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# RADIOLOGICAL SURVEY OF THE HEALTH DIVISION DIAGNOSTIC X-RAY FACILITY

by

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Industrial Hygiene and Safety

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## DISCLAIMER

# RADIOLOGICAL SURVEY OF THE HEALTH DIVISION DIAGNOSTIC X-RAY FACILITY

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Surveys of the Health Division X-Ray Facility at Argonne National Laboratory were initiated during the month of December 1958 to determine the levels of exposures encountered in scattering under normal operating conditions. Incorporated in the scattering surveys was a study of the air dosages received by operating personnel and those undergoing diagnostic study.

The primary purpose of this facility is for diagnostic work using radiographic and fluoroscopic methods. Although all phases of this type of operation are employed, approximately 80 percent of the studies made consist of posterior-anterior chest radiographs in conjunction with annual recheck, pre-employment, and termination physical examinations. The major portion of the data contained herein is based on the settings for posterior-anterior chest radiographs, i.e., 85 kvp (tube voltage) and 100 ma (target current).

The X-ray facility employs a G-E Unit with a Coolidge Rotating Anode X-ray tube. The tube has a maximum voltage rating of 110 kvp with 0.5-mm (of aluminum equivalent) inherent filtration. One millimeter of aluminum has been inserted in front of the beam port for additional filtration. Included in the equipment is a G-E PR Phototimer and a Videx Model C Radiographic Cone. The phototimer, used in approximately 90 percent of all radiographic exposures, serves the purpose of limiting exposure time in accordance with the density of the object being radiographed. For radiographic work involving areas where the phototimer cannot be employed, a preset timer is used. The radiographic cone serves as a beam collimator, allowing the major portion of the beam to be confined to the area to be radiographed and thereby reducing excessive scattering. Voltage settings usually range from 65 kvp and 25 ma for a knee radiograph to 85 kvp and 100 ma for a chest radiograph.

The facility is housed in a 19 ft 5 in. x 14 ft 4 in. x 10 ft room with $\frac{1}{8}$-in. lead sheeting on the walls and doors to protect adjacent facilities from direct or scattered radiation. In addition, the operating personnel are protected by a portable screen covered with 0.5 mm of lead sheeting and a lead-impregnated glass port for viewing the operation. The X-ray unit is normally operated by qualified personnel who stand behind the screen, which is approximately 72 in. from the target.

# INSTRUMENTATION

In order to obtain sufficient cumulative data concerning the orders of magnitude of the scattered X rays throughout the facility, three sets of DuPont #553 film packets were located at each of 26 points in and about the facility (see Figures 1 and 2).

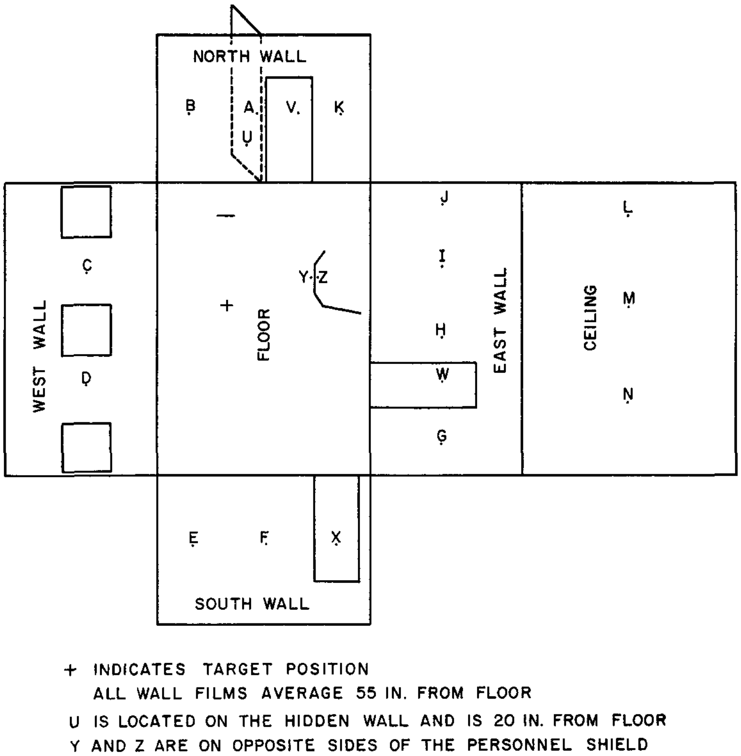


Figure 1

Diagnostic X-ray Facility

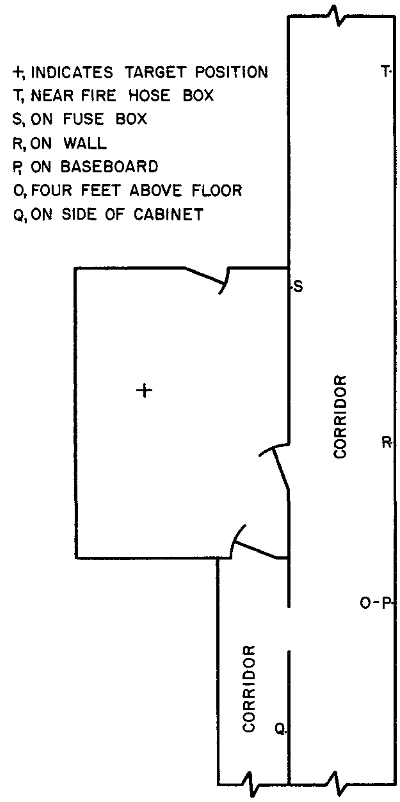


Figure 2

Corridors Adjacent to the X-ray Facility

Each film was partially shielded by 1 mm of cadmium. The films were exposed for one, two, and three-week intervals, and after the end of each period the films were removed and stored under refrigeration to retard fading of the latent image. In conjunction with the diagnostic studies, DuPont #553 film packets were used on an individual and treated in like manner.

