'd.)

LIST OF FIGURES

LIST OF FIGURES
(Cont'd.)

LIST OF FIGURES
(Cont'd.)

LIST OF FIGURES
(Cont'd.)

LIST OF FIGURES
(Cont'd.)

LIST OF TABLES

1.0 INTRODUCTION

The latent potential of neutron radiography for nondestructively inspecting many types of structures which are difficult or impossible to effectively inspect by more conventional means has been generally recognized for many years. Production inspection of pyrotechnics ordnance items and many other small items using reactor neutron radiography facilities is well established. Demonstrations of the sensitivity of the method in various applications to large structures have been made, including inspections for adhesive bond voids, condition of seals and sealants, presence of hidden moisture and corrosion, and others. However, the absence of a practical mobile system for field inspection has delayed early use of neutron radiography for maintenance inspection of aircraft and other large vehicles or structures.

During 1975-1977, in an internal R&D program, Vought Corporation developed and demonstrated the concept of a mobile on-off neutron radiography system which was based on a sealed-tube ion accelerator as neutron source. In the Vought program, a laboratory system based on this concept was designed and fabricated for further exploratory and developmental studies in this technology.

Subsequent to the above-mentioned program, Vought was funded by the Army Materials and Mechanics Research Center (AMMRC) to produce and evaluate a system for the AMMRC laboratories, based on the Vought technology. This report describes the work performed under that contract. The requirement was for a system suitable for laboratory use in applications studies and for limited exploratory field studies. Within the scope of the contract was the provision of a safety system for operating the mobile system in a stationary mode, inside the AMMRC laboratories.

Salient features of the system provided by Vought to meet the AMMRC requirements are:

1. Mobile, self-propelled, versatile positioning capability with height and collimator angle adjustments

2. On-off beam capability

3. Film exposures in a few minutes

4. Dimensions appropriate for entry and exit through AMMRC reactor building air-lock doors

5. Safety interlocks and radiation monitoring and warning devices.

A four-phase effort structured to meet the program objectives encompassed the following:

Phase I - Detailed design of a system tailored for AMMRC laboratory utilization and limited field radiography.

Phase II - Manufacture of system to approved design and initial checkout.

Phase III - Demonstration, validation testing and evaluation of system.

Phase IV - Refurbishment, delivery, installation, and personnel training.

The report includes a system description and a discussion of system characteristics and presents radiographic data accumulated during Phase III in the Vought laboratories, and at Army and Air Force facilities in field demonstrations and operations. The results of radiation measurements from the unshielded system are given, and shielded facility radiation safety surveys are shown. Recommendations are made for features which should be incorporated into a similar neutron radiography system designed for production inspection at the depot level.

2.0 SYSTEM DESCRIPTION

2.1 GENERAL

The mobile neutron radiography system as designed and fabricated at Vought is shown in Figure 1. The system is based on a sealed-tube accelerator as a neutron source which is capable of generating approximately 10^{11}, 14-MeV neutrons per second. Major components of the total radiography system are an inspection head with electrical and cooling support equipment, a positioning vehicle, an imaging system, and a safety system. The vehicle can be motor-driven for positioning adjacent to the structure being inspected, and the accelerator head rotated to direct the neutron beam at an angle appropriate for radiography of the structure. Film cassettes with appropriate neutron converter screens are provided for positioning behind the structure, to record radiographic images. A schematic representation of the radiography system is shown in Figure 2.

2.2 INSPECTION HEAD

The inspection head, which is comprised of a sealed-tube neutron generator and a moderator/collimator assembly, is mounted on one end of the positioning vehicle. A schematic of the head is given in Figure 3.

2.2.1 Sealed-Tube Neutron Generator

A block diagram of the sealed-tube neutron generator, Kaman Instrumentation Corporation's A-711 model, is shown in Figure 4. The accelerator tube contains a gas reservoir, an ion source, a lens gap (which accomplishes extraction and focusing, as well as acceleration), and a target (for the generation of neutrons). The accelerator utilizes the $H^3(d,n)He^4$ reaction to generate a continuous output of neutrons with an energy of approximately 14.3 MeV. Deuterium and tritium gases are ionized by a Penning discharge type ion source. The positive ions extracted from this source are accelerated into a grounded target assembly to provide fast neutrons via the above-mentioned reaction. As gas is consumed, it is replaced from a gas reservoir. The gas emission rate, and consequently, the pressure in the

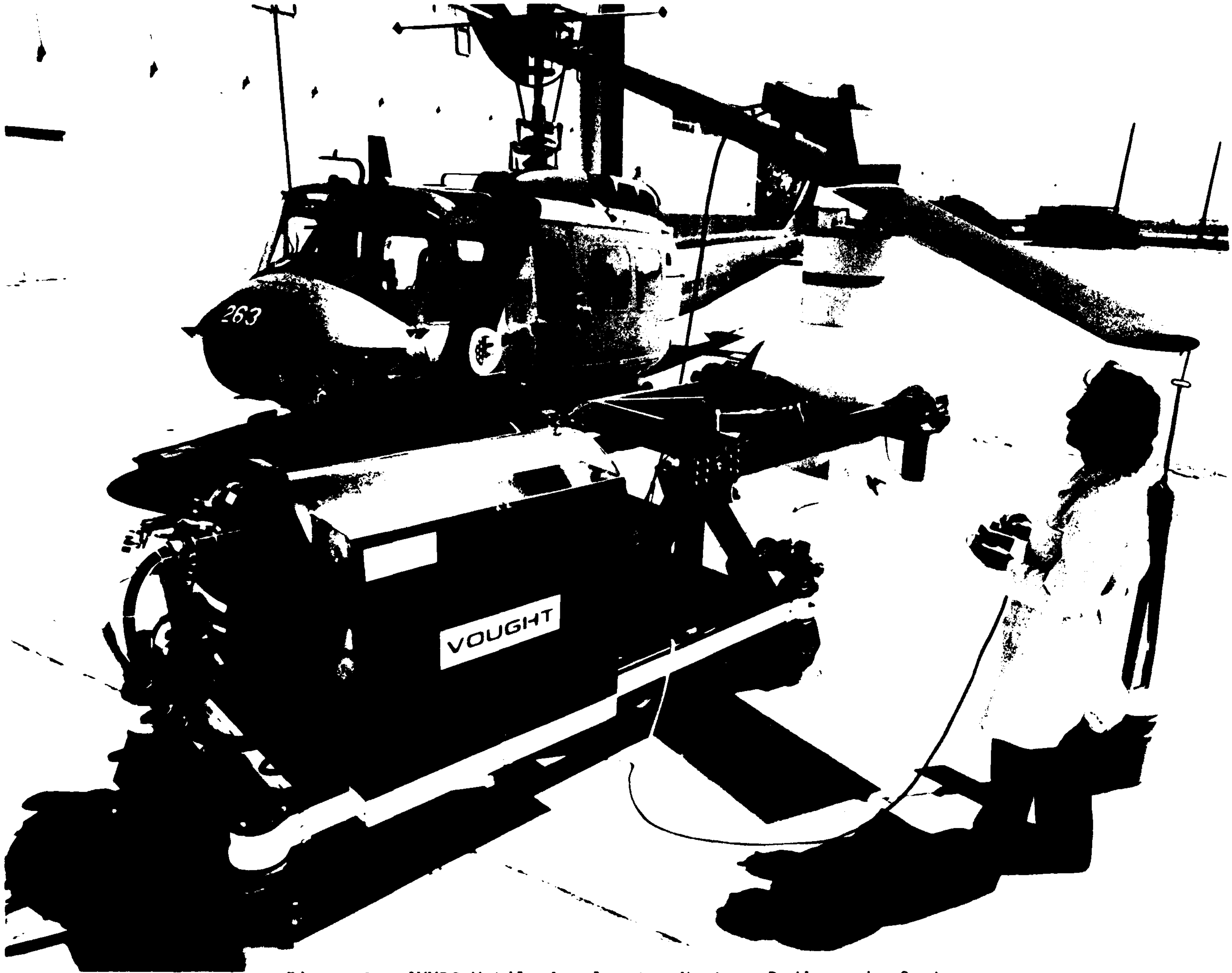


Figure 1. AMMRC Mobile Accelerator Neutron Radiography System

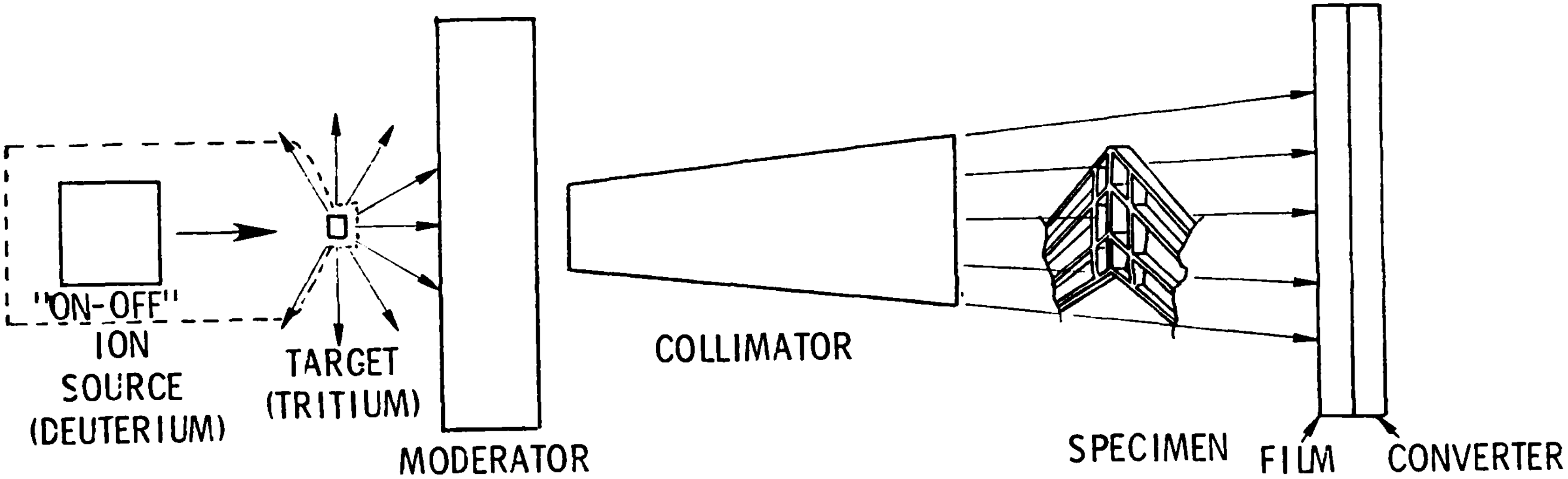
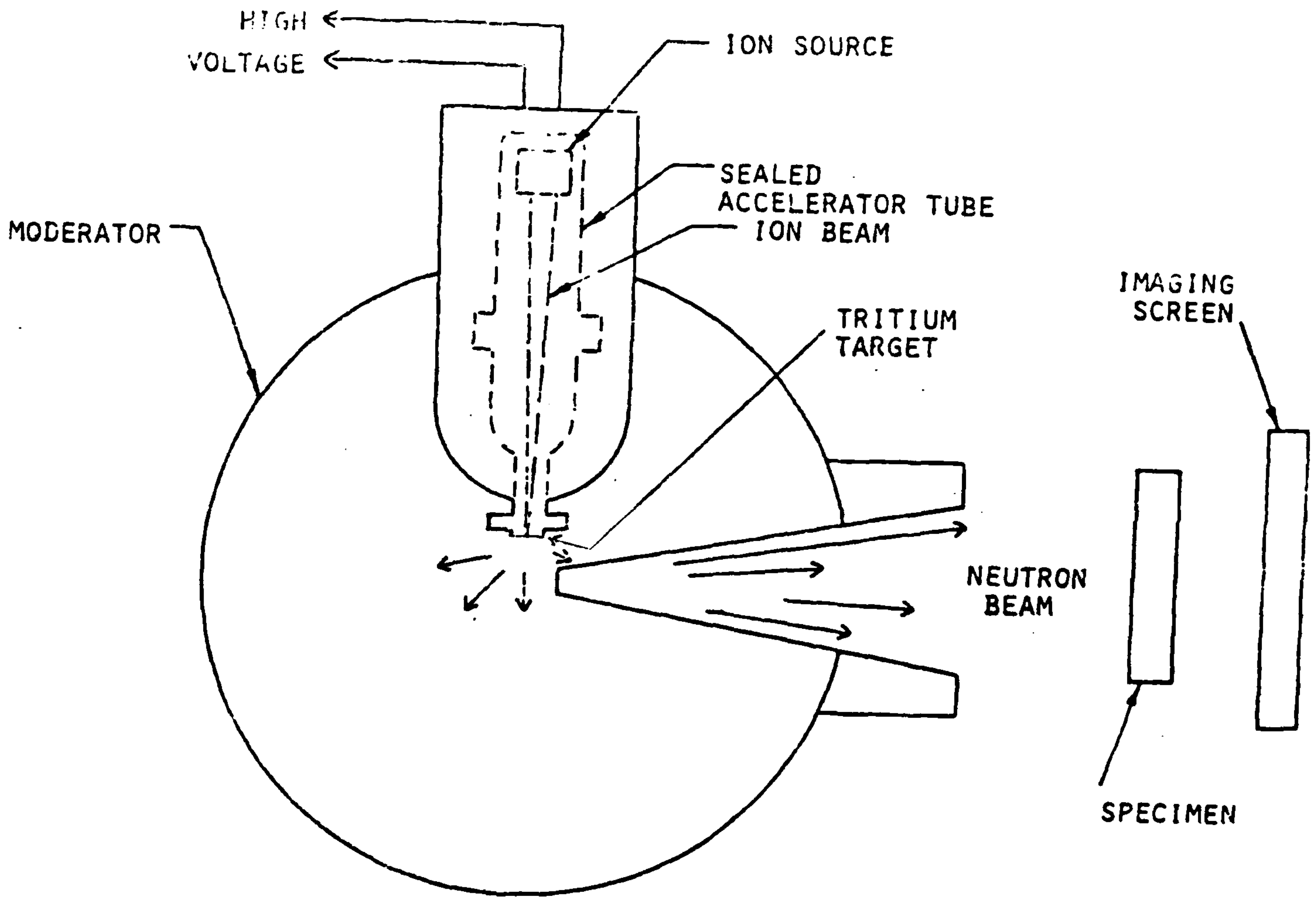


Figure 2. Schematic Representation of Sealed-Tube Neutron Generator Radiography System



ON-OFF FEATURE
ALLOWS FIELD
INSPECTION
WITH PROCEDURES
SIMILAR TO X-RAY.

Figure 3. Schematic of Neutron Radiography System Inspection Head

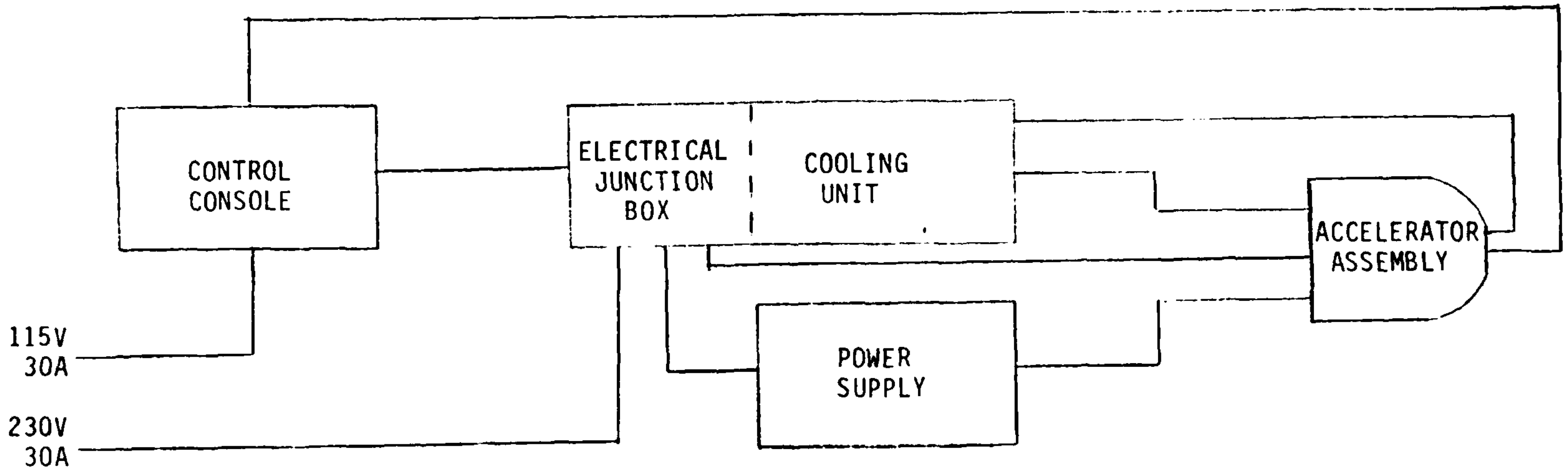


Figure 4. Block Diagram of Fast Neutron Generator

accelerator tube and the beam current, are controlled by changing the current through the reservoir heater element.

High voltage for the ion source is provided by the source power supply, also a full-wave voltage-doubler, which applies a positive dc voltage to the anode of the source. Output voltage of this supply may be varied from 0-10 kv by varying the ac input to the step-up transformer primary. This supply has its negative terminal connected to the +200 kv point of the main high voltage power supply, and therefore it "floats" on top of the 200 kv. Typically operated at 5 kv, its voltage affects the focusing of the ion beam in tne accelerator and is factory-adjusted for optimum ion beam focal conditions.

Cooling for the accelerator head is provided by a completely self-contained system, consisting of three major subsystems: a target cooling loop, a source cooling loop, and a refrigeration unit which exchanges the heat from these loops with the ambient air. With the exception of the coolant lines to the source and target, the components of all three subsystems are enclosed in the cooling unit. The caster-mounted cooling assembly contains a commercial-type refrigeration unit, separate sumps and pumps for target and source cooling loops, and the necessary fittings. Since the system is completely enclosed, with all coolants recirculating, no drain or primary water source is required. Optimum cooling of the target is obtained with clean deionized water. Freon 113 is used in the source cooling loop to withstand high accelerating voltages. Conventional temperature controls are used in the refrigeration system to maintain the temperature slightly above 32°F in the heat exchanger.

A remote control console is provided which permits operation up to 75 feet away from the cooling unit. All necessary controls and indicators for the neutron generator are provided on the console.

2.2.2 Moderator/Collimator Assembly

The moderator/collimator assembly is mounted between the support arms of the positioning vehicle such that the axis of mounting (and rotation) is perpendicular to the collimator axis. Rotation of the assembly is accomplished by a battery-powered rotary actuator mounted on an axial shaft attached to the moderator sphere. Moderation, or thermalization of the fast neutrons, is accomplished by a hydrocarbon oil contained within the moderator assembly. Extraction of neutrons is accomplished by a divergent collimator inserted into the moderator fluid. A counterweight is provided on the side of the moderator sphere opposite the collimator to reduce the power required by the actuator.

2.3 POSITIONING VEHICLE

The vehicle is a battery powered motorized four-wheel carriage as illustrated in Figure 5. Maneuverability is provided by two steerable driven wheels on opposite corners of the carriage. The remaining wheels are of the free-wheeling, swivel type. This arrangement allows vehicle rotation about any point, or movement in any direction. Positioning of the moderator/ collimator assembly and sealed-tube neutron generator is facilitated by a support arm with a motorized screw jack actuator assembly. Battery power for the dc motors is provided by four 6 volt batteries, and controlled by a dc motor controller and relays, all located in the electrical cabinet. All dc motors are manually controlled by a hand-held pendant. Vehicle batteries are charged, as required, by a small power supply mounted on the side of the vehicle. Cooling lines, control wires, and system electrical power are conveniently supplied through the service disconnect panel located near the battery charging power supply.

2.4 IMAGING SYSTEM

Two types of imaging systems are supplied:

a) Vacuum cassettes (2) for radiographic sheet film

b) Modified Picker cassette (1) for Polaroid radiographic film

Specially designed vacuum cassettes were provided for handling films up to 14 x 17 inches in size with converter screens. The cassettes were complete with attached manifolds, gauges, pumpout ports, sealing valves and spacer plates. Also provided were two 14 x 17 inch gadolinium oxysulfide (GOS) converter screens, one regular and one fine-grained, and two sapphire coated, vapor deposited 14 x 17 inch gadolinium converter screens for use in the vacuum cassettes. A Picker x-ray cassette/ processor, modified for neutron

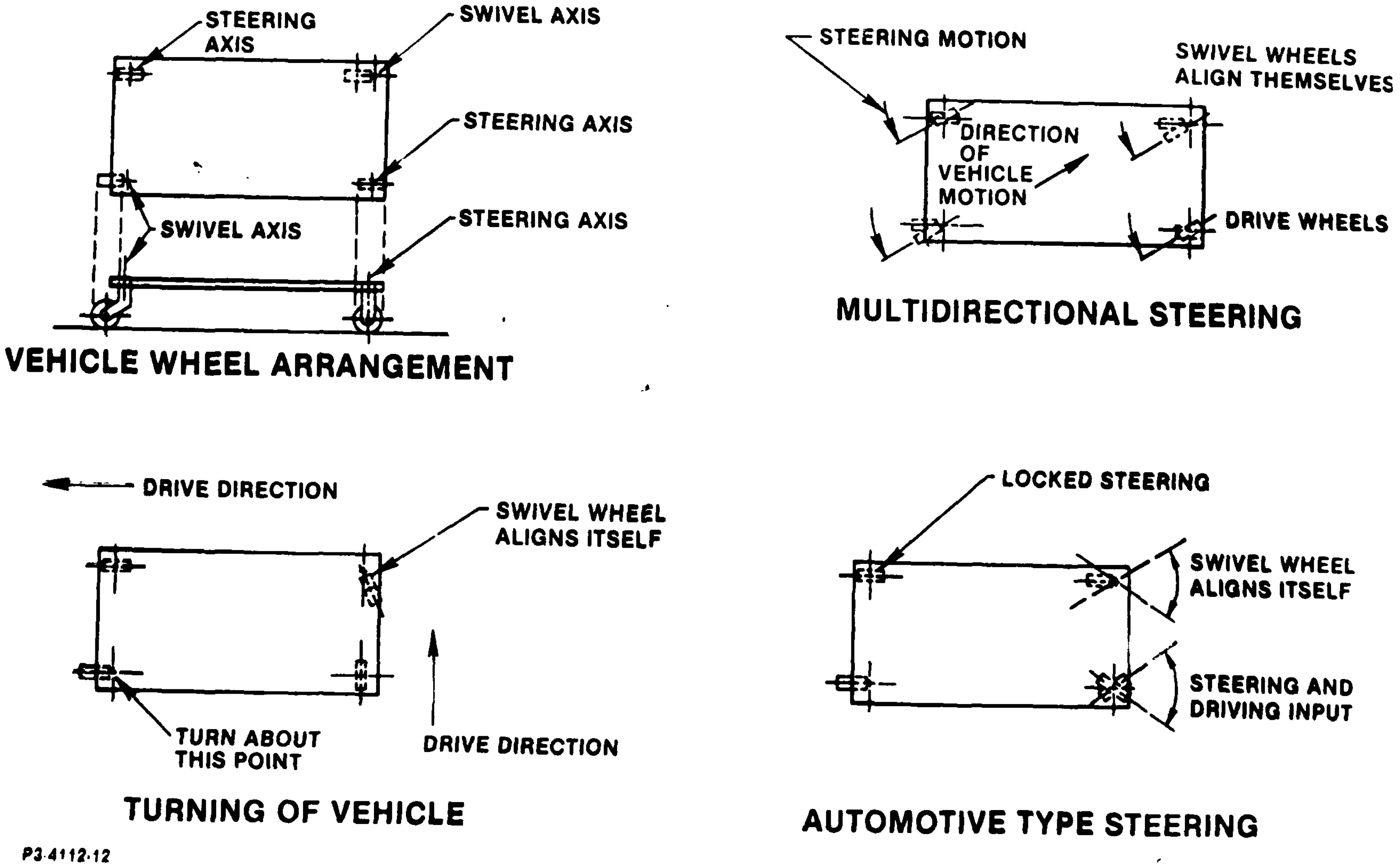


Figure 5. Schematic of System Carriage Drive

radiography by replacement of the backing plate, converter screen, and film compression mechanism, was also supplied. It can provide fast radiographs (with less resolution) because of low exposure times required by the fast film/converter screen combination and the 45 second Polaroid film development time.

Near real time filmless imaging with the AMMRC Mobile Neutron Radiography System was also demonstrated. A low-light television imaging system developed by Vought in another program for use in moderate to very low flux neutron radiography beams was used (seen in Figure 1). Full-size 10" x 10" quality images, enhanced with advanced image processing equipment, were displayed. Rapid hard copies were produced by a video printer.

2.5 SAFETY SYSTEM

A block diagram of the safety system provided for operation of the neutron radiography system inside the AMMRC laboratory is given in Figure 6. The system has three functions: (1) monitor, (2) alert, and (3) abort. Passive monitors are indicators only and do not directly affect the operation of the unit. Neutron flux is measured at the console by a neutron detector; gamma and x-rays are measured by an x-ray detector. In conjunction with these detectors, an alarm is provided that sounds when a predetermined flux level is exceeded. An operator thus has a real time indication of the relative radiation output of the neutron radiography system. Another x-ray detector, located in the radiography exposure room, is used to detect X-ray radiation from the accelerator. A beeper, a flashing light, and a lighted "radiation on" sign are connected to this detector and are used to alert personnel in the radiation area to the presence of ionizing radiation. X-rays are monitored because of the possibility of x-ray generation without neutrons, whereas neutrons cannot be produced without x-rays. A "High Voltage - Evacuate Area" sign, and a second beeper are provided for the radiation operating area. The second beeper is activated when the high voltage switch is depressed. Additionally, an "Accelerator On" sign is illuminated when the "Neutrons On" switch is depressed.

Active monitors can sense a predetermined condition and abort a run. Interlocks are on the gates and doors to shut off the system in the case of

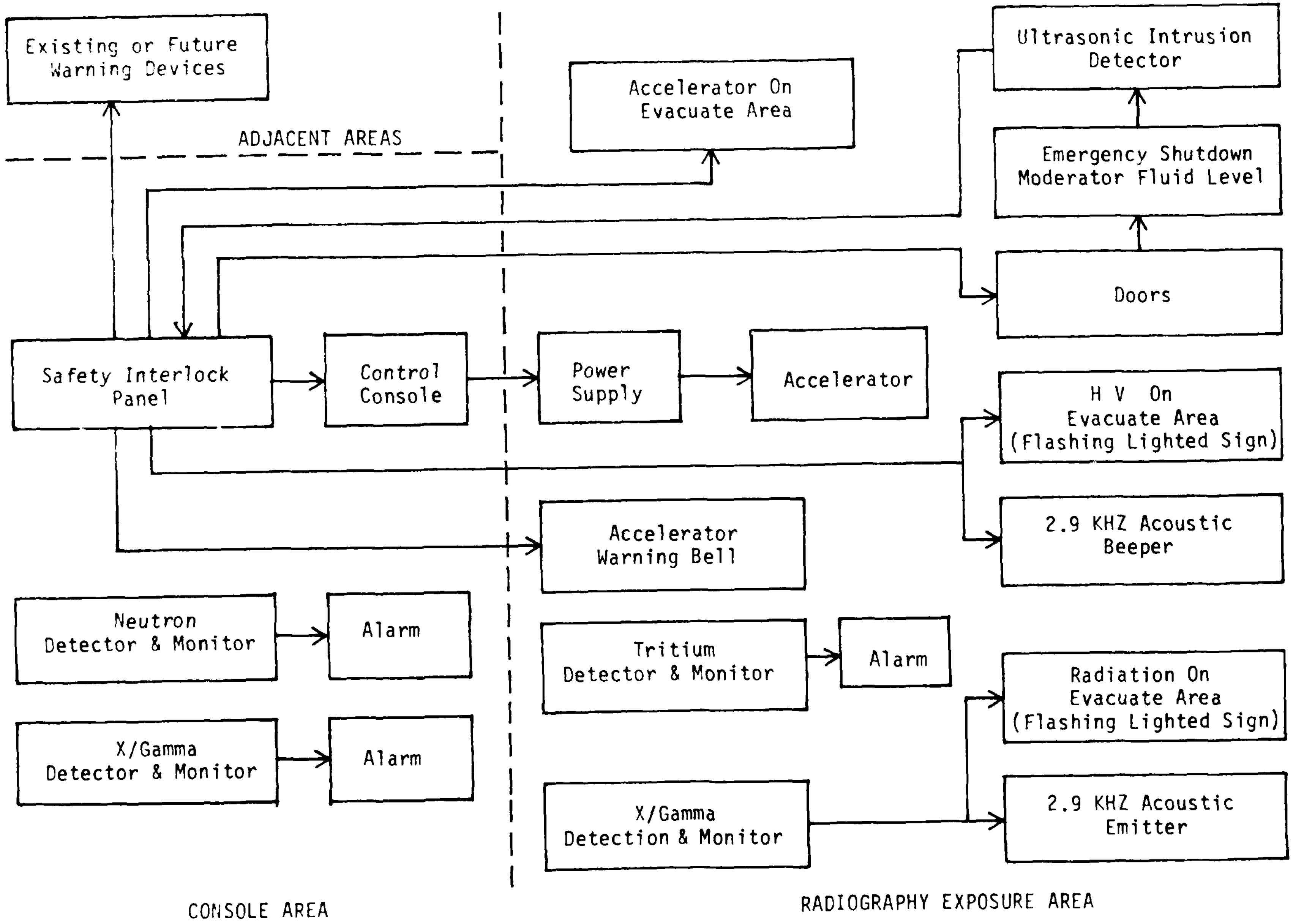


Figure 6. Block Diagram of Radiation Safety System

inadvertent intrusion. Also employed is a manual reset emergency shutdown switch, moderator fluid level switch, and ultrasonic intrusion detector switch system. Cooling units are also equipped with emergency shutdown switches. Personnel safety devices such as badges and dosimeters are required where applicable.

2.6 SYSTEM SPECIFICATIONS

Specifications for the AMMRC mobile N-ray inspection system are given in Table 2-1.

TABLE 2-1. SYSTEM SPECIFICATIONS

Neutron output	10^{11} 14.3 mev neutron/sec
Lifetime	Minimum neutron yield 50% of initial yield after 200 hours operation.
Accelerator Assembly:	
Type	Positive ion
Source	Penning discharge ion source
Voltage	180 kv
Target current	4.0 ma
Beam focus	Fixed, approx. 5/8 inch diameter
Target type	Mixed deuterium & tritium (< 10 curies)
Target diameter	1-1/4 inch OD
Target location	1/8 inch from surface of housing
Control Unit, Electrical Requirements	115 vac at 30 amps, 60 Hz
Power Supply:	
Type	Multiple voltage doubler
Output	0-200 kv dc, 5.0 ma and 0-150 kv dc, 5.0 ma
Source voltage	0-10 kv dc, 20 ma
Cooling Unit:	
Type	Closed loop heat exchanger
Refrigerant	Freon 12 (gaseous)
Source cooling	Freon 113 (liquid)
Target cooling	Deionized water
Refrigeration unit, electrical reqmts.	230 vac, 22 amps, 60 Hz

DIMENSIONS

Accelerator Assembly	22 inches long x 10 in. diameter
Power Supply	72 inches long x 34 in. diameter
Cooling Unit	38 inches long x 27 in. wide x 32 in. high
Control Unit	18 inches high x 22 in. wide x 17 in. deep
Vehicle	15 feet long x 4.4 ft. wide x 4.3 ft. high

TABLE 2-1. (Cont'd)

Arm Length	4.9 feet
Cooling Unit	280 pounds
Control Unit	70 pounds
N-Ray Vehicle	4860 pounds
VEHICLE SPEED	
Under tow	0 to 5 mph
Self-Powered	0 to ~ 2 mph

3.0 SYSTEM EVALUATION

3.1 CHECK-OUT AND DEMONSTRATION

The detailed design and fabrication, Phases I and II, were completed on schedule in ten and eight months, respectively. Check-out of the system after fabrication revealed no malfunctions and was completed on schedule. Within two weeks after completion of fabrication of the system, a briefing and demonstration of the capabilities of the system was performed at the Vought facilities for Army, Navy, and Air Force personnel. Demonstration of the following capabilities were carried out for the Tri-Service Group:

1) System positioning for radiographing aircraft,
2) Wing bond flaw detection,
3) In-situ detection of corrosion in an F-8 aircraft, and
4) "Real time" filmless imaging, utilizing the Vought imager in conjunction with the AMMRC mobile neutron radiography source.

All of the above items were successfully demonstrated as planned.

3.2 SYSTEM CHARACTERIZATION

3.2.1 Neutron Output

The fast neutron (14 MeV) yield from the Kaman A-711 neutron generator is nominally 10^{11} n/cm^{2}-sec. In order to realize the full advantage of the compactness and suitable beam geometry of this type source for neutron radiography, the system is operated at its maximum continuous-duty rated output, which corresponds to the above mentioned yield value. Operating ion beam current in this mode is 4 ma at 180 KV. The relative thermal neutron output of the radiography system (after neutron moderation) was measured at various current and voltage levels below the maximum output. These measurements were made for exposure time reference purposes when the system is operated below maximum. Results of the measurements are shown in Figure 7.

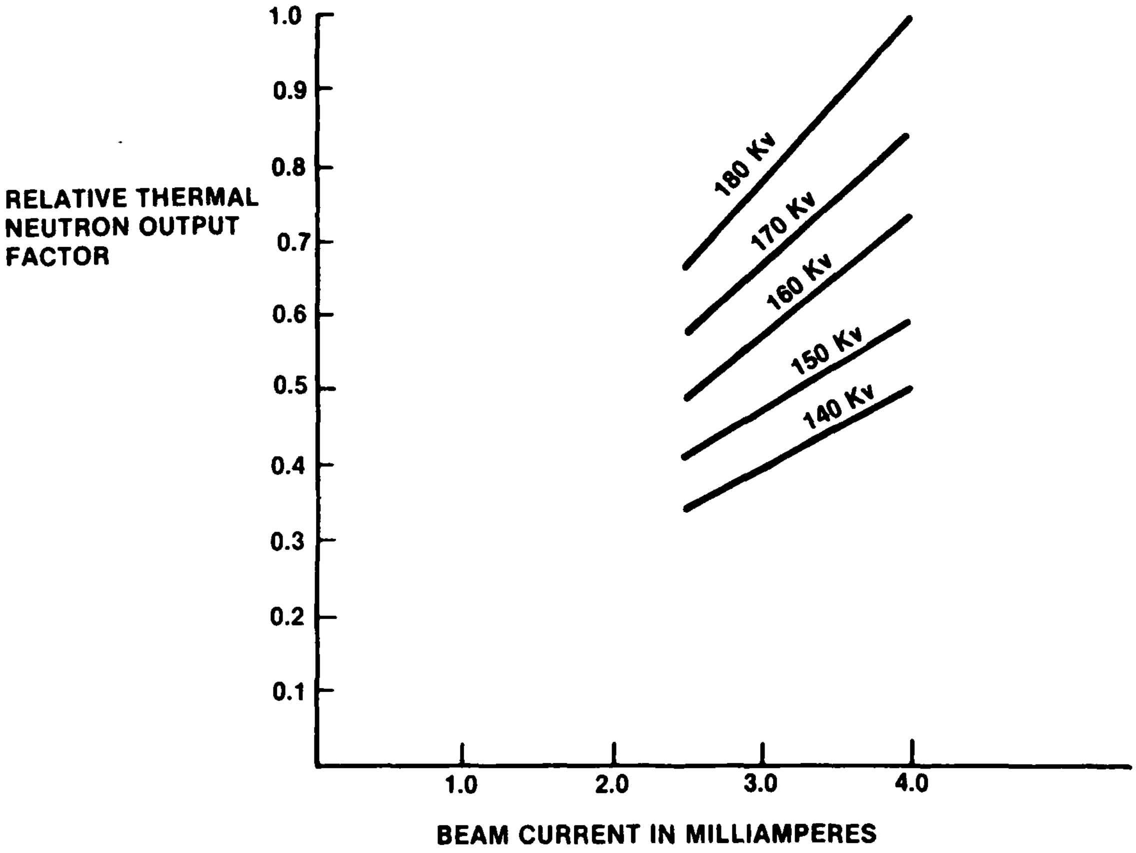


Figure 7. Relative Thermal Neutron Output as a Function of Accelerator Voltage and Ion Beam Current

The curves are based on readings from a Ludlum Model 42-5 scintillation detector, and represent cadmium difference (.080" Cd) readings.

Relative radiographic neutron output of the initial generator tube over its lifetime of 558 hours, as determined by a radiographic analysis, is shown in Figure 8. An analysis of the radiographs made over the lifetime of the tube indicates that after a rapid initial decrease during the first few hours, the output decreases slowly over the remainder of tube life. If full output at 100 percent is assigned after approximately three hours run-in period, the 50 percent level occurred at approximately 300 hours operation.

Measurements of thermal neutron flux from the collimator, at L/D=12 were made using a neutron detector. These measurements indicate that the flux from The collimator was 6.4×10^4 n/cm^2-sec at the three hour point and 2.3×10^4 n/cm-sec after 557 hours of operation.

3.2.2 Film/Screen Evaluation

A number of different types of converter screens and films were evaluated for application with the AMMRC neutron radiography system. When working with nonreactor mobile neutron radiography systems, the choice of appropriate film/screen combination becomes a critical one. The chief criterion is to achieve short-exposure radiographs of the best quality consistent with practical exposure times and image quality sufficient to see the defects on the radiograph. Converter screens investigated were:

1) Gadolinium foil
2) NE-425, 426
3) Gadolinium oxysulfide (Lanex)
4) Trimax -3
5) Vought's DC screens.

Films studied were:

1) M
2) AA

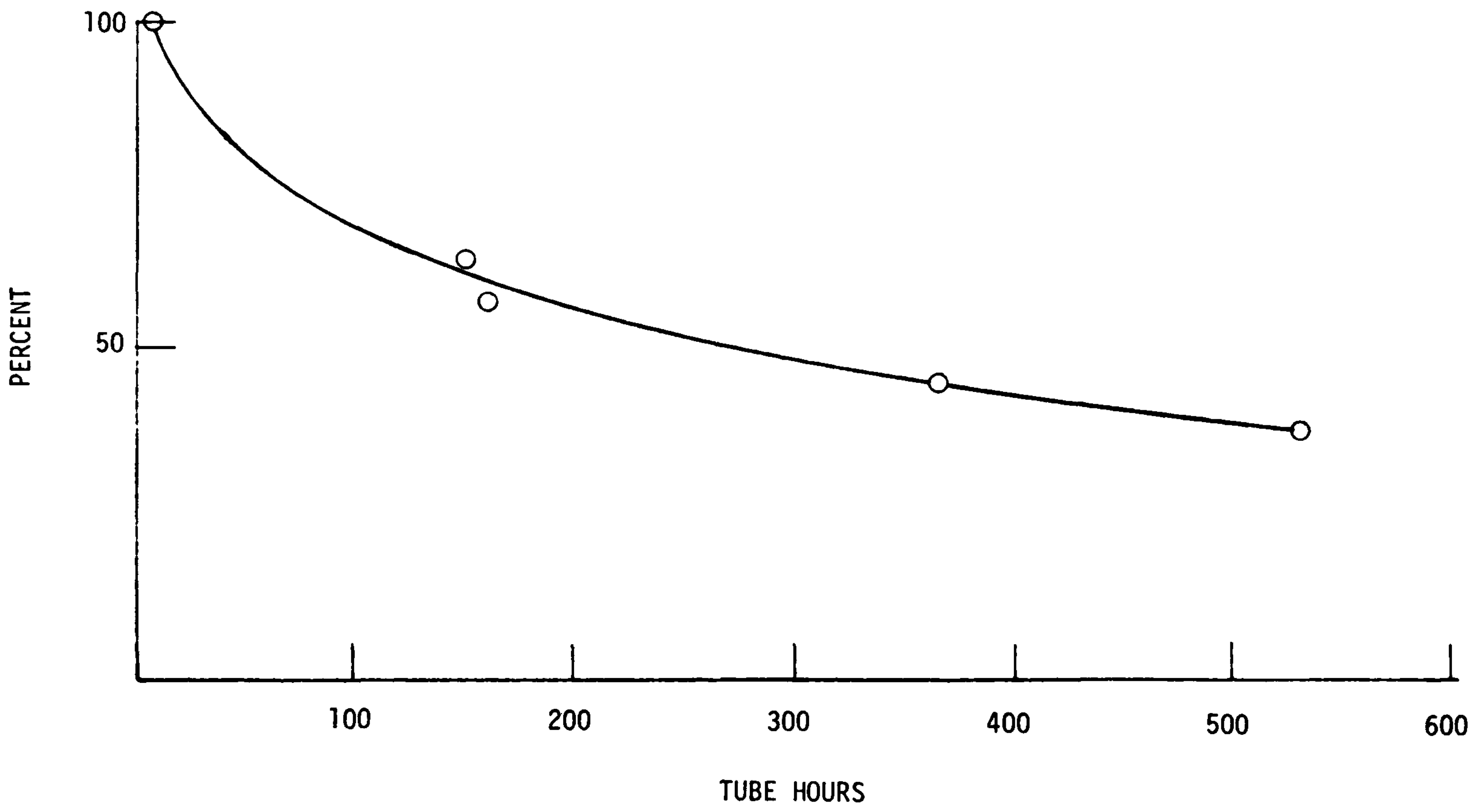


Figure 8. Relative Neutron Output Vs. Tube Hours for AMMRC Mobile N-ray System

3) T
4) SB
5) NDT 45
6) NDT 55
7) NDT 65
8) NDT 70
9) NDT 75
10) NDT 90

From analysis of the radiographic data the exposure times required for various converter/film combinations were calculated, and are shown in Figure 9 for L/D=12. It is seen that the fast combinations such as SB/Lanex and NDT 70/Vought DC offer substantial savings in exposure time over AA/Gd. Comparison of images from various combinations are given in Section 3.3.1.1, Reference Specimens.

3.2.3 Radiation Measurements and Shielding

During the initial conception of the sealed-tube based neutron radiography system, it was obvious that a beam of unwanted radiation, including primary high energy neutrons, would leak out through the cable end of the accelerator head, producing a substantial lobe in the radiation pattern around the system. This lobe was observed experimentally on Vought's in-house sealed-tube accelerator based neutron radiography system which was operational in early 1977. At that time, the leakage beam was also characterized by a film exposure of the beam. Consequently, throughout the evaluation phase, special care was taken during all operations to direct and point the leakage end of the accelerator (cable end) away from nearby shielding materials, and toward unoccupied open areas where possible, to reduce room scatter. During off-site field operations, additional operator shielding, additional shielding to block the leakage radiation, and distance separation were techniques employed to assure that personnel were clear of the neutron leakage beam.

Under a continuing Vought in-house R&D program utilizing the Vought sealed-tube accelerator radiography system, a unique accelerator head shielding system was conceived and incorporated into the Vought experimental radiography system. Before delivery of the AMMRC system, this type shield

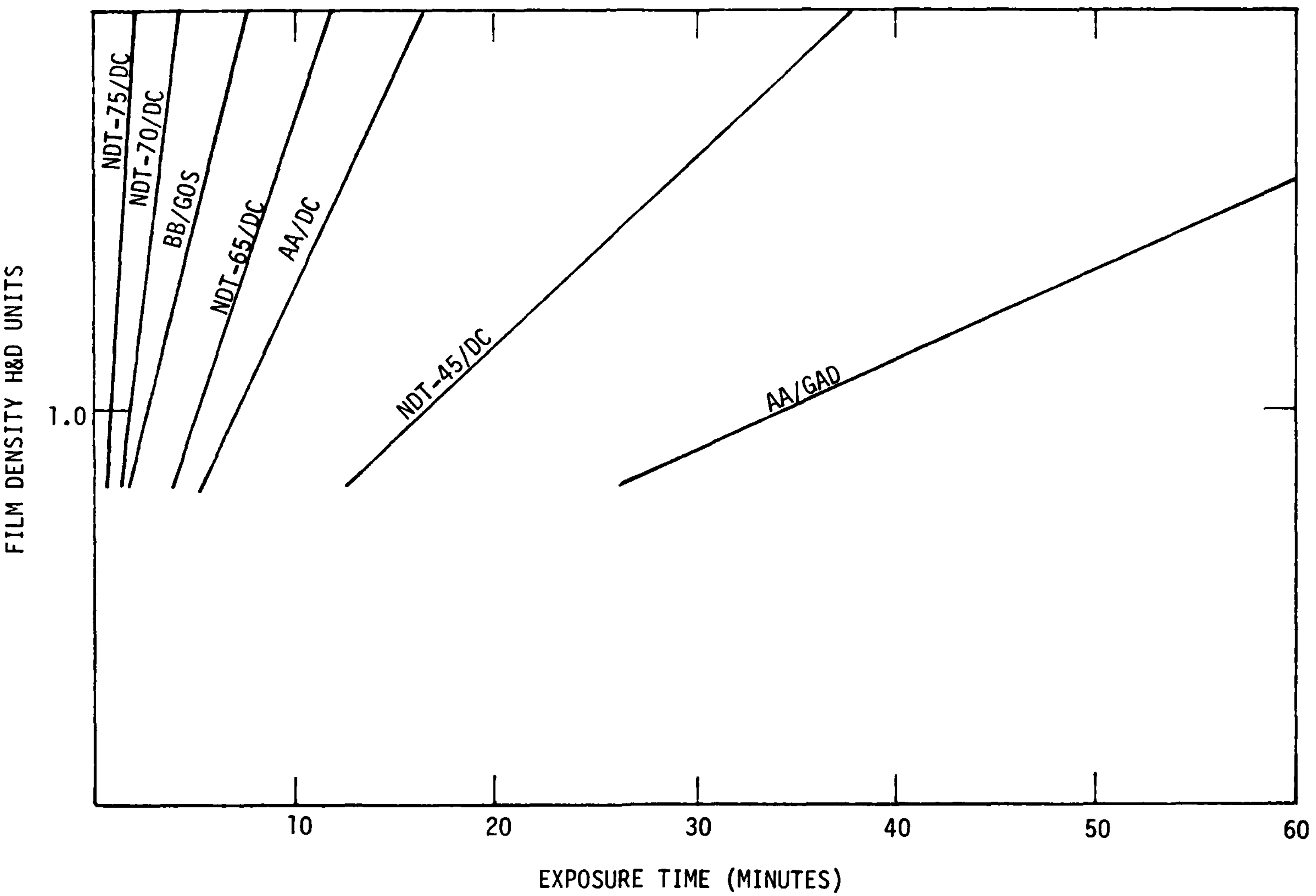


Figure 9. Typical Exposure Curves For AMMRC Mobile N-Ray System for L/D=12

system subsequently was also incorporated into the AMMRC system under an increase in scope.

