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Radiation Protection Safety Protocol for Industrial X-ray Backscatter Radiography Experiments

Prepared by
Janine Guadagno, Dr. Ramachandra K. Bhat, Alan Teets,
Michael Funkhouser, Keven Terrell, Howard Horner,
and SSG Raul Sotomayor

Report Date
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Backscatter radiation has been identified as the most promising nondestructive, nonmagnetic, atomic technique for mine detection. The National Bureau of Standards (NBS) Handbook 114, *General Safety Standards for Installations Using Nonmedical X-ray and Sealed Energies up to 10 MeV,* is the regulatory guide that pertains to this research. Using this guide as a basis, the Radiation Research Group of the Materials, Fuels, and Lubricants Laboratory, has developed a model laboratory that provides for critical mine detection experimentation to be conducted at the lowest possible level of radiation exposure.

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PREFACE

Scattered radiation has been used in medical and engineering applications to determine properties and form images of irradiated objects. Scattered radiation is ideally suited to the geometry of mine detection which depends upon differences between the number of photons scattered from mines and soil to produce an image as opposed to conventional radiography which uses the transmission of photons through an irradiated object to produce an image.

Mine detection through backscatter radiation measures the amount of radiation that is backscattered from the ground to a NaI detector which is mounted next to the x-ray source. To generate sufficient backscatter radiation to image buried land mines, an industrial x-ray unit must be operated continuously at or above 150 kVp for 2 to 3 hours. Operating an industrial x-ray unit at this level and duration for the purpose of mine detection requires a complete radiological review of both the exposure room and the x-ray unit itself. The National Bureau of Standards (NBS) Handbook 114, *General Safety Standards for Installations Using Nonmedical X-ray and Sealed Source Energies up to 10 MeV*, is the regulatory guide that must be adhered to for operation of industrial x-ray units for backscatter research.

This technical report, prepared by the Materials, Fuels and Lubricants Laboratory of the US Army Belvoir Research, Development and Engineering (RD&E) Center, Fort Belvoir, VA, was sponsored and funded by the US Army Materiel Command (AMC), Alexandria, VA. It discusses the radiation protection safety protocols initiated by the Radiation Research Group to conduct mine detection research through x-ray backscatter radiography experiments while maintaining radiation levels as low as reasonably possible. The x-ray backscatter facility created by the group should serve as a model for all installations attempting this type of research.

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SECTION I. METHODS

EQUIPMENT ACCESS

The x-ray backscatter radiography team of the Belvoir RD&E Center utilizes a General Electric Company's Model OX-250 industrial radiographic unit. This model consists of three distinct components, as shown in Figure 1.

- Control unit which contains all the controls and indicating meters (1A).
- Tube (x-ray) head suspended on a swing arm (1B) which includes the x-ray tube and high voltage equipment immersed in oil therein.
- Oil-cooling unit. (Not shown)

The x-ray head and cooling unit are located inside a lead-lined exposure room (1C) which constitutes the main x-ray laboratory. The ceiling of the room is not lined. The control unit is located directly outside the exposure room in a hallway which adjoins several offices designated unrestricted, non radiation areas (Figure 2 A, B, C). Access by non radiation personnel to the radiographic unit is prohibited by the locked power supply box located next to the control unit (1D). The acquisition of a quad counter, NaI detectors, power supply, single channel analyzer, soil box positioner, remote TV, computer hardware, and software peripherals (1E) necessary for the collection and imaging of backscatter photons required the addition of a room to secure the equipment. Six feet of the hallway in front of the control panel was allocated, and permanent walls were built. These walls created approximately 4 feet of secured space surround the exposure room on two sides (1F, G). One side of the exposure room is a lead-lined wall separating a non radiation equipment laboratory (2C) which is occupied for a maximum of 2 hours per day. The other side faces the exterior of the building (2D) with the large double bay doors.

EXPOSURE ROOM

The exposure room can be readily accessed through a double swinging door (1H) which opens into the newly constructed exterior office space and, with greater difficulty, through the lead-lined retractable bay doors (2D) which open to the outside. Interlocks are connected to both doors which terminate the x-ray beam upon opening the doors. Because of the location of the control unit, the operator initially could not easily see if the exposure room was occupied; therefore, two remote TV cameras were installed. One is stationary (Figure 3A) and provides a panoramic view of the room, and the other has a zoom lens with scanning capabilities (3B). The monitors (1J) are mounted next to the control unit and provide the operator with full visibility of the room during the unit's operation. Additionally, rotating beacons were installed and are operated when the line switch is activated according to the procedures established in an in-house Standing Operating Procedure (SOP) PR-90, *Operation of the OX-250 Radiographic Unit in Backscatter Radiography Experimentation* (see Appendix A). The rotating beacons are located both inside (3C) and outside (1J) of the readily accessible door, and non-rotating beacons are located in the enclosed hallway (1K) surround the laboratory, on the roof of the building (Figure 4A) and on the exterior wall (2E) by the retractable doors. In accordance with SOP PR-90, these lights are activated to operate approximately 30 seconds before the x-ray tube is energized. Assuming no interlock interruption, the rotating lights remain active throughout the irradiation. A delay timer is installed that automatically delays the x-ray tube from being energized for a full 30 seconds after power is provided. Signs are posted on all interior doors of the exposure room instructing personnel that if they have inadvertently become trapped in the laboratory, push against the door and break the interlock, thereby shutting off the x-ray tube and preventing exposure within 30 seconds following illumination of the rotating beacons. If the interlocks are interrupted, the x-ray tube cannot be energized until the interlock circuit is restored and the x-ray tube is manually activated from the control panel.