A second method to detect X-ray scattering occurring in and about the facility involved the use of an end-window ($\sim$2 mg/cm$^2$) G-M Counter.

The third and final method to detect X-ray scattering was a Patterson Fluorescent Screen. In order to determine if stray beams were emerging from the sides of the filtering cone area of the unit, the screen was placed at various locations about the unit. The screen was also placed on the edge of the film holder (Cassette Changer) in order to determine the effectiveness of the beam collimation.

A Victoreen Model 70 Condenser r-Meter was used as the basis for air-dose rates for film calibration, inverse-square-law study, and distance vs. dose vs. kvp determinations.

## DATA

The Victoreen instrument was used with thimble chamber #227; 1 r rated at 0.065 r/sec with an efficiency of ±10% and chamber #70-5; 25 r rated at 15 r/sec with an efficiency of ±2%. Both chambers have a rated effective energy range of 30-400 kev. The reason for using the 1-r chamber in conjunction with the 25-r chamber was due primarily to the expected dose rates to be encountered. Insofar as the Condenser r-Meter scale is fixed and independent of the chambers, the smallest scale increment when using the 25-r chamber is 500 mr, whereas the smallest scale increment for the 1-r chamber is 20 mr. Although the 1-r chamber was more accurate in reading low-order dosages, the dose-rate response of this chamber introduced an error, which was resolved by correlating the response of the 25-r and 1-r chambers in similar fields of radiation. The results with the 25-r chamber were used as the basis for the true dose because of its high response rating (15 r/sec) vs. the dose rate encountered. From these data a correction factor vs. distance curve was plotted (see Figure 3 and Table 1). Correction factors from this curve were utilized whenever the 1-r chamber was used.

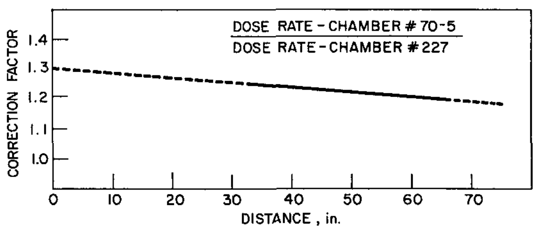


Figure 3

Correction Factor for 1-r Chamber #227 (85 kvp, 100 ma)

Table 1

INVERSE-SQUARE LAW AND CORRECTION-FACTOR DATA
(Tube voltage, 85 kvp; target current, 100 ma; time, 0.5 sec)

| Dosimeter | Distance, (in.) | Dose* (r) | Correction Factor, (a/b) |
|---|---|---|---|
| 25 r | 65.5 | 0.185 (a) | 1.194 |
| 1 r | 65.5 | 0.155 (b) | |
| 25 r | 49.5 | 0.350 (a) | 1.228 |
| 1 r | 49.5 | 0.285 (b) | |
| 25 r | 32.5 | 0.800 (a) | 1.243 |
| 1 r | 32.5 | 0.644 (b) | |
| 25 r | 16.5 | 2.86 | |

* The dose results are the average of five exposures per dosimeter at each distance.

Readings with both chambers were taken at various target-to-chamber distances in order to verify whether or not the inverse-square law would be applicable for this particular type of facility (see Figure 4 and Table 1).

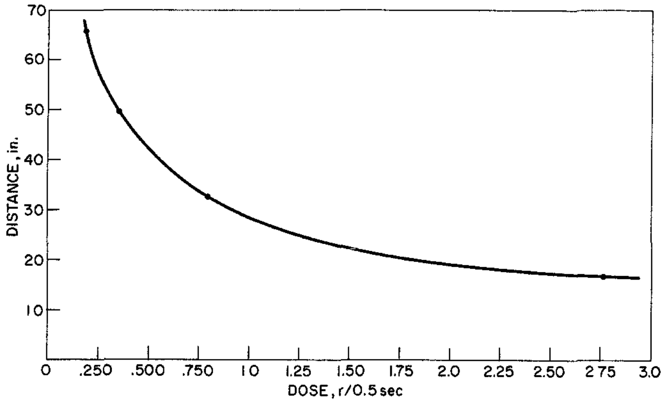


Figure 4

Data for Inverse Square Law
85 kvp, 100 ma

Two separate sets of calibrated film standards were made to determine the conversion of the film density to air dose (see Table 2).

Table 2

FILM DENSITY - AIR DOSE

Radium Calibration Densities

| Film No. | Dose (r) | Density (Shield) | Density (Window) |
|---|---|---|---|
| 1 | 0.025 | 0.005 | 0.01 |
| 2 | 0.050 | 0.015 | 0.02 |
| 3 | 0.100 | 0.035 | 0.06 |
| 4 | 0.150 | 0.055 | 0.09 |
| 5 | 0.200 | 0.085 | 0.14 |
| 6 | 0.400 | 0.190 | 0.30 |
| 7 | 0.800 | 0.400 | 0.58 |
| 8 | 1.000 | 0.490 | 0.72 |
| 9 | 2.000 | 0.950 | 1.27 |
| 10 | 3.000 | 1.270 | 1.63 |
| 11 | 5.000 | 1.790 | 2.20 |
| 12 | 10.000 | 2.480 | 2.97 |