The effectiveness of this shielding as measured on the beam tube axis at a distance of 20 feet from the moderator is shown by Figure 10. A Ludlum model 2200 count rate meter and a 42-5 detector, which utilizes a set of polyethylene moderator spheres, were used for the radiation measurements. The larger spheres are generally more sensitive to higher neutron energies. All measured radiation was reduced by the added shield by factors of 1.6 to 3.8, with the largest reductions measured with the largest "Bonner" sphere moderator. Although the shielding appears to be more effective for the higher energy neutrons, it is recognized that the higher energy neutrons are moderated to lower energies by the system moderator and shield; hence, the measurements are not contradictory, as the lower energy neutrons are reinforced by the moderated higher energy neutrons and thus do not exhibit as great a radiation reduction factor as those with higher energies.

Figure 11 graphically shows that measurements made at 0 and 90° to the beam tube axis are very similar for the shielded system; thus near optimum head shield performance is reached with this system. The unshielded data is included for reference.

In absolute terms, using the Vought head shielding technique the radiation dose rate as measured at 100' at both 0 and 90° to the accelerator tube axis in open air is 12 mrem of neutrons as measured with a Ludlum Model 12 with a 42-4 neutron detector, and 2 mrem of gammas as measured with Ludlum Model 5 and Victorean Model 440 survey instruments. Results of a radiation survey with the system in operation in the AMMRC laboratory are presented in Section 4.3.

3.2.4 System Reliability

The AMMRC neutron radiography system operated reliably throughout the program, after an early transformer failure in the high voltage power supply. Upon receipt of the neutron generator, it was noted that the normal operating parameters of 4.0 ma beam current at 180 kilovolts became increasingly

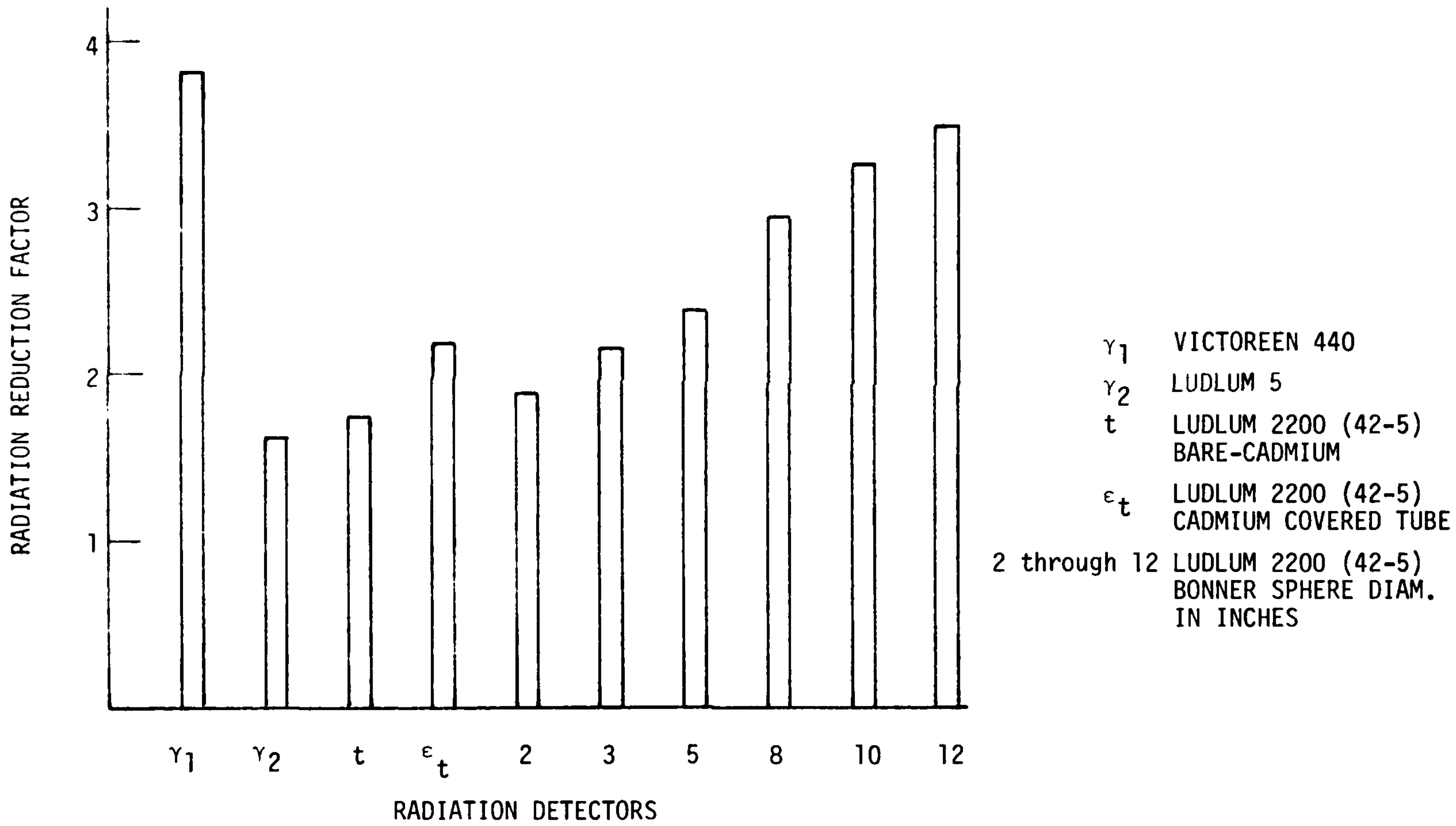


Figure 10. Accelerator Tube Shielding Effectiveness As Measured At 20 Feet on Beam Tube Axis

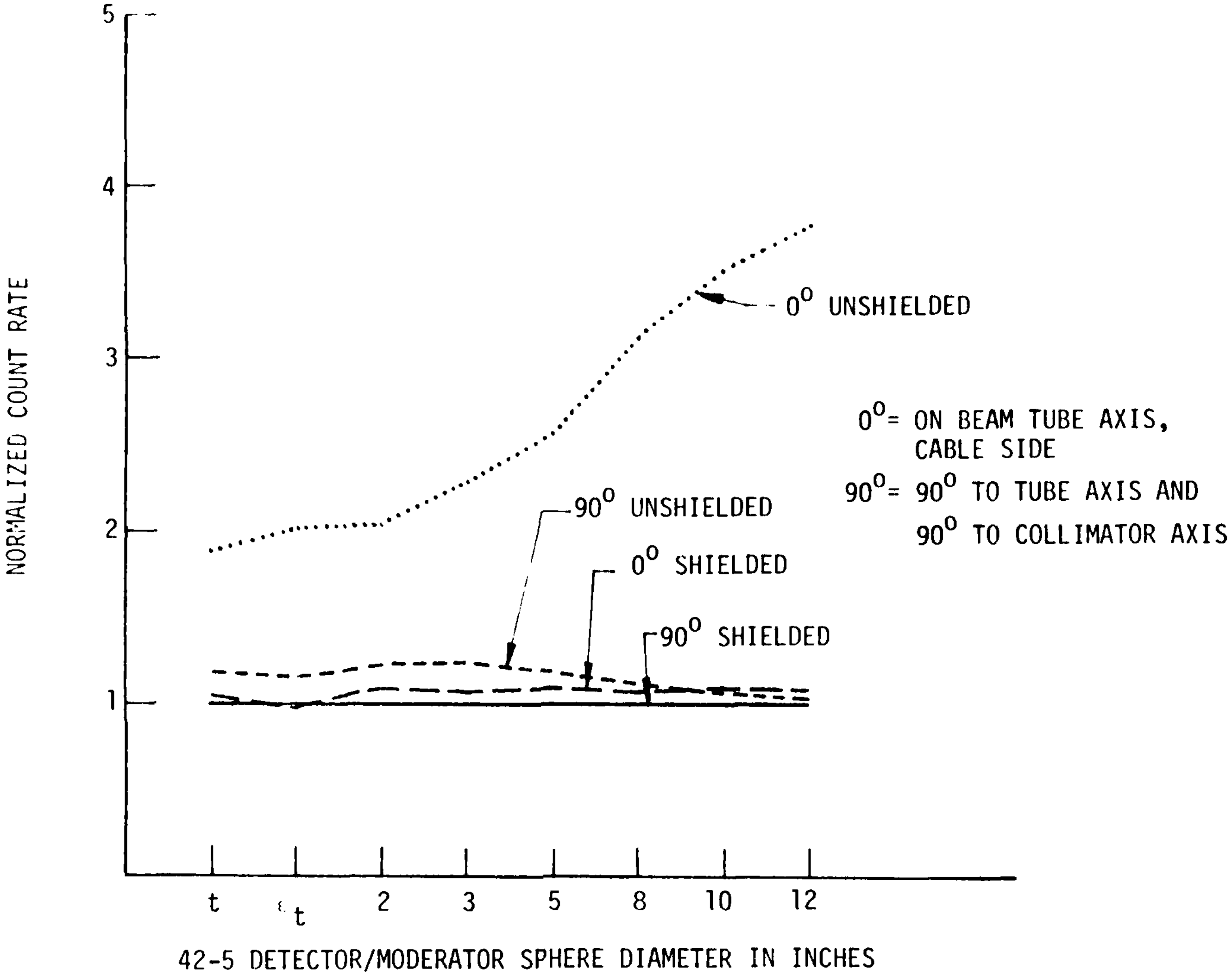


Figure 11. Accelerator Tube Neutron Shield Effectiveness on Beam Axis and at 90°, 20 Feet From Moderator Assembly

difficult to attain. After the defective power transformer was replaced, operation was completely normal. No other major failures occurred.

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 degrees F. During the six week period, only two malfunctions occurred, which were considered to be normal wear and were not attributed to the non-laboratory environment. The first failure occurred 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 degrees 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 reliably through the remainder of the operations.

The original neutron generator tube, with guaranteed output of at least 50 percent for 200 hours, operated for 560 hours. The output just prior to failure was approximately 40 percent of its original output.

3.2.5 Environmental

Although specifically designed for a laboratory environment, utilization of the system in a remote outdoor area was demonstrated at Vought. At the Yuma Proving Ground, operations were partially outdoors, and at the Sacramento Air Logistics Center the work was performed in a maintenance hangar.

System limitations at temperature extremes are essentially those of the neutron generator assembly. Operating range of the generator is specified by the manufacturer as 55°F to 85°F. An independent assessment of the upper temperature limit was made in an instrumented, controlled test performed on an A711 generator identical to the delivered system. Steady state operation at an acceleration voltage of 180 KV and a beam current of 4 ma was achieved at an ambient temperature of 90°F. Thus, the generator, as purchased, is capable of running continuously at this temperature without anomalous or detrimental effects.

System operation at 95° in Sacramento was achieved by directing an auxiliary fan at the cooling unit, preventing local accumulation of heat around the cooling unit. Damage to the neutron generator, if operated at excessive temperature, is prevented by a group of six temperature, flow rate, and pressure switches which are interlocked through the control console. A "low" indication on any of these operating parameters prevents system initialization and operation, and can also abort operation.

3.3 RADIOGRAPHY OPERATIONS

A substantial portion of the evaluation or validation testing phase (Phase III) of the program was dedicated to performing neutron radiographic inspection on a variety of structures and components. Many of these radiographs were made to assess the applicability of this type system for inspecting specific items on current and anticipated DoD programs. Another significant portion of this effort was devoted to radiography of a set of reference specimens, utilizing various different converter screen/film combinations and varying other operational parameters, for evaluation of source and imaging components and for determining the optimum technique for utilization of such a system.

Approximately 700 neutron radiographs were run during the evaluation program, utilizing a variety of different converter/film combinations. X-ray radiography was also performed on many of the specimens to compare the applicability of the two types of radiography. In addition, the ability of the system to generate filmless, near real time images with an electronic imaging system was evaluated. For this evaluation, the low flux neutron imager developed by Vought was utilized.

As part of the evaluation phase (Phase III) of the program, field radiography operations were carried out at two military installations. A four week operation on-site at the Sacramento Air Logistics Center (SM-ALC) McClellan Air Force Base, was carried out. The purpose of this operation was to evaluate the applicability of such a system for detection of corrosion and moisture in aircraft structures during rework, and the potential for adapting this type system for production purposes in a depot environment. A six-week operation at U.S. Army Yuma Proving Ground (USAYPG) was carried out to assess the applicability of neutron radiography to the non-destructive inspection of specific ordnance devices and to provide USAYPG radiography personnel with "hands-on" experience in utilizing the technique. A summary description of these operations with representative radiographic results follow in paragraphs 3.3.2.1 and 3.3.2.2. Detailed reports covering the work are given in References (1) and (2), respectively.

3.3.1 Vought Laboratories

3.3.1.1 Reference Specimens

Early in the evaluation program, reference plates of specimens were assembled which included:

(a) 4" x 4" x 3/4" aluminum honeycomb panel containing corroded areas, provided by the Air Force (AFWAL)

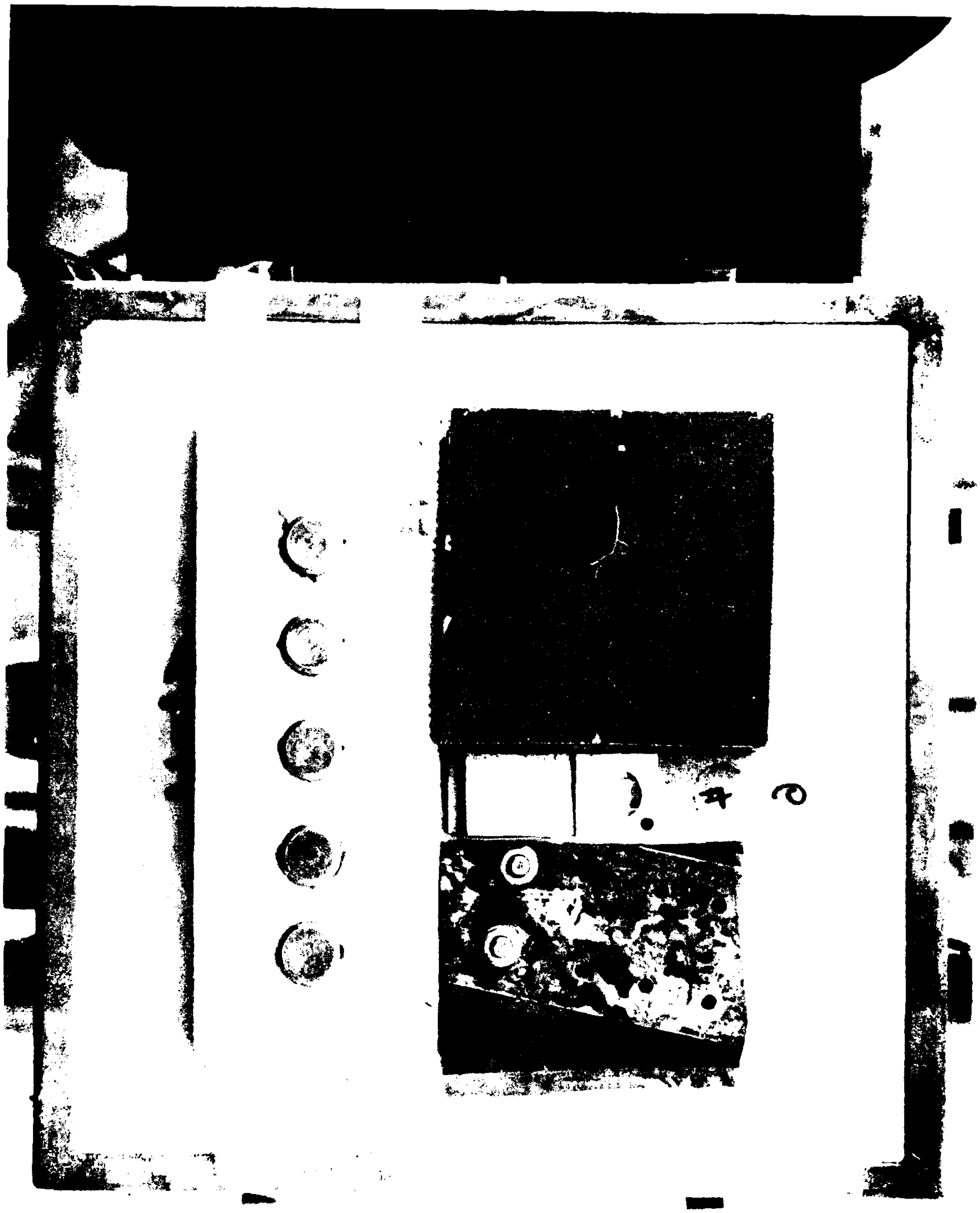
(b) 3" x 8" x 1/2" aluminum honeycomb helicopter panel with multiple adhesively bonded steel tie-down inserts, bonded with various levels of adhesive deficiency provided by Bell Helicopter Corporation.

(c) 3" x 3-3/4" x 1/4" aluminum aircraft structural joint in which a significant quantity of intergranular corrosion is present in the immediate vicinity of fastener holes, provided by the Navy (Naval Air Rework Facility/North Island).

(d) 2 1/2" x 8 1/2" x 3/8" adhesively bonded tapered aluminum honeycomb aircraft panel (Vought).

(e) ASTM image quality indicators.

The photograph of Figure 12 shows a group of these specimens and how they were typically mounted for radiography. The radiographs presented in this



[illegible] 12. Photograph of Reference Specimens Mounted for Radiography report, with the exception of those in Section 3.3.2.2.3, are positive prints produced from the radiograph negatives and reproduced for report copies.

Figures 13X and 13N are X and N radiographs, respectively, of a reference plate with specimens (a), (b), (c) and (e) described above. In the x-ray, corrosion is barely visible in the honeycomb specimen a and not at all around the fastener holes of specimen (c). Also in the x-ray, the adhesive which bonds the steel inserts in specimen (b) is visible only in areas when excess adhesive protrudes outside the diameter of the inserts.

The neutron radiograph, on the other hand, images with good contrast the corrosion in specimens (a) and (c) and the adhesive behind the heads of the steel inserts in specimen (b).

The reference specimens described above were used in a series of radiographs for a comparison of images from various converter/film combinations. Neutron radiographic results from some of the combinations are shown in Figures 14 through 20, which follow:

Figure 14N. Reference specimens (c), (d), and (e). Converter/film - Vought DC/M; Exposure time - 45 min.; L/D=13

Figure 15N. Reference specimens (c), (d), and (e). Converter/film - Lanex F/SB; Exposure time - 20 min.; L/D=13

Figure 16N. Reference specimens (a), (b), (c), and (e). Converter/film - Vought DC/NDT 45; Exposure time - 40 min., L/D=13

Figure 17N. Reference specimens (a), (b), (c), and (e). Converter/film - Vought DC/NDT 55; Exposure time - 50 min.; L/D=13.

Figure 18N. Reference specimens (a), (b), (c), and (e). Converter/film - Vought DC/NDT 65; Exposure time - 20 min.; L/D=13

Figure 19N. Reference specimens (a), (b), (c), and (e). Converter/film - Vought DC/NDT 65; Exposure time - 10 min.; L/D =13

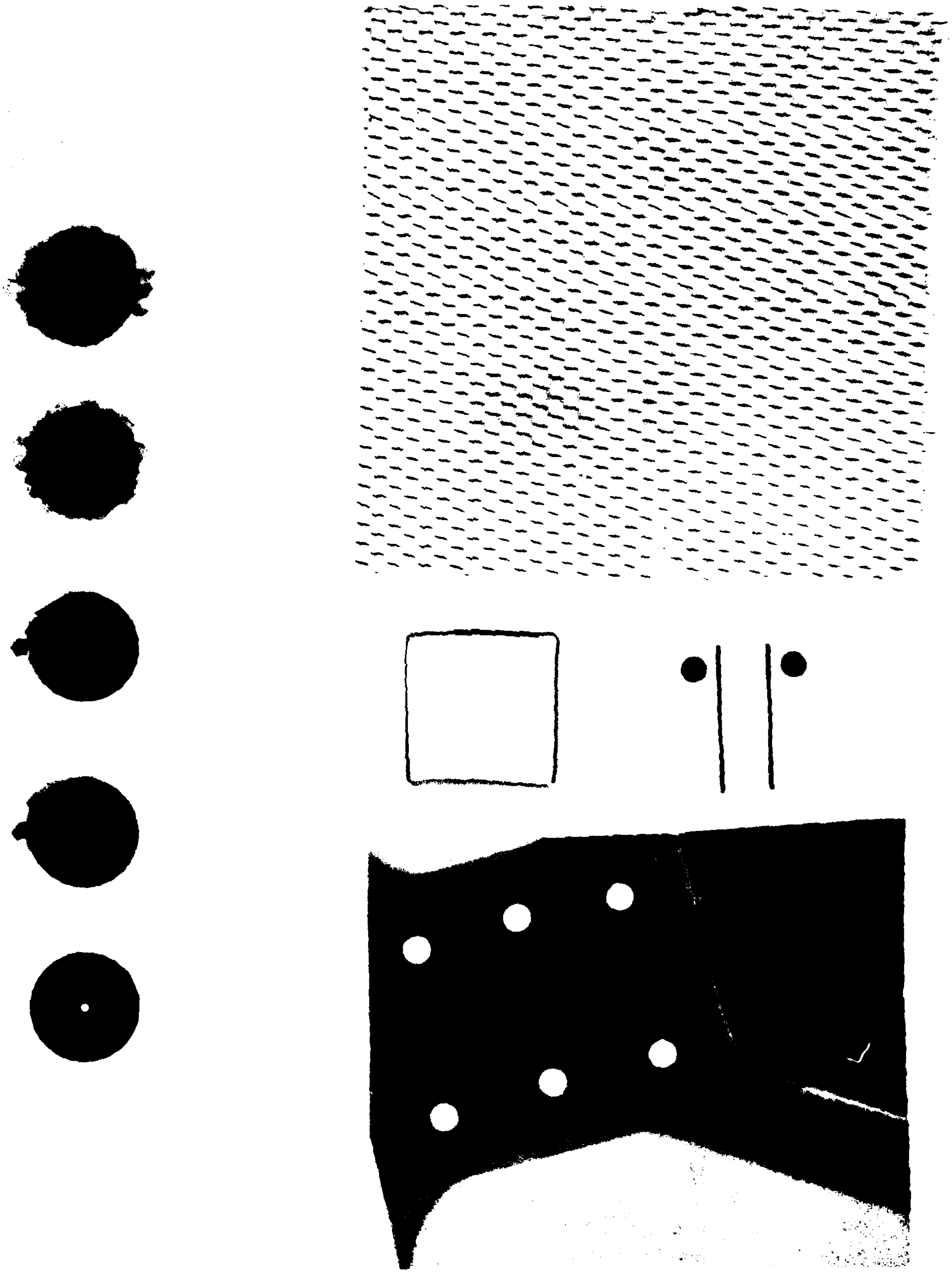


Figure 13X. X-Ray Radiograph of Reference Plate with Specimens (a), (b), (c), (e)

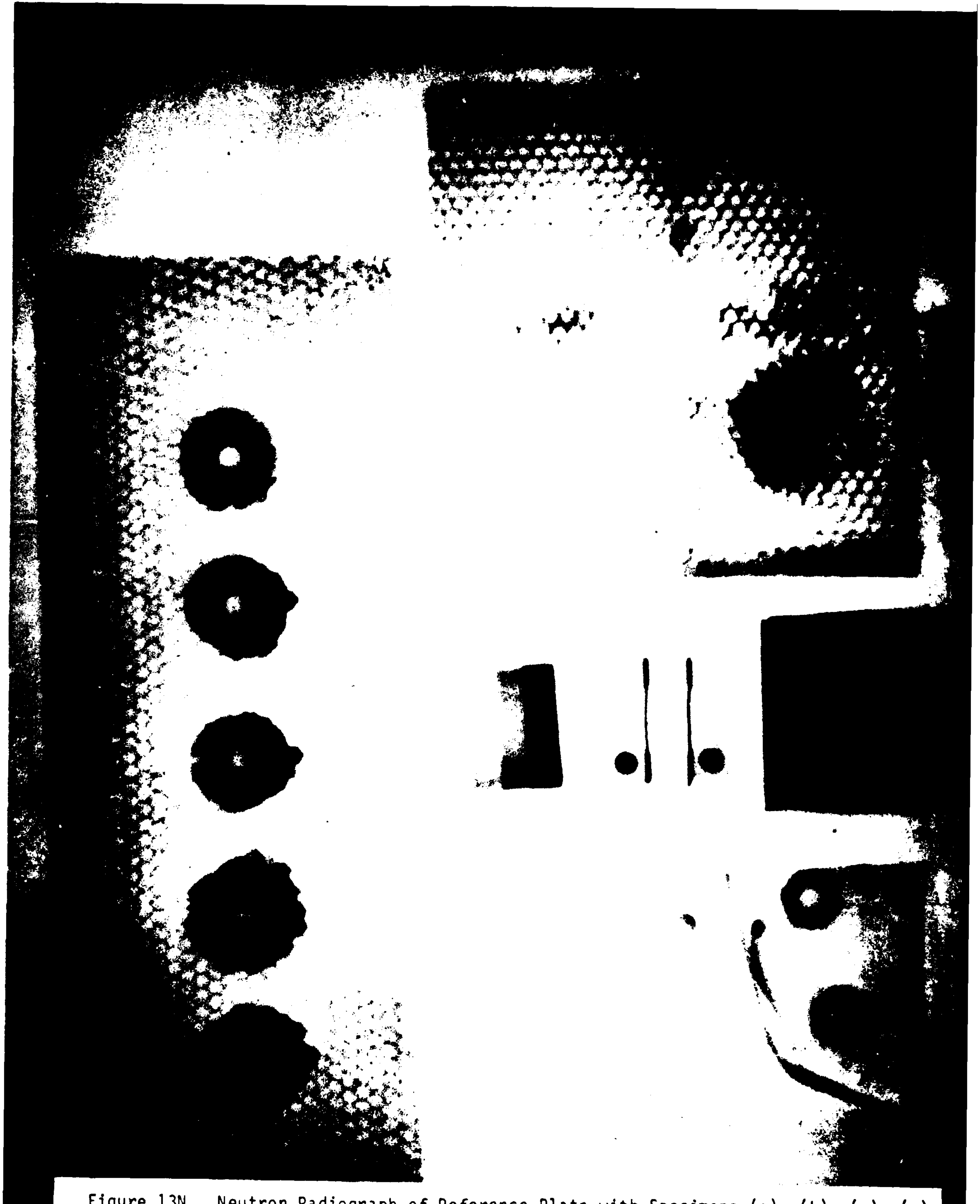


Figure 13N. Neutron Radiograph of Reference Plate with Specimens (a), (b), (c), (e)

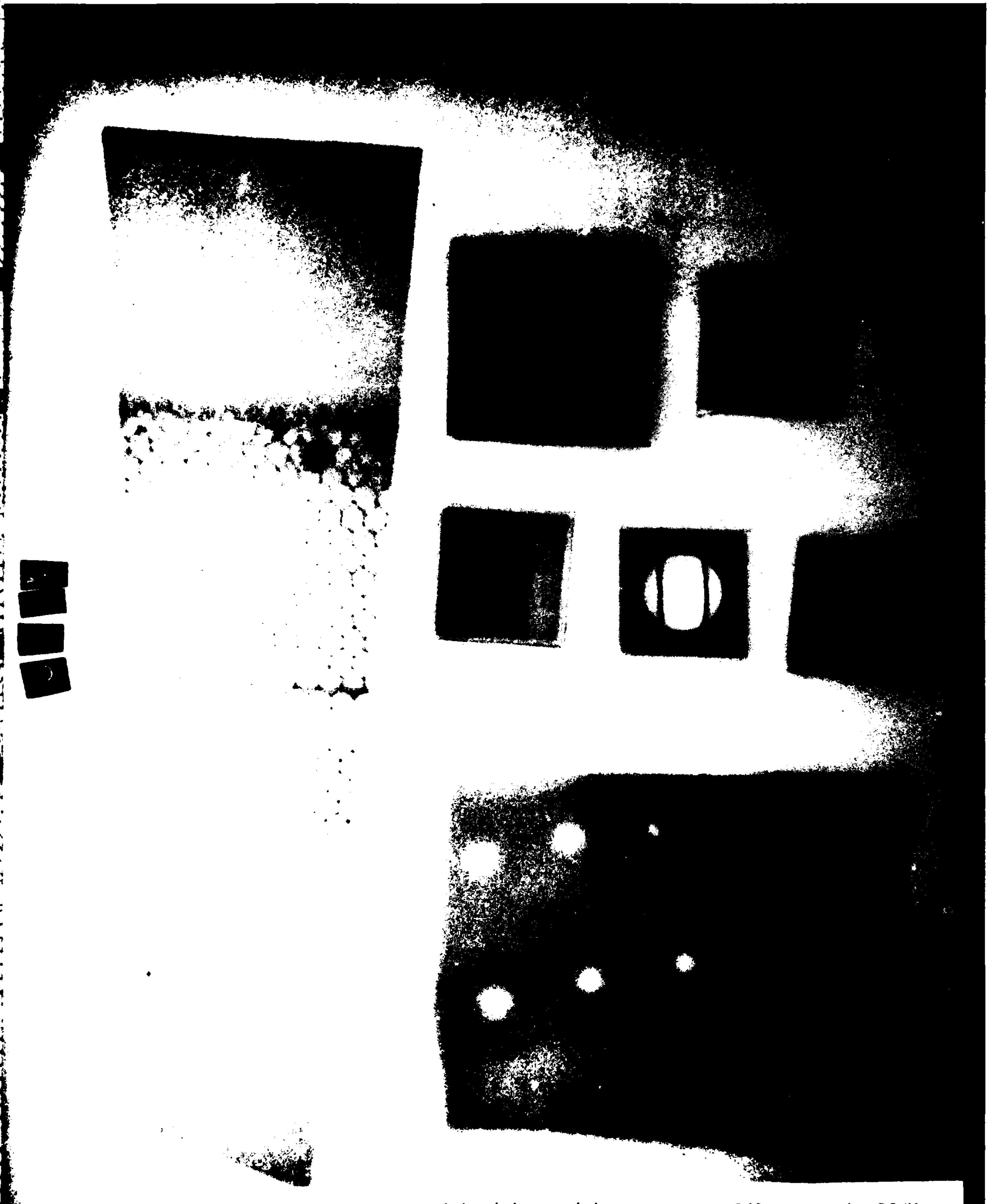


Figure 14N. Reference Specimens (c), (d) and (e). Converter/Film - Vought DC/M; Exposure Time - 45 Min.; L/D = 13

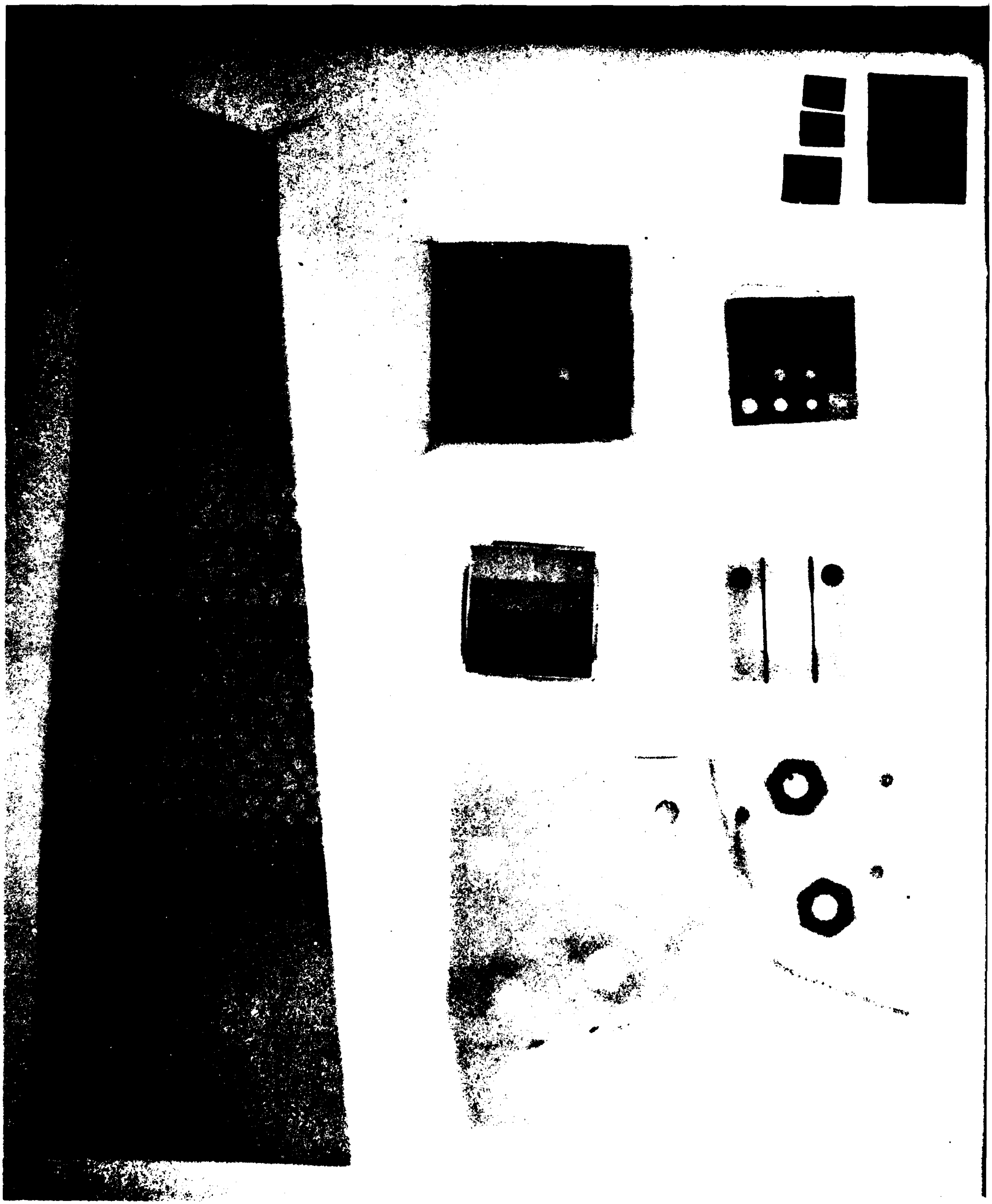


Figure 15N. Reference Specimens (c), (d) and (e). Converter/Film - Lanex F/SB; Exposure Time ~ 20 Min.; L/D = 13

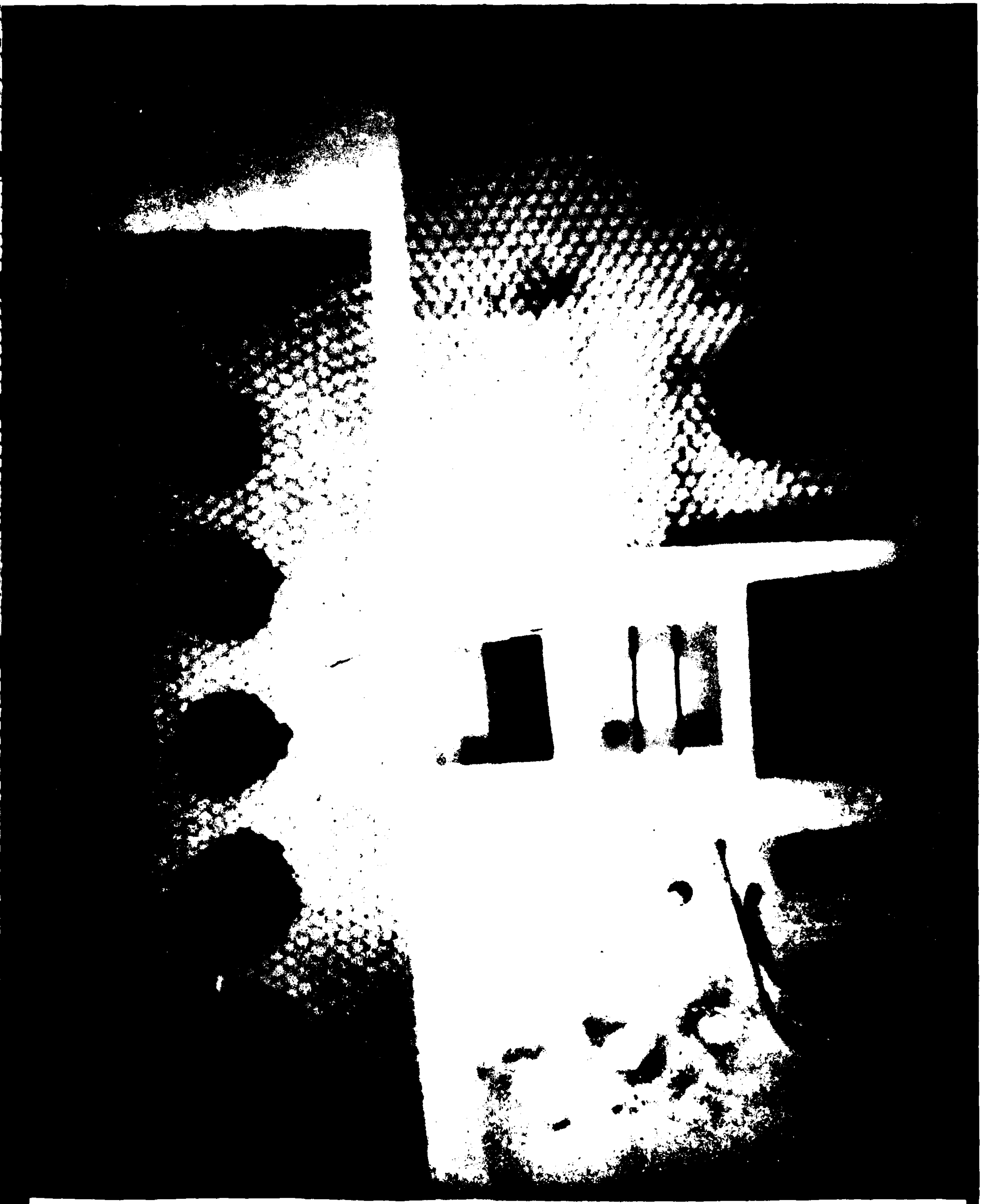


Figure 16N. Reference Specimens (a), (b), (c) and (e). Converter/Film - Vought DC/NDT 45; Exposure Time - 40 Min., L/D = 13

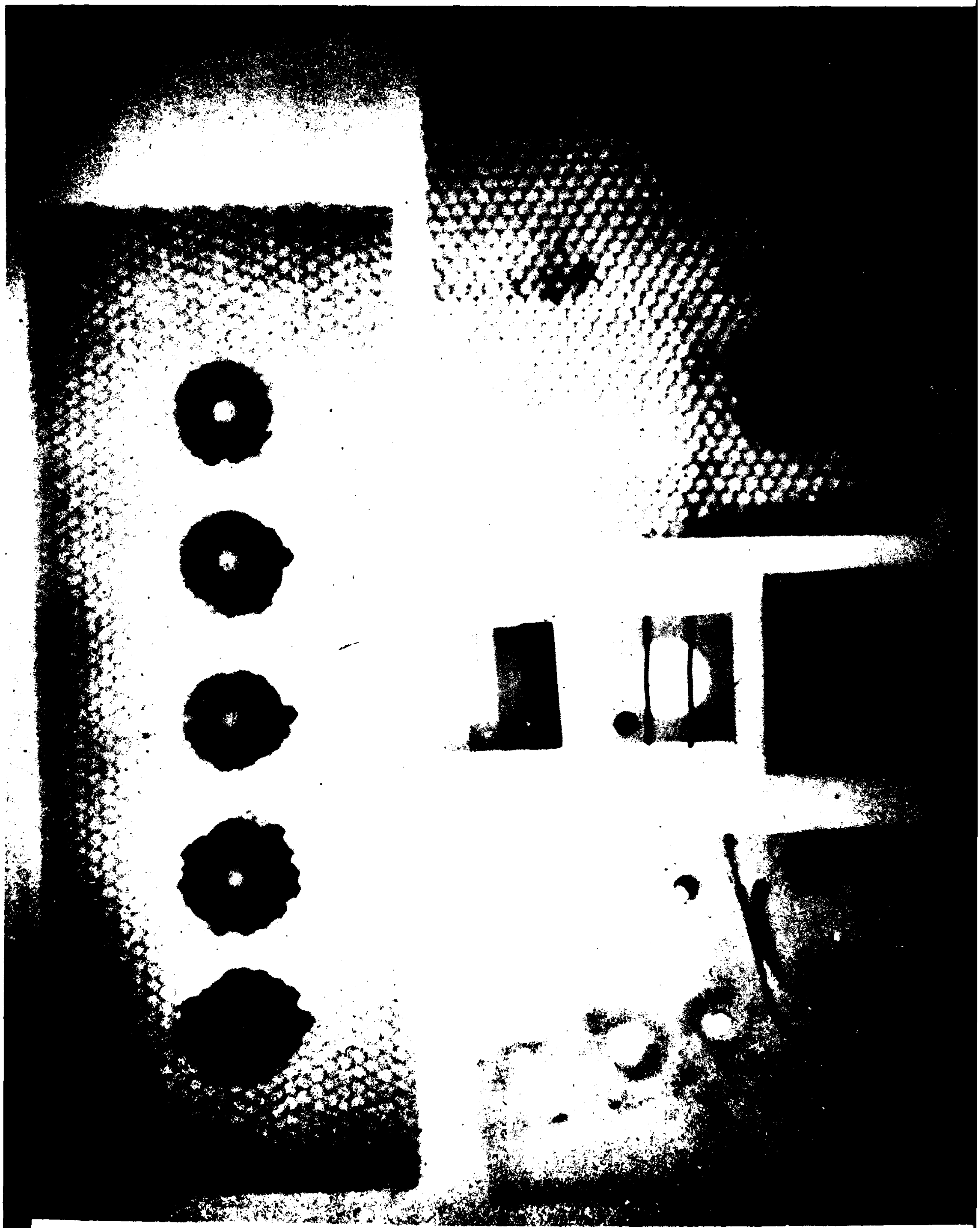


Figure 17N. Reference Specimens (a), (b), (c) and (e). Converter/Film - Vought DC/NDT 55; Exposure Time - 50 Min.; L/D = 13