ROOF ACCESS

Access to the roof of the building, which is unshielded due to weight restrictions, is chained off and posted with warning signs stating "High Radiation Area–Keep Out" (4B). The roof area immediately above the exposure room is also chained off, and a beacon light is located in the center of this restricted area. Signs are posted on the chain stating "Keep Out When Red Light Is Flashing." In accordance with SOP PR-90, this area is checked before the x-ray unit is turned on. Additional signs are posted on the exterior of the bay door and on the exterior of the swinging door accessing the x-ray laboratory. These signs display the radiation symbol and warn that individuals are entering a high radiation area where x-rays are produced. The walls of the exposure room are shielded with lead barriers that are secured with lead nails to prevent cold flow. Lead sheets at joints are in contact with a $^1/_2$" thick lap, and the joints between different materials are constructed so as not to impair shielding. A $1^1/_2$" lap covers the doors of the exposure room over the door jamb and lintel so as to reduce scattered radiation passing through clearance spaces to the allowable limit.

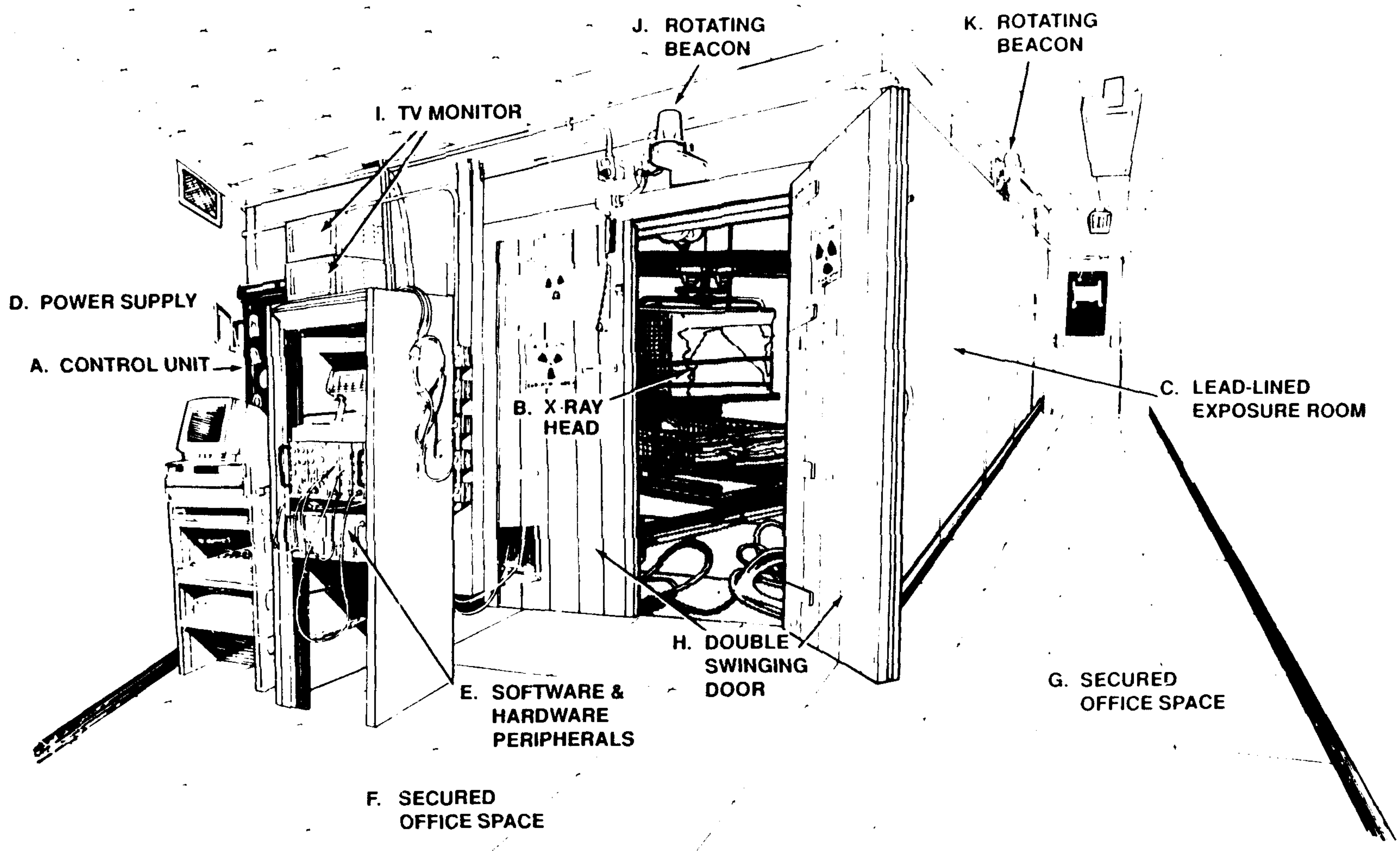

Figure 1. X-ray Laboratory

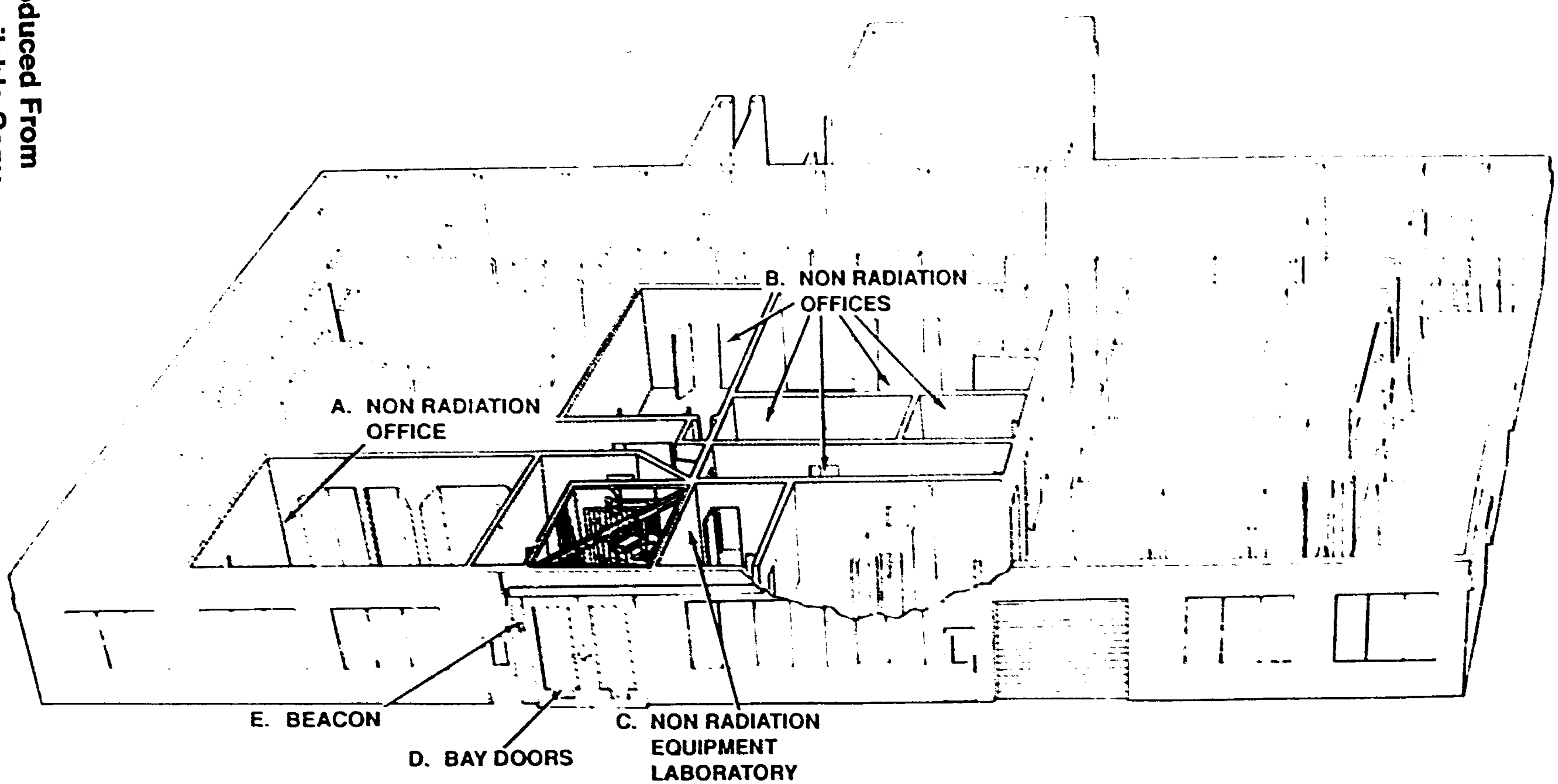

Figure 2. Building Housing X-ray Laboratory

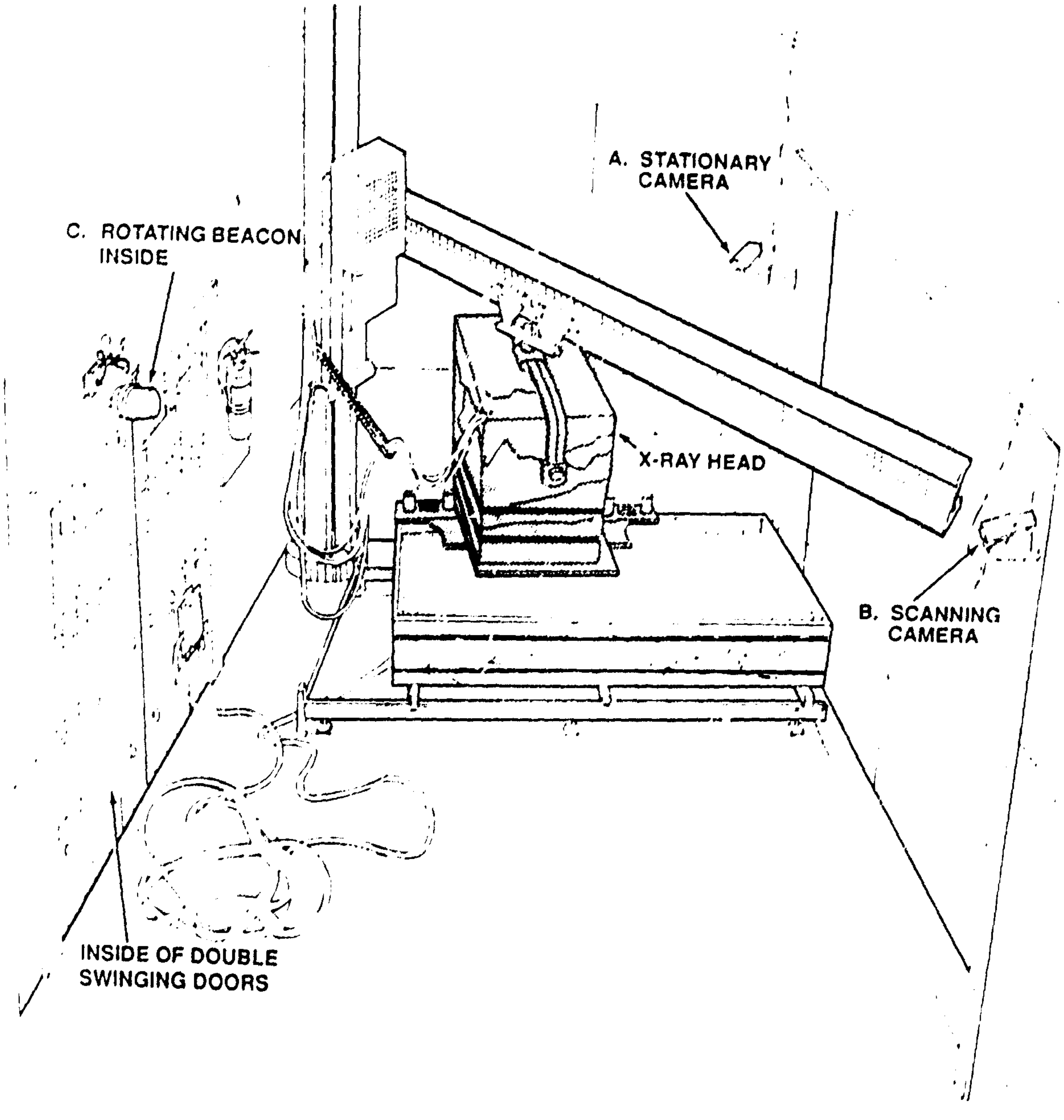

Figure 3. Interior of X-ray Exposure Room

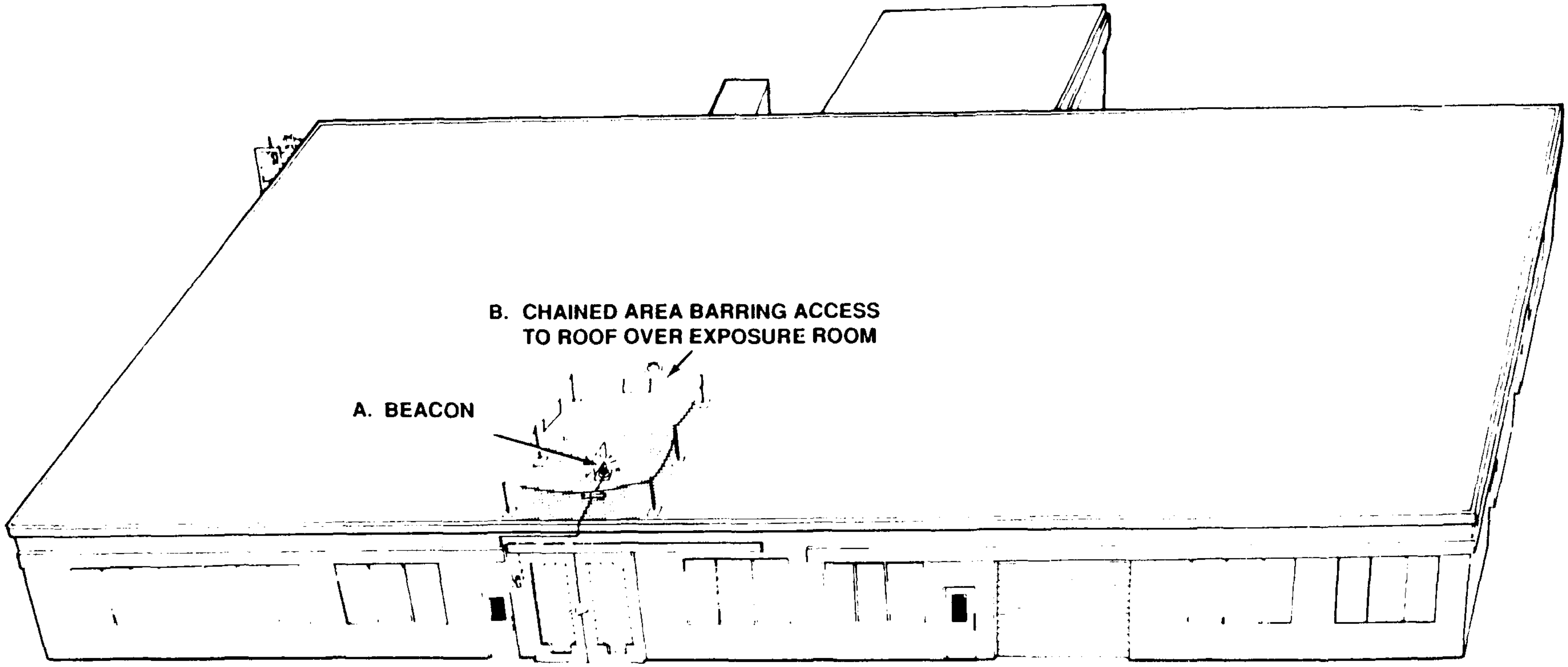

Figure 4. Roof of Building Housing X-ray Laboratory