X-ray Calibration Densities (85 kvp)

| Film No. | Dose Expected (r) | Dose Recorded (r) | Dose Corrected (r) | Density (Window) |
|---|---|---|---|---|
| 1 | 0.02 | 0.020 | 0.024 | 0.26 |
| 2 | 0.06 | 0.045 | 0.054 | 0.64 |
| 3 | 0.10 | 0.095 | 0.113 | 1.08 |
| 4 | 0.16 | 0.140 | 0.178 | 1.43 |
| 5 | 0.20 | 0.200 | 0.254 | 1.90 |
| 6 | 0.40 | 0.370 | 0.470 | 2.50 |
| 7 | 0.80 | 0.695 | 0.883 | 3.+ |
| 8 | 1.0 | 0.825 | 1.049 | - |
| 9 | 2.0 | 2.100 | 2.100 | - |
| 10 | 3.0 | 3.100 | 3.100 | - |
| 11 | 5.0 | 4.500 | 4.500 | - |
| 12 | 10.0 | 8.800 | 8.800 | - |

Note: Densities greater than 3 were beyond the capacity of the densitometer used.

Two sets of curves (see Figures 5 and 6) were obtained. One set is the result of timed exposures of the #553 film packet in a known gamma field emanating from a radium source. The curves were plotted for shielded (1 mm Cd) and unshielded film (see Figure 5). A second curve was plotted from the exposure of the #553 film packet (unshielded) to the beam of the X-ray unit (see Figure 6).

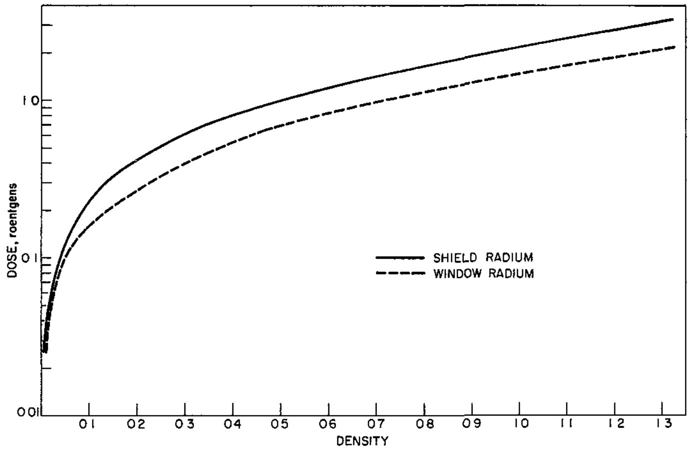


Figure 5

Calibration of Sensitive Film #502 (Radium Standard)

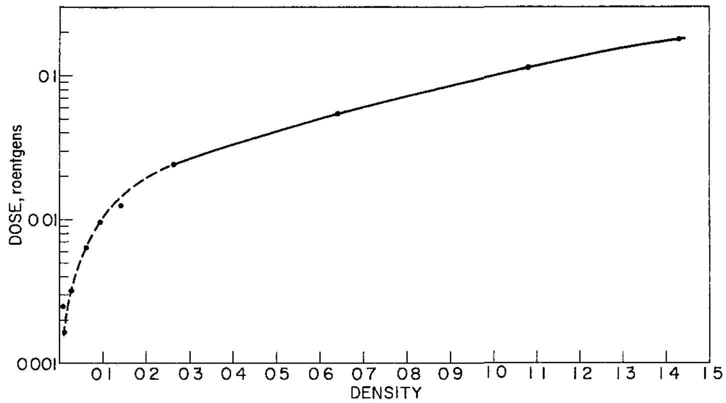


Figure 6

Calibration of Sensitive Film #502
(X-ray; 85 kvp 100 ma)

This was accomplished by locating a film packet and a thimble chamber side by side in the beam simultaneously. The distance to the target and time of exposure were then varied to obtain the desired dose on each film, with the thimble chamber acting as the exposure-recording device. The unit was set at 85 kvp for all the X-ray film calibrations. Upon completion of the standards, all of the film was developed in one batch and read.

A study of the radium and 85-kvp X-ray curves indicate a significant difference in orders of magnitude, 15.5 radium window to 1, 85-kvp X-ray, between the two standards. This 15.5 to 1 ratio is primarily due to the energy dependence of the film to the X- and gamma-ray energies involved. Even assuming the 85-kvp curve cannot reproduce the exact energies impinged on each film packet, the 85-kvp curve remains the more realistic approximation of the equivalent-air-dose rates encountered. The radium curves are included as a point of interest and should not be considered as an approximate air-dose reading.

Although the unit is operated at 85 kvp and 100 ma for a major portion of the time, various combinations of tube voltage and target current settings can be employed based on the unit's inherent capacity. Because of this flexibility, data were obtained for certain combinations of tube voltage and target current settings and distances to determine changes of air-dose rate due to these variables (see Figure 7 and Table 3).

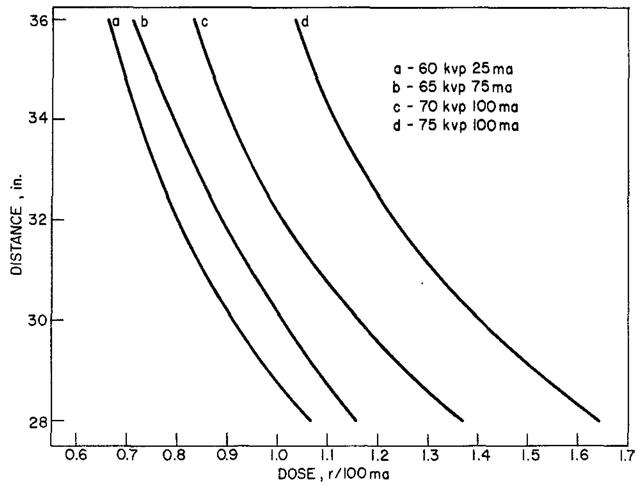


Figure 7

Distance - Dose - kvp

Scattering exposures received by the DuPont #553 film packets located at each of 26 points in and about the facility may be found in Tables 4, 5, and 6.