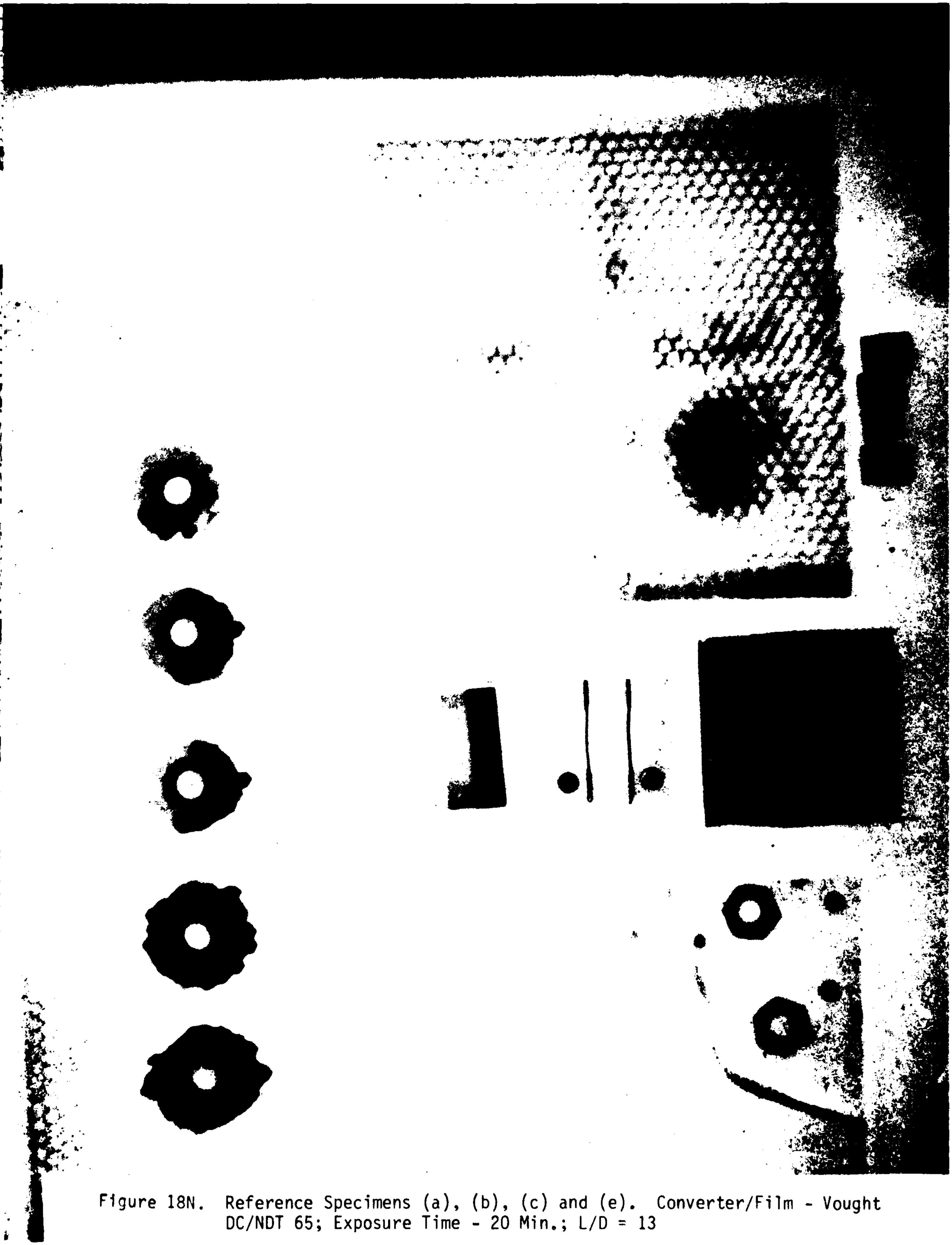


Figure 18N. Reference Specimens (a), (b), (c) and (e). Converter/Film - Vought DC/NDT 65; Exposure Time - 20 Min.; L/D = 13

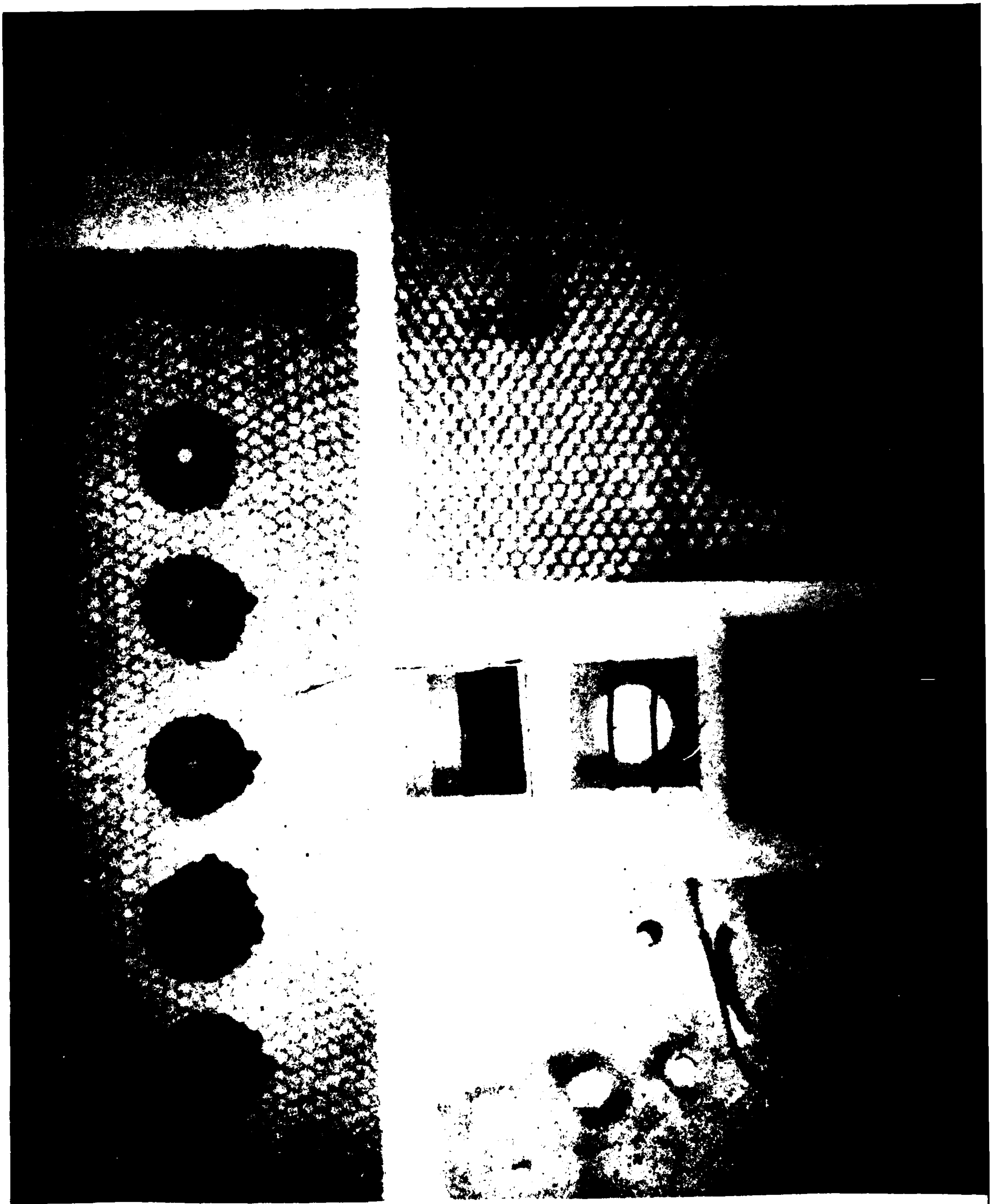


Figure 19N. Reference Specimens (a), (b), (c) and (e). Converter/Film - Vought DC/NDT 65; Exposure Time - 10 Min.; L/D = 13

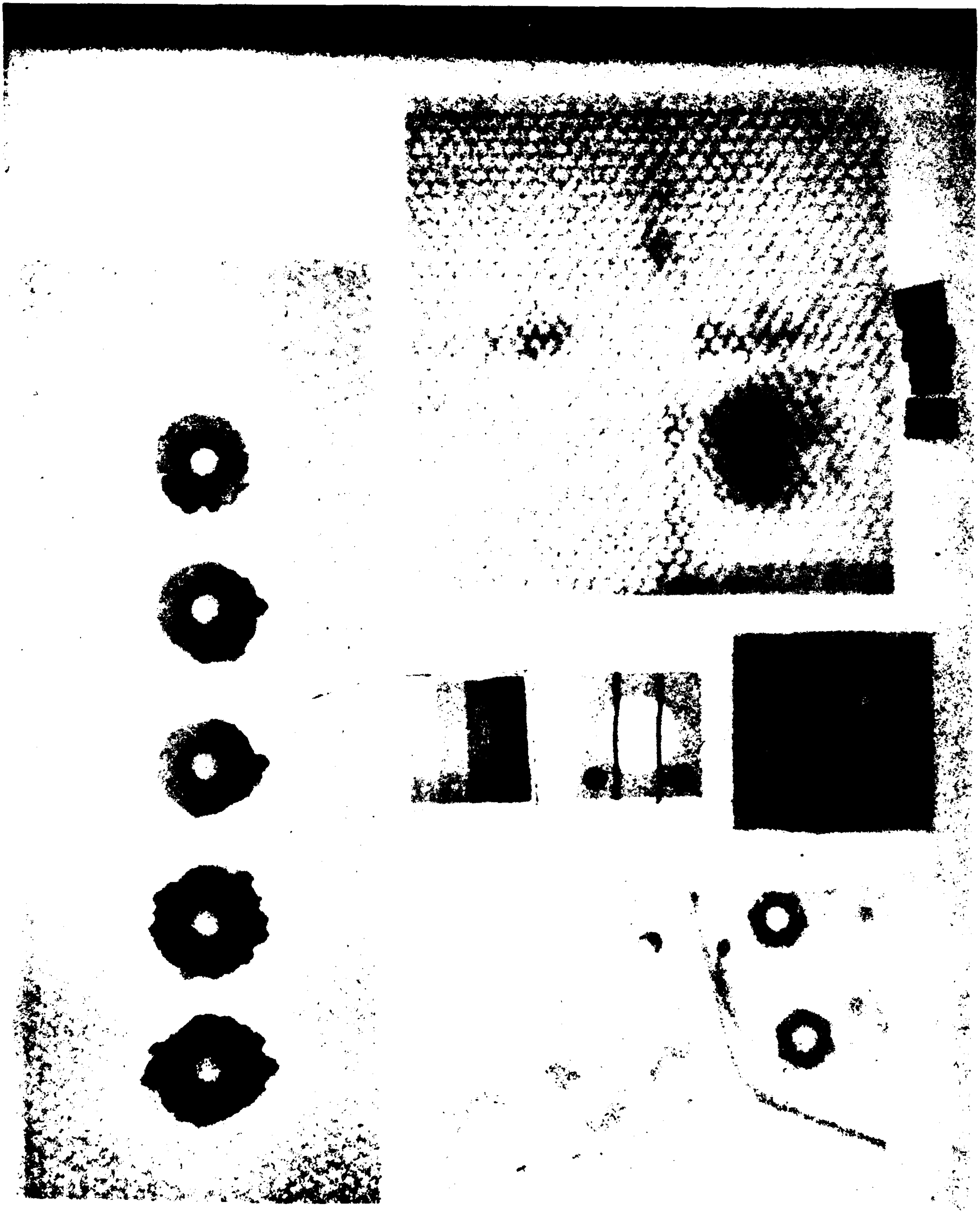
Figure 20N. Reference specimens (a), (b), (c), and (e). Converter/film - Vought DC/NDT 75; Exposure time - 2.5 min.; L/D=13

3.3.1.2 Bell Helicopter Specimens

In order to evaluate the effectiveness of the mobile neutron radiography system for inspection of Army helicopter structures, Vought enlisted the support of Bell Helicopter Corporation NDE personnel in providing additional appropriate radiographic test specimens. In addition to a number of helicopter NDT specimens on hand in the Bell NDE labs, two large sections of helicopter rotor blades were provided by Bell, modified for this program to include built-in flaws as specified by Vought. One of these blade sections was from a metal blade, near the root end, having a chord of 27 in. The other large blade section was cut from a composite blade having a chord of approximately 18 inches. Built into these blade sections were adhesive voids and internal damage in various areas.

The metal blade specimen is shown in the photograph of Figure 21. In one area on the heavy metal blade at the lower edge, to the immediate right of center in the photo, a special bonding material developed by Vought in an earlier in-house program was utilized. The Vought technique enhances the neutron radiographic contrast when imaging bondline flaws in thick metallic or composite specimens. The radiographs presented in this section provide neutron images of portions of these blade sections and of various other helicopter specimens provided by Bell for this study. As will be seen, both built-in and accidential bond flaws are present and detected in some of the radiographs.

Figure 22N is a neutron radiograph of the trailing edge of the metal blade (right edge in photo, just below center) showing lack of bonding material at skin close-out (lower left in radiograph). Figure 23N is the neutron image of a section of the leading edge/blade spar. In the upper left of the radiograph, a large built-in bond void is clearly imaged, in addition to several small accidental voids near the center of the radiograph. The inset photo shows the collimator/specimen geometry used for this exposure. Figure 24N shows large areas of adhesive porosity near the leading edge at the opposite end of the blade section (see inset). A neutron radiograph and an



Reference Specimens (a), (b), (c) and (e). Converter [illegible]
[illegible] NDT 75; Exposure Time - 2.5 Min.; L/D - 13

Figure 21. Metal Rotor Blade Specimen Provided by Bell Helicopter Corporation

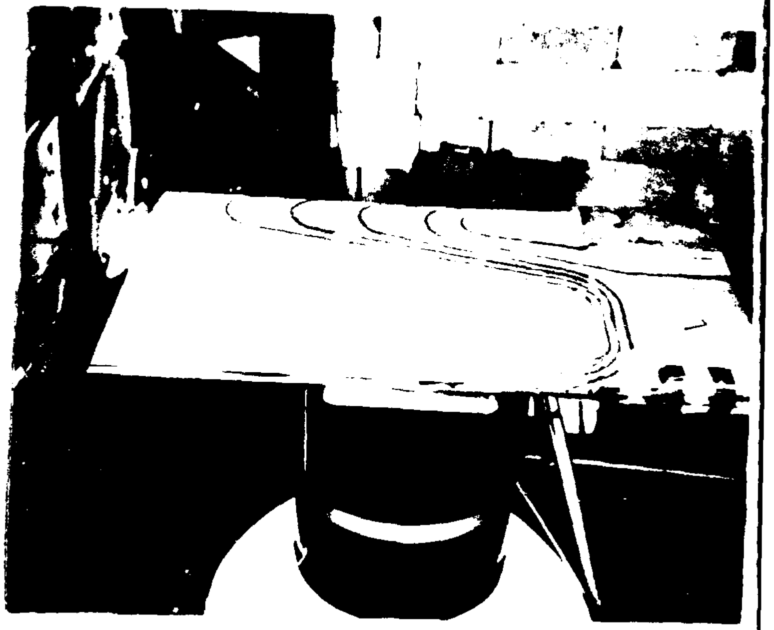


Figure 22N. Neutron Radiograph of Metal Rotor Blade Trailing Edge

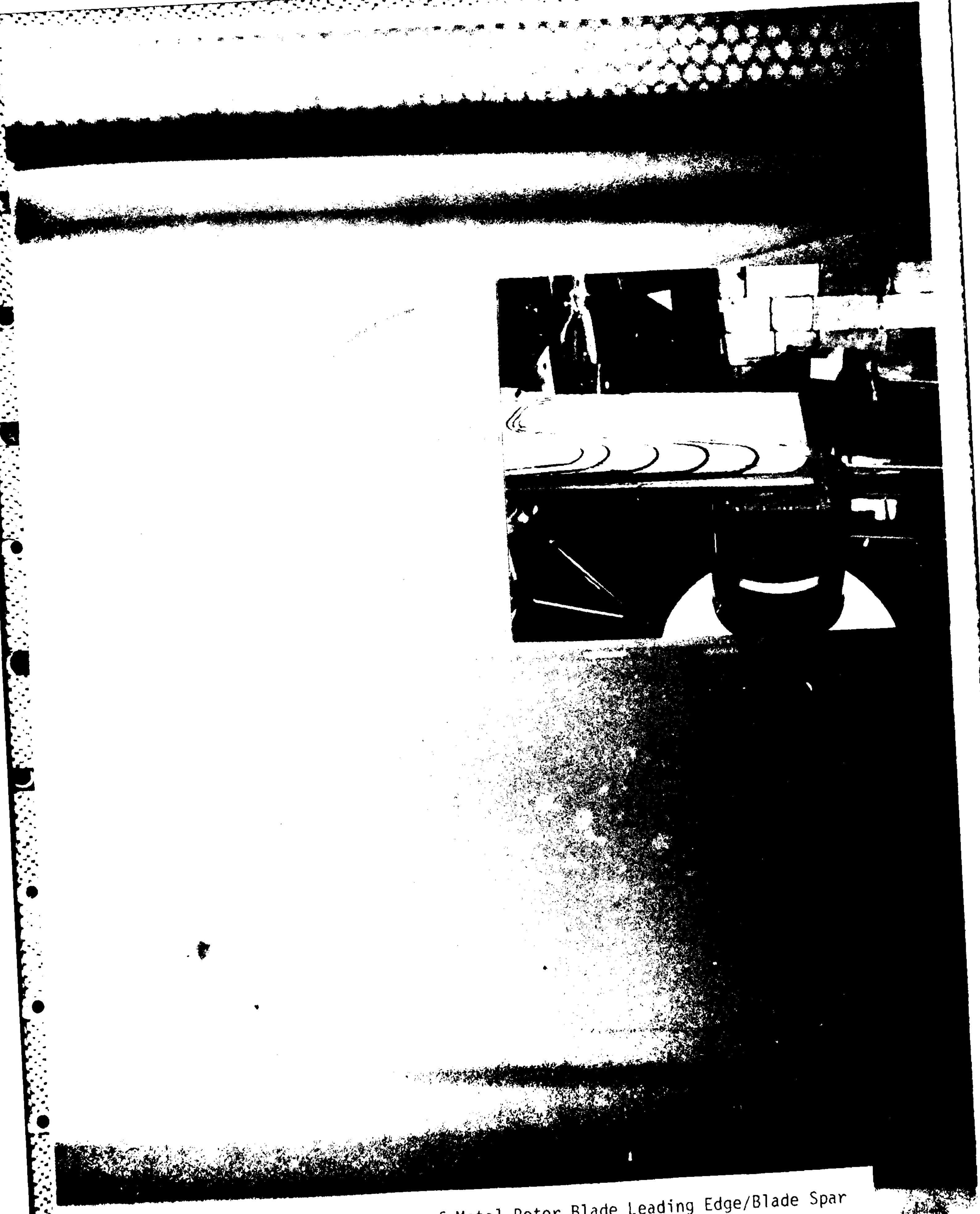


Figure 23N. Neutron Image of Metal Rotor Blade Leading Edge/Blade Spar

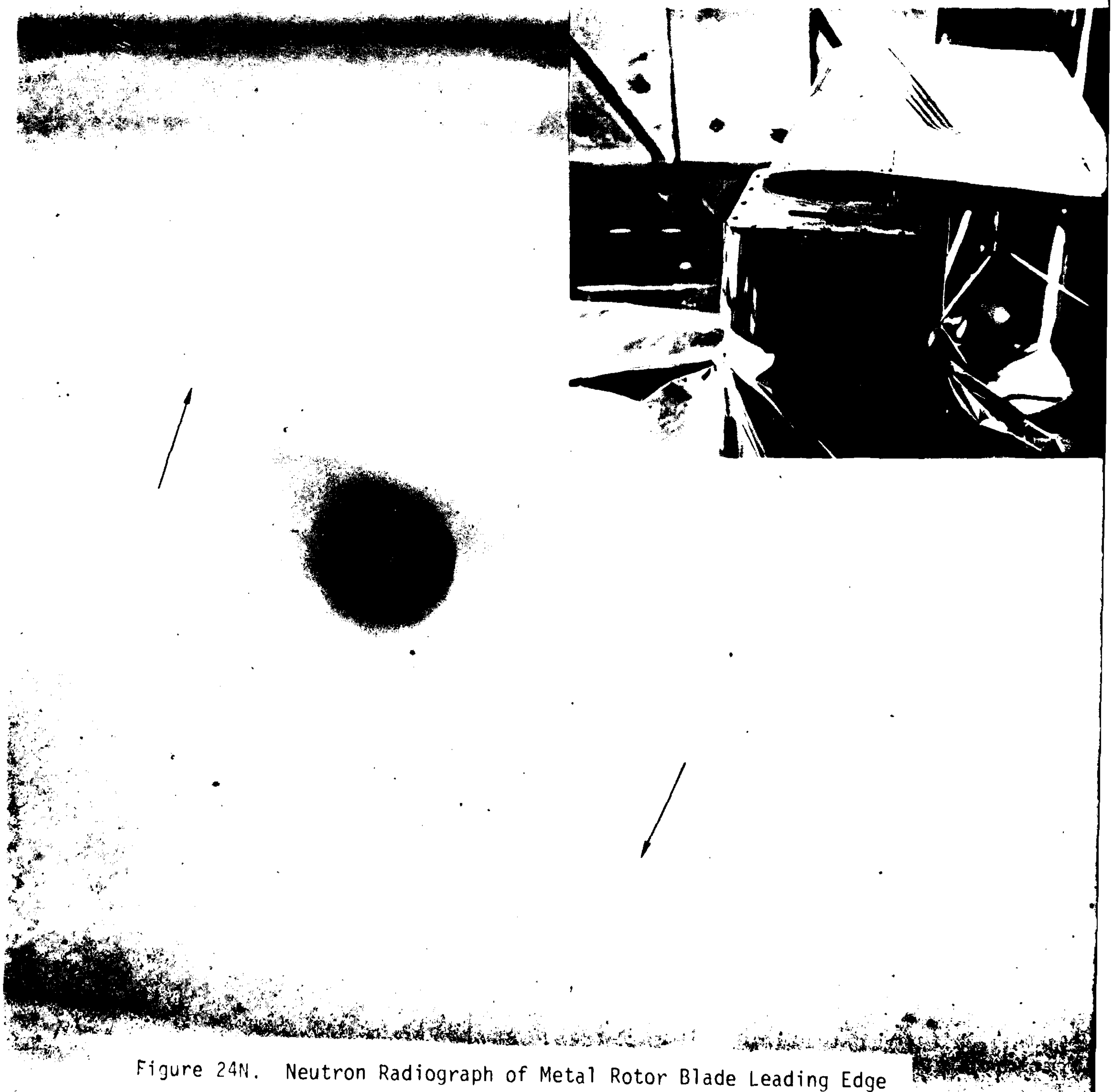


Figure 24N. Neutron Radiograph of Metal Rotor Blade Leading Edge x-ray of the area in which the Vought contrast enhancement technique was used are given in Figures 25N and 25X, respectively. The circular and square images are "built-in" adhesive voids, and the long finger-like areas near the center are accidental ones. The many small (~ 1 mm) light spots are small voids or deficiencies in the amount of adhesive which often occur after cure of film adhesive, and which are associated with, and follow the pattern of, the carrier cloth or grid. In the x-ray, only faint images of these defects are present, and the image of the metal honeycomb and skin, with its stepped thicknesses (upper end of radiograph) predominate.

The next two radiographs resulted from neutron exposures of a composite rotor blade section, shown in the photograph of Figure 26. Figure 27N is a neutron radiograph of a section which includes the trailing edge. Adhesive voids are imaged in the core-to-skin close-out bond (noted by arrows). The radiograph of an adjacent section, Figure 28N, images three defects which are intentional unbonds created by local machining of the core in those areas (noted by arrows) prior to blade assembly. In addition, in the uppermost of the three areas, a resin-rich area (dark portion) created by a local pooling of resin is clearly imaged.

Figures 29N and 29X are neutron and x-ray radiographs, respectively, of another metal rotor blade section. The section shown includes the trailing edge skin-to-honeycomb close-out. This critical bond area is often a particularly troublesome one in the fabrication process, due to the frequent "worm-hole" voids in the bond. Such voids are clearly depicted at the edge of the honeycomb near the top of the neutron radiograph, whereas in the x-ray, the voids are only faintly visible and are subject to being overlooked in the course of routine radiographic inspection.

The next pair of radiographs (Figures 30N and 30X) is a comparison of n- and x-ray for imaging water in honeycomb structures. The series of spots are images of water droplets confined to single core cells, in various amounts, and at various depths in the honeycomb. In the upper right portion, it is seen that the quantity of water decreases as the filled cells progress toward the upper right hand corner. It is seen also that the neutron radiograph has greater contrast sensitivity for imaging water droplets than the X-ray. Also, from the neutron radiograph the relative depth of the warer drops in the panel

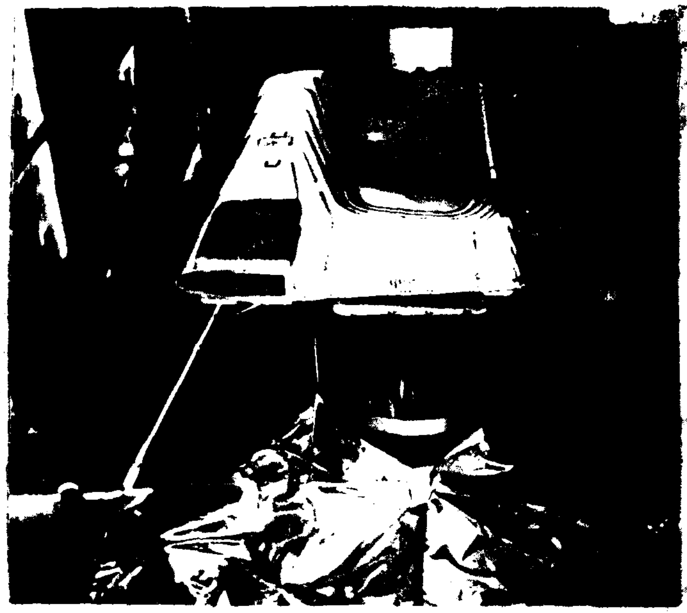


Figure 25N. Neutron Radiograph of Metal Rotor Blade Section with [illegible] Contrast Enhancer and Built-In Flaws

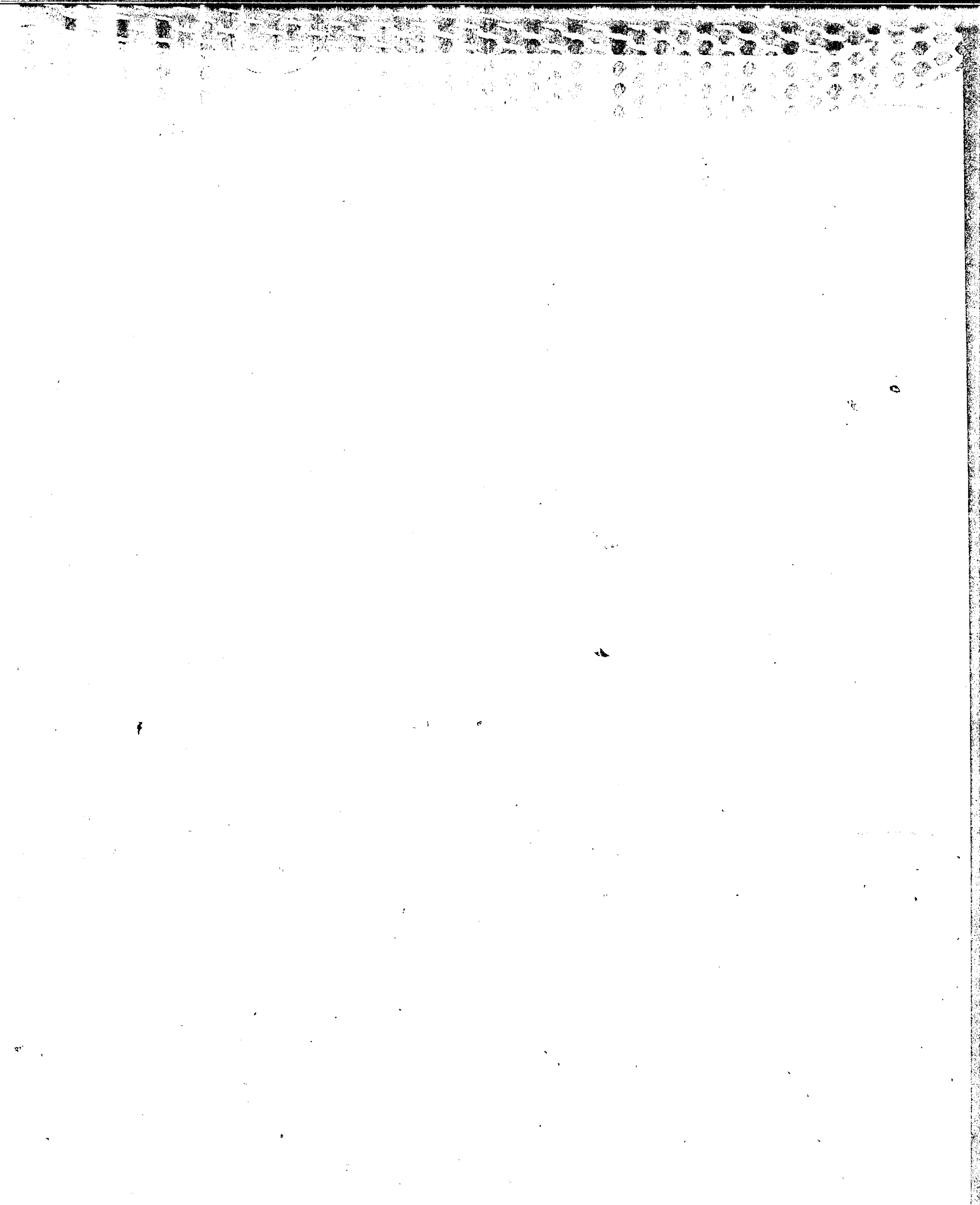


Figure 2[illegible]X. X-Ray Radiograph of Metal Rotor Blade Section with Adhesive Contrast Enhancer and Built-In Flaws

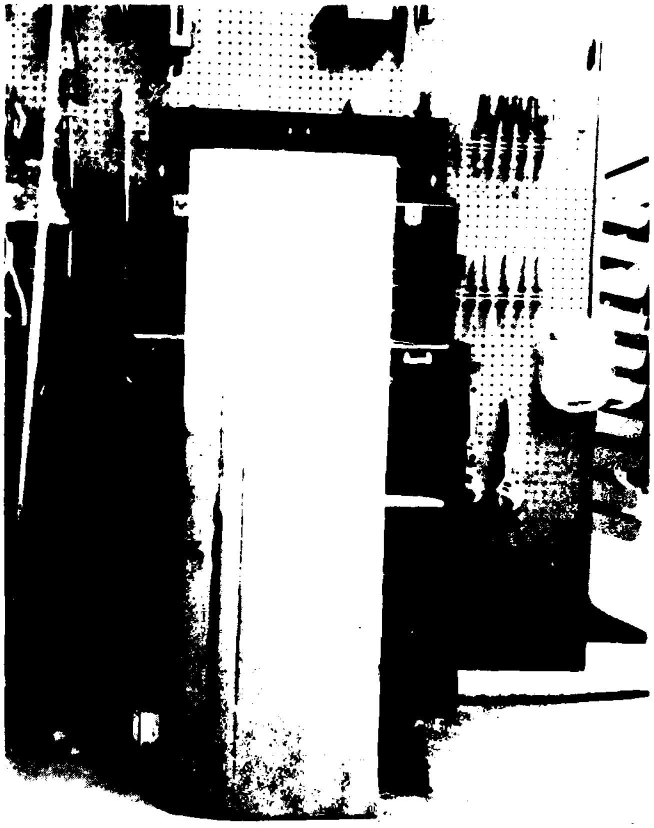


Figure 26. Photograph of Composite Rotor Blade

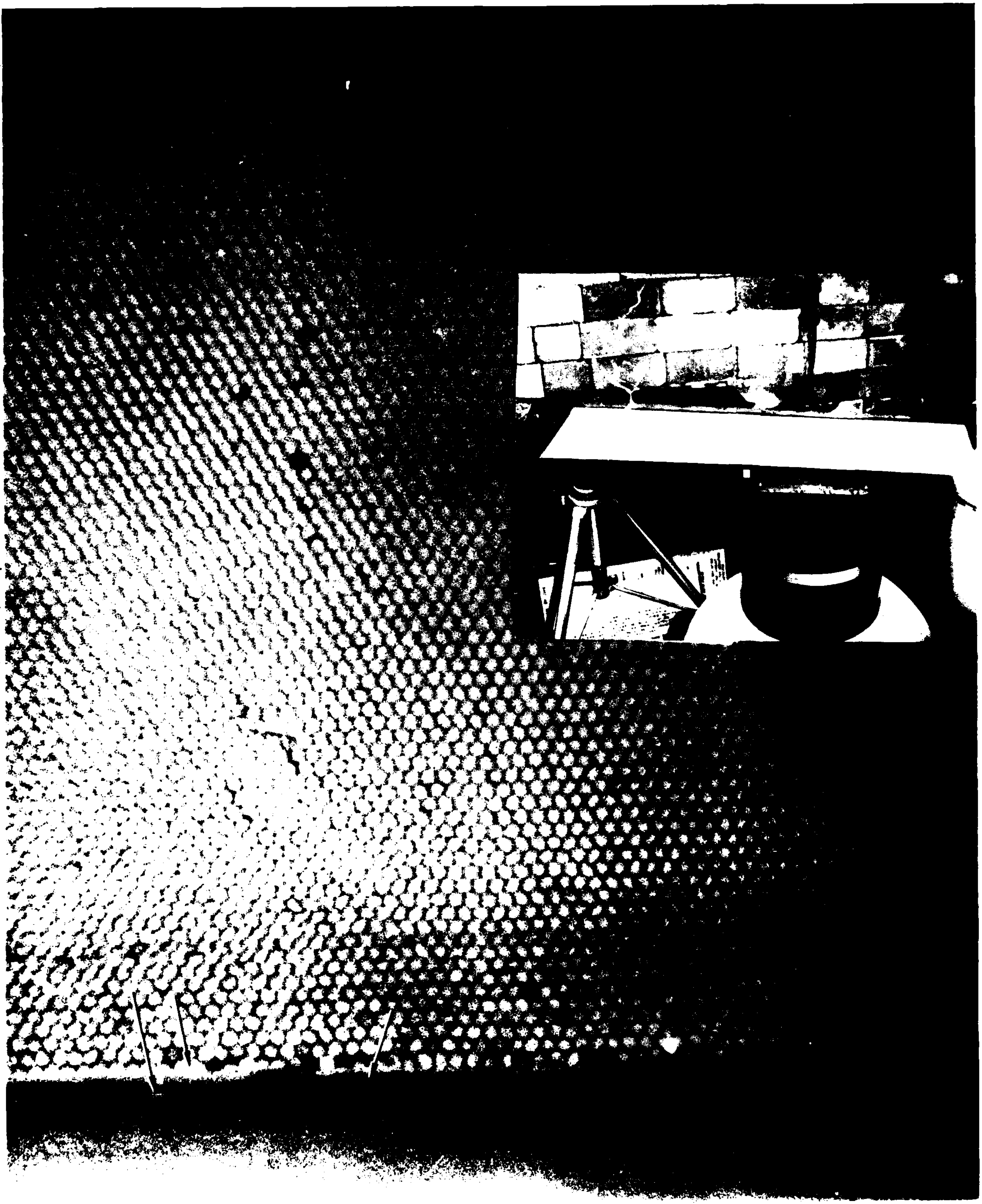


Figure 27N. Neutron Radiograph of Composite Rotor Blade, Trailing Edge Section

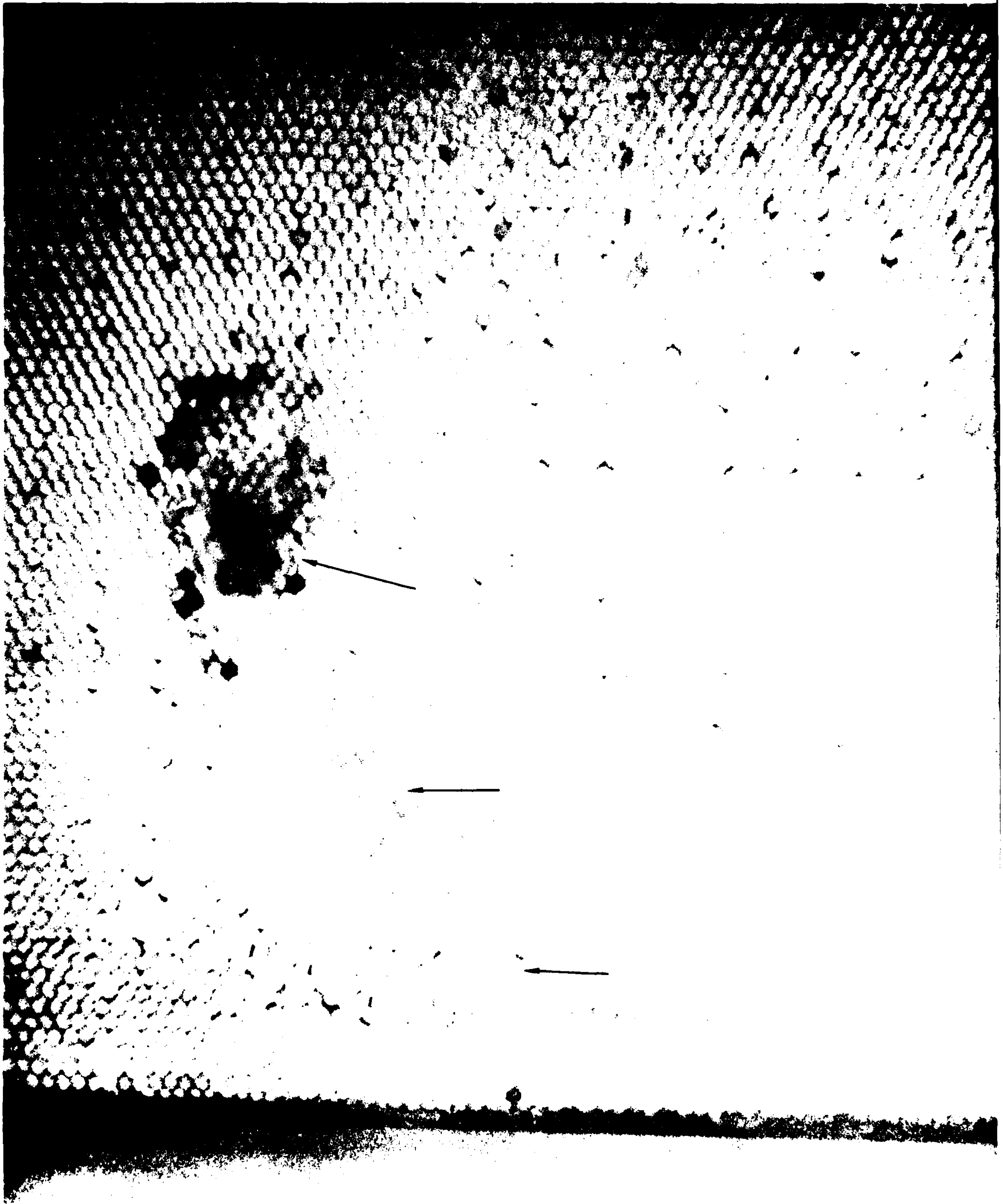


Figure 28N. Neutron Radiograph of Composite Rotor Blade, Trailing Edge Section

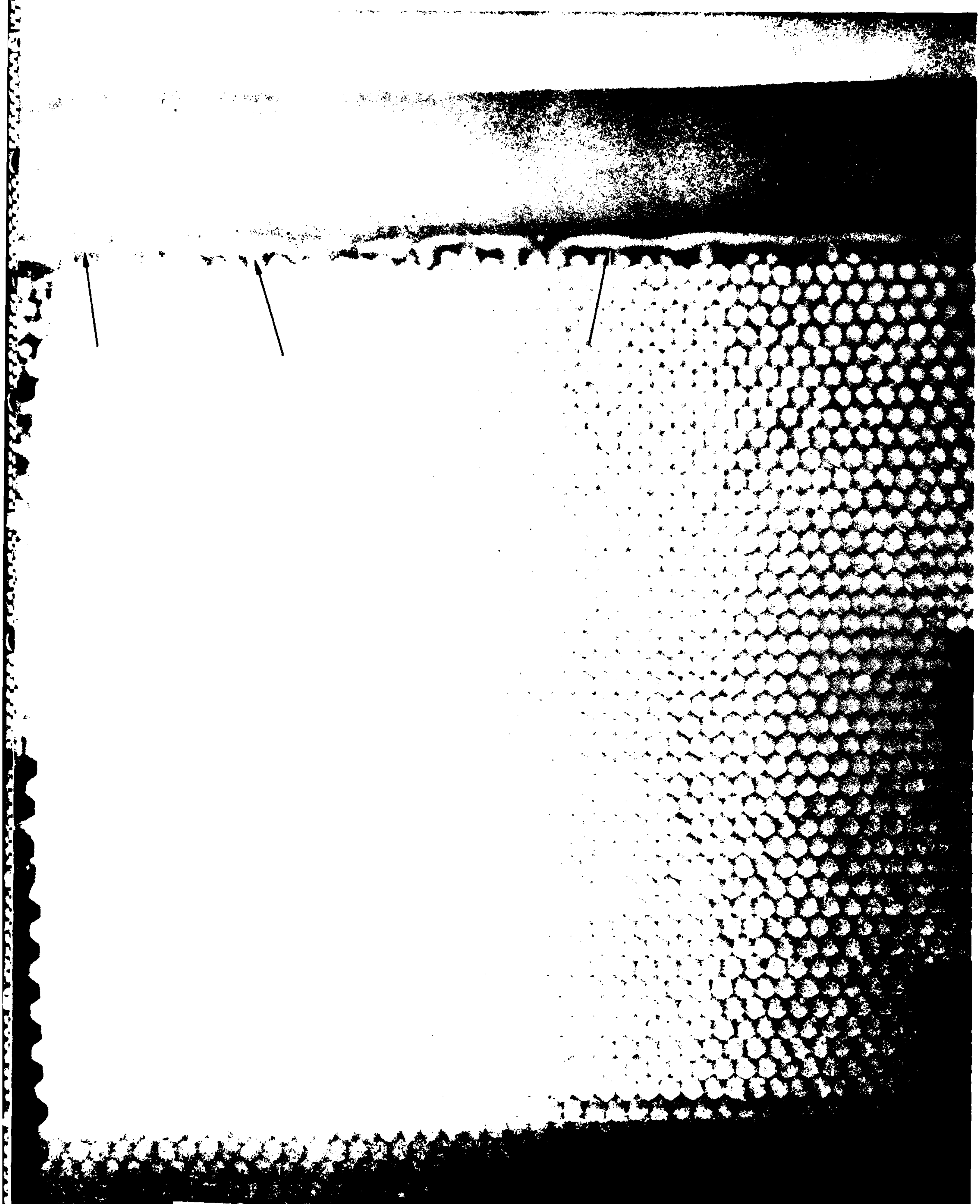


Figure 29N. Neutron Radiograph of Metal Rotor Blade Section

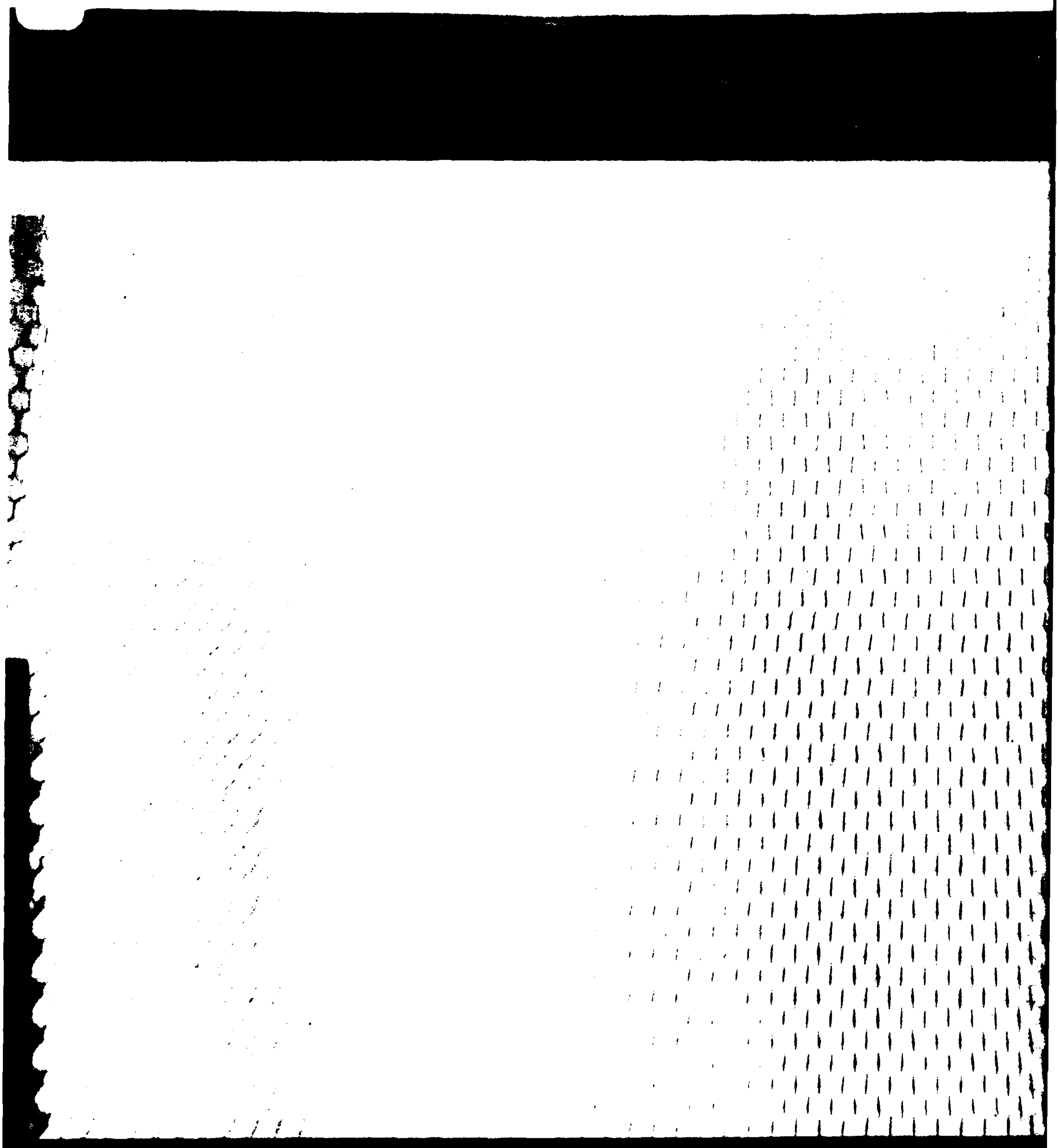


Figure 29X. X-Ray Radiograph of Metal Rotor Blade Section

Figure 30N. Neutron Radiograph of Honeycomb with Entrapped Water

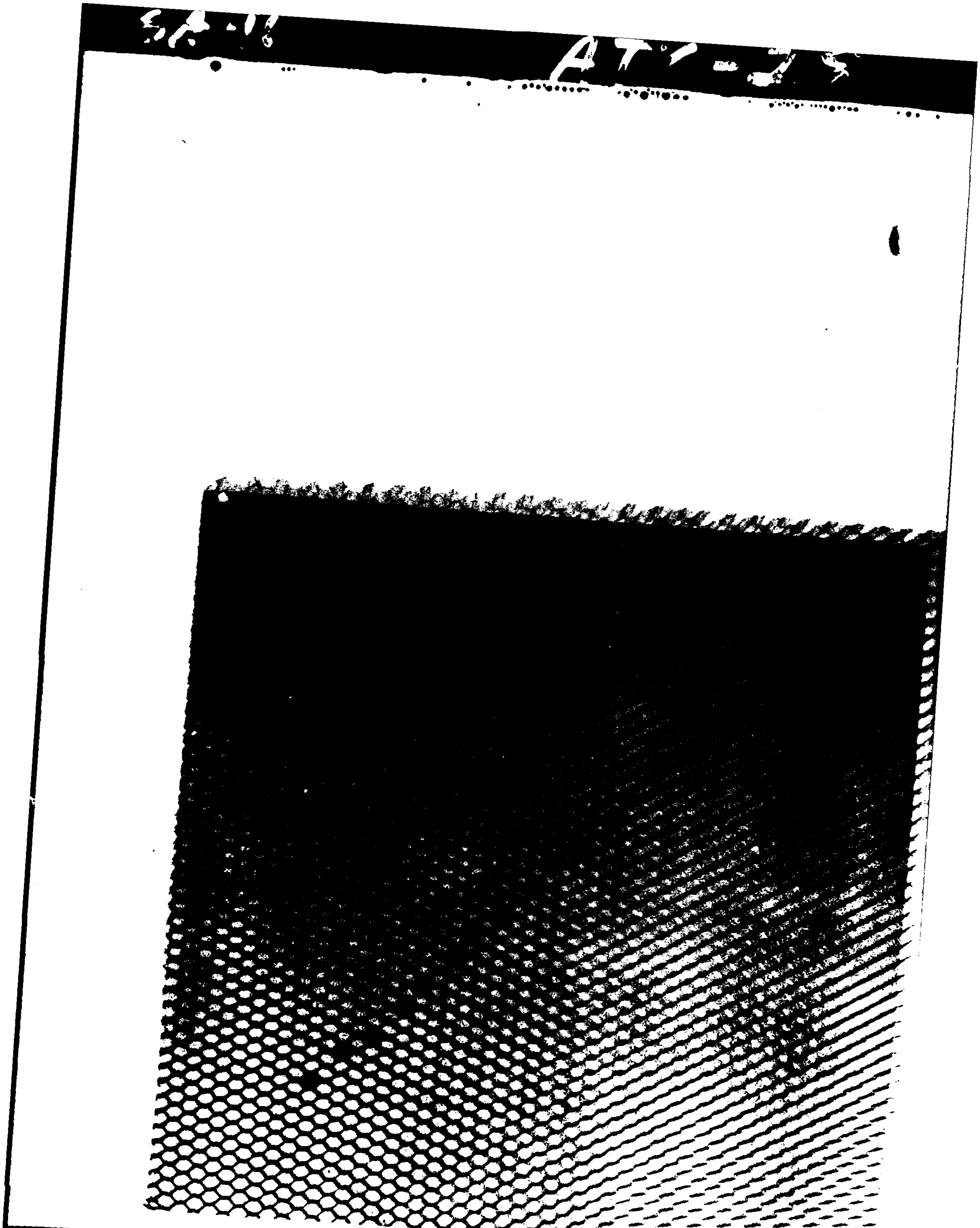


Figure 30X. Neutron Radiograph of Honeycomb with Entrapped Water is indicated, since the image sharpness decreases as the object-to-film distance increases, due to the low L/D (~ 12) of this exposure. For example, beginning at lower left, the fifth droplet is sharpest and hence is the closest one to the film side of the specimen; the third one is next in closeness; nos. 6 through 11 all appear to be at the same depth; and nos. 2 and 12 through 16 all appear at approximately the same depth, farthest from the specimen's film side of the specimen. The x-ray image cannot be used in a similar manner to ascertain depth since all the spots appear with rather uniform sharpness, due to the "point source" nature of x-ray exposure geometry. The neutron radiograph also indicates that the adhesive layer is highly non-uniform in thickness, which is a condition not readily detected in the X-ray.