INSTRUMENT CONTROLS

X-ray backscatter radiography experiments require the operation of remotely controlled instruments such as the detector train counting equipment and the x/y table positioner. Although the actual equipment is located inside the exposure room, their controls have to be accessible to the operator throughout the x-ray irradiation. Therefore, a passageway is required to pass the electrical cables through the shielded room into the operator's area in order to prevent any significant radiological hazard to the operator. The first method examined to provide this passage was to drill a hole through the shielded wall thereby minimizing the length of the electrical cable. The length of the electrical cable was of significant consideration because of the linear correlation between electrical noise distortion and cable length. This method of drilling through the wall was rejected because the lead-lined wall was covered with panel asbestos sheets that would introduce yet another health hazard. It was decided that the only acceptable method for providing the passageway would be to drill a hole through one of the swinging doors and acquire cables with a greater resistance coefficients. Lead baffles were then installed on both sides of the door so that no significant radiation would pass through the electrical conduit.

LEAKAGE CONTROL

Before research in backscatter radiography was initiated, the primary use of the x-ray unit was to obtain radiographic images of objects, welds, and castings on x-ray film. This work required considerably shorter exposure times and was relatively insensitive to x-ray leakage through the x-ray head. The x-ray backscatter radiography experiments, however, are extremely sensitive to x-ray leakage and cannot tolerate this leakage greater than 10 percent of the signal collected during an experiment. To determine the degree of head leakage when the x-ray beam was collimated to irradiate a 1-inch square spot on the soil at a focal spot to object distance of 18 inches, a 3 x 3" NaI detector was placed at different locations around the x-ray head. Readings were taken when the beam was sealed off with a lead plug and energized to 150 – 200 kVp at 5 milliamps. Results of these readings are shown in Tables 1 and 2. Besides identifying an intolerable amount of x-ray head leakage, the test results showed an interesting anomaly. In all locations except the front side of the head, leakage—when the x-ray beam was energized to 150 kVp—was less than that when the beam was energized to 200 kVp. This was to be expected reasoning that the stronger the beam the greater leakage. However, leakage in front of the head was found to be higher at 150 kVp than at 200 kVp. Subsequent investigation showed this anomaly to be attributed to detector saturation occurring when the beam was energized to 200 kVp. To reduce the degree of leakage, the x-ray head was wrapped in lead sheets. Similar measurements were again made with the NaI detector and results are shown in Tables 3 and 4.