In using an end-window (~2 mg/cm$^2$) G-M Counter* with the X-ray unit operating under normal conditions (primarily for chest radiographs), no detectable radiation could be found emanating through the walls of the facility. Surveys were made around the three entrances to the room with the doors closed and the detector placed at the top, sides, and bottom breaks between door and frame. The results of these surveys were as in Table 7.

*G-M readings must be considered as orders of magnitude for this purpose, due to the energy dependence and lag in time of response of the instrument.

Tablé 3

DOSE-DISTANCE - KVP DATA

| Distance (in.) | Tube Voltage (kvp) | Target Current (ma) | Dose (r/sec) | Dose (r/100 ma) |
|---|---|---|---|---|
| 36 | 60 | 25 | 0.166 | 0.664 |
| 32 | 60 | 25 | 0.200 | 0.800 |
| 28 | 60 | 25 | 0.266 | 1.064 |
| 36 | 65 | 75 | 0.533 | 0.710 |
| 32 | 65 | 75 | 0.666 | 0.889 |
| 28 | 65 | 75 | 0.866 | 1.155 |
| 36 | 70 | 100 | 0.833 | 0.833 |
| 32 | 70 | 100 | 1.011 | 1.011 |
| 28 | 70 | 100 | 1.370 | 1.370 |
| 36 | 75 | 100 | 1.033 | 1.033 |
| 32 | 75 | 100 | 1.233 | 1.233 |
| 28 | 75 | 100 | 1.644 | 1.644 |

Notes: 1) 25-r dosimeter #70-5 used in all measurements.
2) All dose results are the average of three exposures per distance.

Table 4

WALL EXPOSURE - 1 WEEK

| No. | Pos. | Shield Density | Window Density | Ra Source, (mr) | Ra Source, (a.u.)[a] | 85-kvp X-ray Source, (mr) |
|---|---|---|---|---|---|---|
| 1-A | A-1 | - | 0.32 | 0 | 420 | 28 |
| 2-A | B-1 | - | 0.30 | 0 | 400 | 26 |
| 3-A | C-1 | 0.005 | 0.61 | 25 | 830 | 50 |
| 4-A | D-1 | - | 0.13 | 0 | 195 | 12* |
| 5-A | E-1 | - | 0.07 | 0 | 120 | 7* |
| 6-A | F-1 | - | 0.17 | 0 | 240 | 16* |
| 7-A | G-1 | - | 0.19 | 0 | 260 | 18* |
| 8-A | H-1 | - | 0.26 | 0 | 350 | 24 |
| 9-A | I-1 | - | 0.03 | 0 | 70 | 4* |
| 10-A | J-1 | - | 0.06 | 0 | 105 | 5* |
| 11-A | K-1 | - | 0.17 | 0 | 240 | 16* |
| 12-A | L-1 | - | 0.33 | 0 | 440 | 28 |
| 13-A | M-1 | 0.01 | 0.89 | 40 | 1280 | 83 |
| 14-A | N-1 | 0.005 | 0.62 | 25 | 850 | 51 |
| 15-A | O-1 | - | - | 0 | 0 | 0 |
| 16-A | P-1 | - | - | 0 | 0 | 0 |
| 17-A | Q-1 | - | - | 0 | 0 | 0 |
| 18-A | R-1 | - | - | 0 | 0 | 0 |
| 19-A | S-1 | - | - | 0 | 0 | 0 |
| 20-A | T-1 | - | - | 0 | 0 | 0 |
| 21-A | U-1 | - | - | 0 | 0 | 0 |
| 22-A | V-1 | 0.005 | 0.23 | 25 | 310 | 21* |
| 23-A | W-1 | 0.01 | 0.29 | 40 | 385 | 26 |
| 24-A | X-1 | - | 0.19 | 0 | 260 | 18* |
| 25-A | Y-1 | - | 0.64 | 0 | 880 | 53 |
| 26-A | Z-1 | - | - | 0 | 0 | 0 |

* Approximate value, no calibration made below 24 mr.

[a] An a.u. (arbitrary unit) is a unit used to compare the density of a film in the badge window position caused by exposure to unknown beta-gamma and/or X radiation to the equivalent density of a film in the badge window position caused by exposure to a known $Ra^{226}$ source expressed in milliroentgens.