3.3.1.3 Vought Specimens

During the course of the evaluation phase in the Vought laboratories, several specimens taken from various past and ongoing Vought programs were utilized. These specimens were chosen to assess the applicability of this type of neutron radiography system to a variety of inspection problems. A series of radiographic results from these studies are included in this section.

Figures 31N and 31X are neutron and x-ray exposures of an adhesively bonded aircraft wingbox assembly, in an area where a thick aluminum skin assembly (3/4") is bonded to the rib/spar assembly. The wing section at this point was 10 in. thick with a total aluminum metal thickness of 1-3/4 in. The neutron image clearly shows the bond flaws in the skin-to-spar bondline, through approximately 1-3/4 in. aluminum. Similar radiographs have been made imaging effectively through 2 1/2 inches of aluminum material. The x-ray, on the other hand,, clearly images the steps (thickness changes) in the metal skin. Both techniques image excess sealant material which is present in the wingbox.

Figure 32N is a neutron radiograph resulting from the in-situ exposure of the rudder on an F-8 aircraft, using the AMMRC radiography system. The rather curious panels with swirl-like patterns are bonded-in balsa wood components of Vought's earlier "metalite" structure. The swirls correspond to the grain of

Figure 31N. Neutron Radiograph of Adhesively Bonded Aircraft Wingbox Assembly

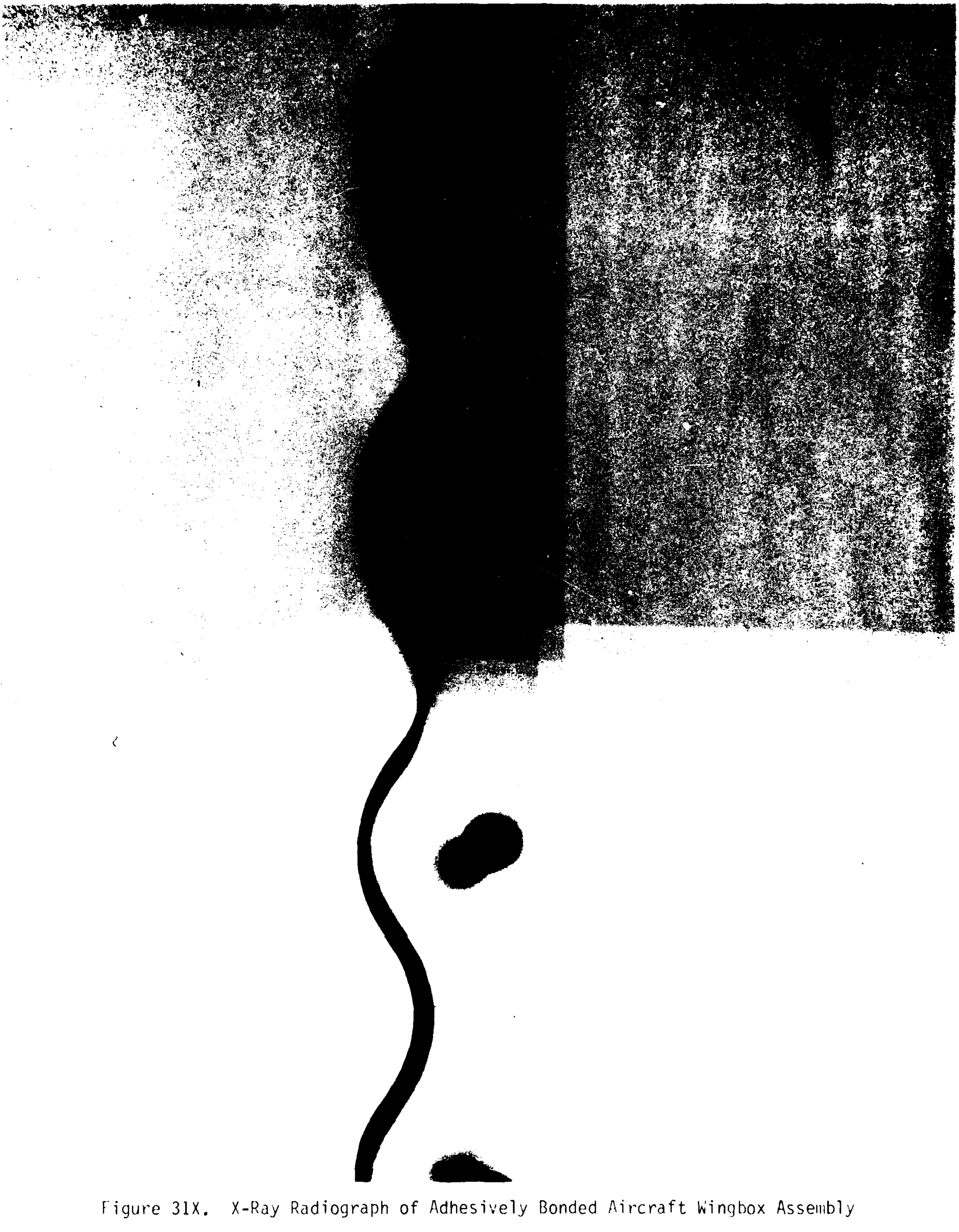


Figure 31X. X-Ray Radiograph of Adhesively Bonded Aircraft Wingbox Assembly

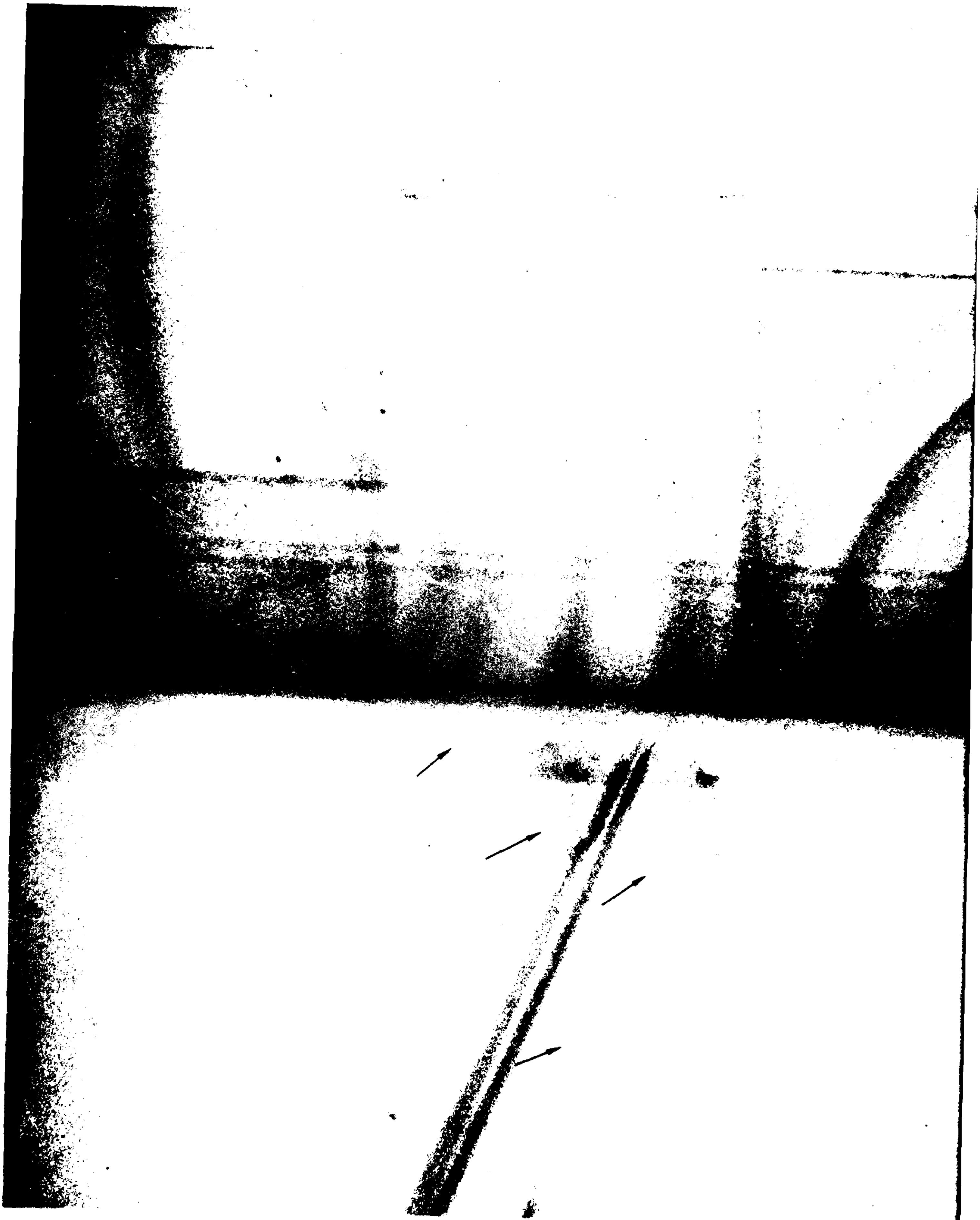


Figure 32N. Neutron Radiograph from In-Situ Exposure of F-8 Rudder Section the wood. In addition to indicating the quality of edge bonding of these components, the neutron exposure shows that corrosion is present under many of the skin fasteners.

A series of radiographs was made to evaluate application of this type mobile system to inspection of large structures such as the space shuttle thermal radiator panels manufactured by Vought. Figures 33X and 33N are x and neutron radiographs of one of these panels in the area of an aluminum fixture bonded into the panel. In this case, the specific area in question was the edge bond between two components comprising the fixture. As seen, the x-ray does not image this bondline, and the neutron radiograph images all the bonding material in the structure, indicating an inadequate bond in the area denoted. Figure 34N is a neutron exposure made at an oblique angle of approximately 40 degrees from perpendicular to the beam, in order to determine the depth of the questionable edge bond. As seen, the depth profile of this bondline is faithfully imaged. Based on these images, a repair of this area by simple adhesive injection at the appropriate points was effected, which obviated the need for skin removal.

Application of the AMMRC system for inspection of certain pyrotechnic devices was evaluated. For this purpose, a missile assembly was inspected to determine the position and spacings of explosive charges in critical skin-cutting devices built into the skin/cover. Figure 35N is a neutron radiograph of the nose skin assembly, radiographed in place showing the detonators at the ends of the circumferential and side cutters, and their positions relative to each other. The image indicates good proximity of the detonators for the required continuity in the explosive train.

3.3.1.4 Air Force Specimens

A group of aircraft corrosion specimens provided through the Air Force Materials Laboratory was utilized in the Vought laboratories in the system evaluation phase. Representative radiographic results from these specimens are included in this section. One of these specimens, a C-130 wing section centroid pad, was examined for hidden corrosion. Intergranular corrosion was imaged in several locations. In addition, corrosion was detected under the majority of fastener holes. These results are shown in Figure 36.

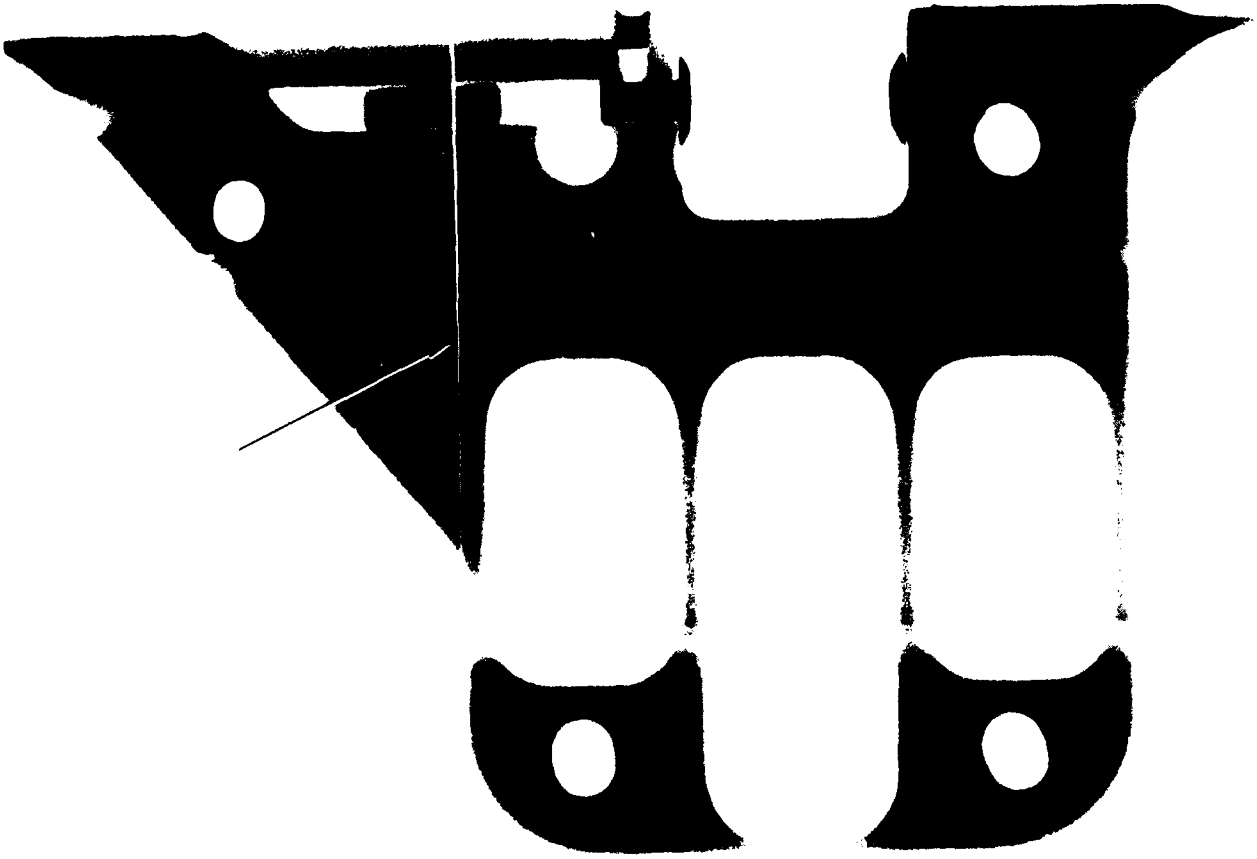


Figure 33X. X-Ray Radiograph of Space Shuttle Thermal Radiator Panel Assembly

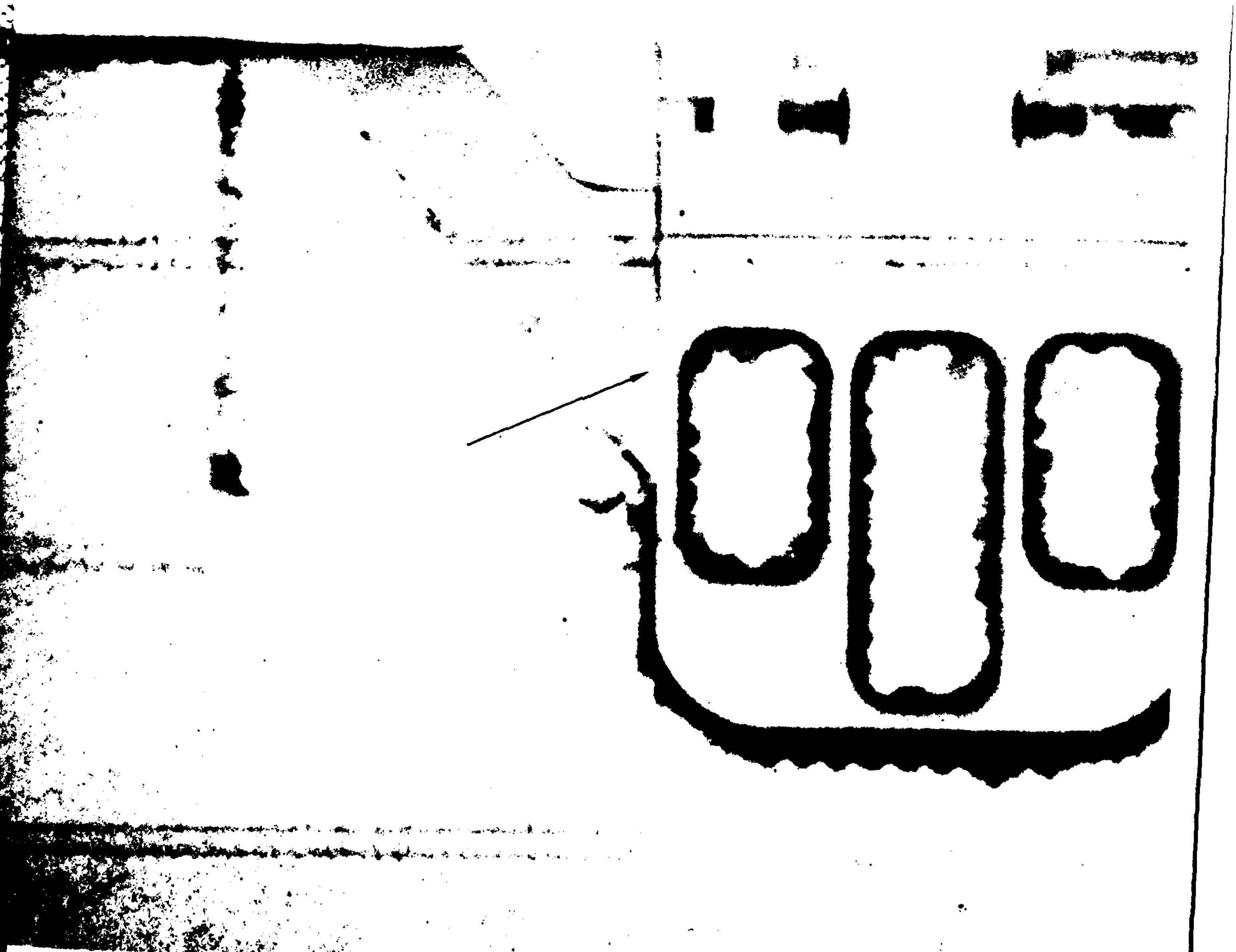


Figure 33N. Neutron Radiograph of Space Shuttle Thermal Radiator Panel Assembly, Showing Adhesive Bonding Deficiencies

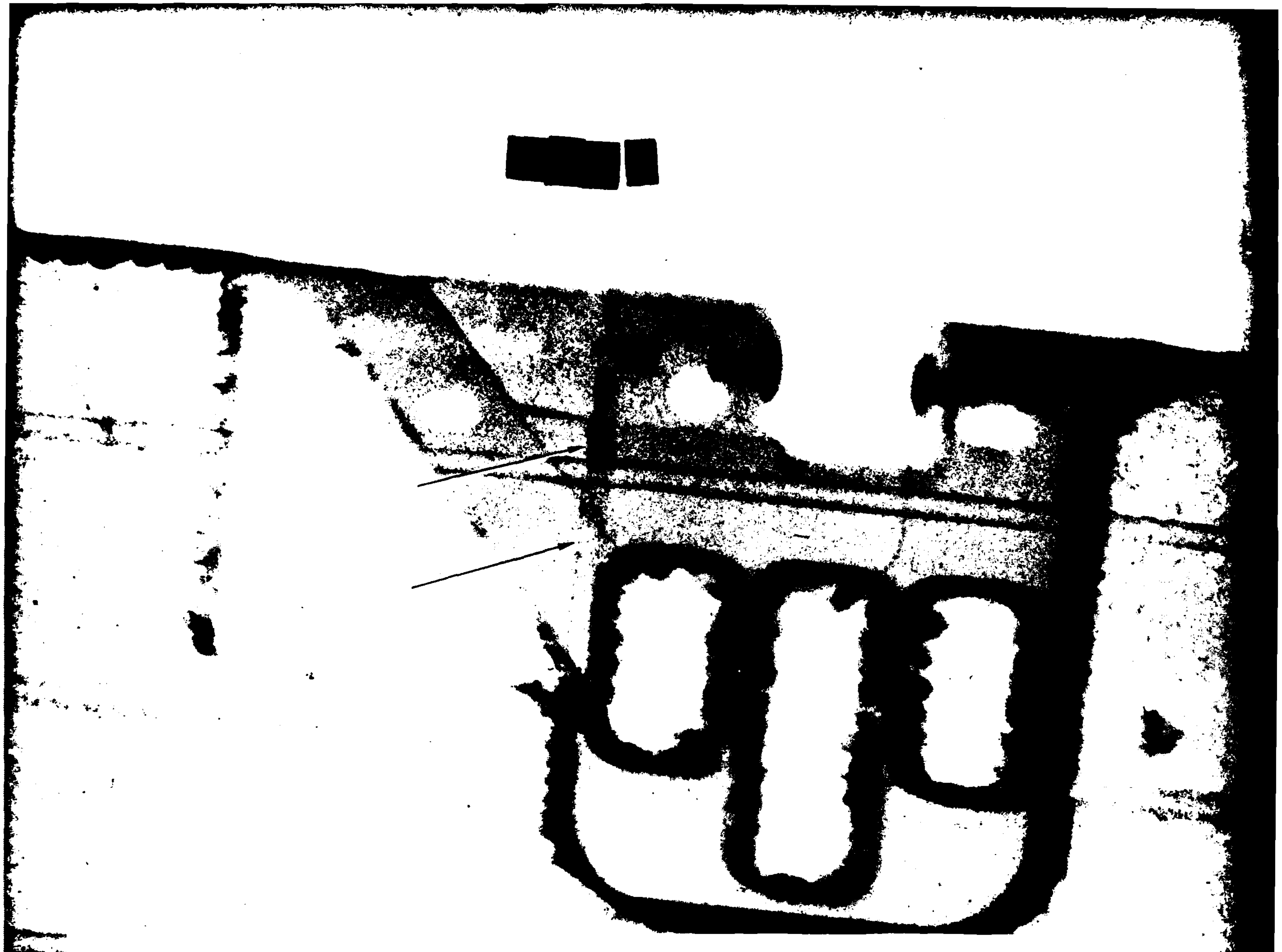
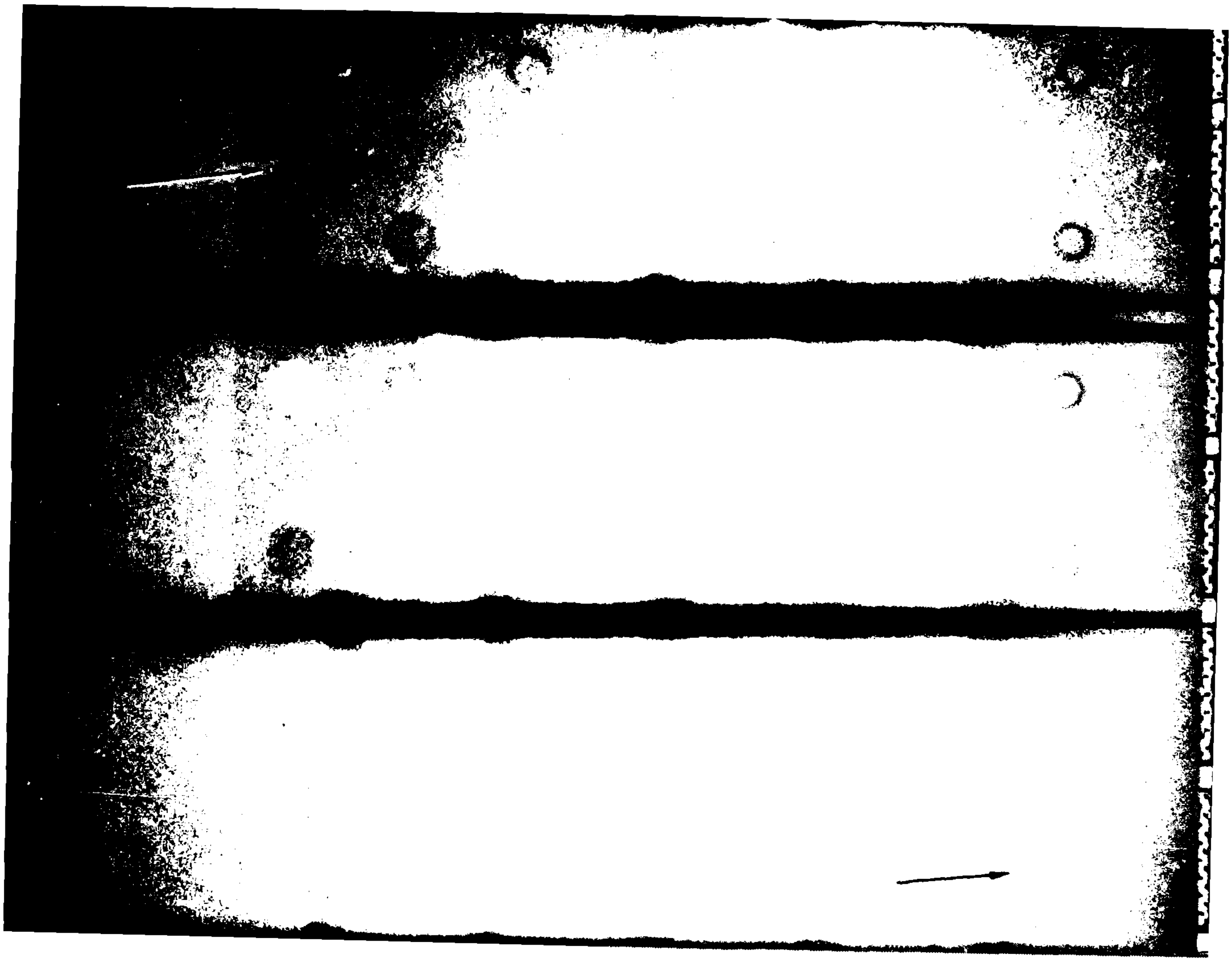


Figure 34N. Neutron Radiograph of Space Shuttle Thermal Radar (Oblique Angle), Showing Adhesive Bonding Deficiencies

Figure 35N. Neutron Radiograph of Missile Nose Skin Assembly Showing Skin Cutter Detonators



Figures 37X and 37N are the result of radiographic inspection of a simulated F-111 engine nacelle panel which is a lamination of ceramic tiles and metal skins, adhesively bonded. The x-ray images the tiles in high contrast, while the neutron radiograph (Figure 37N) images the adhesive bonding material between the tiles and the distribution of the adhesive layer between tiles and metal skin. In the latter case, the image shows large inhomogenieties in the adhesive thickness and several "worm-hole" adhesive voids. A real production panel imaged in the radiograph of Figure 38N shows greater inhomogeneities in adhesive distribution, both between tiles and between tiles and skin. Radiographic results from additional Air Force specimens are presented in the next section on field operations.

3.3.2 Field Operations

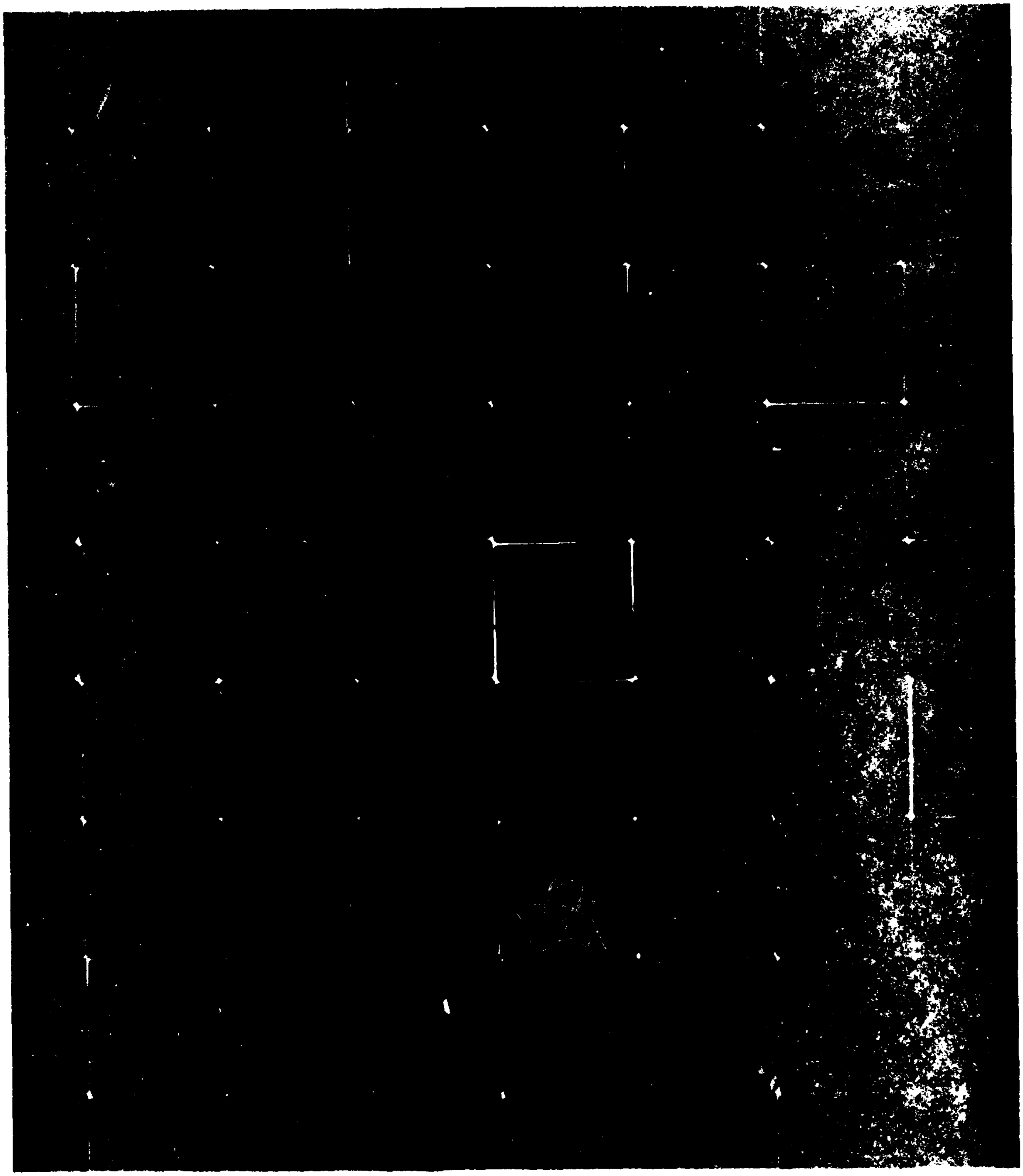
A summary description of field radiography operations and results are given here.

3.3.2.1 Sacramento Air Logistics Center (SM-ALC)

Neutron radiography operations at the SM-ALC, McClellan AFB, CA, were centered around inspections of an F-111 aircraft, which was made available on a daily basis for the four week period for radiographing portions in place on the aircraft. An F-106 was available for one eight hour shift, also for in-situ inspections. Components removed from other F-111 and from T-39 and A-10 aircraft constituted the remainder of the specimens.

Arrangement of a satisfactory exposure area location at the Air Force Logistics Center (AFLC) was made through early contacts with the Air Force Project Officer at the San Antonio Air Logistics Center (SA-ALC/MMEI), and a preliminary visit was made to the SM-ALC site at McClellan AFB selected for the work. The general radiation safety plan to cover the on-site operations at AFLC was developed by Vought in cooperation with SA-ALC and SM-ALC project personnel and coordinated with the USAF Occupational and Environmental Health Laboratory, Brooks Air Force Base.

Shipment of the neutron radiography system and the necessary support equipment for these operations was by Vought Corporation truck. To assure



ATC31

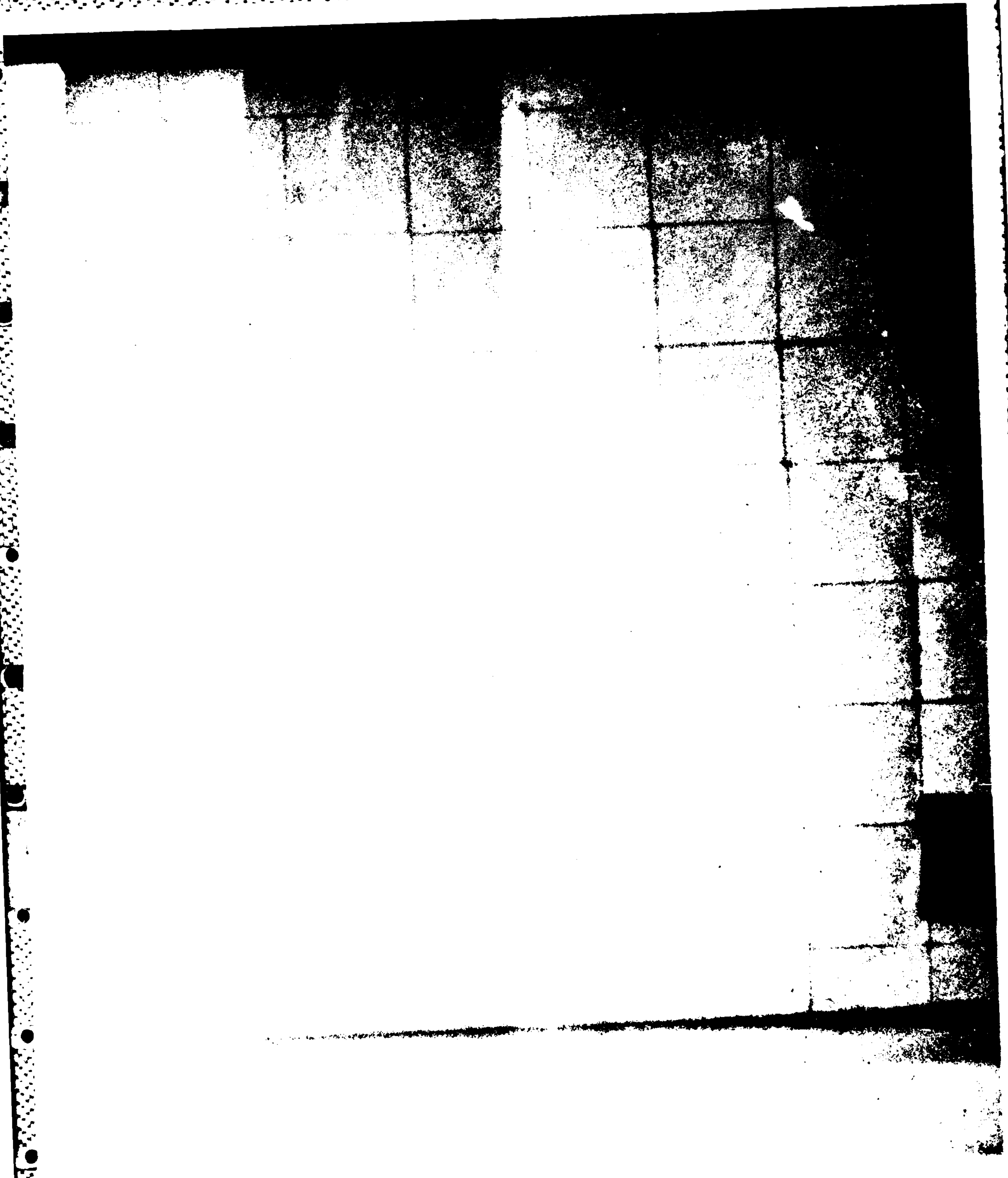
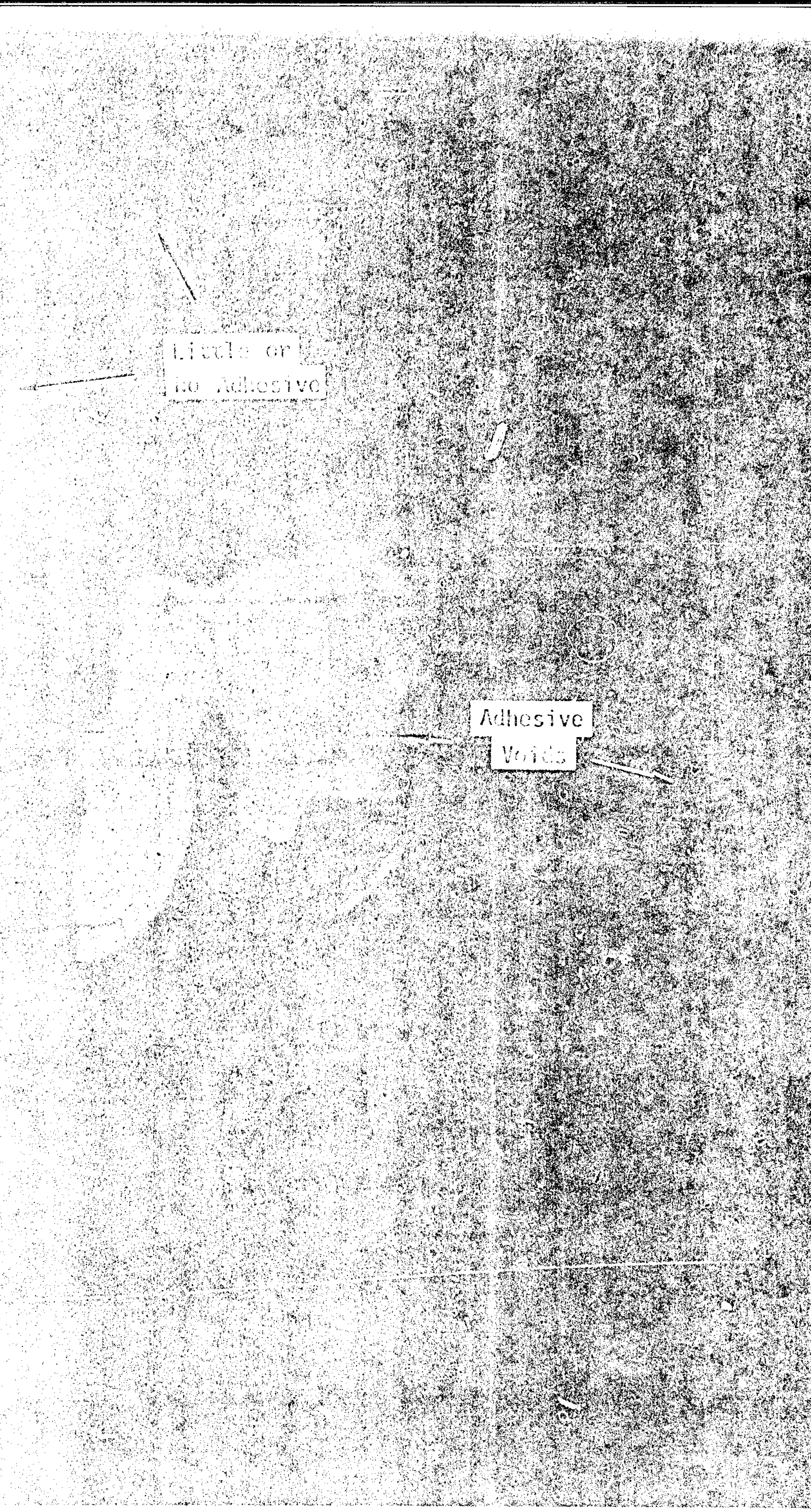


Figure 37N. Neutron Radiograph of Simulated F-111 Engine Nacelle Panel Showing Bonding Anomalies



[illegible] Neutron Radiograph of Production F-111 Engine Nacelle Panel, Showing [illegible] Distribution meeting the available schedule window and to reduce risk of undue delays on this first shipment of the new type of system, the Vought Radiological Safety Officer accompanied the truck and carried the necessary materials license and permits.

Upon arrival at McClellan AFB, the equipment was off-loaded by McClellan personnel and transported by flatbed truck to its site of operation inside Building 704, a large maintenance hangar located west of the main north-south runway near the west boundary of the base. Building 704 is shown in Figure 39. This location is rather remote and out of the mainstream of vehicle and pedestrian traffic and thus well suited to the exploratory neutron radiography operations.