Table 1. Head Leakage (Counts per Second) for Head without Shielding—
Beam Energized to 150 kVp

DETECTOR LOCATION AROUND HEAD			
Beneath	Right	Front	Rear
6,917	2,064	19,996	1,199
6,967	2,048	19,942	1,215
6,980	2,036	19,964	1,194

Table 2. Head Leakage (Counts per Second) for Head without Shielding—
Beam Energized to 200 kVp

DETECTOR LOCATION AROUND HEAD		
Right	Front	Rear
22,823	17,366	25,330
22,914	17,277	25,617
22,850	17,330	25,266

Table 3. Head Leakage (Counts per Second) for Beam Shielded and Energized to 150 kVp

DETECTOR LOCATION AROUND HEAD			
Right	Left	Front	Rear
106	96	328	184
84	69	344	183
72	79	320	208
97	82	329	175

Table 4. Head Leakage (Counts per Second) for Beam Shielded and Energized to 200 kVp

DETECTOR LOCATION AROUND HEAD			
Right	Left	Front	Rear
6,387	4,401	5,566	8,874
6,351	4,543	5,666	8,603
6,417	4,365	5,732	8,756

PERSONNEL PROTECTION

Monitoring personnel was a sensitive issue because backscatter radiography required the operation of the x-ray unit for extended periods of time, and the exposure room was surrounded by non radiation areas and offices. Because the occupational dose limit for non radiation workers in accordance with the Department of the Army Regulation 40-14 is 2 millirem or 2,000 microrem in any one hour, coupled with the unease of non radiation workers in the building when the unit was operated, an extensive monitoring program was initiated. All x-ray operators were issued both wrist and whole-body film badges which have been replaced with Thermoluminescent Dosimeters (TLDs). Records of their monthly readings are filed in 385-11f, Personnel Dosimetry Records, under the Modern Army Record Keeping System following evaluation by the US Army Ionizing Radiation Dosimetry Center. Additionally, TLDs are mounted on the exterior of the swinging door of the exposure room, the exterior of the retractable lead-lined bay doors, and on the roof directly above the laboratory. A monthly record of these readings are also maintained in files 385-11f. A Reuter Stokes RS-111 environmental monitor, calibrated yearly, is operated according to SOP PR-90 whenever the x-ray tube is energized. The RS-111 is located in the office space in front of the control panel. Quarterly surveys are recorded utilizing a Ludlum model 12S micro-R meter, calibrated quarterly by the US Army Test, Measurement, Diagnostic, and Evaluation Support Operation. These surveys include measurements on the roof at positions outside of the exposure room and in the surrounding non radiation areas and office spaces. Survey results are shown in Table 5 and are posted on the door at the entrance of the laboratory for radiation and non radiation workers to review. To help alleviate the fears of the non radiation workers, information was circulated explaining the risks and acceptable x-ray dose levels along with survey results to all non radiation employees working in the vicinity of the exposure room. Non radiation employees were also encouraged to speak with the radiation protection officer if they had any further questions. All x-ray operators are required to undergo radiation safety training and are not allowed to operate the unit without completing the X-ray Safety Check List (see Appendix B). New employees must be accompanied by an experienced operator to use the unit, and the users must be present at all times that the x-ray tube is energized. SOP PR-90 is issued to all operators, and a copy is posted next to the x-ray control panel.

Table 5. Quarterly Survey (Counts in Millirem) of X-ray Building

SITE DESCRIPTION (refer to Figures 1, 2, 3, 4)	150 kVp m' r	200 kVp mR/hr
Roof outside chain perimeter (4B)	0.002	0.008
Roof inside chain perimeter (4A)	0.003	0.014
Exterior to bay doors (2D)	0.008	0.008
Outside of lab entrance (1H)	0.008	0.008
Hallway inside of lab (1G)	0.002	0.002
Non radiation laboratory (2C)	0.007	0.007
Hallway exterior to lab (2B)	0.002	0.002
Non radiation office (2B)	0.002	0.002
X-ray operator location (1E)	0.002	0.002

SECTION II. RESULTS

All measurements inside the building's exterior to the exposure room using the Ludlum micro-R meter while the x-ray unit was energized to 150 and 200 kVp at 5 milliamps were found to be less than 0.007 millirem per hour. By comparison, background is less than 0.005 millirem per hour. The maximum measurements on top of the roof, inside of the chain fence, directly above the exposure room, were less than 0.02 millirem per hour. This area, however, is posted, and access is prohibited to non radiation workers when irradiation is in progress. Strip recording measurements on the Reuter Stokes environmental monitor were not found to vary significantly above background when the x-ray unit was operated at 200 kVp at 5 milliamps regardless of the duration of the irradiation. TLDs mounted on the exterior of the retractable and swinging doors were found to be at background. No personal TLD or film badge was found to be significantly above background.

Typical responses for soil irradiated at 150 kVp, 5 milliamps were 6,000 counts per second as measured by a collimated 3" by 3" NaI detector. Previous research demonstrated that x-ray leakage, as determined by sealing off the primary exit path of the beam, energizing the beam and counting subsequent leakage of x-rays from secondary paths, below 10 percent of background could be ignored. With the additional shielding, our system has a maximum x-ray leakage of 344 counts per second when the beam is energized to 150 kVp and 4,000 when the beam is energized to 200 kVp as measured by a collimated 3" by 3" NaI detector. Because the x-ray head is supported on a swing arm, it was decided that 150 kVp would be our maximum operating voltage due to the excessive leakage at higher voltages despite the fact that greater penetration through soil can be achieved with higher voltages. The additional weight that would be added by the shielding required for operation at 200 kVp was judged too risky for the swing arm to support.