Table 5

WALL EXPOSURE - 2 WEEKS

| No | Pos. | Shield Density | Window Density | Ra Source (mr) | Ra Source, (a u )[a] | 85 kvp X-ray Source, (mr) |
|---|---|---|---|---|---|---|
| 1-B | A-2 | - | 0.35 | 0 | 460 | 30 |
| 2-B | B-2 | - | 0 37 | 0 | 490 | 31 |
| 3-B | C-2 | 0.01 | 0 73 | 40 | 1030 | 63 |
| 4-B | D-2 | - | 0 16 | 0 | 230 | 15* |
| 5-B | E-2 | - | 0 09 | 0 | 150 | 9* |
| 6-B | F-2 | - | 0 23 | 0 | 310 | 21* |
| 7-B | G-2 | - | 0.24 | 0 | 320 | 22* |
| 8-B | H-2 | - | 0 34 | 0 | 450 | 29 |
| 9-B | I-2 | - | 0 05 | 0 | 95 | 5 5* |
| 10-B | J-2 | - | 0 08 | 0 | 130 | 8* |
| 11-B | K-2 | - | 0 20 | 0 | 270 | 18* |
| 12-B | L-2 | - | 0 41 | 0 | 540 | 34 |
| 13-B | M-2 | 0.01 | 1 08 | 40 | 1600 | 112 |
| 14-B | N-2 | 0 01 | 0 78 | 40 | 1100 | 69 |
| 15-B | O-2 | - | - | 0 | 0 | 0 |
| 16-B | P-2 | - | - | 0 | 0 | 0 |
| 17-B | Q-2 | - | - | 0 | 0 | 0 |
| 18-B | R-2 | - | - | 0 | 0 | 0 |
| 19-B | S-2 | - | - | 0 | 0 | 0 |
| 20-B | T-2 | - | - | 0 | 0 | 0 |
| 21-B | U-2 | - | - | 0 | 0 | 0 |
| 22-B | V-2 | 0 005 | 0 28 | 25 | 375 | 25 |
| 23-B | W-2 | 0 02 | 0 36 | 70 | 480 | 30 |
| 24-B | X-2 | 0 01 | 0 24 | 40 | 325 | 22* |
| 25-B | Y-2 | 0 01 | 0 80 | 40 | 1140 | 71 |
| 26-B | Z-2 | - | 0 01 | 0 | 25 | 1 6* |

* Approximate value no calibration made below 24 mr

[a] An a u. (arbitrary unit) is a unit used to compare the density of a film in the badge window position caused by exposure to unknown beta-gamma and/or X radiation to the equivalent density of a film in the badge window position caused by exposure to a known $Ra^{226}$ source expressed in milliroentgens

Table 6

WALL EXPOSURE - 3 WEEKS

| No | Pos | Shield Density | Window Density | Ra Source, (mr) | Ra Source (a u )[a] | 85 kvp X-ray Source (mr) |
|---|---|---|---|---|---|---|
| 1-C | A-3 | 0 005 | 0 40 | 25 | 530 | 33 |
| 2-C | B-3 | - | 0 46 | 0 | 620 | 38 |
| 3-C | C-3 | 0 01 | 0 89 | 40 | 1280 | 83 |
| 4-C | D-3 | - | 0 20 | 0 | 270 | 18* |
| 5 C | E-3 | - | 0 12 | 0 | 170 | 11* |
| 6-C | F-3 | - | 0 29 | 0 | 385 | 26 |
| 7-C | G-3 | - | 0 30 | 0 | 400 | 26 |
| 8 C | H-3 | - | 0 41 | 0 | 540 | 34 |
| 9-C | I-3 | - | 0 05 | 0 | 95 | 5 5* |
| 10-C | J-3 | - | 0 09 | 0 | 150 | 9* |
| 11-C | K-3 | - | 0 24 | 0 | 370 | 22* |
| 12-C | L-3 | 0 005 | 0 51 | 25 | 680 | 42 |
| 13-C | M-3 | 0 015 | 1 29 | 55 | 2020 | 148 |
| 14-C | N-3 | 0 01 | 0 96 | 40 | 1390 | 93 |
| 15-C | O-3 | - | - | 0 | 0 | 0 |
| 16-C | P-3 | - | - | 0 | 0 | 0 |
| 17-C | Q-3 | - | - | 0 | 0 | 0 |
| 18-C | R-3 | - | - | 0 | 0 | 0 |
| 19-C | S-3 | - | - | 0 | 0 | 0 |
| 20-C | T-3 | - | - | 0 | 0 | 0 |
| 21-C | U-3 | - | - | 0 | 0 | 0 |
| 22-C | V-3 | 0 02 | 0 36 | 70 | 480 | 30 |
| 23-C | W-3 | 0 02 | 0 44 | 70 | 590 | 36 |
| 24-C | X-3 | 0 015 | 0 32 | 55 | 430 | 28 |
| 25-C | Y-3 | 0 015 | 0 98 | 55 | 1420 | 96 |
| 26-C | Z-3 | - | 0 015 | 0 | 35 | 2 5* |

* Approximate value, no calibration made below 24 mr

[a] An a u (arbitrary unit) is a unit used to compare the density of a film in the badge window position caused by exposure to unknown beta-gamma and/or X radiation to the equivalent density of a film in the badge window position caused by exposure to a known $Ra^{226}$ source expressed in milliroentgens

Table 7

RADIATION DETECTION AT DOORS

| Location | Top | Left Side | Right Side | Bottom |
|---|---|---|---|---|
| | During Chest Radiographs (85 kvp, 100 ma) | | | |
| South Door | $<$0.1 mr/hr | $<$0.1 mr/hr | $<$0.1 mr/hr | 0.4 mr/hr |
| East Door | $<$0.1 mr/hr | $<$0.1 mr/hr | $<$0.1 mr/hr | 0.4 mr/hr |
| North Door | $<$0.1 mr/hr | $<$0.1 mr/hr | $<$0.1 mr/hr | 0.4 mr/hr |
| | During Spine Radiographs (85 kvp, 100 ma) | | | |
| East Door | - | - | - | 1.3 mr/hr |

Results of all surveys with the G-M Counter indicated that the bottom cracks of the three doorways were the only locations where detectable radiation was emitted from the facility.

The Patterson Fluorescent Screen was used in an attempt to observe beam divergence. The unit was operated for three seconds at each of four locations. It was observed that excitation of the screen occurred only as a result of general scattering, and no divergent beams were noted. With the screen placed on the edge of the film holder, it was noted that the beam had a sharp cutoff within the area on which it was set to focus, thereby indicating a minimum of beam divergence from the cone to the film.