An air-conditioned transportable laboratory, Figure 40, was provided by SM-ALC for use as a system control room and film and real time imaging display area, as well as a dark room for cassette loading. Three tanks filled with water, each 5 ft. in diameter and 6 ft. in length, were placed between the control room and radiography zone for additional biological shielding, which lowered the control room radiation levels to acceptable levels. Figure 41 shows the layout of the operations area with the location of radiation safety barriers and beacons. The results of the radiation survey with system operating are given in Figure 42.

Operations were conducted during the second and third shifts. During these shifts, only a few McClellan personnel were present in Bldg. 704 and thus radiation safety surveillance of the area was simplified. Subsequent to the radiation survey, the detailed site safety plan for operation was finalized by Vought and SM-ALC and McClellan AFB personnel. Doors leading to the hangar and hi-bay area from office and laboratory areas were secured by lock and chain (or locked doors). Radiation levels were monitored and recorded by both McClellan AFB and Vought Corporation radiation safety officers. Safe and successful operation was due to the complete support and cooperation of SM-ALC and McClellan AFB personnel and to close adherence to the Radiation Safety Operation Plan. SM-ALC personnel provided complete support to the daily operations, including the use of X-ray facilities, a portion of the film required, selection of specimens and their availability in a timely manner, and a minimum of two personnel at all times during the

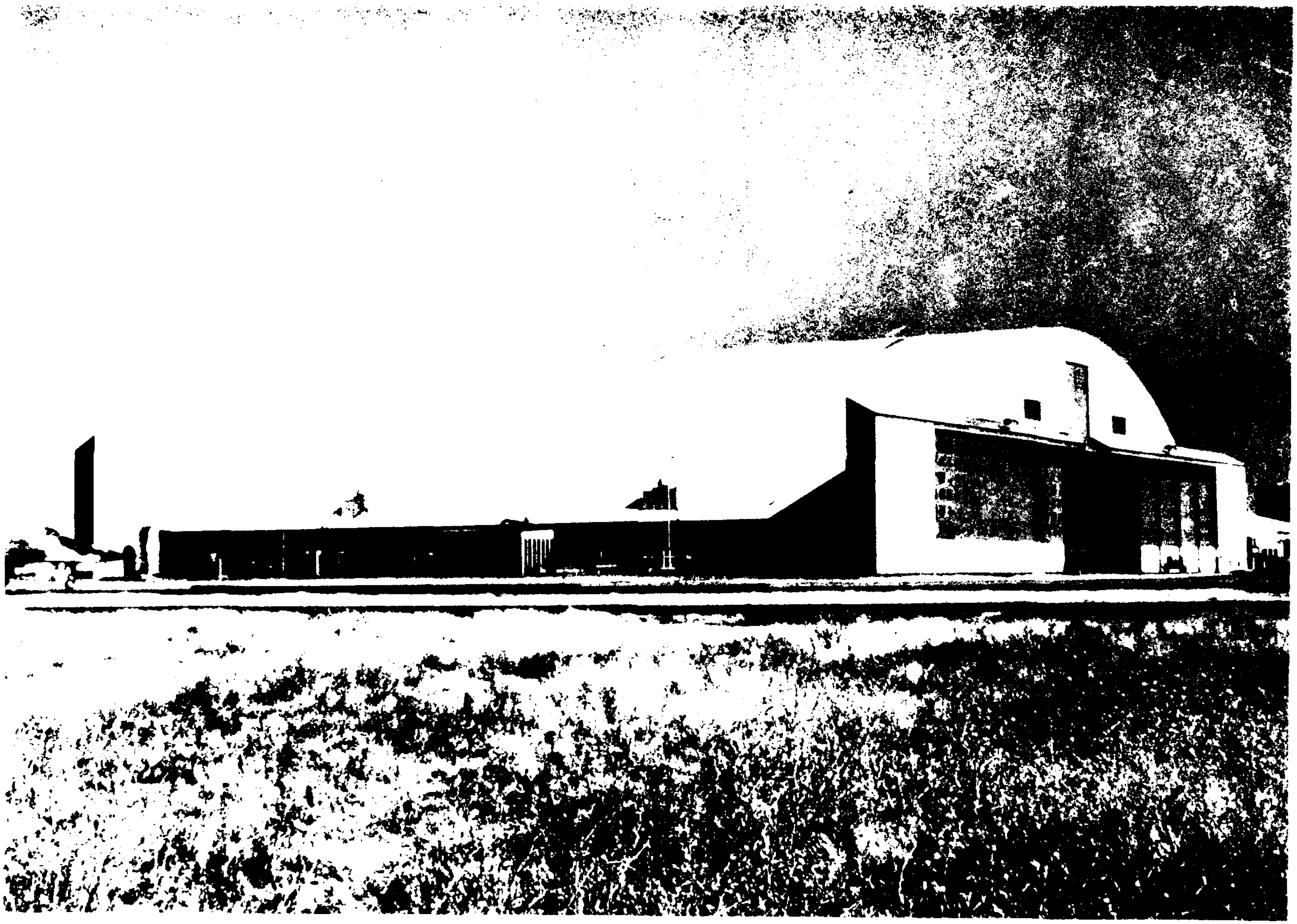
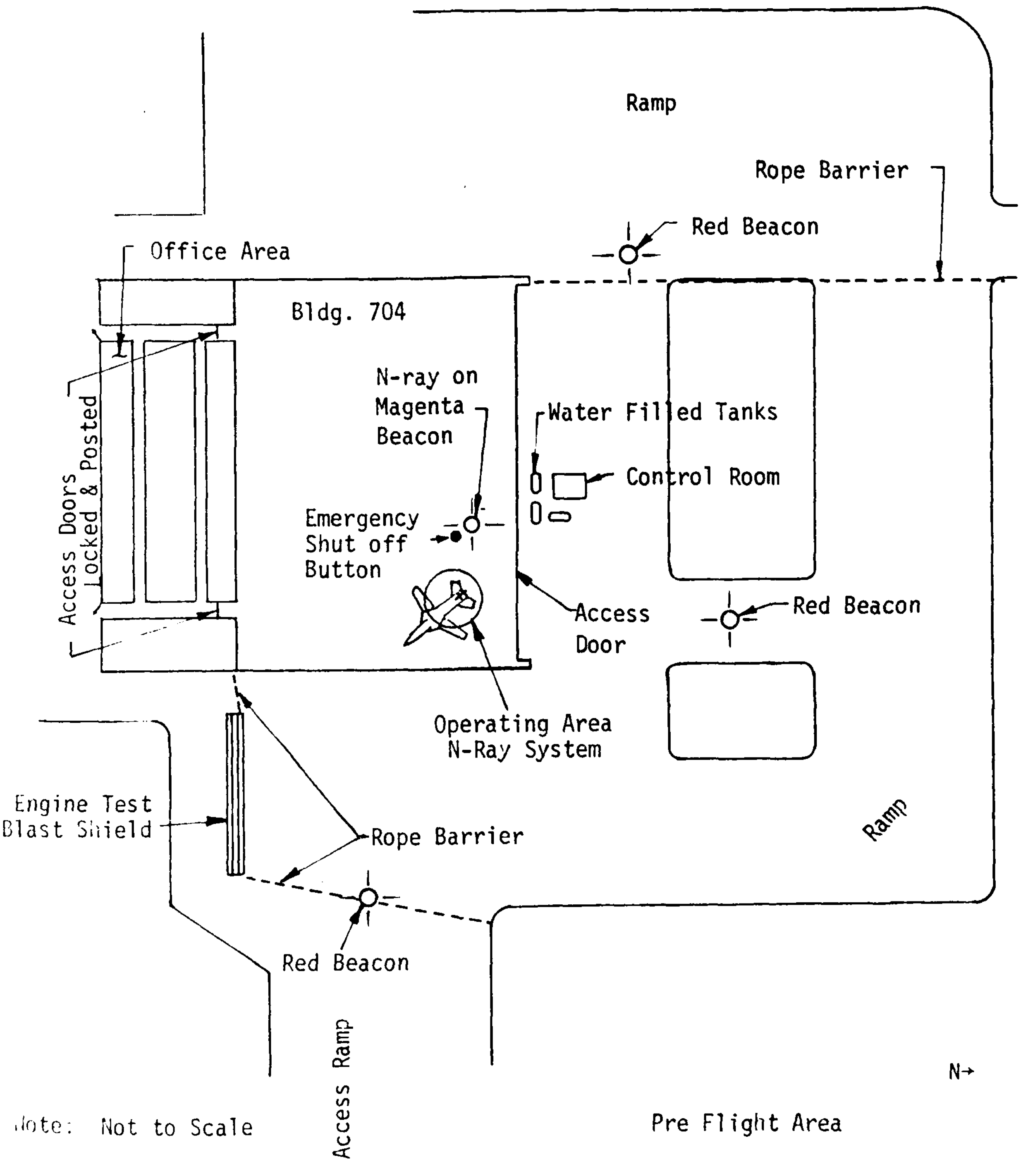


Figure 39. McClellan AFB Site of Mobile Neutron Radiography Operations, Building 704

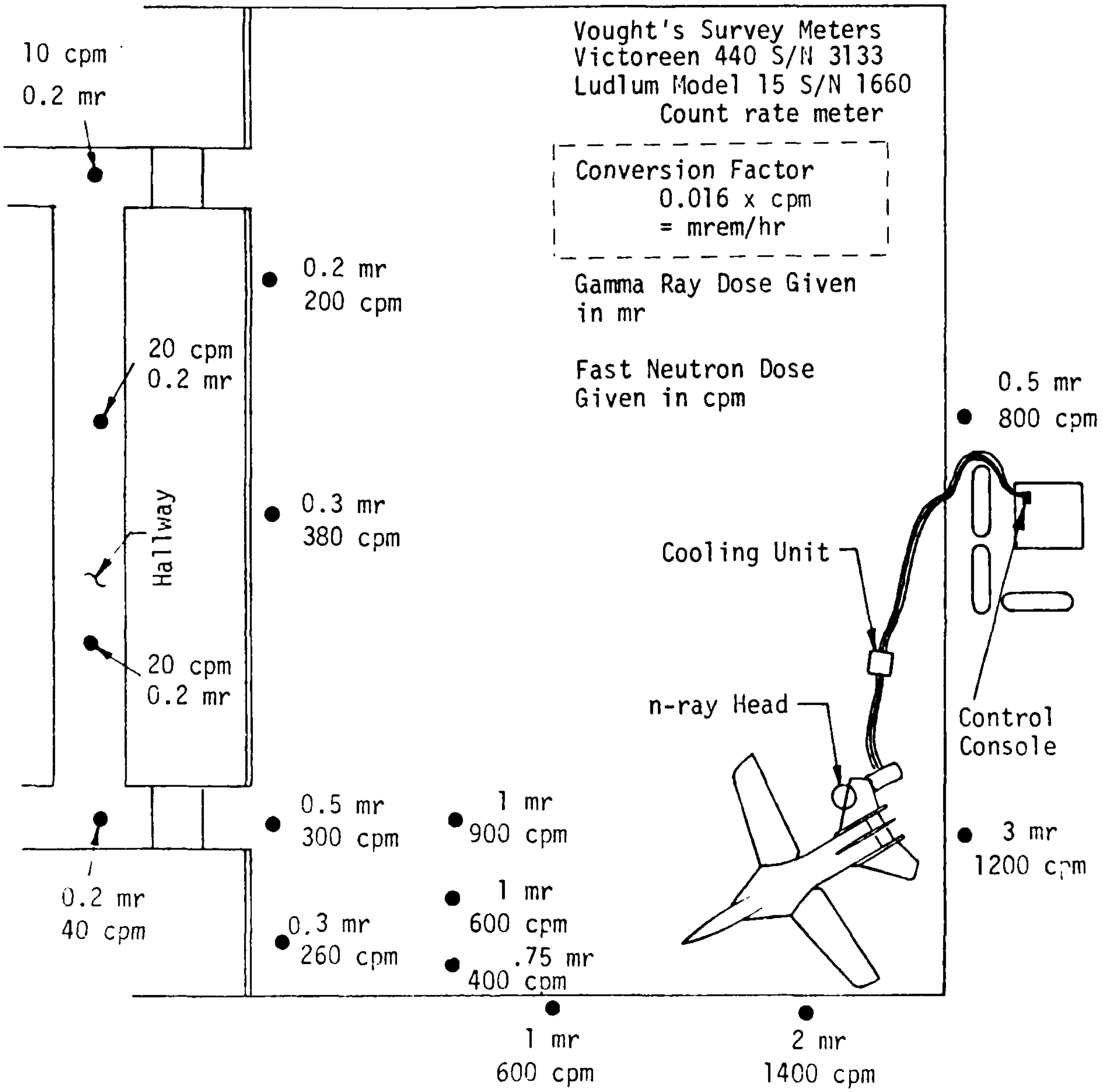
Figure 40. Portable Lab Used for System Control, Dark Room and Image Viewing



N-RAY SAFETY, BUILDING 704

Figure 41. Layout of Neutron Radiography Operating Area and Controlled Access Area

Date: 28 May 81 Radiation Survey



Note: Not Drawn to Scale

Figure 42. Neutron Radiography Radiation Survey, Building 704

radiography operations for safety monitoring and setting up and taking down the safety ropes and related equipment, transporting the exposed film to the x-ray laboratory and processing, and setup of exposures.

The first neutron radiograph made after arrival and setup at SM-ALC was a fast (12 minute) exposure of an F-111 right hand horizontal stabilizer attached to the aircraft. As seen in the neutron radiograph, Figure 43N, the detail is sufficient to indicate that this area was in a normal "as bonded" condition and free from significant quantities of moisture or corrosion. Subsequently, a similar component which had been removed from a different aircraft for rework because of indications of moisture and corrosion was made available by SM-ALC personnel for comparison, and the same area was neutron radiographed. This radiograph, Figure 44N, shows a very large amount of moisture and corrosion, in striking contrast to the previous radiograph of the "clean" component. The x-ray of the same area as that is shown in Figure 44X. The neutron radiograph dramatically shows more of the moisture and corrosion than does the x-ray and provides a clear indication of the boundaries and severity of these defects. Neutron inspection of a different area of the same stabilizer resulted in the radiograph shown in Figure 45N. Additional moisture and corrosion is revealed in this area of the stabilizer.

The next neutron radiograph in this series, Figure 46N, resulted from inspection of an F-111 forward engine access panel. Moisture and corrosion are clearly imaged, in addition to adhesive fillets and sealants. A very fast (3 minute) exposure of a similar panel, Figure 47N, is compared with a 90 minute exposure of the same area, Figure 48N. This comparison is made here to assess the extent to which one can trade high resolution for speed in a mobile operation and still adequately detect the defect(s) in question. As noted, the 3 minute radiograph shows sufficient detail to interpret most of the features of the 90-minute image.

The next radiograph, Figure 49N, is the result of inspecting an F-111 horizontal stabilizer tip cap, which is shown in the photograph of Figure 50, after post-radiography removal of the skin. Prior to neutron inspection, the part was inspected by x-ray and acoustic emission, and areas of suspected moisture and corrosion as indicated by these techniques were marked on the surface of the part, as seen in the above photograph. Cell-wall corrosion is

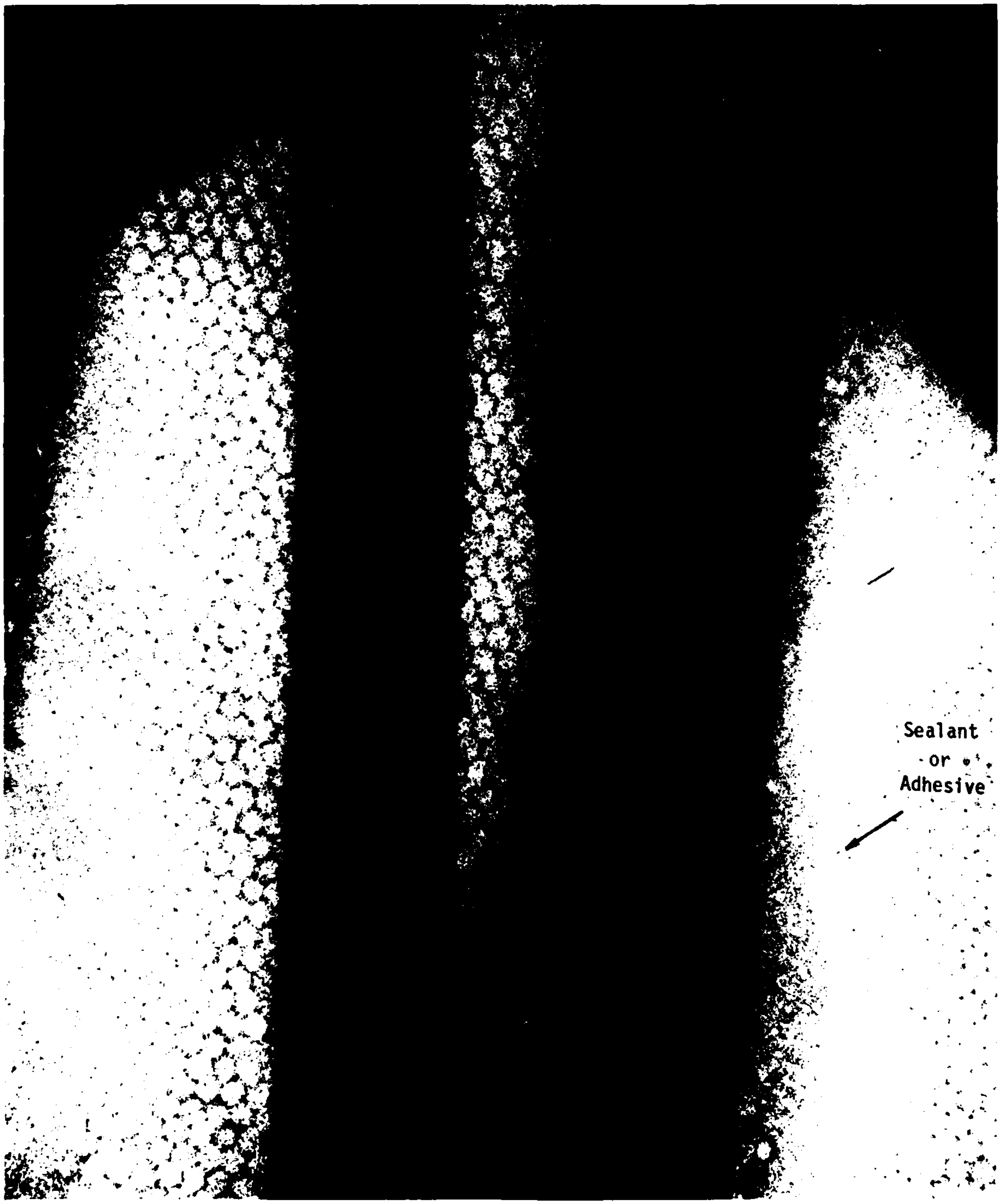


Figure 43N. Rapid In-Situ Neutron Radiograph (12 Minutes) of F-111 Horizontal Stabilizer: No Significant Moisture or Corrosion Indicated

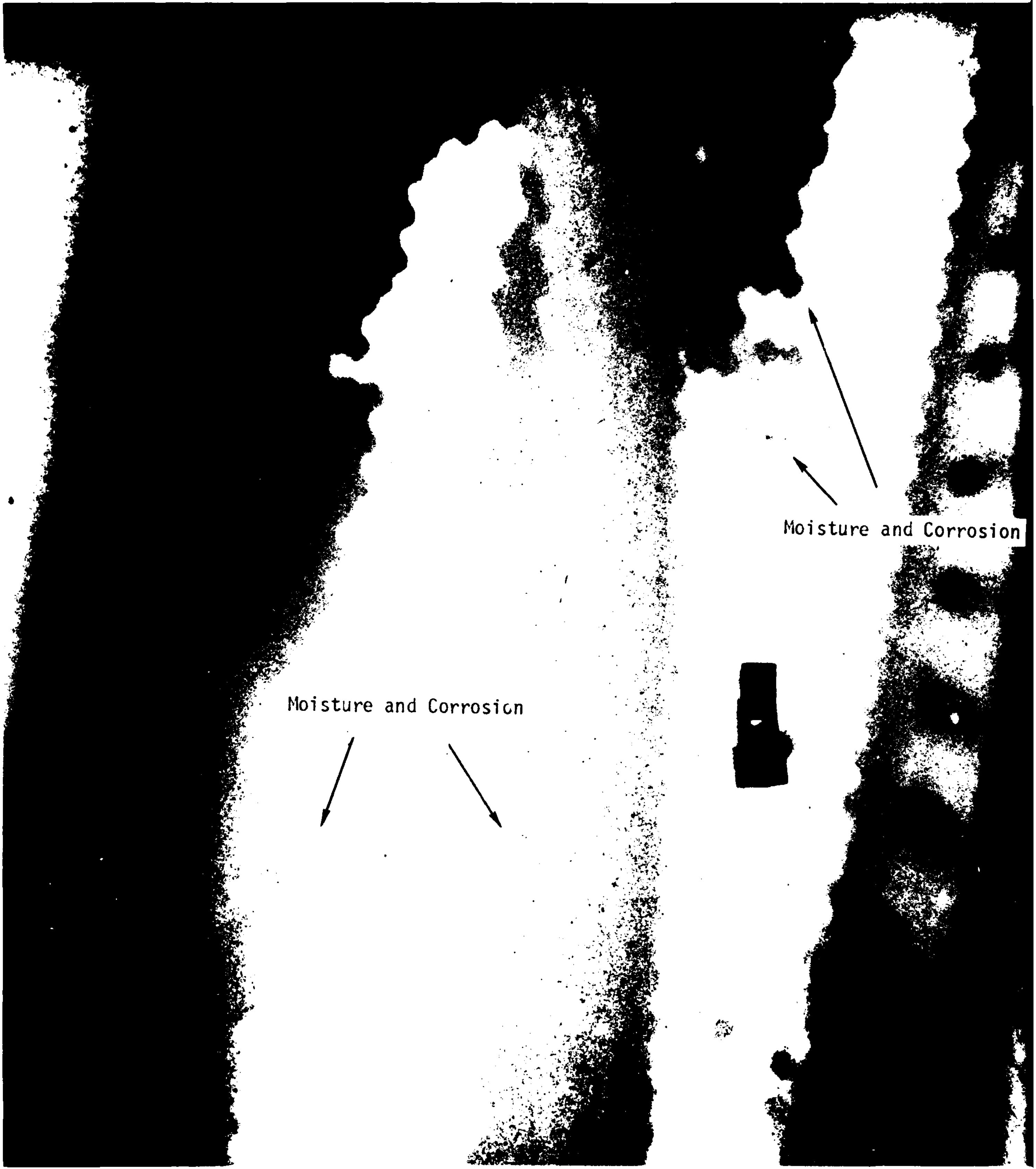


Figure 44N. Neutron Radiograph of F-111 Horizontal Stabilizer Showing Substantial Quantities of Moisture and Corrosion

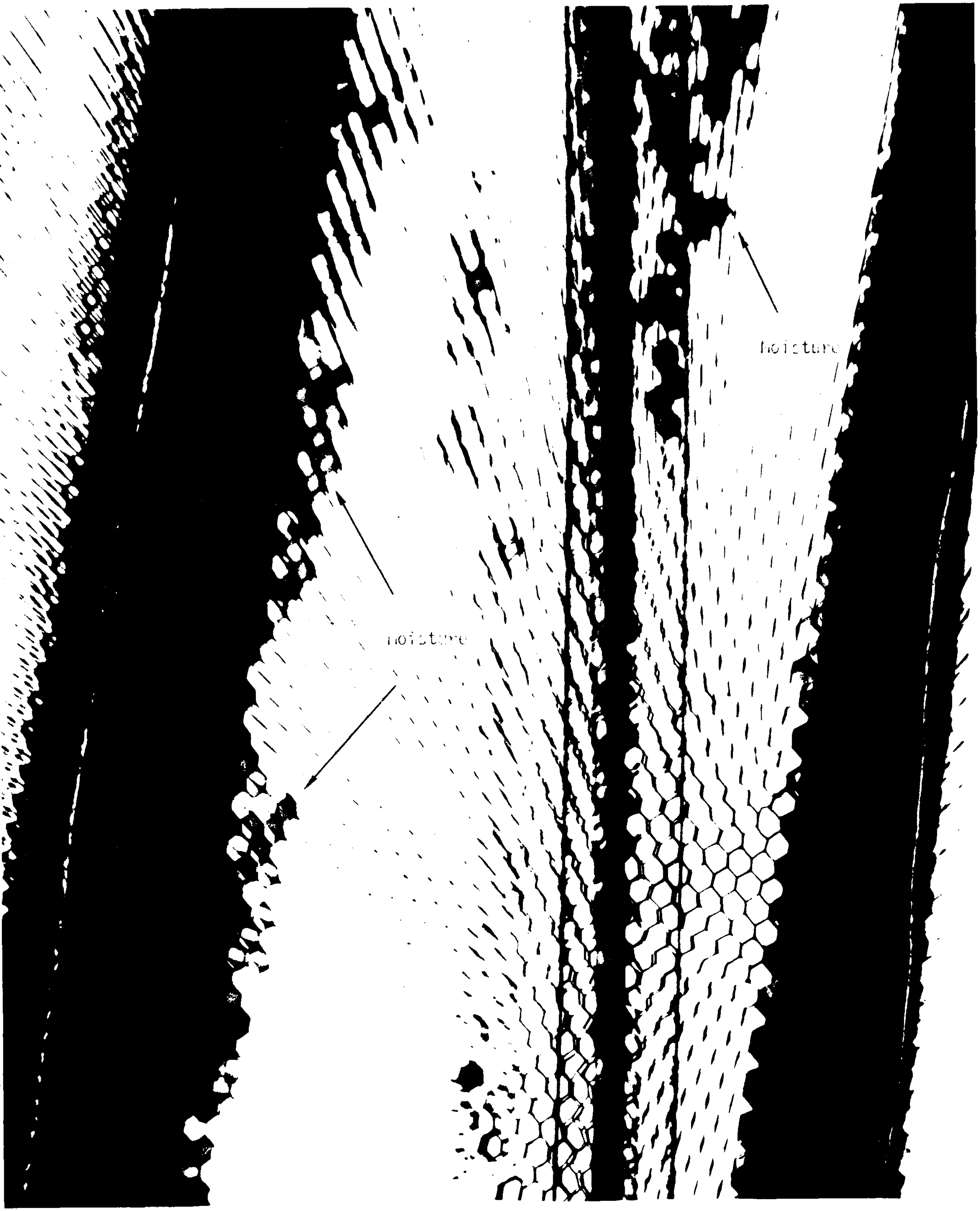


Figure 44X. X-Ray of F-111 Horizontal Stabilizer

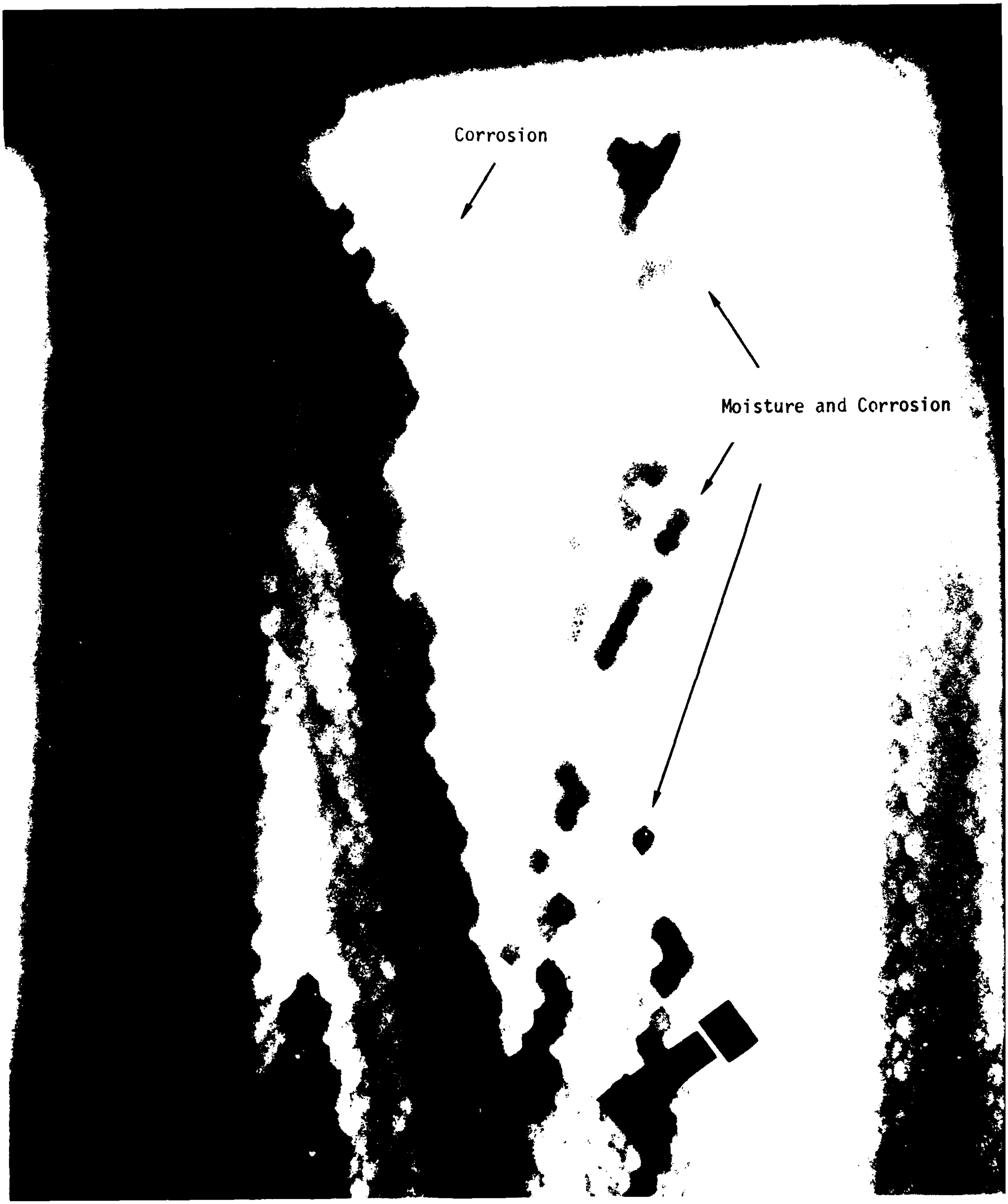


Figure 45N. Neutron Radiograph of F-111 Horizontal Stabilizer Showing Substantial Quantities of Moisture and Corrosion

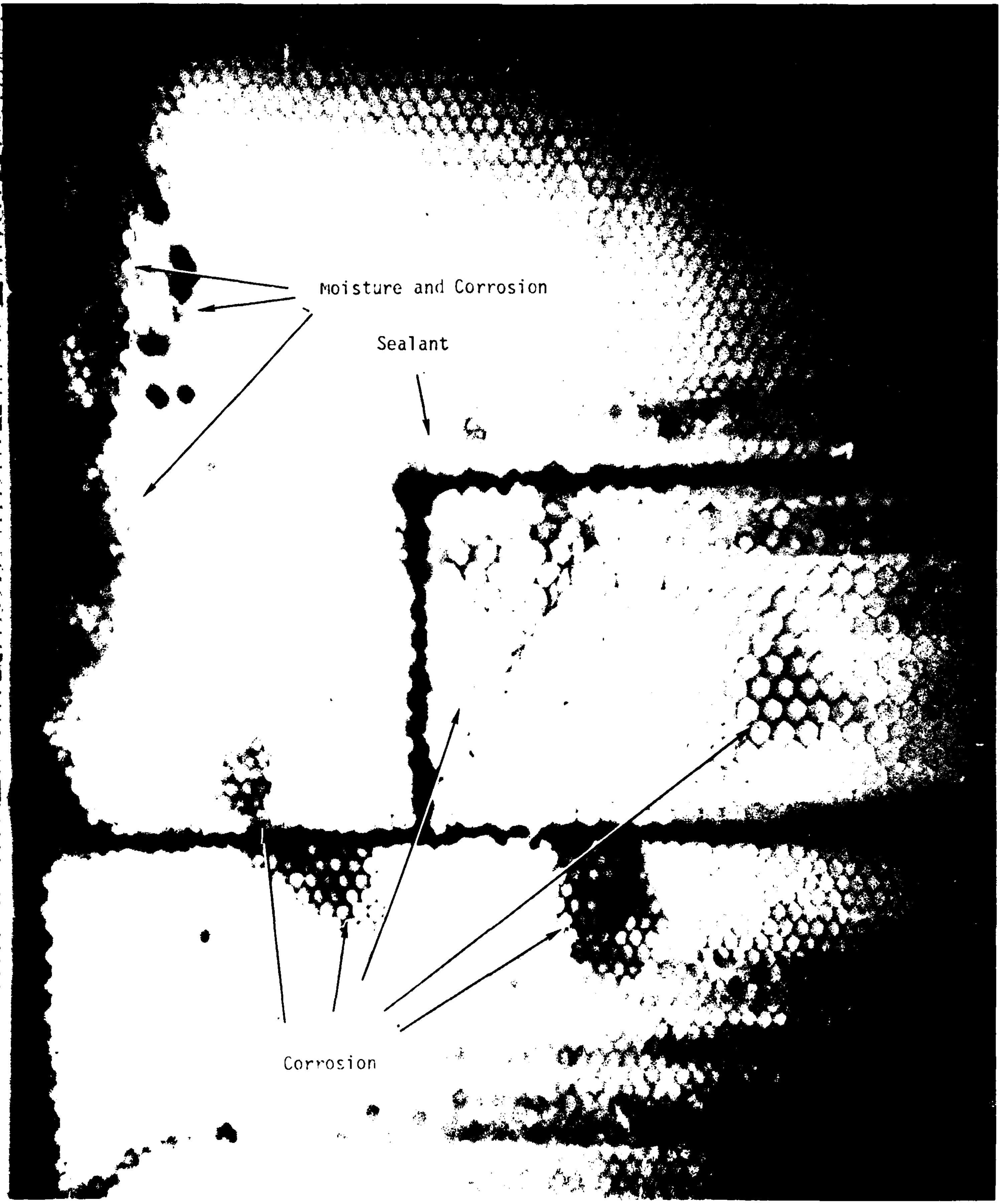


Figure 46N. Neutron Radiograph of F-111 Forward Engine Access Panel Showing Corrosion, Moisture, Adhesive and Sealants

Figure 47N. Rapid Neutron Radiograph (3 Minutes) of F-111 Forward Engine Access Panel

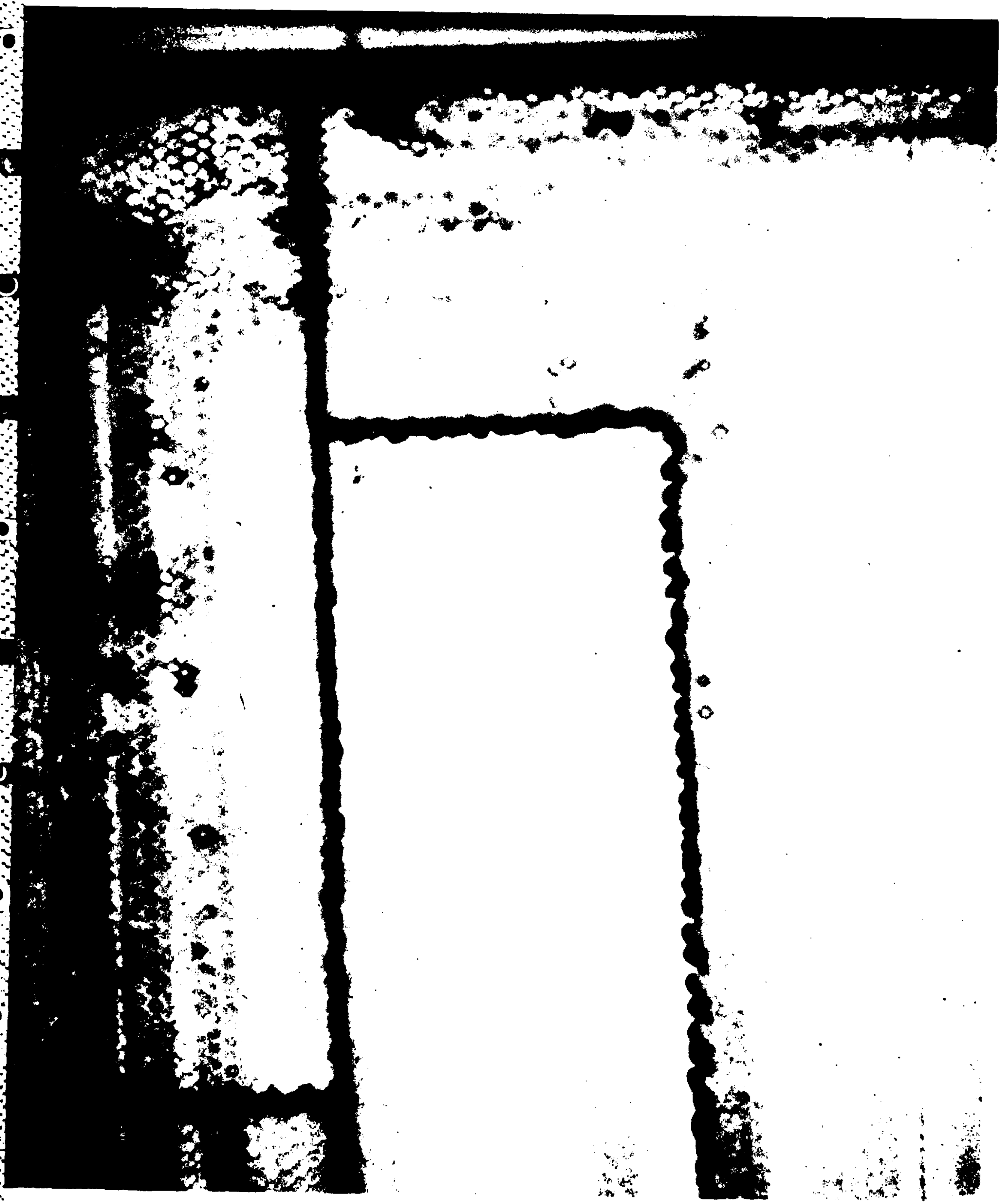


Figure 48N. Slow Film Neutron Radiograph (90 Minutes) of F-111 Forward Engine Access Panel

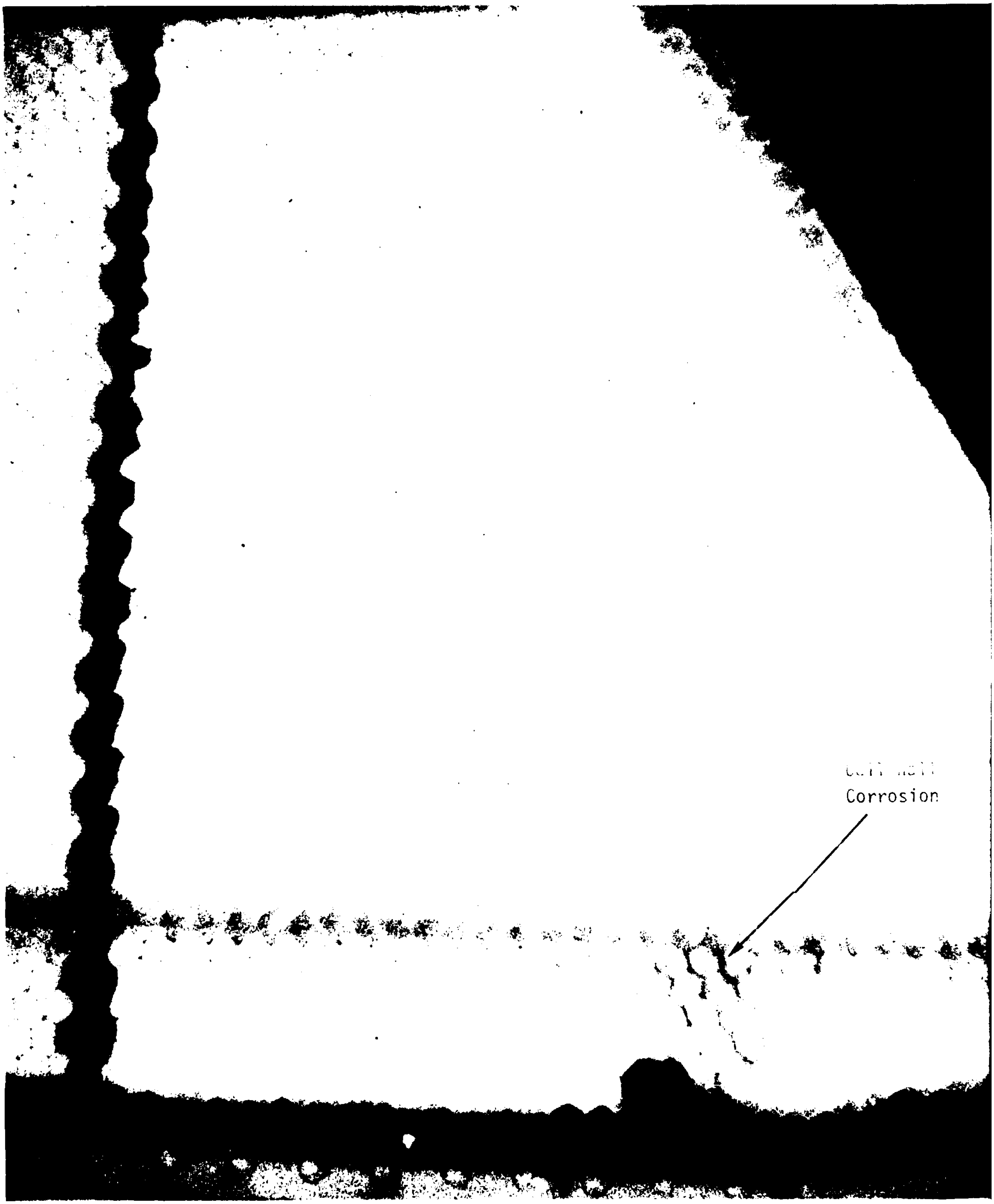


Figure 49N. Neutron Radiograph of F-111 Horizontal Stabilizer Tip Cap Indicating Cell Wall Corrosion

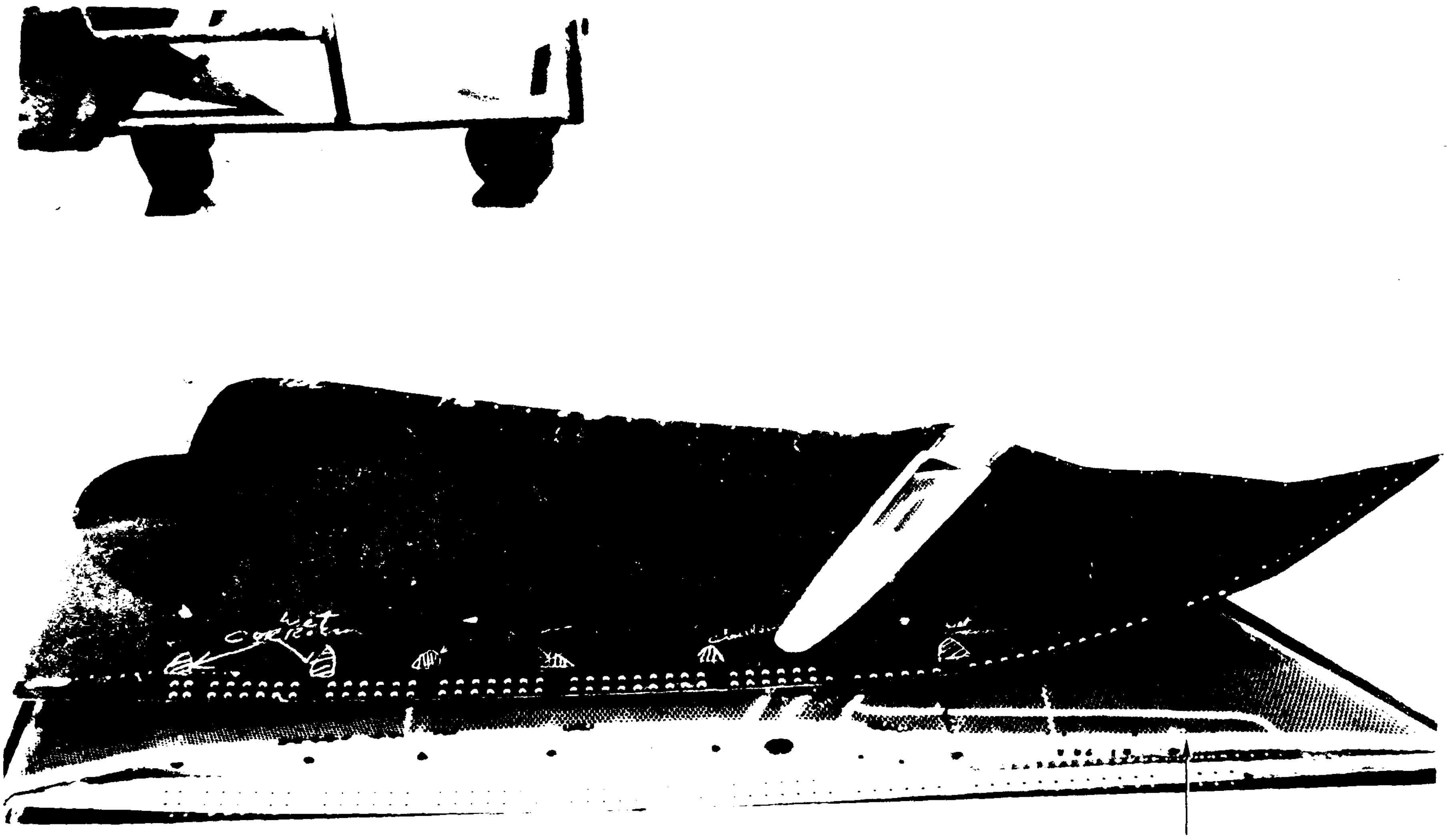


Figure 50. Photograph of Horizontal Stabilizer Tip Cap Showing Areas of Corrosion and Moisture

indicated in the neutron radiograph as noted by the arrow. This was verified by visual inspection after removal of the skin, as shown in the close-up photograph, Figure 51. Although acoustic emission indicated defects, x-ray inspection indicated no cell-wall corrosion.