SECTION III. DISCUSSION

X-ray backscatter radiography is identified as the most promising nondestructive, nonmagnetic, atomic technique for mine detection. However, additional research needs to be conducted concerning its application to unique field conditions. Because the development of a prototype field unit is dependent upon realistic laboratory research on the effects of field variables, additional research is also necessary in environmentally controlled laboratories such as the one developed by the Belvoir RD&E Center. This Center has constructed an exposure room that can best simulate environmental conditions and yet maintain the maximum radiological safety requirements. Through it, valuable research can be conducted on the feasibility and limitations of x-ray backscatter radiography for mine detection without compromising the health or safety of the researchers.

APPENDIX A

US ARMY RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
RADIATION RESEARCH GROUP
ATTN: STRBE-VR
FORT BELVOIR, VIRGINIA 22060-5606

File: 385-11c: Radiation SOP file

SUBJECT: Standard Operating Procedures for Operation of the OX-250 Radiographic X-ray Unit in Backscatter Radiography Experimentation.

SOP NO: PR-90; Tab J, Book 5, Disk 5

Date: 30 June 1989

Prepared by: Kevin Terrell

Reviewed by: Janine Guadagno

Approved by: Dr. Ramachandra K. Bhat

1) Discussion: This SOP provides step-by-step instructions on the proper operation of the OX-250 Radiographic Unit to prevent potential damage to the unit and accidental exposure to x-ray radiation by personnel operating the unit. Refer to the instruction manual for details on the x-ray equipment, description of the controls and main components of the equipment, and explanation of the functions of the controls and indicating devices. See Enclosure 1 of this SOP for illustration of the x-ray control unit showing the locations of the controls and indicating devices on the front panel.

2) Equipment:
   a. OX-250 Industrial Radiographic Unit
   b. Environmental monitors (TLDs, GM meter)
   c. Detector train
   d. Remote TV and monitors
   e. Soil Box positioner
   f. Zenith Computer and perpherials with IEEE board

3) Procedure

THREE SECTIONS

I. BEFORE OPERATING THE X-RAY UNIT
II. OPERATING THE X-RAY UNIT
III. AFTER OPERATING THE X-RAY UNIT

I. BEFORE OPERATING THE X-RAY UNIT

1. Locate the X-ray backscatter research loose leaf data note book and insure that all safety checks listed on the X-Ray Safety Check List (Enclosure 2) are being checked and will be observed throughout the operation of the unit.

2. Unlock the main door to the x-ray exposure room.

3. Unlock the door to the panel box that encloses both the main power line disconnect switch box and the red warning light switch.

NOTE: The panel box is attached to the wall outside the x-ray room and adjacent to the x-ray control unit in the left side.

4. Turn on the main power line by pushing the large switch handle up.

5. Turn on the warning light switch next to the main switch box.

NOTE: The red lights outside and inside the x-ray room should be flashing.

6. Check the roof of Building 318 to make sure the red warning light is flashing and no one is on the roof. Be sure the gate to the stairway is locked and the x-ray warning sign is placed across the gate.

NOTE: The stairway to the roof is located outside on the left side of the building facing the main entrance from the outside.

7. Check that the radiation dosimeters are in place room 143.

NOTE: There are two (2) dosimeters hanging on the exterior of the exposure room walls, inside of room 143, and a third inside the equipment laboratory on the outside wall of the exposure room.

8. Check that you and others involved in the x-ray work are wearing personal dosimeters before conducting x-ray exposures (energizing x-ray tube).

9. Insure that an appropriate environmental monitor, using either an audible monitor or a tape recording device, is operating. Any visitor present for a period greater than 2 hours with the beam energized must be issued a personal dosimeter.

10. Turn off the warning light switch.

11. Turn on both power strips in the instrument cabinet.

12. Turn on TV monitors and verify that they are working properly by viewing the screens.

13. Position the x-ray tube head inside the x-ray room in any desirable position.

NOTES:

a. The head is mounted on rotating trunnions attached to the rollers on the horizontal I-beam boom.
b. The head can be moved sideways by swinging the boom by hand and back and forth.
c. The head can be set at an angle by manual adjustment.

d. The head can be moved up and down by using the up and down control switch to the electric motor that moves the boom up and down. The power to the motor is connected to a separate switch box on the wall inside the room and is always on. Therefore, the head can be positioned at any time with the x-ray tube turned off.

14. Position the soil box in the "home" position by turning the unit on and pressing the menu select key. Then press the home key and then each axis key. The box must be in the home position to begin imaging.

II. OPERATING THE X-RAY UNIT

1. Set the scale selector switch, below the voltmeter to "high" position (0-250 volt scale) or "Low" position (0-125 volt scale), as desired.

2. Turn on the line switch to the x-ray control unit by momentarily pressing the "on" button above the resistance control.

NOTE: The oil cooling unit to the x-ray tube head will come on inside the x-ray room.

3. Set the kilovolt selector to produce the proper kVp, taking into account the known drop as the load is put on.

NOTES:
a. The kilovolt setting is determined by reference to the calibration chart, see Enclosure 3.
b. The voltmeter reading for a particular setting will be always higher than the voltage shown on the calibration chart, which is based on the voltmeter reading under load when the resistance control (position #23) is entirely cut out.

4. Turn the resistance control to position #1 (fully counterclockwise).

NOTE: The x-ray tube would not be energized unless the resistance control is fully counterclockwise.

5. Set the exposure timer, below the ammeter, to the desired time value.

NOTES:
a. The x-ray unit should be allowed 30 minutes to operate before backscatter imaging is conducted. Because of this and the amount of time it takes to complete on pass (approximately 45 minutes) it is best not to use the timer.
b. The outer scale represents the minutes (up to 20 minutes) and the inner scale represents the seconds.
c. With the timer switch on, the timer will automatically control the time of exposure.
d. The timer resets itself to zero after the x-ray is turned off for any reason.
e. The exposure time can be terminated by momentarily pressing the "off" button, above the kilovolt selector, to the x-ray tube.