Data were accumulated from posterior-anterior chest radiographs of one hundred subjects, seventy-five male and twenty-five female. In all cases, the units phototimer was employed. The exposure for each individual subject was recorded in milliampere-seconds (mas) as read directly from the ma-mas meter (see Table 8).

Table 8

POSTERIOR-ANTERIOR CHEST RADIOGRAPHIC STUDIES
(Tube voltage 85 kvp; target current 100 ma)

| | Exposure, milliampere-seconds | | | Subject |
|---|---|---|---|---|
| Subject No. | Individual | Subtotal | Average | Male or Female |
| 1 | 17.0 | 17.0 | 17.00 | m |
| 2 | 11.0 | 28.0 | 14.00 | m |
| 3 | 12.0 | 40.0 | 13.30 | m |
| 4 | 12.0 | 52.0 | 13.00 | m |
| 5 | 13.0 | 65.0 | 13.00 | m |
| 6 | 16.0 | 81.0 | 13.50 | m |

Table 8 (Cont'd.)

| | Exposure, milliampere-seconds | | | Subject |
|---|---|---|---|---|
| Subject No. | Individual | Subtotal | Average | Male or Female |
| 7 | 11.0 | 92.0 | 13.14 | m |
| 8 | 9.0 | 101.0 | 12.62 | f |
| 9 | 10.0 | 111.0 | 12.33 | m |
| 10 | 12.0 | 123.0 | 12.30 | m |
| 11 | 9.0 | 132.0 | 12.00 | m |
| 12 | 9.0 | 141.0 | 11.75 | f |
| 13 | 14.0 | 155.0 | 11.92 | f |
| 14 | 12.0 | 167.0 | 11.93 | m |
| 15 | 10.5 | 177.5 | 11.83 | f |
| 16 | 11.5 | 189.0 | 11.81 | m |
| 17 | 8.0 | 197.0 | 11.59 | f |
| 18 | 7.0 | 204.0 | 11.32 | f |
| 19 | 10.5 | 214.5 | 11.28 | f |
| 20 | 9.0 | 223.5 | 11.18 | m |
| 21 | 10.5 | 234.0 | 11.15 | m |
| 22 | 9.0 | 243.0 | 11.05 | m |
| 23 | 24.0 | 267.0 | 11.51 | m |
| 24 | 18.0 | 285.0 | 11.88 | m |
| 25 | 17.0 | 302.0 | 12.08 | m |
| 26 | 11.5 | 313.5 | 12.06 | m |
| 27 | 8.5 | 322.0 | 11.93 | m |
| 28 | 11.0 | 333.0 | 11.89 | m |
| 29 | 11.0 | 344.0 | 11.86 | m |
| 30 | 9.0 | 353.0 | 11.77 | f |
| 31 | 12.0 | 365.0 | 11.77 | m |
| 32 | 10.0 | 375.0 | 11.72 | m |
| 33 | 16.0 | 391.0 | 11.85 | m |
| 34 | 24.0 | 415.0 | 12.21 | f |
| 35 | 17.0 | 432.0 | 12.35 | f |
| 36 | 11.0 | 443.0 | 12.31 | m |
| 37 | 11.5 | 454.5 | 12.28 | m |
| 38 | 12.0 | 466.5 | 12.28 | m |
| 39 | 12.0 | 478.5 | 12.27 | m |
| 40 | 11.5 | 490.0 | 12.25 | f |
| 41 | 11.5 | 501.5 | 12.23 | m |
| 42 | 10.5 | 512.0 | 12.19 | m |
| 43 | 11.0 | 523.0 | 12.16 | m |
| 44 | 16.0 | 539.0 | 12.25 | m |
| 45 | 13.0 | 552.0 | 12.27 | m |
| 46 | 9.0 | 561.0 | 12.19 | m |
| 47 | 9.0 | 570.0 | 12.13 | m |
| 48 | 10.0 | 580.0 | 12.08 | m |

Table 8 (Cont'd.)

| | Exposure, milliampere-seconds | | | Subject |
|---|---|---|---|---|
| Subject No. | Individual | Subtotal | Average | Male or Female |
| 49 | 10.5 | 590.5 | 12.05 | f |
| 50 | 14.0 | 604.5 | 12.09 | m |
| 51 | 9.0 | 613.5 | 12.03 | m |
| 52 | 11.0 | 624.5 | 12.01 | m |
| 53 | 10.5 | 635.0 | 11.98 | m |
| 54 | 11.0 | 646.0 | 11.96 | m |
| 55 | 11.0 | 657.0 | 11.95 | m |
| 56 | 9.0 | 666.0 | 11.89 | f |
| 57 | 10.5 | 676.5 | 11.87 | m |
| 58 | 12.5 | 689.0 | 11.88 | m |
| 59 | 10.0 | 699.0 | 11.85 | m |
| 60 | 9.0 | 708.0 | 11.80 | m |
| 61 | 8.0 | 716.0 | 11.74 | f |
| 62 | 12.0 | 728.0 | 11.74 | m |
| 63 | 12.0 | 740.0 | 11.75 | m |
| 64 | 10.0 | 750.0 | 11.72 | f |
| 65 | 8.5 | 758.5 | 11.67 | m |
| 66 | 11.0 | 769.5 | 11.66 | m |
| 67 | 18.5 | 788.0 | 11.76 | m |
| 68 | 10.0 | 798.0 | 11.75 | f |
| 69 | 9.5 | 807.5 | 11.70 | m |
| 70 | 14.0 | 821.5 | 11.74 | f |
| 71 | 8.0 | 829.5 | 11.68 | f |
| 72 | 7.0 | 836.5 | 11.62 | m |
| 73 | 13.0 | 849.5 | 11.64 | f |
| 74 | 9.0 | 858.5 | 11.60 | m |
| 75 | 14.5 | 873.0 | 11.64 | m |
| 76 | 9.0 | 882.0 | 11.61 | m |
| 77 | 8.0 | 890.0 | 11.56 | m |
| 78 | 8.0 | 898.0 | 11.51 | f |
| 79 | 11.0 | 909.0 | 11.51 | m |
| 80 | 15.0 | 924.0 | 11.55 | m |
| 81 | 8.5 | 932.5 | 11.51 | m |
| 82 | 11.0 | 943.5 | 11.51 | m |
| 83 | 15.0 | 958.5 | 11.55 | m |
| 84 | 9.0 | 967.5 | 11.52 | m |
| 85 | 12.0 | 979.5 | 11.52 | m |
| 86 | 16.0 | 995.5 | 11.57 | m |
| 87 | 15.0 | 1010.5 | 11.61 | f |
| 88 | 22.0 | 1032.5 | 11.73 | m |
| 89 | 13.0 | 1045.5 | 11.75 | m |
| 90 | 14.0 | 1059.5 | 11.77 | m |