A vertical stabilizer leading edge (removed from F-111 aircraft) was also inspected. The neutron radiograph revealed "worm-hole" type voids in the adhesive at the leading edge close-out bond. This type void in the critical leading edge location is a likely area for moisture to enter the honeycomb structure. This radiograph is shown in Figure 52N.

Another portion of the F-111 aircraft which was subjected to in-situ inspection by neutron radiography is the saddle tank cover area located above the engine bays. With the engines removed, the neutron inspection head was positioned inside the engine bay and the neutron beam directed upward toward the left hand saddle tank cover, as depicted in the inset photograph, of Figure 53N. One of the exposures indicating excessive adhesive and/or moisture in several of the honeycomb cells is shown as the figure.

A series of T-39 aircraft structures containing significant quantities of moisture and corrosion was made available for radiography throughout the duration of the operation. Since a T-39 aircraft was not available for moving to building 704 during the four week period of operation, All T-39 structures examined were specimens which had been removed from aircraft in the T-39 overhaul facility. One of the most severe cases of moisture and corrosion encountered was in a T-39 floor panel, Figures 54N and 55N. This pair of radiographs compares a 90 minute exposure using M film with a rapid 3 minute exposure using NDT 70 film, each used with the fast DC converter screen. Again, even the 3 minute radiograph images the moisture and corrosion with enough detail to evaluate the severity of the condition. Only a portion of the moisture in this panel was imaged by x-ray.

Figure 56N is the neutron image of a T-39 main landing gear door, exhibiting corrosion in the thin aluminum panel between the stiffeners, and in the stiffener itself in some areas. An x-ray of the same specimen is shown in Figure 56X. The x-ray also images the more severe areas of corrosion by indicating loss of metal in those areas and in some cases by imaging [illegible]

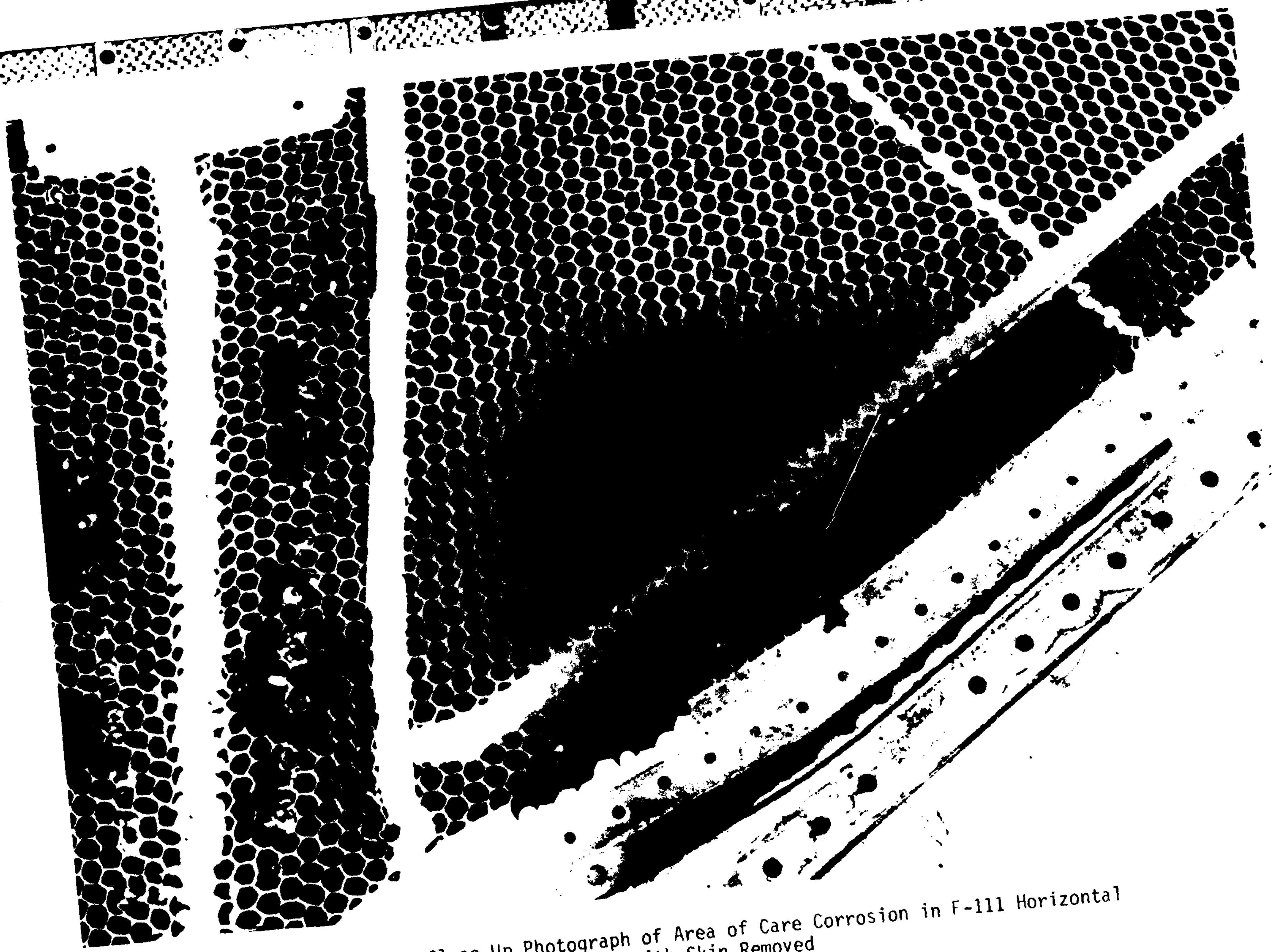


Figure 51. Close-Up Photograph of Area of Care Corrosion in F-111 Horizontal Stabilizer Tip Cap with Skin Removed

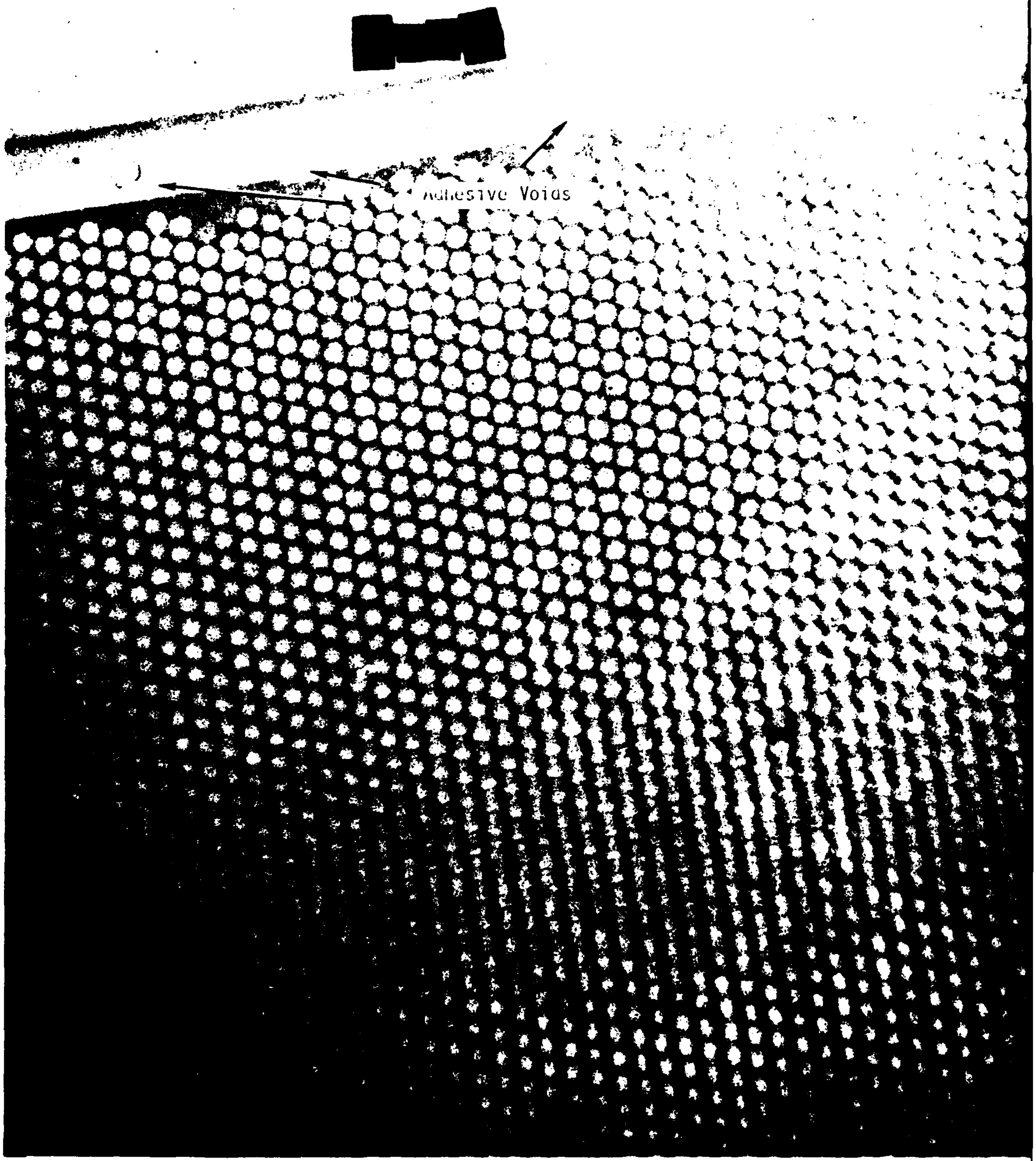


Figure 52N. 15-Minute Neutron Radiograph of Leading Edge of F-111 Vertical Stabilizer Showing "Wormhole" Voids in Adhesive

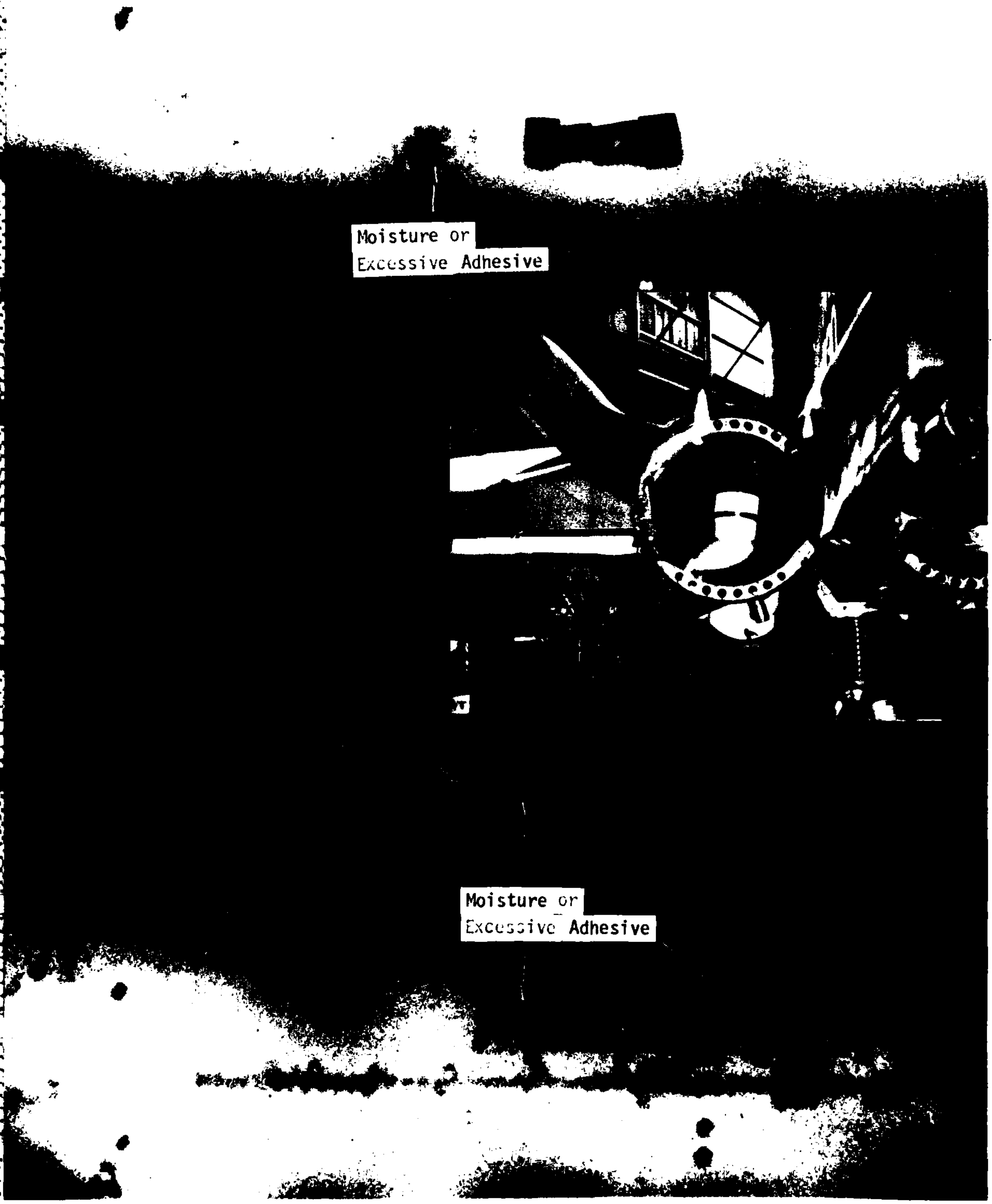


Figure 53N. In-Situ Neutron Radiograph of F-111 Saddle Tank Cover

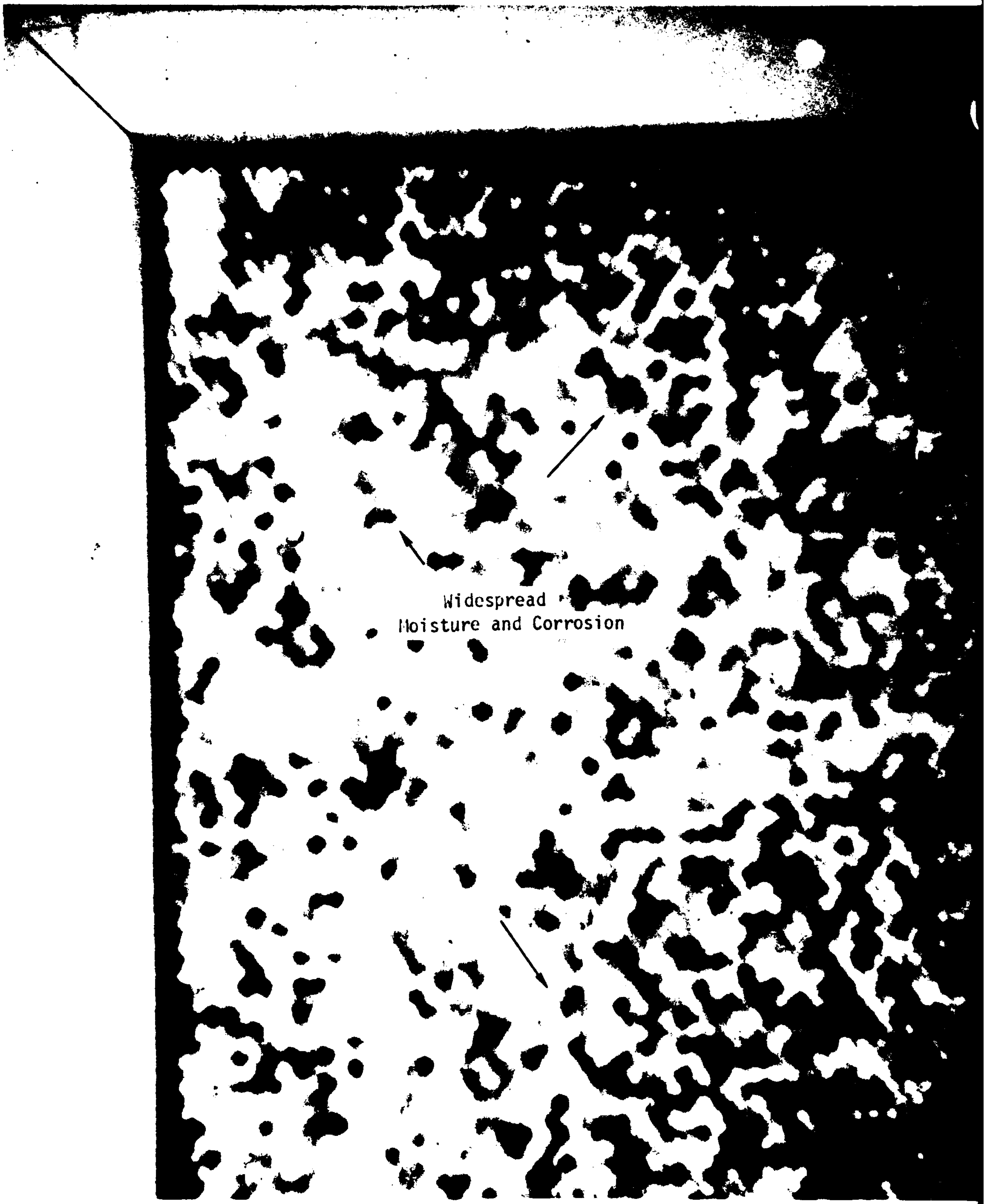


Figure 54N. Neutron Radiograph of T-39 Floor Panel Showing Large Quantities of Moisture and Corrosion (90 Minutes)

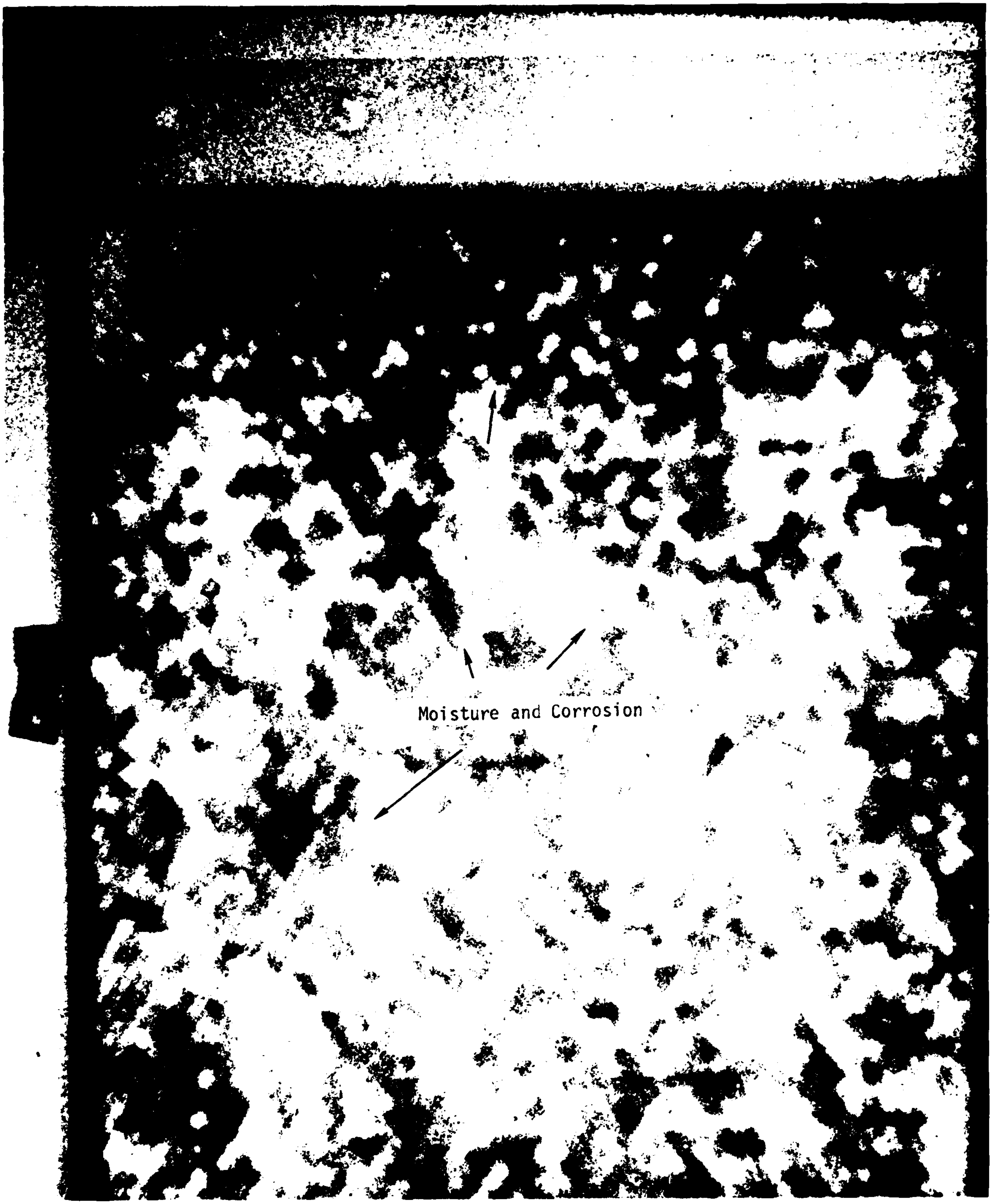


Figure 55N. Rapid Neutron Radiograph (3 Minutes) of T-39 Floor Panel Showing Moisture and Corrosion

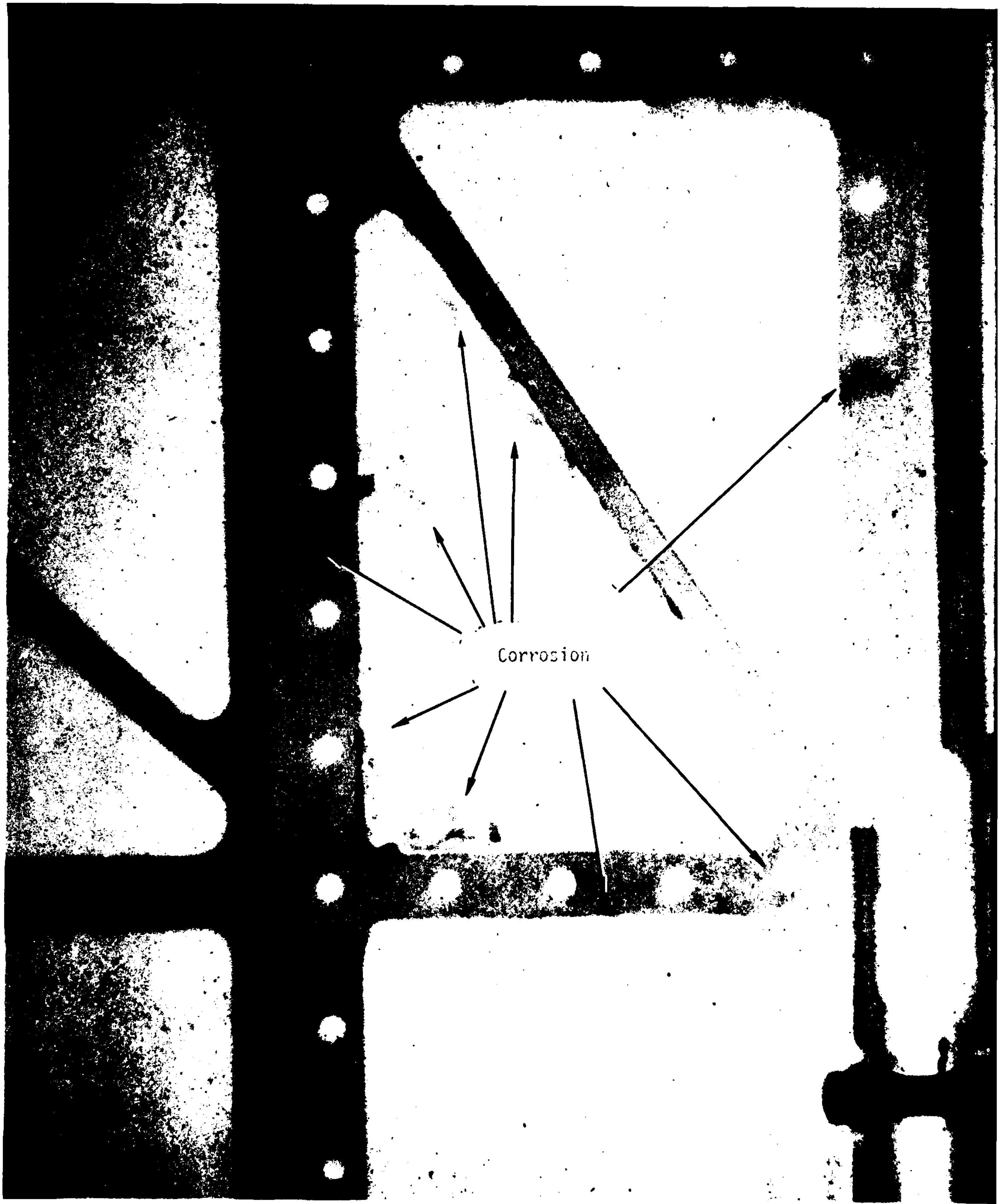


Figure 56N. Neutron Radiograph of T-39 Main Landing Gear Door Showing Corrosion

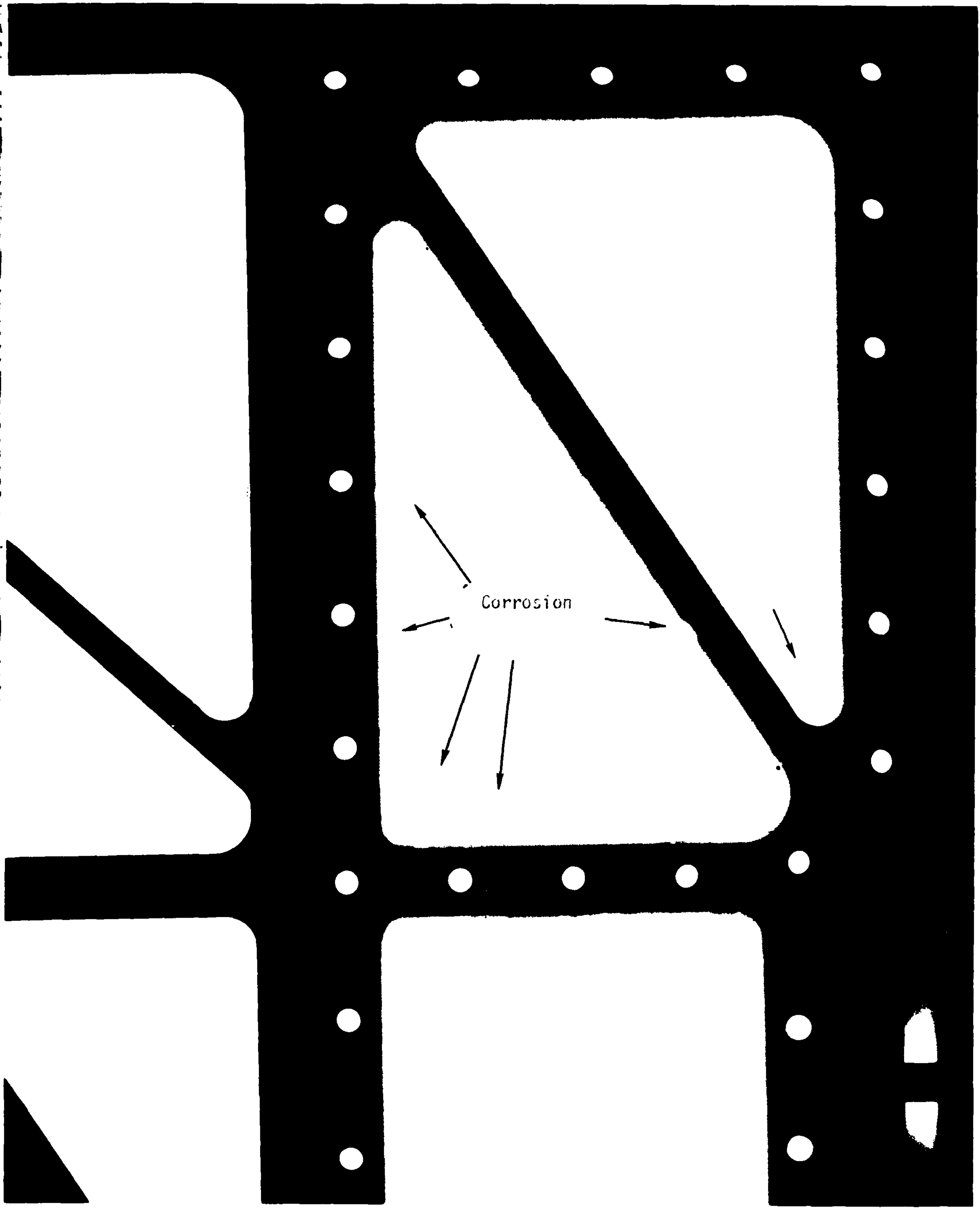


Figure 56X. X-Ray Radiograph of T-39 Main Landing Gear Door Showing Pitted Areas in Thin Webb Area associated with the corrosion products. The corrosion in the stiffener areas imaged by N-ray is not imaged by x-ray, however, due to the additional thickness of aluminum.

3.3.2.2 U. S. Army Yuma Proving Ground (USAYPG)

3.3.2.2.1 Facilities

Neutron radiography operations at USAYPG were performed in an area adjacent to the 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. Complete laboratory support was provided by YPG including lab personnel, as required.

An overview of the site of operation is shown in Figure 57. The concrete-block structure used for radiation shielding is shown in detail in Figure 58. Blocks were stacked in a staggered fashion to prevent radiation streaming through the cracks. A schematic diagram of the shielding is given in Figure 59. Figure 60 shows the control van.

3.3.2.2.2 Operational Safety

Army authorization to operate the radiation-producing device at USAYPG was granted under DARCOM Permit No. P42-81-01. An environmental impact statement, prepared earlier by AMMRC personnel, was accepted by the area Environmental Protection Agency office.

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

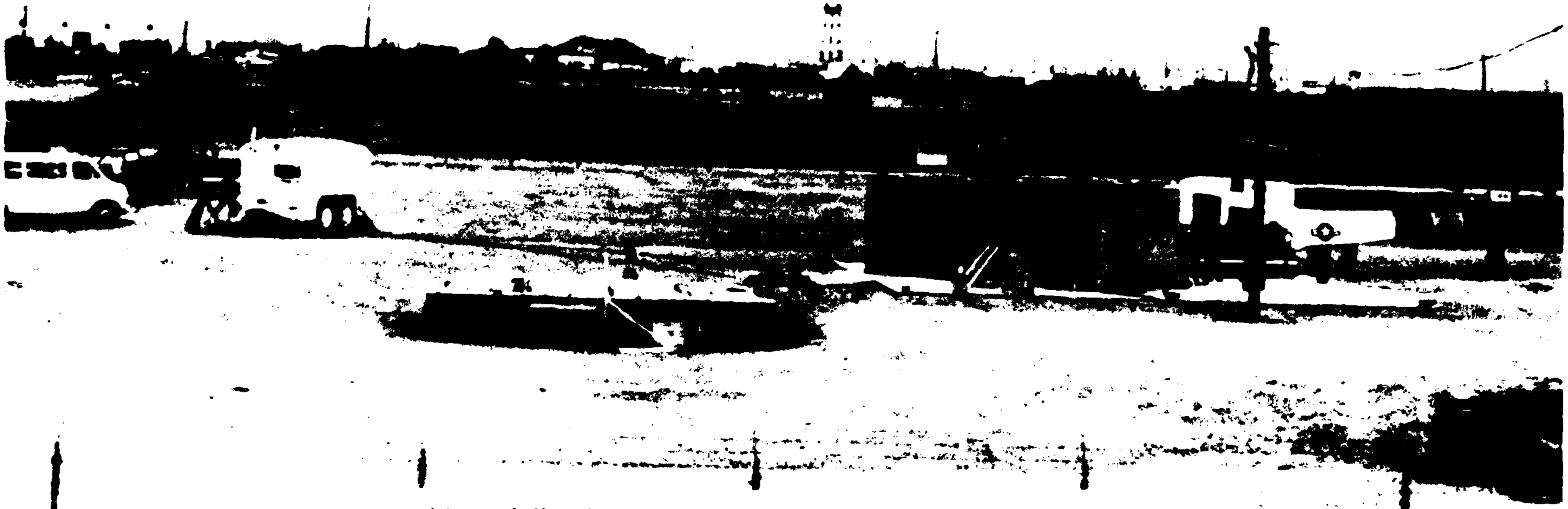


Figure 57. Site of Mobile Neutron System Neutron Radiograph, Operations - [illegible]
U.S. Army Yuma Proving Ground

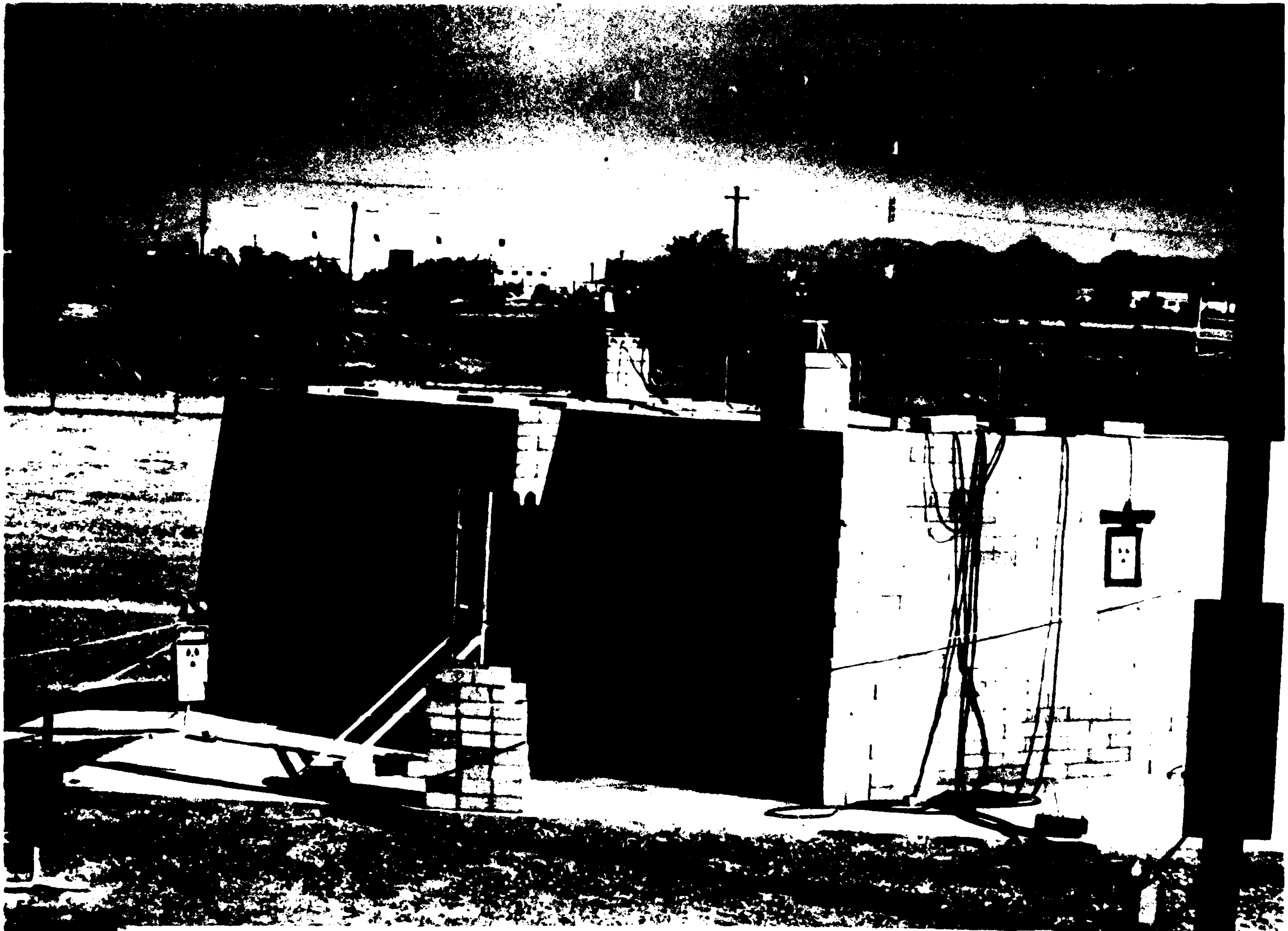


Figure 58. Concrete Shielding Structure for Neutron Radiography Operations

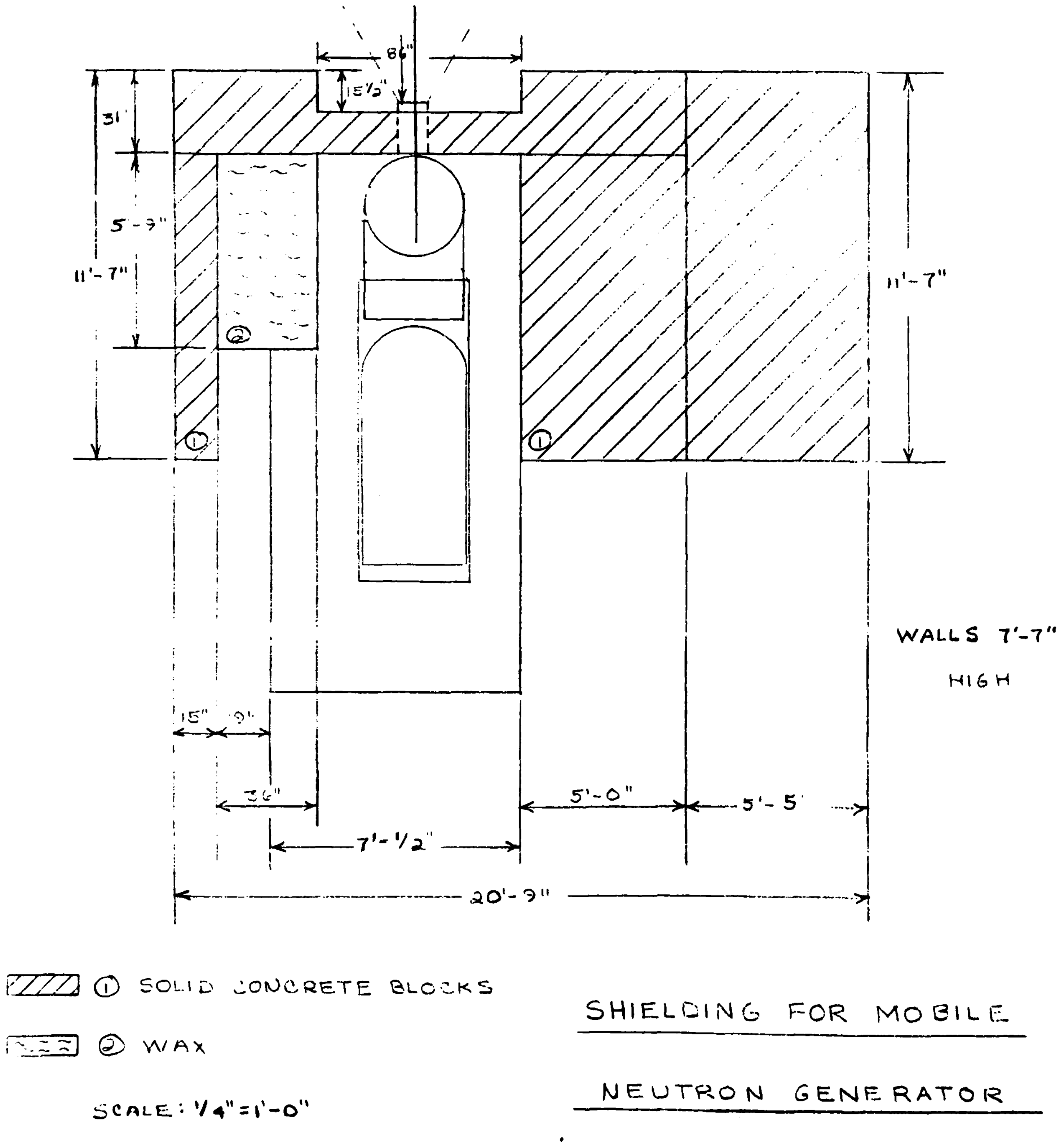
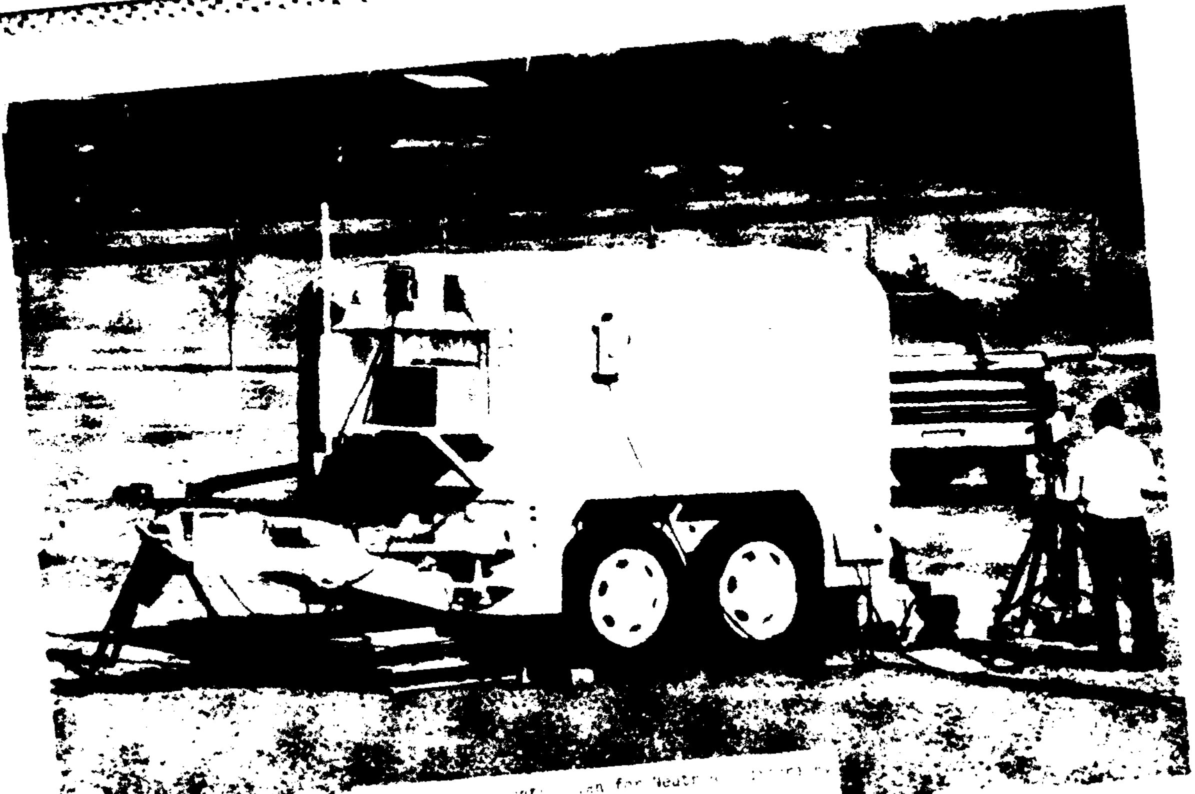
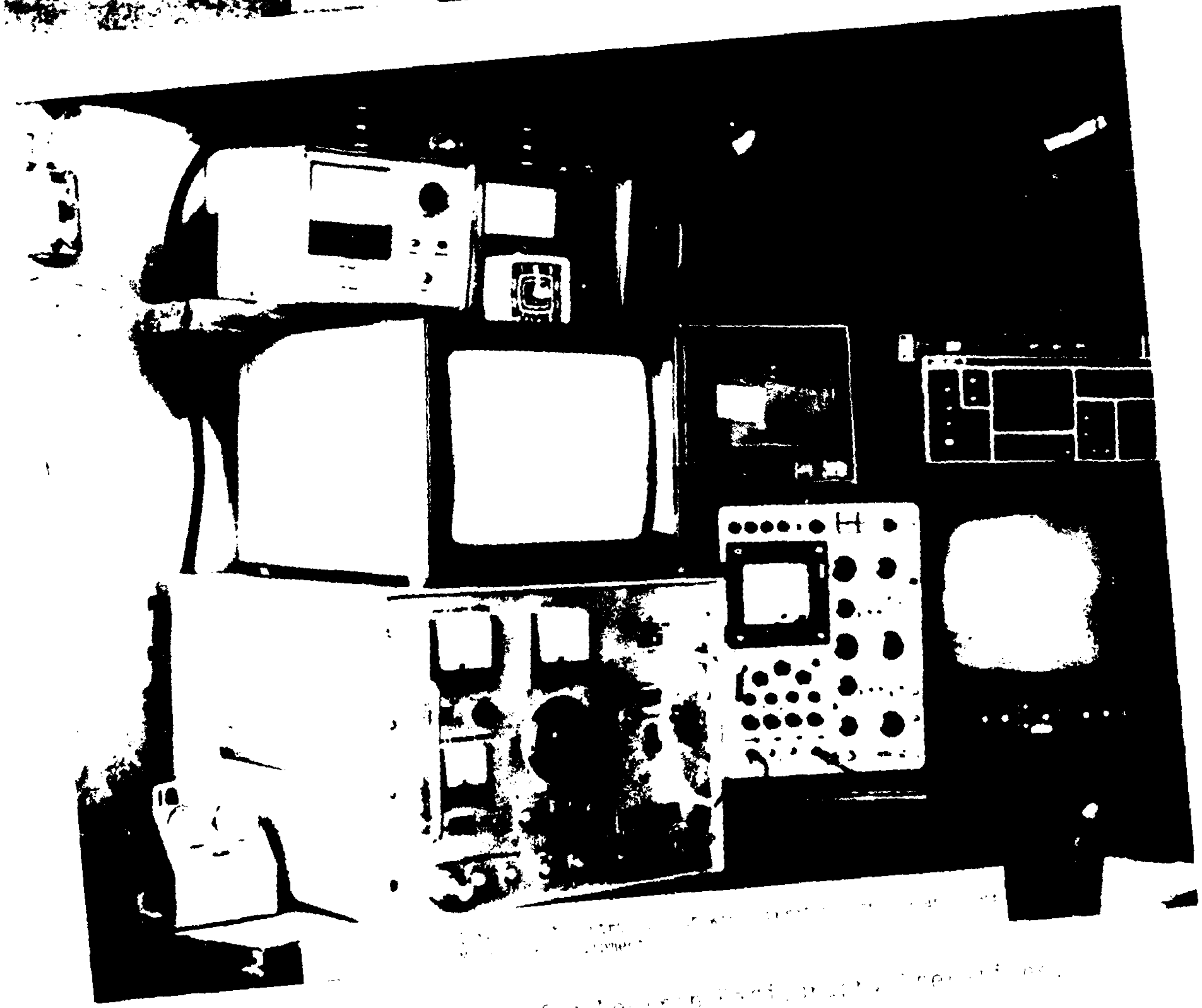


Figure 59. Schematic Diagram of Radiation Shielding for Neutron Radiography Operations



ontr [illegible] an for Neutr [illegible]
Operat [illegible]



[illegible]

Figure C[illegible] Control Van for Neutron Radiography Operations.