6. Set the timer switch to the "on" position for timing the exposure.

NOTE: With the timer switch off, the exposure can be started and stopped by momentarily pressing the "on" and "off" buttons, respectively, to the x-ray tube.

7. Before turning the x-ray on, first check that no one is remaining inside the x-ray room.

8. Close the main door to the x-ray room.

NOTE: The door must be properly closed to activate the interlock so that the x-ray tube could be energized.

9. View the TV monitors to be sure no one is left inside the x-ray room.

10. Turn on the warning light switch, and then close the x-ray switch by momentarily pressing the "on" button to energize the x-ray tube.

NOTE: A delay timer is connected to the x-ray circuitry so that there is an automatic 30 second delay before the x-ray tube is energized. During this delay an audible beeper is sounded and the warning lights will be flashing, alerting that the beam will become energized. During operation, the beam can be cut off at any time by pushing against the door and breaking the interlock.

11. Simultaneously adjust the filament control to give proper milliamperage and advance the resistance control toward position #23.

NOTES:
a. The resistance control should be advanced somewhat rapidly to the kilovoltage value desired.
b. The resistance control should not be more than 5 points remaining in the circuit when the desired kilovoltage is reached.
c. Do not change the kilovoltage setting while the x-ray tube is energized. Shut the x-ray tube off first before changing the setting.

12. Allow the unit to run 30 minutes at the desired settings before running an experiment. It takes approximately 30 minutes to obtain a stable reading.

13. After the exposure time has elapsed, return the resistance control to position #1.

NOTE: The x-ray tube will be shut off automatically at the end of exposure time if the timer was used.

14. *****YOU MUST MAKE SURE THAT ONE PERSON REMAINS WITH THE X-RAY UNIT THE ENTIRE TIME IN WHICH IT IS OPERATED.*****

15. Turn off the warning light switch.

16. Repeat steps 1 through 15 for subsequent x-ray exposures.

III. AFTER OPERATING THE X-RAY UNIT

1. To stop energizing the beam, press the "off" button of the line switch. Allow at least three minutes (it is best to allow the unit to cool for 30 minutes if it has run for more than an hour) for the oil cooler to cool the x-ray tube sufficiently before shutting of the x-ray control unit.

2. Turn off the x-ray control unit by turning off the main power line switch by pulling the large switch handle, located in the panel power box, down.

3. Lock the door to the panel box on the wall outside the x-ray room.

4. Lock the main door to the x-ray room.

5. Turn off all powered instruments.

6. Be sure to sign, date and make appropriate comments on the X-RAY SAFETY CHECK LIST located in the x-ray backscatter mine detection black binder under the x-ray operation log section.