Table 8 (Cont'd.)

| Subject No. | Exposure, milliampere-seconds Individual | Subtotal | Average | Subject Male or Female |
|---|---|---|---|---|
| 91 | 12.5 | 1072.0 | 11.78 | f |
| 92 | 16.0 | 1088.0 | 11.83 | m |
| 93 | 15.0 | 1103.0 | 11.86 | f |
| 94 | 8.0 | 1111.0 | 11.82 | m |
| 95 | 8.5 | 1119.5 | 11.78 | m |
| 96 | 10.0 | 1129.5 | 11.77 | f |
| 97 | 12.0 | 1141.5 | 11.77 | m |
| 98 | 12.5 | 1154.0 | 11.79 | m |
| 99 | 7.5 | 1161.5 | 11.73 | m |
| 100 | 19.5 | 1181.0 | 11.81 | f |

| | |
|---|---|
| Total Male and Female - 100 Subjects | 1181 mas |
| Maximum | 24 mas |
| Minimum | 7 mas |
| Average | 11.81 mas |
| Total Male - 75 Subjects | 889.0 mas |
| Maximum | 24.0 mas |
| Minimum | 7.0 mas |
| Average | 11.85 mas |
| Total Female - 25 Subjects | 292.0 mas |
| Maximum | 24.0 mas |
| Minimum | 7.0 mas |
| Average | 11.68 mas |

In order to correlate the air-dose rates vs. mas exposures, a series of thimble chamber measurements was made at 85 kvp and 100 ma (the setting at which posterior-anterior chest radiographs are taken). A target to chamber distance of 65.5 in. was utilized, and times of exposures varied from 0.1 to 1.0 second (see Table 9). The 65.5-in. distance was measured and assumed to be the distance from target to the center of an average subject in position for a posterior-anterior chest radiograph. From the results of these data, a graph of time of exposure vs. air dose was made (see Figure 8). Under these operating conditions, use of this graph and knowing an individual's exposure permits an approximate air dose to be determined.

Table 9

DOSE-TIME VARIABLE DATA
(Tube voltage 85 kvp; target current 100 ma, c= 1.194
target to chamber 65.5 in., dosimeter 1-r #227)

| Time of Exposure (sec) | Dose (mr/time) | Corrected Dose (mr/time) |
|---|---|---|
| 0.10 | 34.4 | 41.1 |
| 0.20 | 66.4 | 79.3 |
| 0.30 | 101.4 | 121.1 |
| 0.40 | 133.0 | 158.9 |
| 0.50 | 160.8 | 192.0 |
| 0.75 | 233.0 | 278.0 |
| 1.00 | 310.0 | 370.0 |

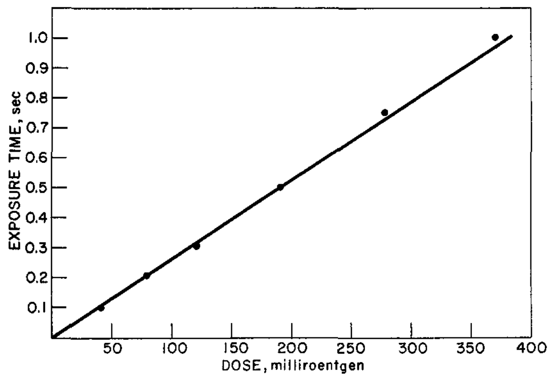


Figure 8

Dose - Time Variable
(85 kvp, 100 ma)

A series of three posterior-anterior chest radiographs was given to one male subject to observe the resultant exposures. The following technique was employed:

Exposure 1 - Subject radiographed under normal unit conditions; full inspiration.
Exposure 2 - Subject radiographed under normal unit conditions; full expiration.
Exposure 3 - Subject radiographed under normal unit conditions; full inspiration and #553 film packets at 15 points of interest on the body (see Table 10).

From the results (Table 10) it is assumed that the zero readings on packets 1-5 inclusive were due to low exposures and the insensitivity of the film used. The discrepancy noted in exposures 1 and 3 was probably due to the density difference of the film packets which added to the total density as seen by the phototimer.