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. 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 Officers. The concrete and paraffin shielding, as well as distance, provided excellent biological protection, which lowered the control room radiation to well below acceptable levels.

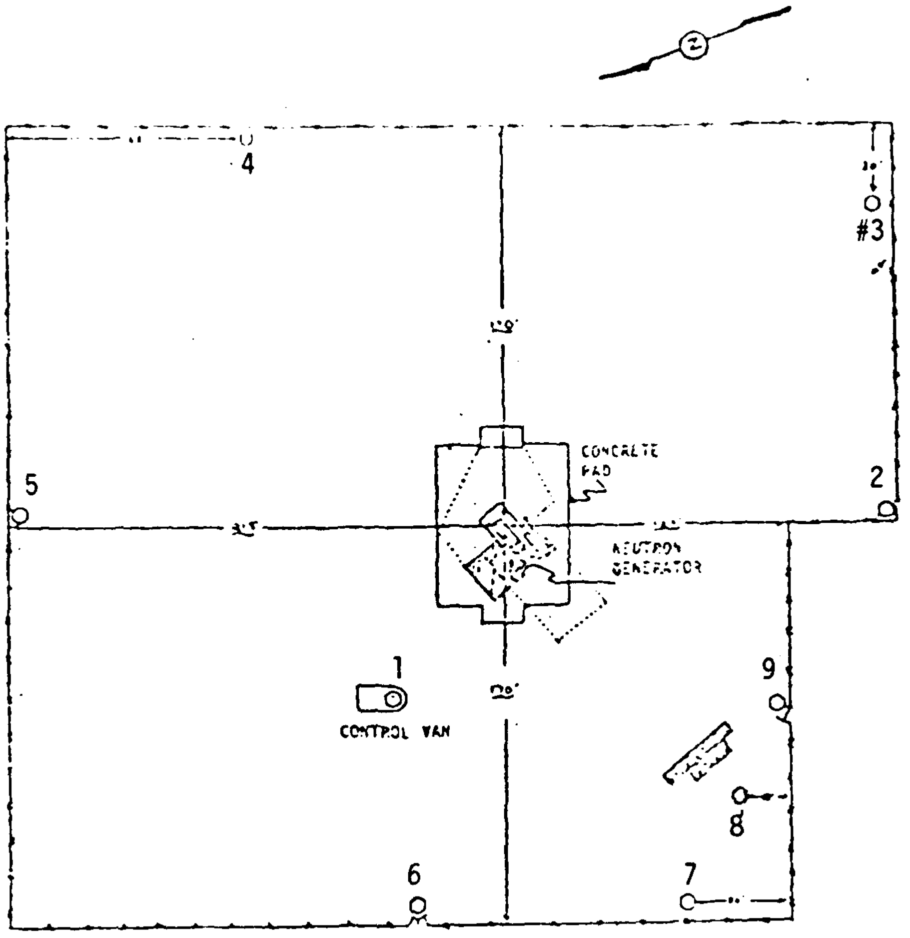
Radiation levels for neutrons and x/gammas outside the controlled area and within the control station during radiography operations were substantially lower than values acceptable by NRC regulation 10 CFR. Figure 61 shows the results of dose rate measurements at various locations around the perimeter of the controlled area, and at the control van. Dose rates measured inside the controlled area, in the immediate vicinity of the neutron radiography source, are shown in Figure 62.

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.

3.3.2.2.3 Radiography

All radiography specimens were provided by YPG technical personnel. Effort was concentrated on the application of neutron radiographic inspection to specific 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.

The majority of radiography runs were made using a fast, high-contrast Vought experimental converter screen, designated DC, or a medical screen,

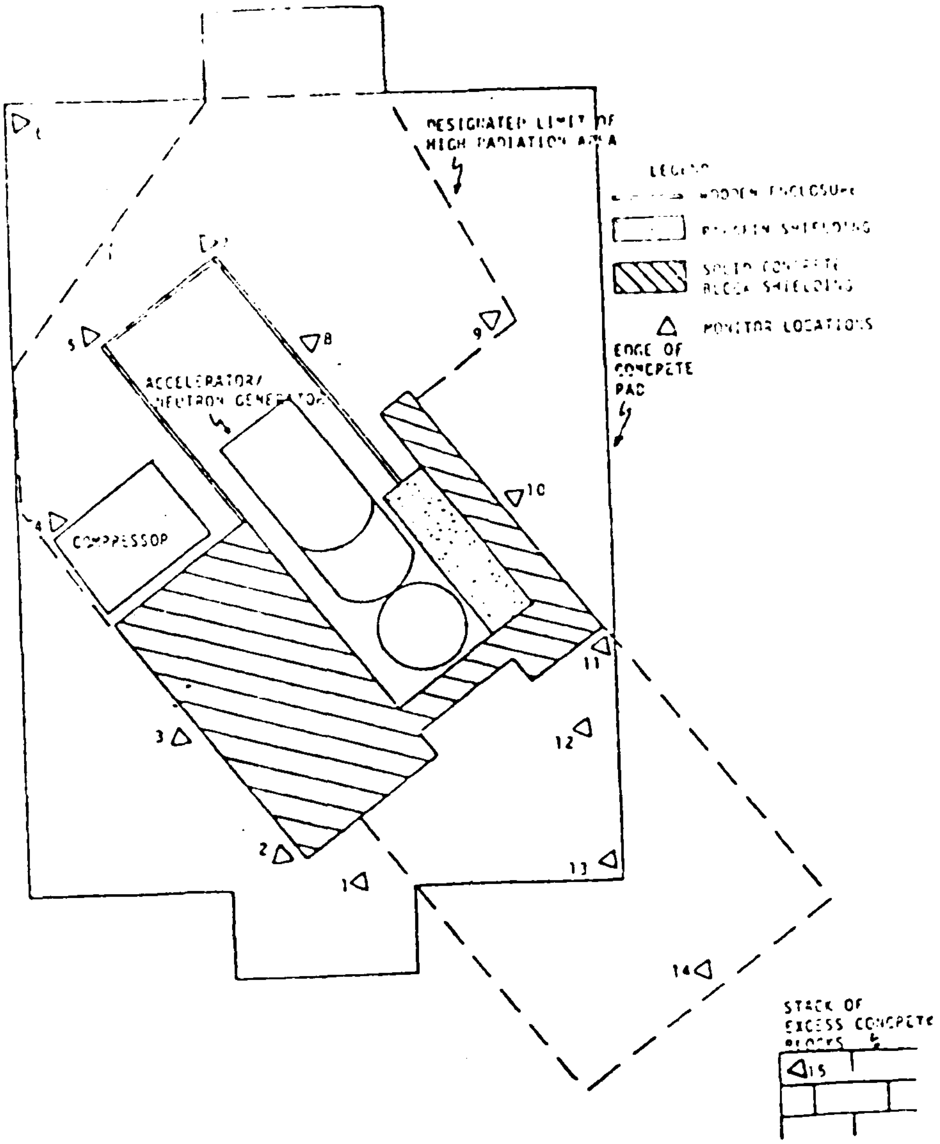


SYMBOLS:
—x— Fence Line
—⋀— Gate
▨ Solid Concrete Block (shielding)
▭ Paraffin (shielding)
.... Designated Limit Of High Radiation Area
○ Radiation Measurement Point

DOSE EQUIVALENT RATES (mRem/hr)

LOCATION	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 61. 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 62. Dose Rate Measurements in Vicinity of Neutron Generator Radiography Source, Inside Controlled Area

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.

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 neutron 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 one case, the corresponding x-ray radiograph is shown, for representative comparisons.

The items shown in the radiographs of Figures 63X and 63N are, left to right, Safe and Arm device (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).

On the X-ray, Figure 63X, 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 XM599, 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 63N, on the left is an image of the S&A (2 each) 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

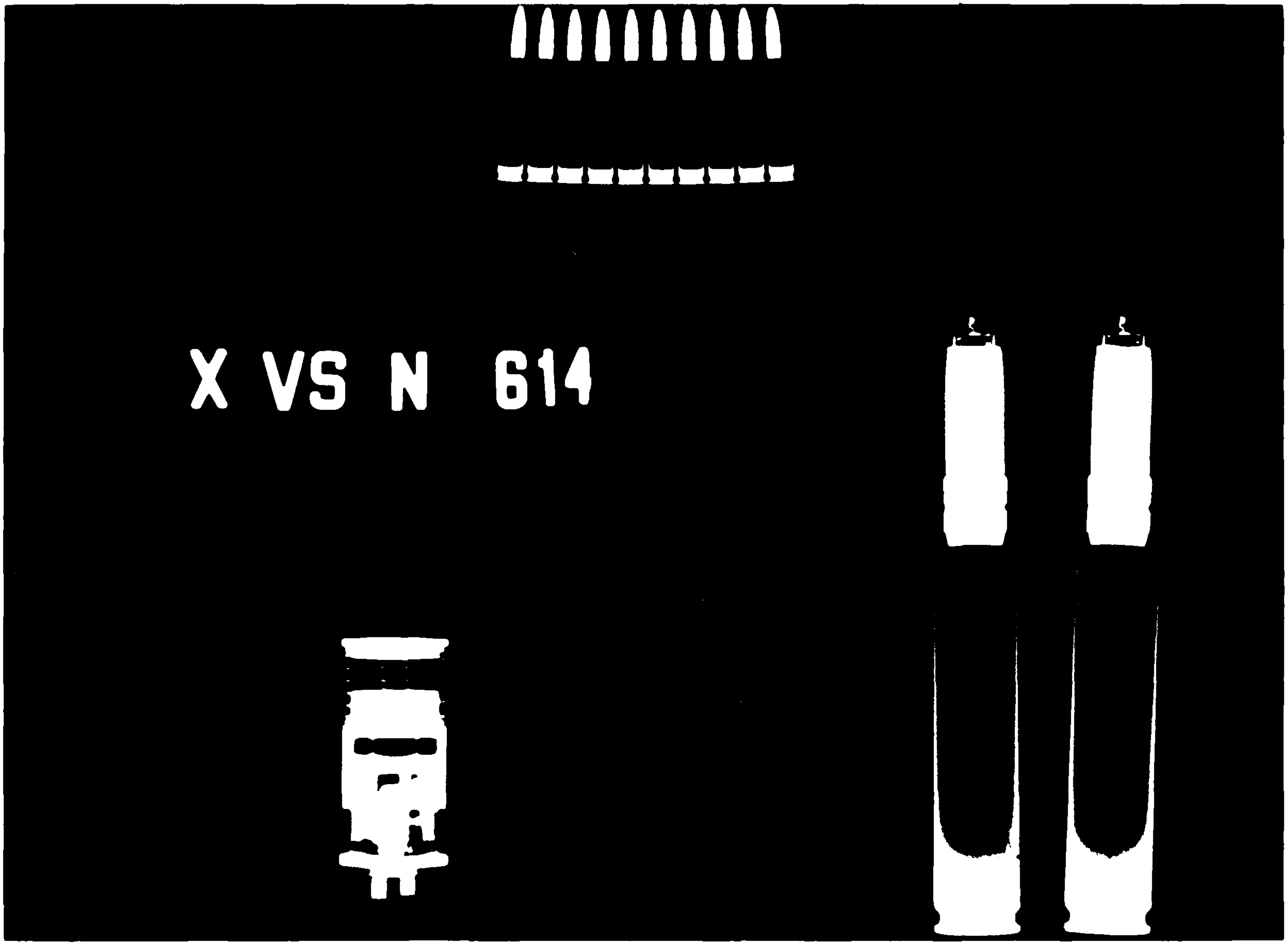


Figure 63X. X-Ray Radiograph of 2.75 Rocket Fuse, 20 mm XM599 Projectile, 7.62 mm Projectiles

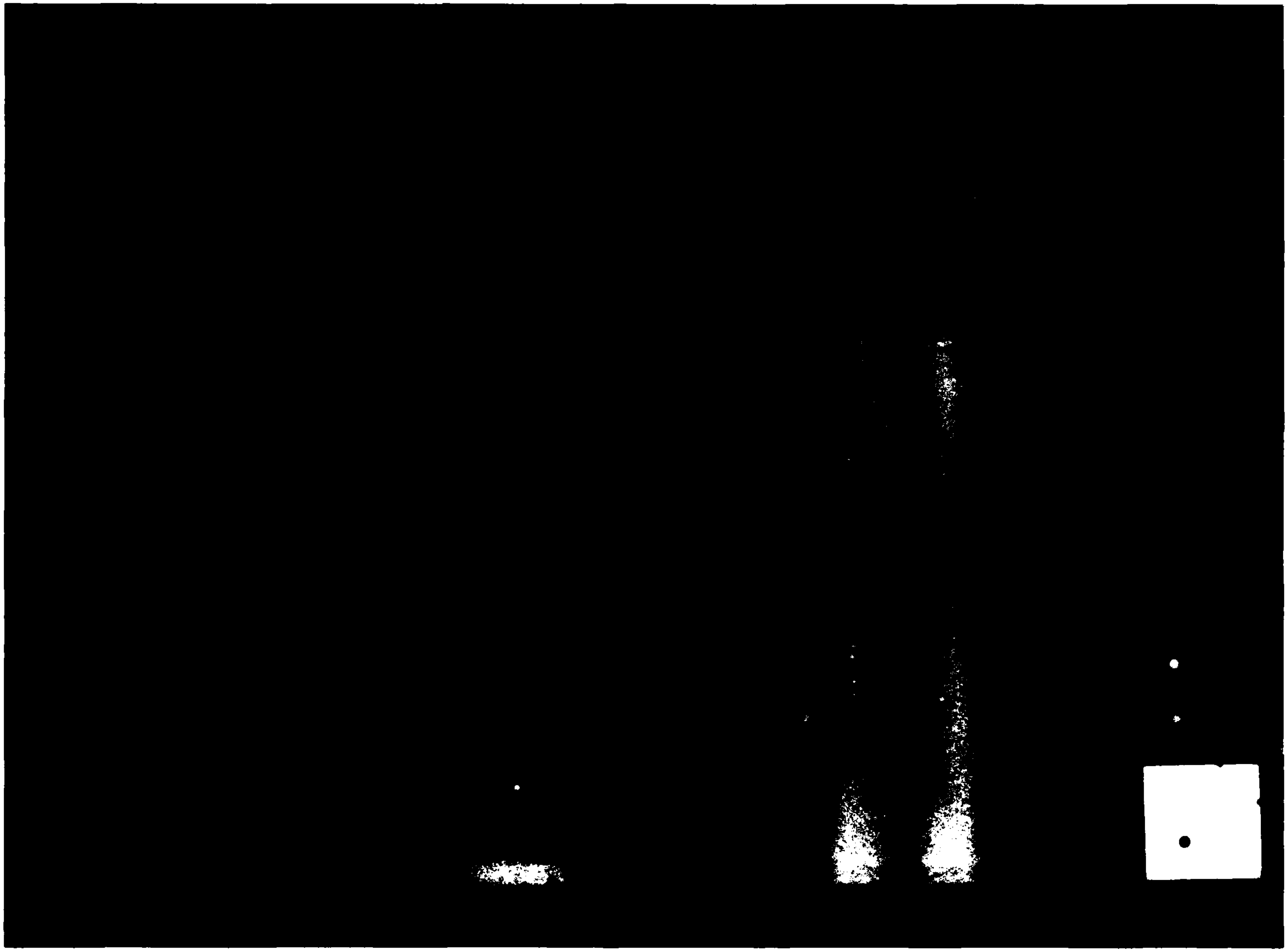


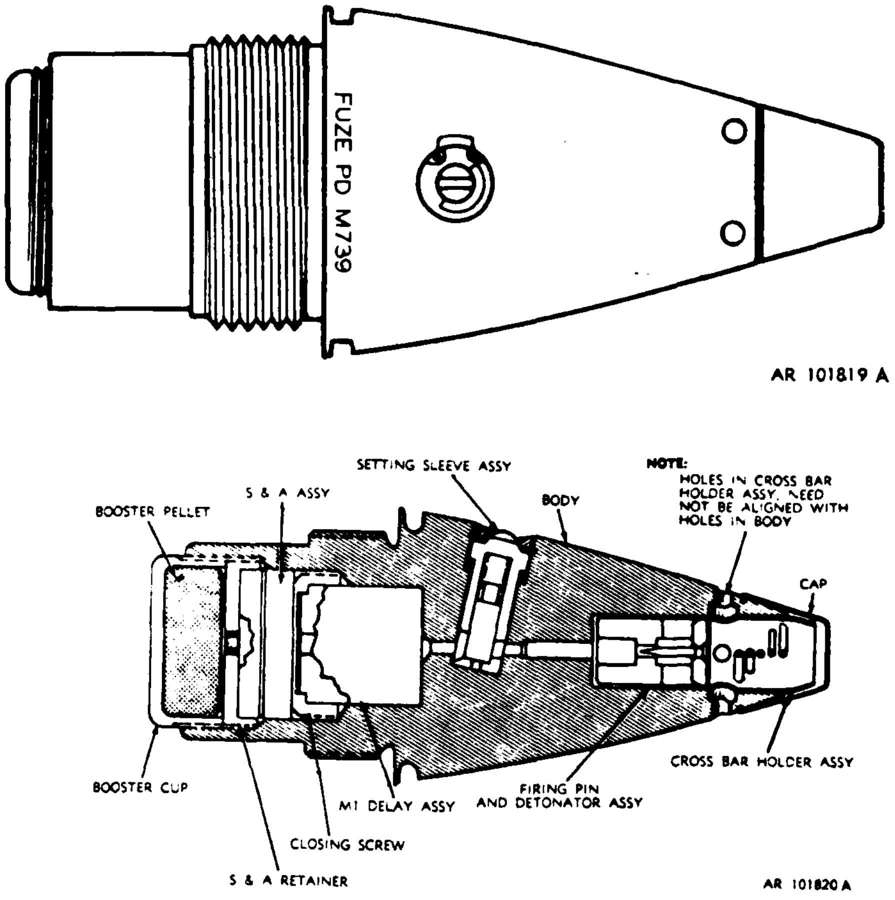
Figure 63N. Neutron Radiograph of S&A Device from M718 Mine, 2.75 Rocket Fuse, 20 mm XM599 Projectile, 7.62 mm Projectile

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.

Figures 64 and 65 are illustrations of two types of common ordnance fuzes. These fuzes, along with some additional items, are the specimens shown in the neutron radiograph of Figure 66N. The items imaged are: left-to-right, bottom -20 and 30 mm projectiles M577 fuze, M564 fuze, M739 fuze, M115A2 simulator, top three different types of ignition cartridges for 81 mm mortars. In three fuzes, bottom center, several components/parts are shown on the NR which would not be imaged by 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 (withe 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. 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. Exposure parameters used in this neutron radiograph were: Film Kodak SB; converter - Lanex Fine; L/D=36; Exposure time - 30 min. at full output.

The neutron radiograph presented in Figure 67N 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. As seen in the X-ray radiograph of these projectiles, Figure 67X, the internal portions of the flash tube are not imaged and hence, as mentioned above, the X-ray method cannot be used to detect this unsafe condition.

FUZE, POINT DETONATING: M739



AR 101819 A

NOTE:
HOLES IN CROSS BAR HOLDER ASSY. NEED NOT BE ALIGNED WITH HOLES IN BODY

AR 101820 A

Figure 64. Diagrams of M739 Point Detonating Fuze.

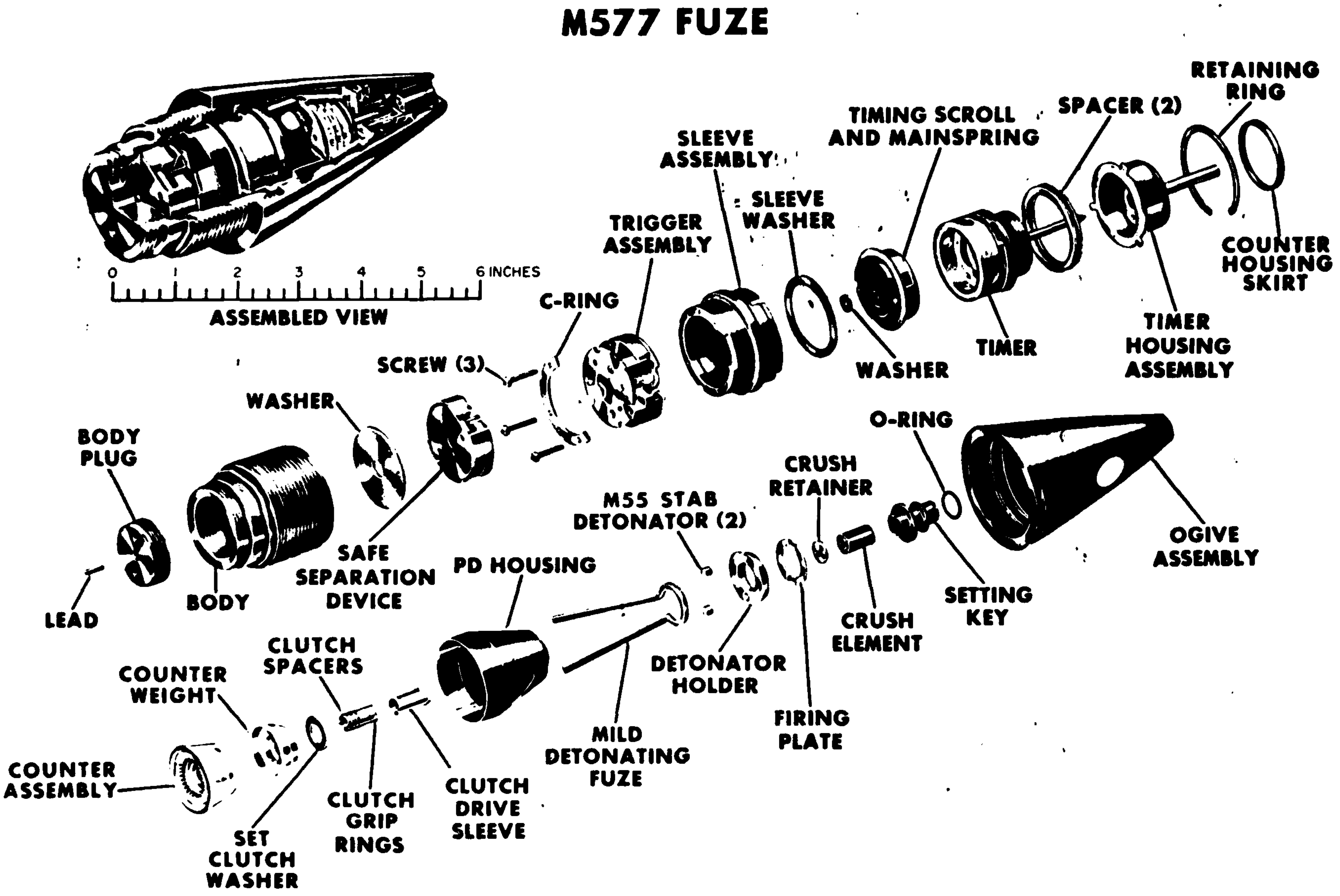


Figure 65. Diagram Showing Components of M577 Fuze

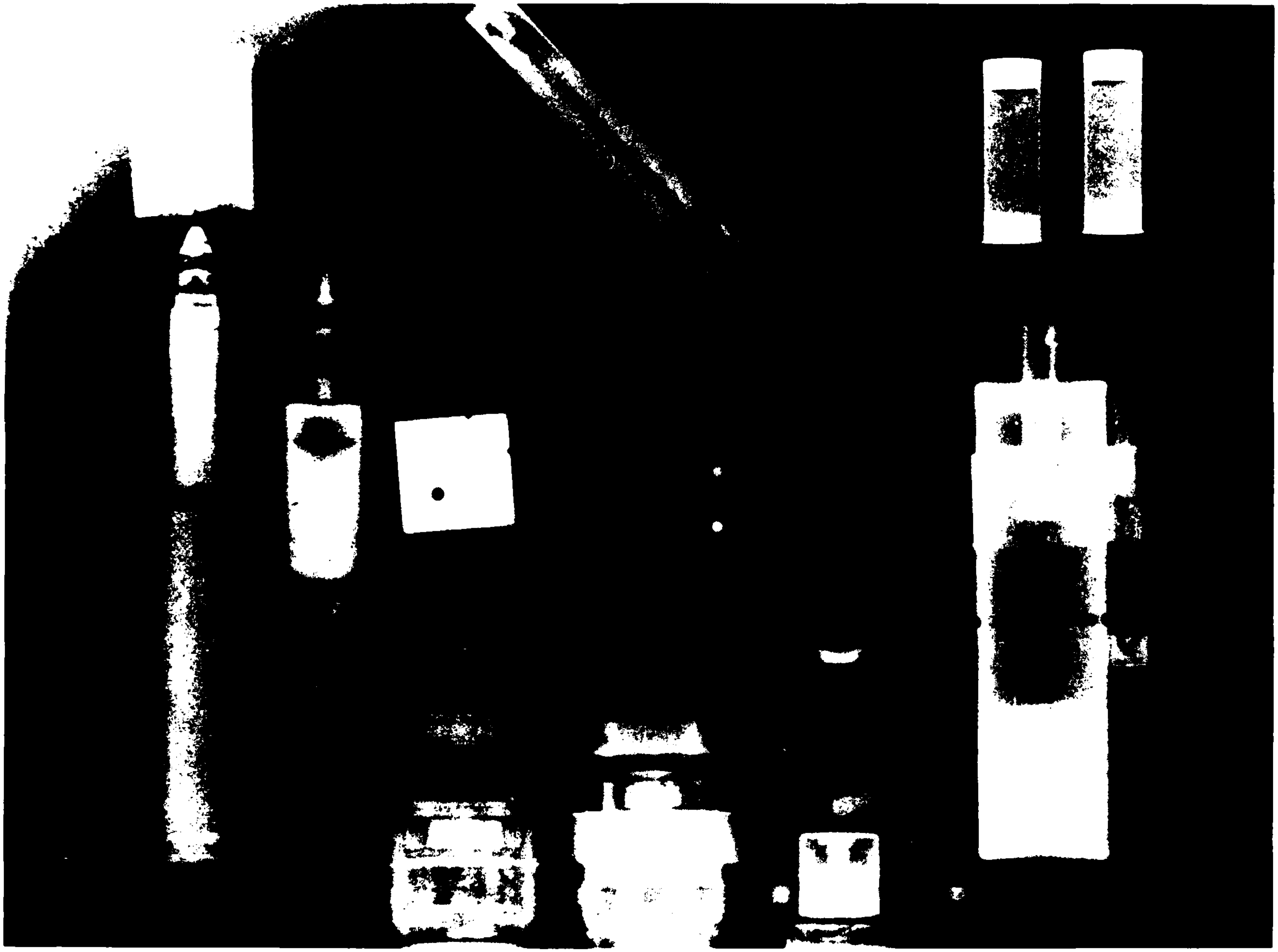


Figure 66N. Neutron Radiograph of M739, M564 and M577 Fuzes and Additional Munitions Items

Figure 67N. Neutron Radiograph of 30 mm XM Projectiles Showing Unacceptably Random Positions of Flash Elements Along Projectile Axes (Bottom of Projectiles)

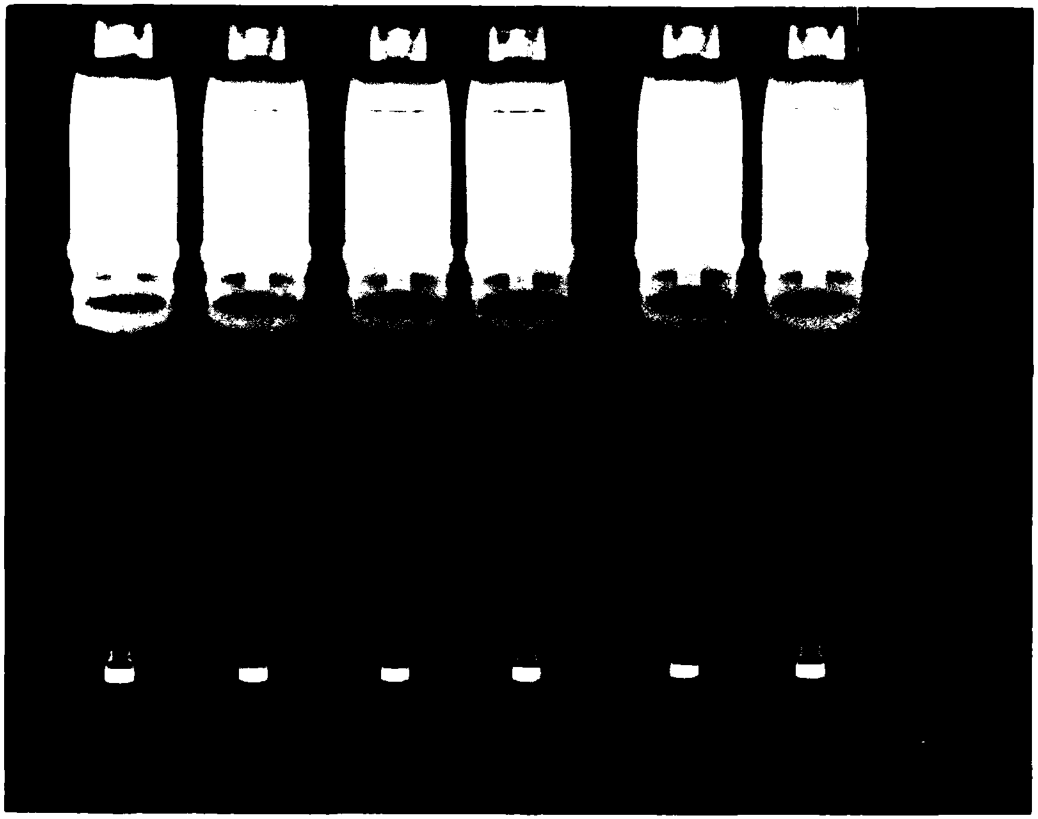


Figure 67X. X-Ray Radiograph of 30 mm XM Projectiles

The next series of neutron radiographs, Figures 68N through 73N, 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 68N: An example of results obtained with a very fast film/screen combination: DuPont NDT 91/Vought DC-4. Exposure time 4 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 69N: Film/screen - DuPont NDT-75/Vought DC-4; exposure time 40 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 70N: DuPont NDT 65/Vought DC-4; exposure time 45 minutes 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 71N: DuPont NDT 55/Vought DC-4; exposure time 45 minutes 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

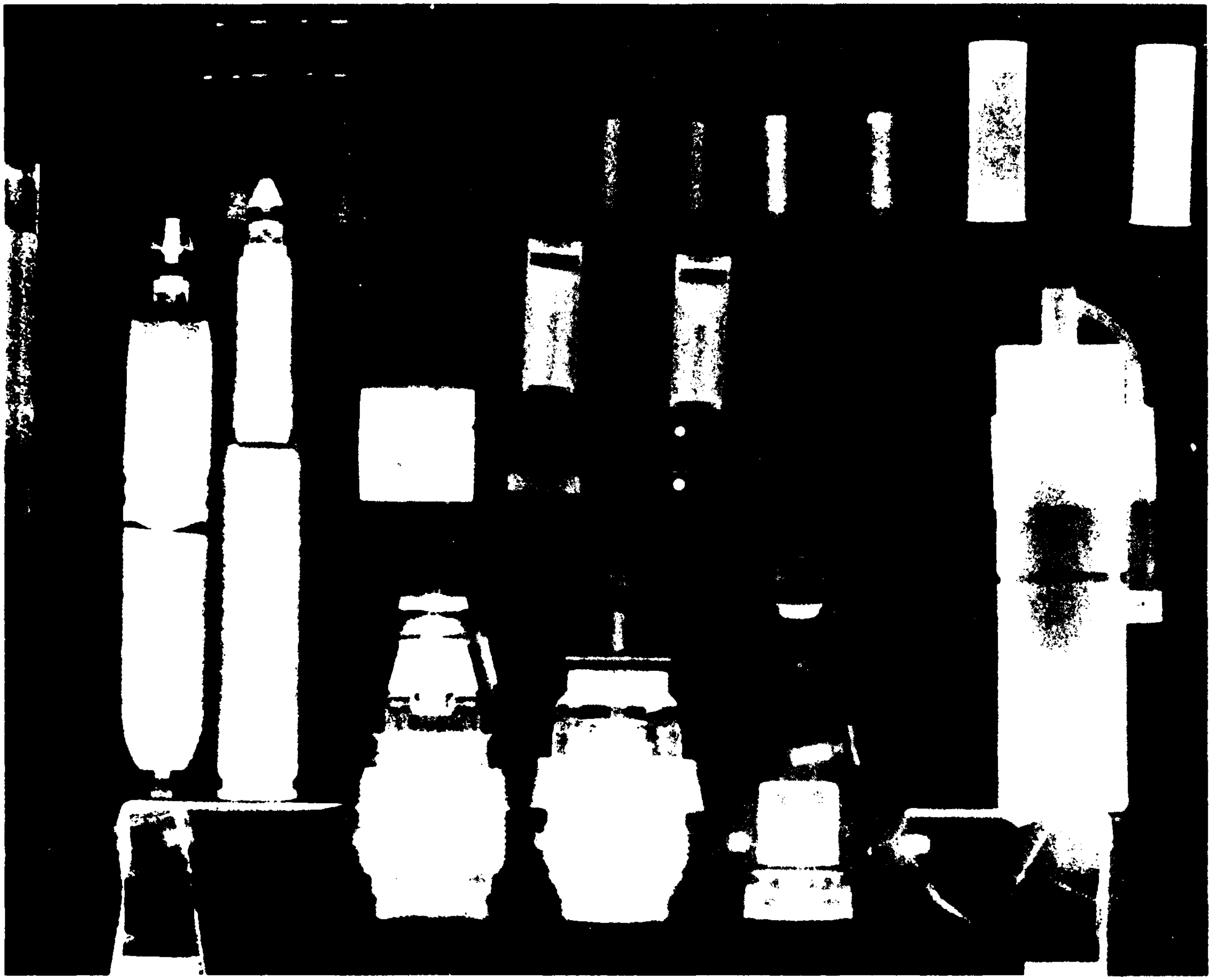


Figure 68N. Neutron Radiograph of Various Ordnance Devices, Film/Converter: DuPont NDT 91/Vought DC-4

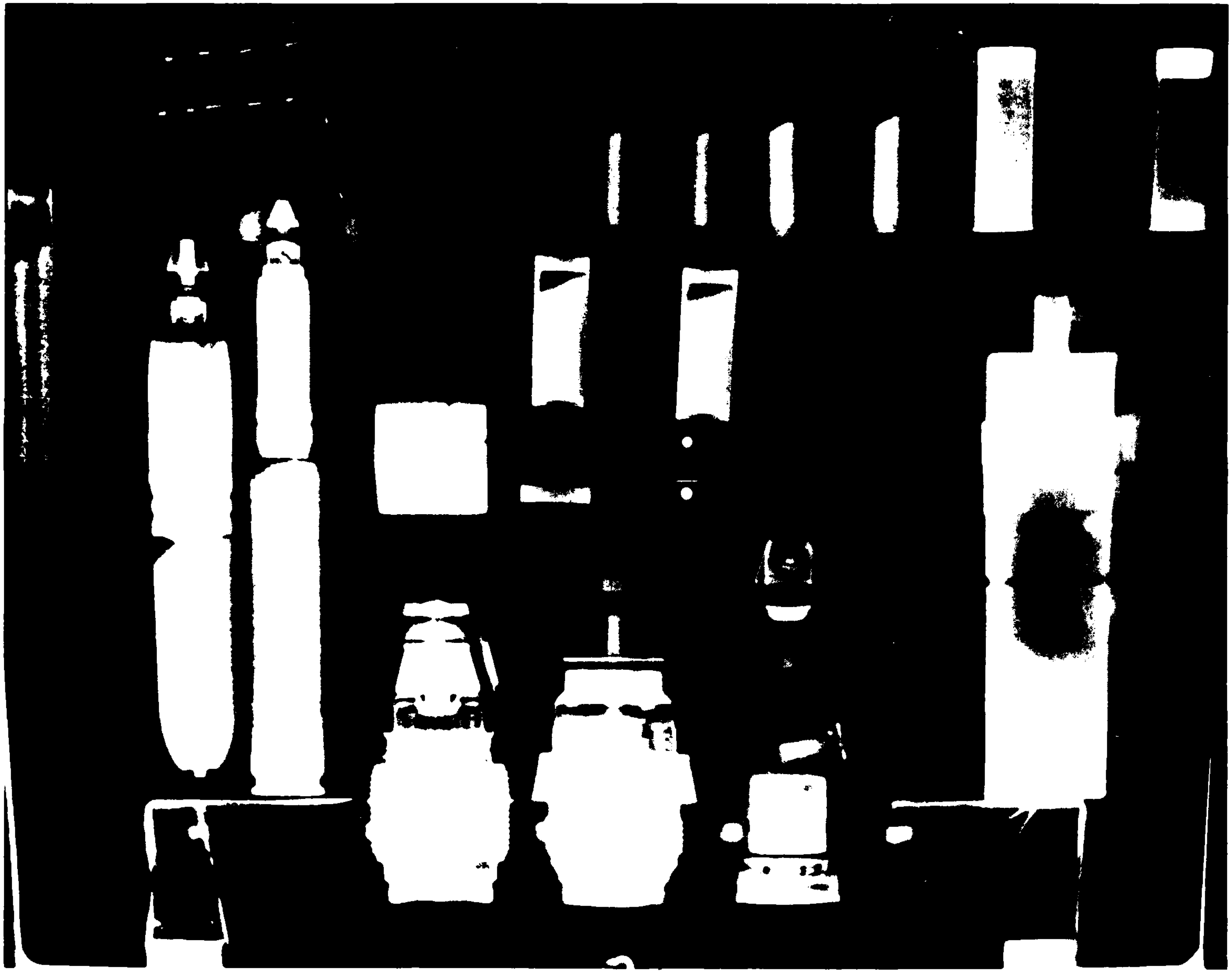


Figure 69N. Neutron Radiograph of Various Ordnance Devices, Film/Converter: DuPont NDT 75/Vought DC-4

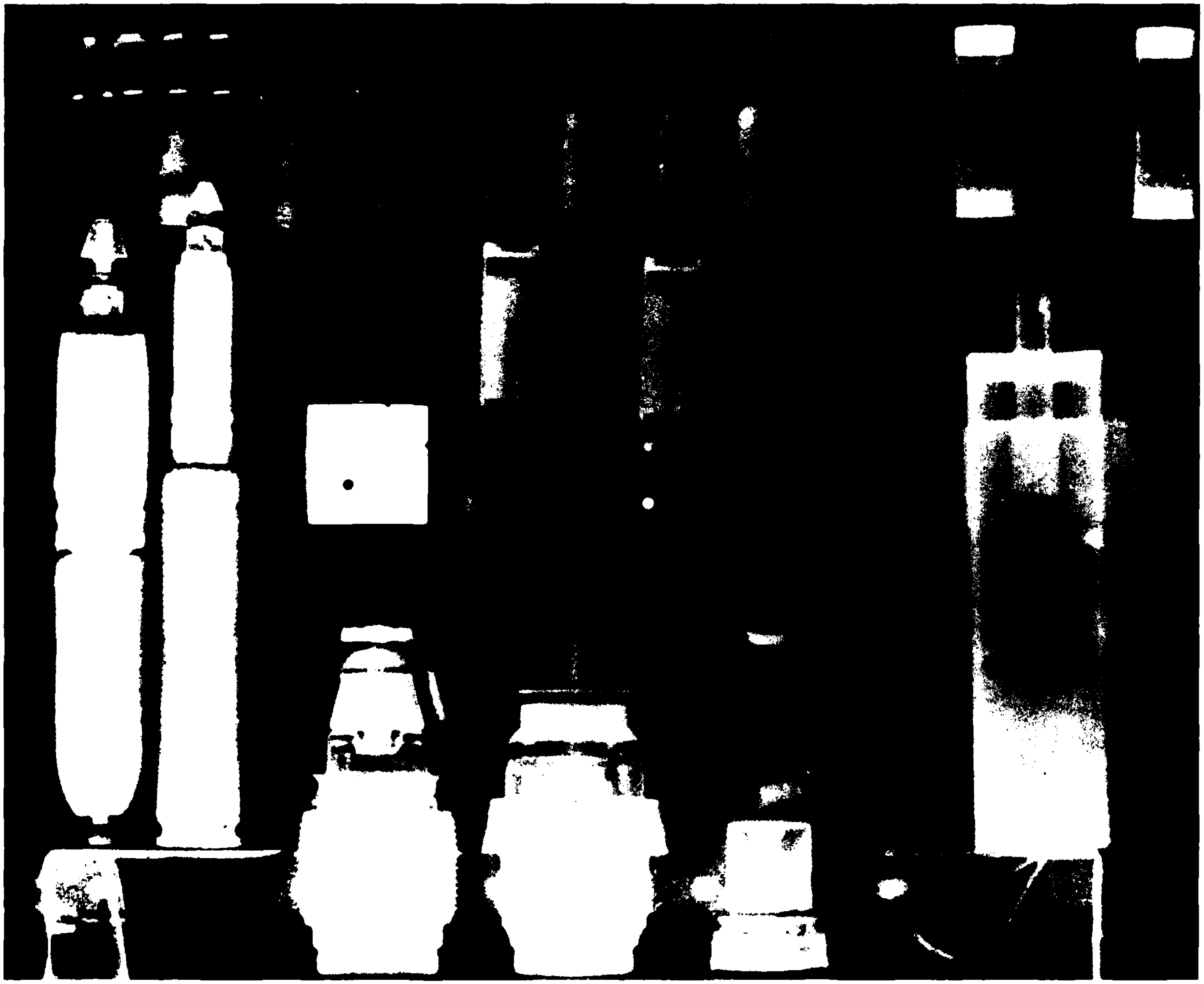


Figure 70N. Neutron Radiograph of Various Ordnance Devices, Film/Converter: DuPont NDT 65/Vought DC-4

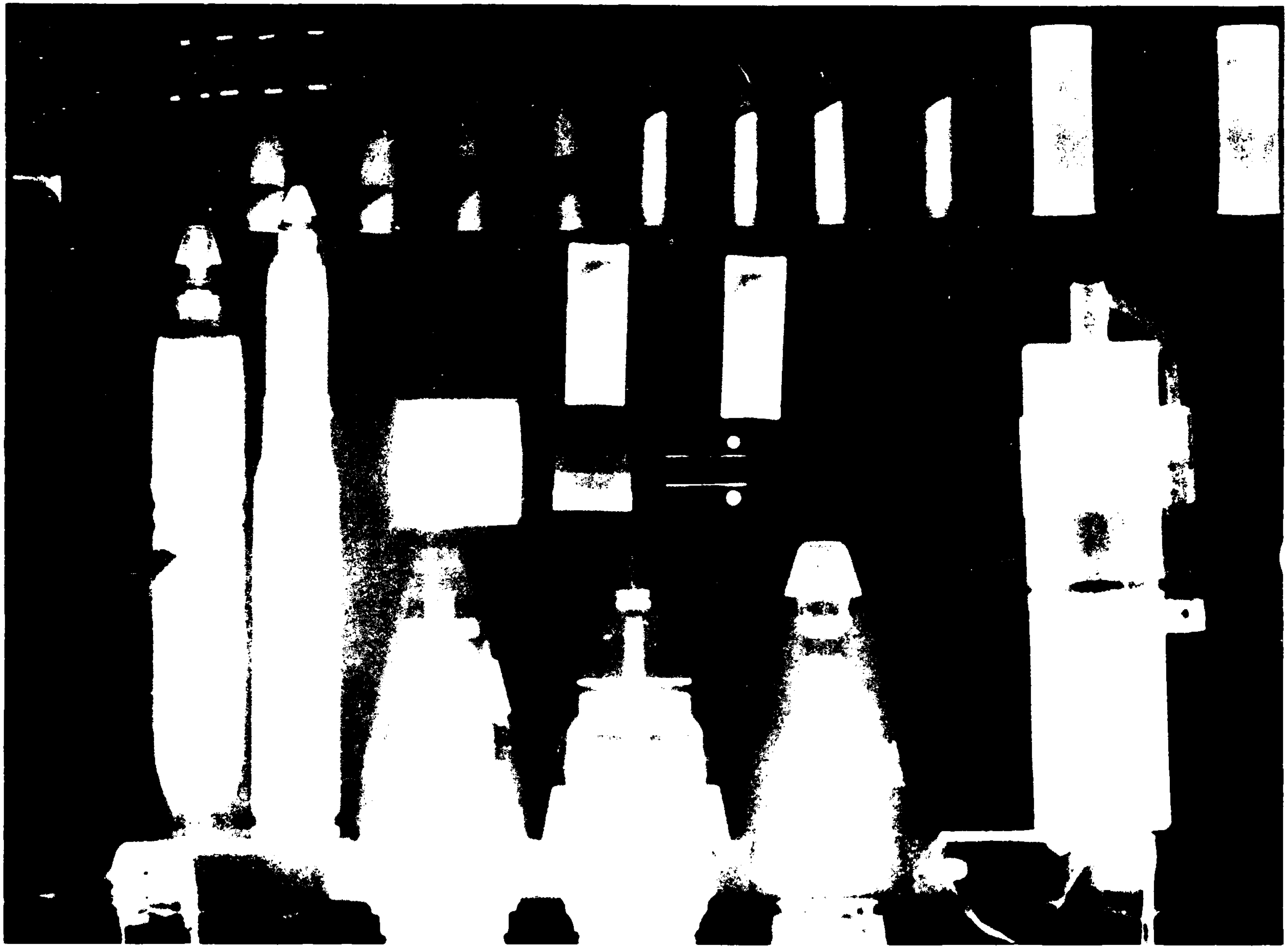


Figure 71N. Neutron Radiograph of Various Ordnance Devices, Film/Converter: DuPont DTD 55/Vought DC-4 is not offset by the slight gain in image sharpness over the NDT 75 film, and hence does not appear to be as useful for mobile neutron radiography.