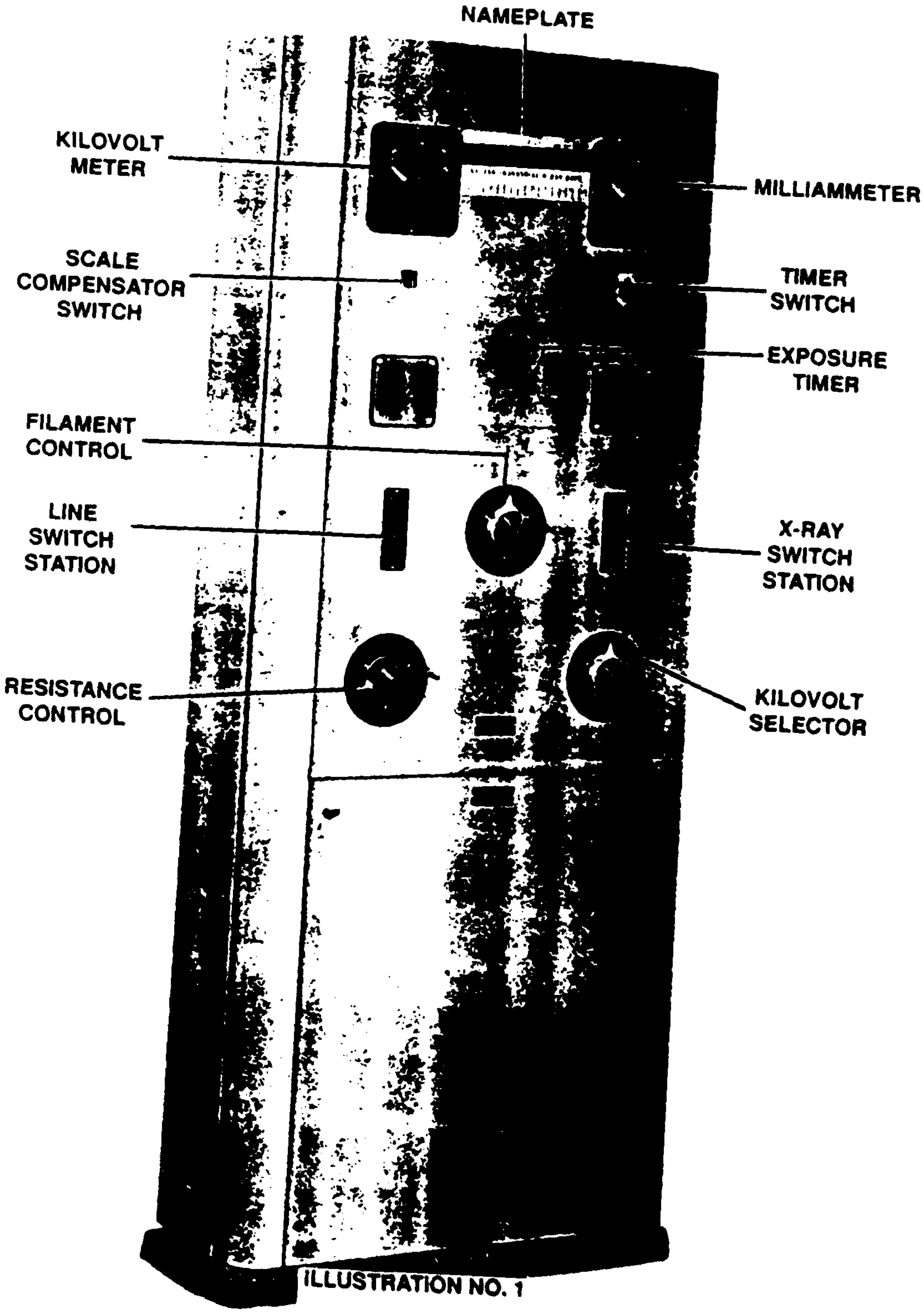

ILLUSTRATION NO. 1

OX-250 CONTROL

Enclosure 2

X-RAY SAFETY CHECK LIST

DIRECTIONS

ANY DAY THE X-RAY BEAM IS ENERGIZED THE FOLLOWING SAFETY PROCEDURES ARE TO BE VERIFIED:

1. ALL OPERATORS ARE WEARING A PERSONAL DOSIMETER.
2. FLASHING LIGHTS ARE FUNCTIONAL.
3. NO PERSONNEL ARE ON ROOF WHEN BEAM IS ENERGIZED.
4. TV MONITORS ARE FUNCTIONAL AND EXPOSURE ROOM SURVEYED TO ENSURE NO PERSONNEL ARE PRESENT WHEN BEAM IS ENERGIZED.
5. ENVIRONMENTAL MONITORING DEVICE IS FUNCTIONAL AND OPERATING, AND NEVER EXCEEDS BACKGROUND LEVELS.
6. OPERATOR IS ALWAYS PRESENT WHEN BEAM IS ENERGIZED.
7. AT CLOSE OF DAY X-RAY POWER IS TURNED OFF, BOX IS LOCKED AND OTHER POWER SUPPLIES ARE TURNED OFF.
8. OPERATOR HAS SIGNED AND DATED SHEET VERIFYING CHECKS PERFORMED AND HAS RECORDED LENGTH OF TIME BEAM WAS ENERGIZED AND DESCRIBED ANY DEVIATIONS FROM PRESCRIBED SAFETY PROCEDURES.

DATE	OPERATOR INITIALS	LENGTH OF TIME BEAM ENERGIZED	COMMENTS

Enclosure 3

CALIBRATION CHART FOR OX-250 INDUSTRIAL X-RAY UNIT WITH FORCED OIL COOLING

Useful KVP	For 5 ma. Voltmeter Reading Under Load	For 8 ma. Voltmeter Reading Under Load	For 10 ma. Voltmeter Reading Under Load
60	59.0	61.5	62.0
65	63.0	65.5	66.0
70	67.0	69.5	70.0
75	71.0	73.5	74.0
80	75.0	77.0	78.0
85	79.0	81.0	82.0
90	82.5	85.0	86.0
95	86.0	84.9	90.0
100	90.0	93.0	94.0
105	94.0	96.5	98.0
110	98.0	100.5	101.5
115	101.5	104.0	105.5
120	105.5	108.0	109.5
125	110.0	112.0	113.0
130	113.0	116.0	117.0
135	117.0	120.0	121.0
140	121.0	124.0	125.0
145	125.0	128.0	129.0
150	129.0	131.5	133.0
155	132.5	135.5	137.0
160	136.5	139.5	141.0
165	140.0	143.0	145.0
170	144.0	147.0	148.5
175	148.0	151.0	152.0
180	152.0	155.0	156.0
185	155.5	159.0	160.0
190	159.5	162.5	164.0
195	163.0	166.5	168.0
200	167.0	170.5	172.0
205	171.0	174.5	176.0
210	175.0	178.0	180.0
215	178.5	182.0	184.0
220	182.5	186.0	188.0
225	186.0	190.0	192.0
230	190.0	194.0	196.0
235	194.0	197.5	200.0
240	198.0	201.5	204.0
245	201.5	205.5	208.0
250	205.0	209.0	212.0

CAUTION: ALWAYS OPEN THE X-RAY CONTRACTOR SWITCH BEFORE CHANGING THE SETTING OF AUTOTRANSFORMER CONTROL

APPENDIX B

X-RAY SAFETY CHECK LIST

DIRECTIONS

ANY DAY THE X-RAY BEAM IS ENERGIZED THE FOLLOWING SAFETY PROCEDURES ARE TO BE VERIFIED:

1. ALL OPERATORS ARE WEARING A PERSONAL DOSIMETER.
2. FLASHING LIGHTS ARE FUNCTIONAL.
3. NO PERSONNEL ARE ON ROOF WHEN BEAM IS ENERGIZED.
4. TV MONITORS ARE FUNCTIONAL AND EXPOSURE ROOM SURVEYED TO ENSURE NO PERSONNEL ARE PRESENT WHEN BEAM IS ENERGIZED.
5. ENVIRONMENTAL MONITORING DEVICE IS FUNCTIONAL AND OPERATING, AND NEVER EXCEEDS BACKGROUND LEVELS.
6. OPERATOR IS ALWAYS PRESENT WHEN BEAM IS ENERGIZED.
7. AT CLOSE OF DAY X-RAY POWER IS TURNED OFF, BOX IS LOCKED AND OTHER POWER SUPPLIES ARE TURNED OFF.
8. OPERATOR HAS SIGNED AND DATED SHEET VERIFYING CHECKS PERFORMED AND HAS RECORDED LENGTH OF TIME BEAM WAS ENERGIZED AND DESCRIBED ANY DEVIATIONS FROM PRESCRIBED SAFETY PROCEDURES.

DATE	OPERATOR INITIALS	LENGTH OF TIME BEAM ENERGIZED	COMMENTS

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