Table 10

Personnel Exposure

Exposure 1; full inspiration 10.0 mas - ≈38 mr
Exposure 2; full expiration 16.0 mas - ≈62 mr
Exposure 3; full inspiration 15 film packets 11.5 mas - ≈44 mr

Personnel Film Results

| Film No. | Position | Density | Ra Source (mr) | X-ray Source (mr) |
|---|---|---|---|---|
| 1 | Gonad; Front | - | 0 | 0 |
| 2 | Gonad; Back | - | 0 | 0 |
| 3 | Gonad; Bottom | - | 0 | 0 |
| 4 | Gonad; Right | - | 0 | 0 |
| 5 | Gonad; Left | - | 0 | 0 |
| 6 | Back of Head | 0.05 | 140 | 12* |
| 7 | Forehead | - | 0 | 0 |
| 8 | Eye; Left | - | 0 | 0 |
| 9 | Eye; Right | - | 0 | 0 |
| 10 | Back; Left | 0.58 | 1170 | 48 |
| 11 | Back; Middle | 0.63 | 1260 | 52 |
| 12 | Back; Right | 0.64 | 1280 | 53 |
| 13 | Chest; Left | 0.06 | 155 | 13* |
| 14 | Chest; Middle | 0.02 | 70 | 11* |
| 15 | Chest; Right | 0.05 | 140 | 12* |

* Approximate values, no calibration made below 24 mr.

Packets 1-5 inclusive were worn for all three personnel exposures.

Table 10 shows results of the density variable between full inspiration and full expiration in terms of mas. It also indicates the various air dose results at points of interest about the body in terms of mr.

## INTERPRETATION

The results obtained from inverse-square-law and distance-dose-kvp studies seem to indicate that the inverse square law is applicable in this type of facility. Some degree of error is encountered due to minute amounts of scattered radiation in, and scale interpolation of, the thimble chambers used. An approximate air dose at any distance can then be predetermined by knowing tube voltage, target current and employing Figures 4 and 7.

The results of the film survey revealed three significant points of interest involving the scattering problem. First, no reading greater than

100 mr/week was noted in or about the facility. Secondly, no discernible exposure was found in areas immediately adjacent to the facility. Thirdly, film locations I and Z received negligible exposures, less than an approximated 6 mr for a three-week period. This is particularly important in that the operating personnel are stationed in this area during operation of the units. It may be noted that the readings of the first-week exposures are greater than the following two and three-week exposures averaged on a weekly basis. An explanation for this is that the operational time of the unit was much greater during the first week, due in part to thimble chamber measurements, than during the succeeding two weeks.

Results of the end-window survey and fluorescent-screen observations tend to indicate that scattered radiation in and about the facility is at a minimum.

From the results of the cumulative data of 100 subjects, maximum, minimum, and average exposures (see Table 8) correlated with air dose (Figure 8) revealed information of interest. For example, while the maximum and minimum dosages for male and female were found to be the same, their average exposures differed by a small amount, approximately an air dose of 1 mr. On the other hand, the ranges from maximum to minimum for each group and for the total subjects observed revealed a significant variance that precluded any accurate predetermination of an individual subject's exposure. Insofar as the phototimer operates on a density principle, the physical characteristics of the subject determine to a great degree his or her exposure. From observation of the 100 subjects sampled, it was noted that a large percentage of exposures were around the average of 11.81 mas (10 mas - 13 mas). The remaining subjects, above and below the average exposure, distributed equally in percentage but not in spread, thus producing a nonsymmetrical distribution curve (see Figure 9), which was not expected.

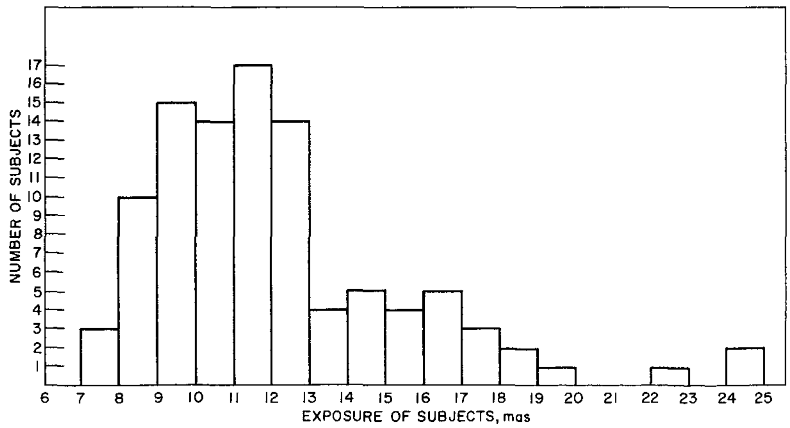


Figure 9

Subject Exposure Distribution

A study of the data from the three exposures given to one male subject reveal a significant variation in the dose received. In this particular case, the inspiration dose was less by a factor of 0.625 than the expiration dose. Although only one such determination was made, it is reasonable to expect that for any individual this type of variation would be noted.

The exposure a subject receives is a function of the body density at the time of exposure and is determined by the phototimer. This density can be varied by inflation and deflation of the lungs which, in turn, changes the configuration of the rib cage. This implies that two consecutive exposures to an individual will not necessarily result in identical dosages.

The results of the observation of film packets, placed at points of interest on the body of one male subject, verified the previously expected air doses as recorded by the thimble chambers. These results also indicate the degree of the body attenuation encountered, due to a posterior-anterior chest radiograph, while this type of unit is operating under the previous described conditions.

## CONCLUSION

The results of the study of this diagnostic X-ray facility and of all personnel involved revealed nothing that could be considered as extreme. There is some doubt as to the accuracy of the film exposures because of possible errors in extrapolation of the 85-kvp curve below 24 mr, latent image fading, and interpolation of thimble chamber readings. It is felt that the overall error due to these factors is relatively small, and therefore no attempt was made to determine accurately the finite quality of this error. The results obtained indicate that, when this facility is operated under normal conditions, the exposures received by operating and subject personnel in the facility do not approach permissible radiation exposurelevels recommended as maximum by the National Committee on Radiation Protection.