Figure 72N: Kodak SB/Lanex Fine; exposure time 45 minutes 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 73N: Kodak AA/Gadolinium; exposure time 5-1/2 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 62, 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.

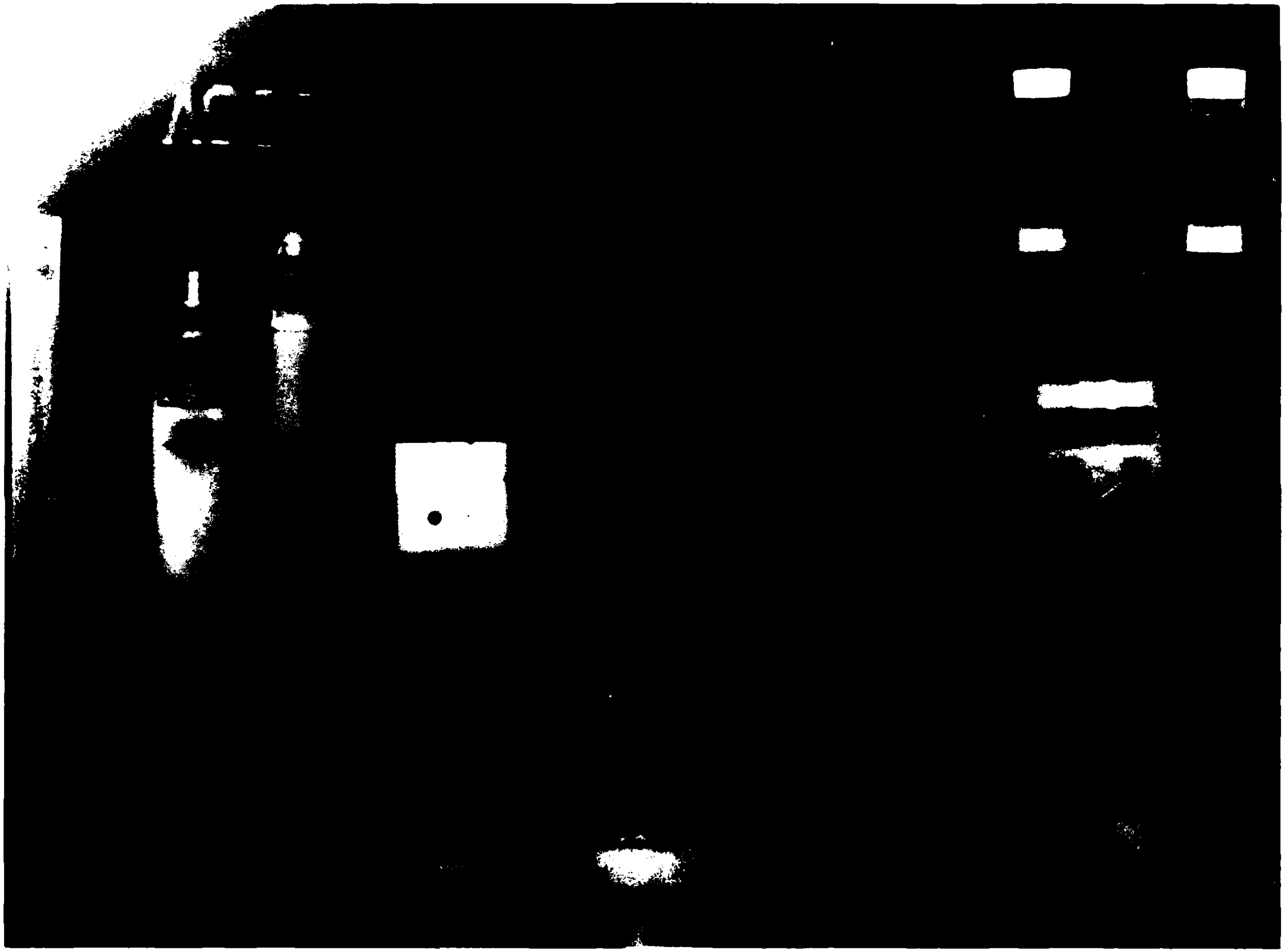


Figure 72N. Neutron Radiograph of Various Ordnance Devices, Film/Converter: Kodak SB/Kodak Lanex Fine

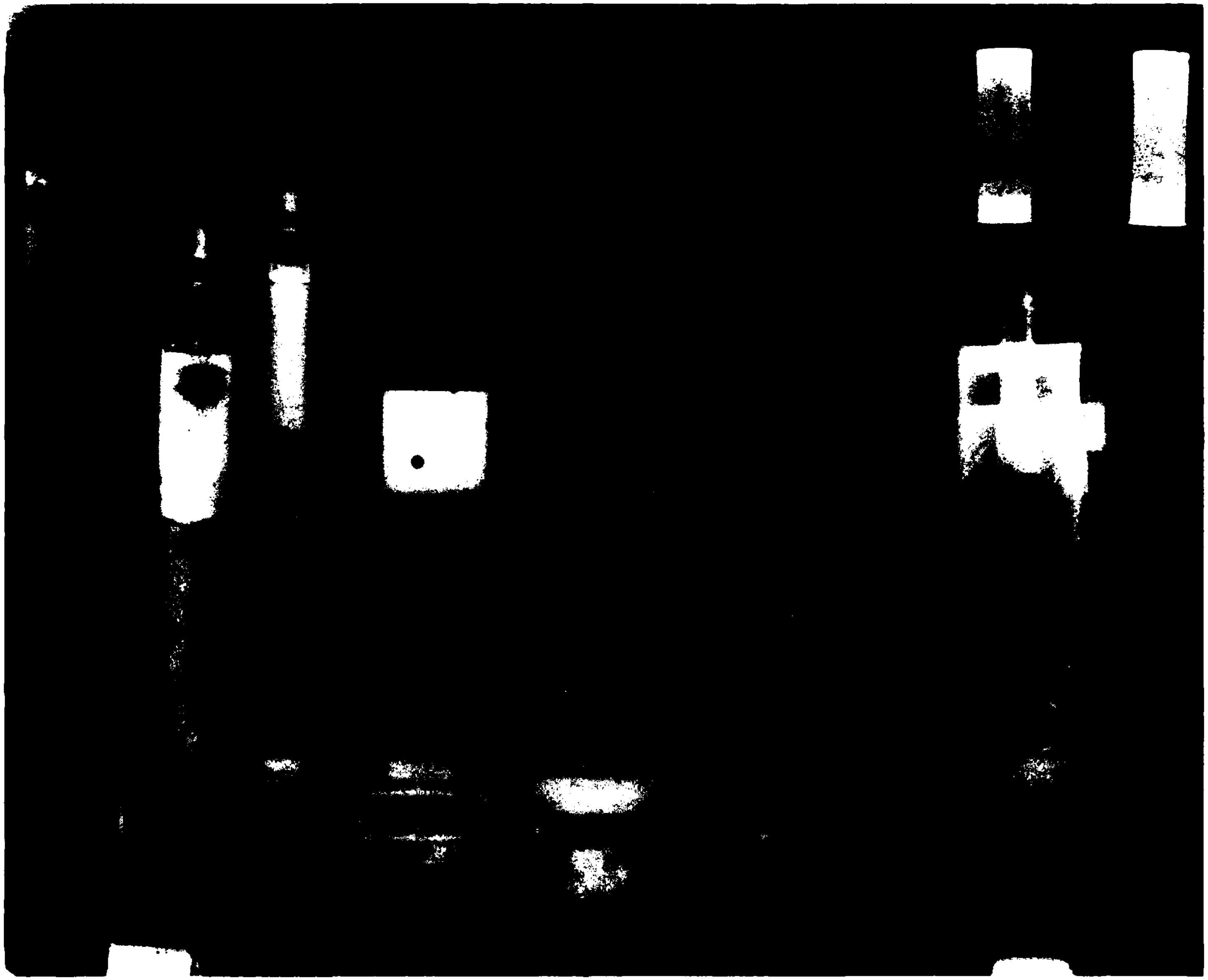


Figure 73N. Neutron Radiograph of Various Ordnance Devices, Film/Converter: Kodak AA/Gadolinium

4.0 SYSTEM INSTALLATION AT AMMRC

At the end of the evaluation phase, the mobile neutron radiography system was refurbished by Vought. Upon completion of the refurbishment, the system was shipped to AMMRC for installation. A one week training program was carried out by Vought personnel, instructing AMMRC personnel in system operational and maintenance procedures.

4.1 DELIVERY

For assurance of total control over the handling of the system and over the shipping schedule, the neutron radiography system was transported via Vought motor van to the AMMRC Laboratories in Watertown, Mass. Prior to shipment, pressure of the sulfur hexafluoride 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 30 psi reservoir. Moderator material was removed and transported in DOT approved containers. The trip was without event and the shipment arrived on schedule.

4.2 SYSTEM INSTALLATION

The neutron radiography laboratory at AMMRC, operating site for the mobile radiograph by system, is the reactor containment shell where nuclear studies were formerly carried out on the research reactor. Prior to system delivery, the interior of this building was refurbished by AMMRC and additional radiation shielding installed in locations appropriate to the planned radiography operations. A floor layout of the laboratory showing the additional shielding designed by Vought and AMMRC personnel for the new system operation is given in Figure 74. Figure 75 shows the radiography system positioned in the radiography exposure area just inside the labyrinth entrance to this area. The sliding gate installed by AMMRC to control access to the radiation area at the entry side of the labyrinth is shown in Figure 76. A similar gate is located on the stairs to the balcony to control access to that area and all other areas above the ground floor. The neutron exposure control station was positioned along the reactor shield face as shown by Figure 77.

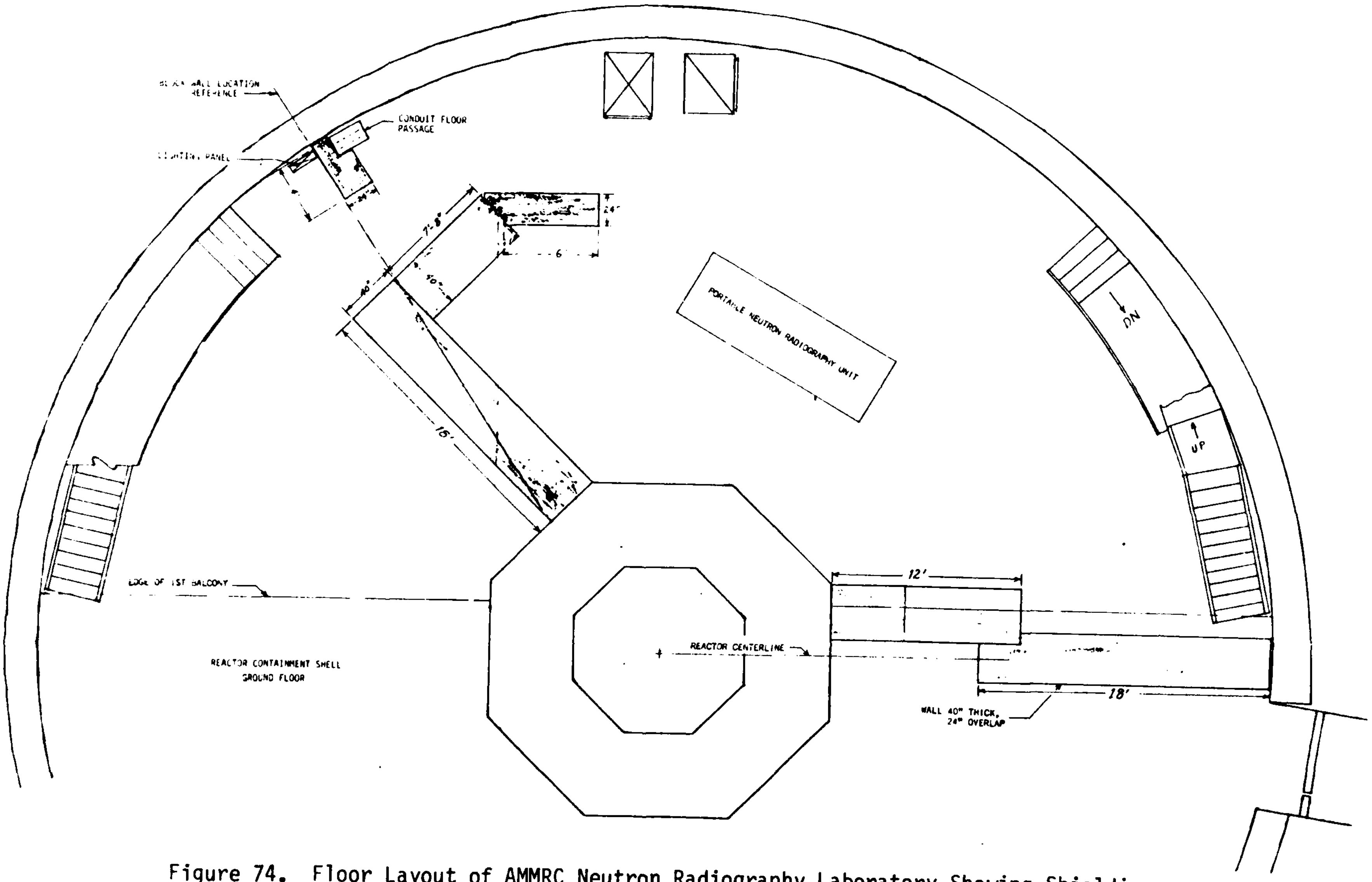


Figure 74. Floor Layout of AMMRC Neutron Radiography Laboratory Showing Shielding for Operation of Mobile System

Figure 75. Mobile Nuetron Radiography System Positioned Behind Labyrinth in Shielded Exposure Area

Figure 76. Gate, with Safety Interlock Switch, at Entry to Shielded Neutron Exposure Area

Figure 77. Neutron Radiography System Control Station

Upon arrival at AMMRC, the special pallet with mobile vehicle was partially removed from the truck by fork lift and lowered to the floor by means of overhead crane cables. After being towed to the N-ray facility, the vehicle self-powered drive was engaged and the unit maneuvered by the operator into the shielded area. The first item on the installation agenda was to install the spare neutron generator tube into the system. Field service personnel from Kaman Instrumentation , suppliers of the accelerator primary fast neutron source, performed the removal of the old tube and installation of the new one.

Upon completion of the reassembly and installation, checkout of the system was routine, with no anomalies occurring. The system was in operation during the second day after unloading from the truck.

4.3 Radiation Survey

After completion of operational checkout, radiation surveys of the adjacent areas external to the shielded exposure room were made with the neutron radiography system in various orientations within the room. The orientation which minimized the radiation was found to be one which places the inspection head such that the cable end of the accelerator head points toward the central reactor shield and such that the labyrinth wall partially shields the outside wall from the inspection head. This position is depicted in Figure 78. The gamma and neutron survey results for this orientation are also shown in the diagram of Figure 78. The numbers beside the survey locations are mrem/hr gamma/mrem/hr neutron. From the figure it is seen that with this machine position, neutron radiography operations can be carried out without the need for establishing a controlled access area external to the building. In addition, the majority of the floor space on the experimental floor outside the exposure room can be utilized for active laboratory space without the need for controlled access to personnel.

4.4 Training

The objectives of the training course were to convey the general principles of neutron radiography to the trainees and to provide instruction

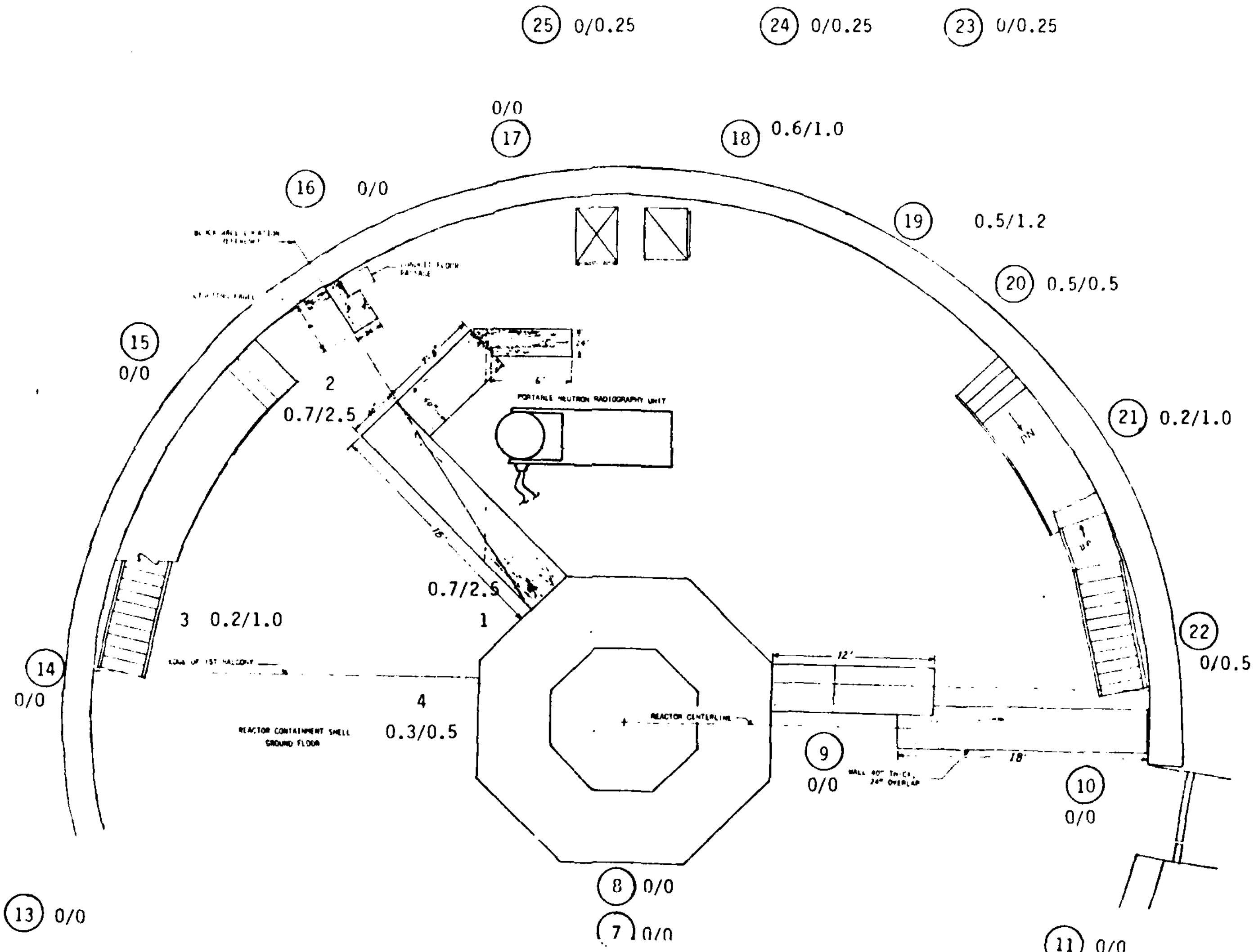


Figure 78. Radiation Survey During Operation of Mobile Neutron Radiography System

such that sufficient knowledge of the delivered system would be available to enable lab personnel to operate and maintain the system effectively and safely.

The initial part of the training began during the installation phase while internal components were more accessible. Following is a list of these topics covered:

1. Moderator material removed and installation
2. Accelerator head assembly removal and installation
3. Collimator cap removal adjustment and installation
4. Collimator removal and installation
5. Gamma filter removal and replacement
6. Vehicle battery removal and replacement

A demonstration of each procedure was given by Vought, followed immediately by supervised hands-on repetition by the students.

After installation and checkout was complete, training became more structured with classroom lectures and discussions, followed by hands-on experience. All major serviceable items were covered and AMMRC personnel were operating the total system by the end of the week's training period.

5.0 CONCLUSIONS

The mobile neutron radiography system produced in this effort, along with the great amount of radiographic data and wide experience in its operation and application to many nondestructive inspection problems, has established the concept of sealed-tube accelerator mobile neutron radiography as a viable and highly useful technology. More specifically, the results and experience lead to the following conclusions:

1. Producibility of a highly useable mobile radiography system using a sealed tube accelerator neutron generator as source has been proven. Although the type neutron generator utilized was not designed or intended for use in a mobile application, a neutron radiography system, the first of its kind, was designed and manufactured in 18 months, and its operation was successfully demonstrated to Army, Navy, and Air Force personnel within ten days after manufacture.

2. As seen in the reproduced prints of radiographic results, a mobile electrically generated neutron radiography system is capable of reliably imaging defects and anomalies in a wide variety of structures. Demonstrated areas of application include detection and imaging of moisture and corrosion in aircraft structures, imaging adhesive distribution and detecting voids and deficiencies in bonded structures, accurately imaging the explosive in detonating devices, and others. Useful inspection images can be obtained for most of these applications in 20 minutes or less using fast converter/film combinations. High resolution radiographs are attainable when fine grain industrial X-ray film and higher L/D ratios are used.

3. The Kaman A-711 sealed-tube neutron generator providing the neutrons for such a radiography system is reliable and is sufficiently rugged to operate in a maintenance hangar environment. On the few occasions during the 48 months usage of the system in which neutron generator component replacement became necessary, Kaman personnel were prompt and efficient in servicing their generator. Down time in a production environment for practically any conceivable failure

would be minimal, with the appropriate spare parts in inventory. Successful demonstrations of in-situ inspection of aircraft using the AMMRC system have provided confidence in extending this technology to depot level systems for production inspection. Prior to this operation, no data were avilable to confirm its ability to function properly day after day for an extended period in that environment (the unit was designed as a laboratory source of fast neutrons for neutron activation analysis). Longer tests under less controlled conditions would yield additional data for ruggedizing the system if needed.

From the above considerations, it is concluded that the program objectives were fully achieved, providing the confidence for subsequent development of a self-contained, field inspection unit.

6.0 RECOMMENDATIONS

Extensive experience has been gained during this work in the design, construction and operation of a mobile neutron radiography system based on the Kaman A-711 neutron generator as source. From this experience, which included field operations at Army, Air Force, and corporate remote facilities, coupled with prior background experience in Vought's in-house program, recommendations are made for design and fabrication of a self-contained, self-propelled neutron radiography inspection system suitable for routine inspection at any Army depot.

6.1 Mechanical System

System design features which are recommended for depot level routine inspection are:

1. Reach capability. Additional reach capability in positioning the inspection head is necessary for inspecting lower surfaces of airfoil sections such as rotor blades, wings, and horizontal tail sections, as well as for the vertical tail surfaces. A reach capability sufficient to position the head over the fuselage and direct the neutron beam downward for inspection of interior surfaces is desirable for some inspection tasks where the interior is accessible for film placement. Additional reach is also needed in the horizontal direction for inspecting the mid-sections of wide components without repositioning the inspection carriage or the specimen, e.g., along the chord of a wing. An extended lift arm or telescoping boom would provide this capability. Its length would be dictated by the tallest aircraft structure for which the inspection requires a downward beam angle.

2. Head rotation. For greater flexibility in positioning the inspection head, rotation about the boom axis is desirable. This would complement the existing rotational capability of the AMMRC unit, providing a "wrist" action which would allow greater

flexibility in setting the carriage angle with respect to the aircraft and reduce the required number and extent of movements of the carriage.

3. Carriage positioning. For production inspection operations, reduced set-up time is required; hence faster carriage movement and head elevation arm motion are needed for that type operation. Simultaneous wheel and steering power, and simultaneous, coordinated alignment of drive wheels in positioning the carriage would signficantly reduce the time required for this operation. This would further contribute to the reduction of overall exposure set-up time. A viable and lower-cost alternate to the AMMRC-type carriage/positioner for application in a depot environment is a commercial truck and crane system, modified to accommodate the mounting of the neutron inspection head on the crane boom.

4. Auxiliary support equipment. Incorporation of the neutron generator cooling unit on board the main system carriage, as the H.V. power was located on the AMMRC system, is desirable for greater convenience in moving the system around the aircraft with minimum lost motion. This would also minimize the length of the coolant lines and preserve the efficiency of cooling when the length of the inspection head boom is increased. A reduction in weight and size of the cooling system would be desirable for compactness. The present system is of conventional refrigeration and heat exchanger design and uses off-the-shelf components. It appears that some reduction in size of the cooling unit could be realized by changes in the mechanical configuration of components, and that a modest savings in weight might also be achieved through careful selection of components and housing/frame structure design. Less conventional approaches to efficient cooling of the ion source and target should be explored to determine if significant savings in weight and volume are feasible.

5. Electrical power supply. An on-board gasoline or diesel powered generator is recommended for operation as a self-contained inspection system. The system could be configured to operate with power from either the chassis-mounted generator or AC power from an external source, if desired.

6. Film cassettes. Due to the absence of a high degree of spatial resolution associated with the relatively low L/D ratios dictated by the practical use of mobile neutron radiography systems, it is important to place the film cassette as close as possible to the surface being inspected. For most of the specimens provided in this study, such as the horizontal and vertical stabilizers, wing sections, etc., the curvature was not so severe as to require a curved cassette to demonstrate the application of neutron radiographic inspection to the part. However, in parts with greater curvature, such as some rotor blades and fuselage sections, and in many others which may require inspection, it would be advantageous for the film to conform to the surface. For such cases, the development of reliable flexible or rigid curved cassettes is needed to achieve the maximum possible image detail.

6.2 Neutron Generator

From a mobility standpoint, and from the standpoint of operational safety procedures, the neutron flux levels available from the Kaman A-711 neutron generator represent the most nearly optimum source available. For some production inspection applications for which only high resolution radiographs will suffice to detect the specific defects in question in minimum amount of time increased neutron output may be needed. In determining the practical upper limit of flux capability to choose as a design goal, the advantages of shorter exposure times must be weighed against the disadvantage of additional shielding in the head, which leads to heavier and bulkier assemblies to position and, generally, the disadvantage of a signficant increase in power supply weight and volume, meaning less mobility. Or, if the flux is increased and the quantity of head shielding is held the same, the advantage of reduced exposure time must be weighed against the disadvantage of greater radiation controlled and restricted zones, and greater quantities of operator shielding and the resulting loss of efficiency of operation and utilization of space. A program to develop techniques for increasing by a moderate amount (up a factor of 2) the output from the Kaman generator tube is recommended. This would retain all of the advantages of an existing neutron generator of proven reliability while enhancing the utilization of neutron radiography in many production inspection applications.

6.3 Real Time/Near Real Time Imaging

For effective utilization of a mobile neutron radiography system in a depot/production application, a filmless, real time/near real time imaging capability is recommended. The ability of such a system to detect moisture and corrosion in aircraft structures was demonstrated in this study utilizing a unique system developed by Vought. Electronic enhancement of the images obtained is further recommended for maximum information yield from the imaging head data. The total imaging system must be one which is compatible with the nonreactor mobile neutron system, preserving its image quality in the lower flux neutron fields obtained as the L/D ratio is varied upward to accommodate specimens of various thicknesses. This capability is considered essential for reducing the inspection time for large area components such as wing and tail surfaces which provide ready access for placement of an imaging head. The economic benefits of such an imaging system appear to be substantial in reduced labor and film costs.

7.0 REFERENCES

1. "Demonstration and Evaluation of Mobile Accelerator Neutron Radiography for Inspection of Aircraft Structures at SM-ALC/McClellan AFB" (W. E. Dance and S. F. Carollo), Vought Corporation Advanced Technology Center Report No. R-92200/2CR-4, 25 January 1982.

2. "AMMRC Mobile Accelerator Neutron Radiography System Operations at U.S. Army Proving Ground," (W. E. Dance and S. F. Carollo), Interim Technical Report, Contract DAAG46-78-C-0007, 15 April 1984.

DISTRIBUTION LIST

No. of
Copies To

1 Office of the Under Secretary of Defense for Research and Engineering,
The Pentagon, Washington, DC 20301

2 Commander, Defense Technical Information Center, Cameron Station, Building 5,
5010 Duke Street, Alexandria, VA 22314

Commander, Army Research Office, P.O. Box 12211, Research Triangle Park,
NC 27709
1 ATTN: Information Processing Office

Commander, U.S. Army Materiel Command, 5001 Eisenhower Avenue,
Alexandria, VA 22333
1 ATTN: AMCLD

Commander, U.S. Army Materiel Systems Analysis Activity,
Aberdeen Proving Ground, MD 21005
1 ATTN: AMXSY-MP, H. Cohen

Commander, U.S. Army Electronics Research and Development Command,
Fort Monmouth, NJ 07703
1 ATTN: AMDSD-L

Commander, U.S. Army Missile Command, Redstone Arsenal, AL 35898
1 ATTN: AMSMI-TB, Redstone Scientific Information Center

Commander, U.S. Army Armament, Munitions and Chemical Command, Dover, NJ 07801
1 ATTN: AMDAR-QAC-E

Commander, U.S. Air Force Wright Aeronautical Laboratories,
Wright-Patterson Air Force Base, OH 45433
1 ATTN: AFWAL/MLLP, D. M. Forney, Jr.
AFWAL/LLP, James Holloway
AFWAL/MLTM, Lee Gulley
AFWAL/FIBAC, Edvins Demuts

Commander, U.S. Army Natick Research and Development Center, Natick, MA 01760
1 ATTN: Technical Library

Commander, U.S. Army Tank-Automotive Command, Warren, MI 48090
1 ATTN: AMSTA-ZSK

Commander, U.S. Army Proving Ground, Yuma, AZ 85365
1 ATTN: STEYP-MLS-P, Mr. Moravec

Commander, White Sands Missile Range, NM 88002
1 ATTN: STEWS-WS-VT

No. of Copies	To
	Commander, U.S. Army Engineer School, Fort Belvoir, VA 22060
1	ATTN: Library
	Commander, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS 39180
1	ATTN: Research Center Library
	U.S. Army Industrial Base Engineering Activity, Rock Island Arsenal, IL 61299
1	ATTN: AMXID-MT, Mr. Del Brim
	Battelle Research Institute, Columbus Laboratories, 505 King Avenue, Columbus, OH 43201
1	ATTN: Mr. D. Hayford
	General Dynamics, Convair Aerospace Division, P.O. Box 748, Fort Worth, TX 76101
1	ATTN: Mfg. Engineering Technical Library
	Aeronautical Research Laboratories, Commonwealth of Australia, Department of Defense, Box 4331 P.O., Melbourne, Australia 300
1	ATTN: Mr. Neil Ryan
1	Mr. Jan G. Scott
1	Mr. Michael Yukish, Code 640, Naval Rework Facility, Norfolk, VA 23512
1	Mr. Dick Zeits, Mgr, Mfg R&D, Hughes Helicopter, Inc., Teale & Centinela Street, Culver City, CA 90230
1	Dr. Jack Hum, Materials Engineering Laboratory, Code 341, Building 44, Alameda Naval Air Station, Alameda, CA 94501
1	Mr. Ernie Balk, Thiokol Rocket Motor Division, Air Force Engineering Management Office, Brigham City, UT 84302
1	Eugene Fairweather, Charles Stark Draper Laboratories, 555 Technology Square, Cambridge, MA 02139
1	Mr. Mike Nelson, AF RPO/MKBB, Stop 24, Edwards Air Force Base, CA 93523
1	Mr. B. Prasad, ESD/SCS-1E, Hanscom Air Force Base, Bedford, MA 01731
1	Mr. George Darcy, Mail Stop 1127, AVCO Systems Division, 201 Lowell Street, Wilmington, MA 01887
1	Mr. Ron Burr, Pratt & Whitney Aircraft, 400 Main Street, Mail Stop 116-01, East Hartford, CT 06118
1	Naval Air Rework Facility, Naval Air Station - North Island, Code 61230, Building 3, San Diego, CA 92135
1	Mr. Hans Vanderveldt, Naval Sea Systems Command, SEA05R15, Washington, DC 20362

No. of
Copies To

Technical Director, Human Engineering Laboratories, Aberdeen Proving Ground,
MD 21005
1 ATTN: Technical Reports Office

Commandant, U.S. Army Quartermaster School, Fort Lee, VA 23801
1 ATTN: Library

National Aeronautics and Space Administration, Washington, DC 20546
1 ATTN: Mr. G. C. Deutsch - Code RW

National Aeronautics and Space Administration, Marshall Space Flight Center,
Huntsville, AL 35812
1 ATTN: R. J. Schwinghammer, EH01, Dir, M&P Lab
1 W. A. Wilson, EH41, Building 4612

Lockheed-Georgia Company, 86 South Cobb Drive, Marietta, GA 30063
1 ATTN: Materials and Processes Engineering Department 71-11, Zone 54

Director, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground,
MD 21005
1 ATTN: AMDAR-TSB-S (STINFO)

Commander, Harry Diamond Laboratories, 2800 Powder Mill Road, Adelphi, MD 20783
1 ATTN: Technical Information Office

Director, Benet Weapons Laboratory, LCWSL, USA AMCCOM, Watervliet, NY 12189
1 ATTN: AMSMC-LCB-R

Commander, U.S. Army Foreign Science and Technology Center, 220 7th Street,
N.E., Charlottesville, VA 22901
1 ATTN: Military Tech, Mr. Marley

Commander, U.S. Army Aeromedical Research Unit, P.O. Box 577, Fort Rucker,
AL 36360
1 ATTN: Technical Library

Director, Eustis Directorate, U.S. Army Air Mobility Research and Development
Laboratory, Fort Eustis, VA 23604
1 ATTN: Mr. J. Robinson, DAVDL-E-MOS (AMCCOM)

U.S. Army Aviation Training Library, Fort Rucker, AL 36360
1 ATTN: Building 5906-5907

Commander, U.S. Army Agency for Aviation Safety, Fort Rucker, AL 36362
1 ATTN: Technical Library

Commander, USACDC Air Defense Agency, Fort Bliss, TX 79916
1 ATTN: Technical Library

No. of Copies	To
1	Mr. Jim Goff, NSWC/Code R34, Silver Spring, MD 20910
1	Mr. Michael Stellabotte, Code 606, Naval Air Development Center, Warminster, PA 18974
1	Mr. Robert Mather, Code 34108, NARF, North Island, San Diego, CA 92135
1	Mr. John H. Parsons, Code 644, NARF, Alemeda, Alemeda, CA 94501
1	Mr. Ray S. Jones, Technical Support Branch, Naval Air Systems Command, Washington, DC 21361
	SM-ALC/MMET, McClellan Air Force Base, CA 95652
1	ATTN: Mr. Al Rogel
1	Mr. Don Johnson
	SA-ALC/MMETT, Kelly Air Force Base, TX 78241
1	ATTN: B. W. Boisvert
1	Mr. J. M. Leland, Code 640C, Building 3, NARF, NORIS, San Diego, CA 92135
	SM-ALC/MANCD, McClellan Air Force Base, CA 95652
1	ATTN: Mr. Steve Moore
	Kaman Instrumentation Corporation, P.O. Box 7463, Colorado Springs, CO 80933
1	ATTN: Dr. J. Reichardt
	TFI Corporation, P.O. Box 1611, New Haven, CT 06506
1	ATTN: P. Ferriolo
	Industrial Quality, Incorporation, P.O. Box 2397, Gaithersburg, MD 20879-0397
1	ATTN: Mr. H. Berger
	N-Ray Engineering, 5709 Waverly Avenue, LaJolla, CA 92037
1	ATTN: Dr. J. Barton
	Southwest Research Institute, P.O. Drawer 28510, San Antonio, TX 78284
1	ATTN: Dr. J. Doherty
	Director, Army Materials and Mechanics Research Center, Watertown, MA 02172-0001
2	ATTN: AMXMR-PL
1	AMXMR-PR
1	AMXMR-K
10	AMXMR-OM, J. Antal

Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172
MOBILE ACCELERATOR
NEUTRON RADIOGRAPHY SYSTEM
W. E. Dance, S. F. Carollo, H. M. Bumgardner
LTV Aerospace and Defense Company
Vought Missiles and Advanced Programs Division
P. O. Box 650003
Dallas, Texas 75265-0003
Technical Report AMMRC TR 84-30, October 1984, 149 pp.
Illus.-tables, Contract DAAG46-78-C-0007
D/A Project M776350
AMCMS Code 53970M6350
Final Report, February 1978 to December 1983

AD______________
UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

Neutron Radiography
Nondestructive Testing

The use of neutron radiography for the inspection and maintenance of large structures such as aircraft has been delayed by the absence of a mobile system particularly suited to the requirements of field use. This report describes the production, extensive field testing, evaluation and disposition of the first mobile neutron radiography system to satisfy the majority of requirements for field use. The system is based upon the concept of a mobile on-off neutron radiography system based on a sealed-tube ion accelerator as neutron source demonstrated earlier by the Vought Corporation. Primary features of the system are its self-propelled mobility, versatile positioning capability scaled to Army helicopter dimensions, an on-off beam capability, exposure capability measured in minutes, and suitability for AMMRC laboratory and field use. Included in the report are a description of all components of the system, an evaluation of the operation of the system, an evaluation of its radiographic capabilities, a description of installation elements for the AMMRC site, and recommendations for next-generation systems.

Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172
MOBILE ACCELERATOR
NEUTRON RADIOGRAPHY SYSTEM
W. E. Dance, S. F. Carollo, H. M. Bumgardner
LTV Aerospace and Defense Company
Vought Missiles and Advanced Programs Division
P. O. Box 650003
Dallas, Texas 75265-0003
Technical Report AMMRC TR 84-30, October 1984, 149 pp.
Illus.-tables, Contract DAAG46-78-C-0007
D/A Project M776350
AMCMS Code 53970M6350
Final Report, February 1978 to December 1983

AD______________
UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

Neutron Radiography
Nondestructive Testing

The use of neutron radiography for the inspection and maintenance of large structures such as aircraft has been delayed by the absence of a mobile system particularly suited to the requirements of field use. This report describes the production, extensive field testing, evaluation and disposition of the first mobile neutron radiography system to satisfy the majority of requirements for field use. The system is based upon the concept of a mobile on-off neutron radiography system based on a sealed-tube ion accelerator as neutron source demonstrated earlier by the Vought Corporation. Primary features of the system are its self-propelled mobility, versatile positioning capability scaled to Army helicopter dimensions, an on-off beam capability, exposure capability measured in minutes, and suitability for AMMRC laboratory and field use. Included in the report are a description of all components of the system, an evaluation of the operation of the system, an evaluation of its radiographic capabilities, a description of installation elements for the AMMRC site, and recommendations for next-generation systems.

Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172
MOBILE ACCELERATOR
NEUTRON RADIOGRAPHY SYSTEM
W. E. Dance, S. F. Carollo, H. M. Bumgardner
LTV Aerospace and Defense Company
Vought Missiles and Advanced Programs Division
P. O. Box 650003
Dallas, Texas 75265-0003
Technical Report AMMRC TR 84-30, October 1984, 149 pp.
Illus.-tables, Contract DAAG46-78-C-0007
D/A Project M776350
AMCMS Code 53970M6350
Final Report, February 1978 to December 1983

AD______________
UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

Neutron Radiography
Nondestructive Testing

The use of neutron radiography for the inspection and maintenance of large structures such as aircraft has been delayed by the absence of a mobile system particularly suited to the requirements of field use. This report describes the production, extensive field testing, evaluation and disposition of the first mobile neutron radiography system to satisfy the majority of requirements for field use. The system is based upon the concept of a mobile on-off neutron radiography system based on a sealed-tube ion accelerator as neutron source demonstrated earlier by the Vought Corporation. Primary features of the system are its self-propelled mobility, versatile positioning capability scaled to Army helicopter dimensions, an on-off beam capability, exposure capability measured in minutes, and suitability for AMMRC laboratory and field use. Included in the report are a description of all components of the system, an evaluation of the operation of the system, an evaluation of its radiographic capabilities, a description of installation elements for the AMMRC site, and recommendations for next-generation systems.

Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172
MOBILE ACCELERATOR
NEUTRON RADIOGRAPHY SYSTEM
W. E. Dance, S. F. Carollo, H. M. Bumgardner
LTV Aerospace and Defense Company
Vought Missiles and Advanced Programs Division
P. O. Box 650003
Dallas, Texas 75265-0003
Technical Report AMMRC TR 84-30, October 1984, 149 pp.
Illus.-tables, Contract DAAG46-78-C-0007
D/A Project M776350
AMCMS Code 53970M6350
Final Report, February 1978 to December 1983

AD______________
UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

Neutron Radiography
Nondestructive Testing

The use of neutron radiography for the inspection and maintenance of large structures such as aircraft has been delayed by the absence of a mobile system particularly suited to the requirements of field use. This report describes the production, extensive field testing, evaluation and disposition of the first mobile neutron radiography system to satisfy the majority of requirements for field use. The system is based upon the concept of a mobile on-off neutron radiography system based on a sealed-tube ion accelerator as neutron source demonstrated earlier by the Vought Corporation. Primary features of the system are its self-propelled mobility, versatile positioning capability scaled to Army helicopter dimensions, an on-off beam capability, exposure capability measured in minutes, and suitability for AMMRC laboratory and field use. Included in the report are a description of all components of the system, an evaluation of the operation of the system, an evaluation of its radiographic capabilities, a description of installation elements for the AMMRC site, and recommendations for next-generation systems.