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LEAKAGE RADIATION FROM A DIAGNOSTIC TUBE HOUSING WHEN OPERATED AT LESS THAN THE MAXIMUM RATED KILOVOLTAGE*

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Abstract—The leakage radiation from a diagnostic tube housing is measured "when the tube is operated at its maximum continuous rated current for the maximum rated tube potential". As the potential across the tube is reduced, the maximum rated continuous current increases to maintain a constant input in heat units per second. On several occasions the question has been asked as to the decrease in leakage radiation as the potential is reduced and the current increased. A study has been done at kilovoltages from 150 to 85 kVp at the maximum rated continuous current. The results have been related to protective barrier requirements.

INTRODUCTION

A DIAGNOSTIC-TYPE protective tube housing is defined in Report No. 34 of the National Council on Radiation Protection and Measurements (1970) as one "so constructed that the leakage radiation measured at a distance of 1 m from the source cannot exceed 100 mR in 1 hr when the tube is operated at its maximum continuous rated current for the maximum rated tube potential". In planning the shielding for medical diagnostic X-ray installations, the question arises as to whether a 150 kVp tube installed in a 150 kVp diagnostic protective tube housing and operated at less than 150 kVp would require secondary protective barriers of lesser thickness, due to the lower leakage, than that required if the tube were operated at 150 kVp. When this question arises, it should be kept in mind that the maximum continuous tube current rating of the X-ray tube increases as the voltage decreases.

NCRP Report No. 34 describes the procedure to follow and presents the data necessary to calculate X-ray protective barriers. For barriers in diagnostic installations the basic procedure is to calculate, separately, the shielding required for scattered radiation and for leakage radiation. If the calculated barrier thicknesses differ by three or more half-value layers, the greater thickness should be used for the secondary barrier. If they differ by less than three half-value layers, then one half-value layer should be added to the greater thickness to obtain the secondary barrier thickness. The calculations for tube housing leakage assume leakage of 100 mR in 1 hr at 1 m from the source.

This study was undertaken to determine what the barrier requirements would be when the X-ray tube is operated at less than its maximum rated voltage. A typical case would be the use of a 150 kVp tube unit on a transformer with a maximum rating of 125 kVp.

EQUIPMENT AND INSTRUMENTATION

Two X-ray generators were used in this study. One was a single-phase, 2-pulse unit with kilovoltage continuously adjustable from 30 to 150 kVp and tube current continuously adjustable from 0.1 to 200 mA. This generator was connected to a 150 kVp rotating anode tube unit. Both 15 ft (4.57 m) and 35 ft (10.7 m) high-voltage cables were used to assess the effect of added capacitance with long cables. The other was a three-phase, 12-pulse unit capable of adjustment in 2 kVp

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steps from 40 to 150 kVp and at 10 selected tube currents from 25 to 700 mA. This generator was connected to a 150 kVp rotating anode tube unit using 35 ft (10.7 m) high-voltage cables.

Kilovoltage calibration of the generators was checked using a resistance divider with calibrated memory oscilloscope readout connected in the high-voltage circuit at the X-ray tube unit. Tube current calibration was checked by a milliammeter of known calibration placed in the high-voltage circuit at the X-ray tube unit.

Exposure measurements were made using a Victoreen Radocon Model 555 with appropriate probes. This instrument had been calibrated against our Intercomparison Standard Chambers which have a calibration traceable to the National Bureau of Standards.

EXPERIMENTAL DATA

The two rotating anode X-ray tube units had the same manufacturer's specified ratings for continuous operation as follows:

85 kVp, 6,0 mA
100 kVp, 5.0 mA
125 kVp, 4.0 mA
150 kVp, 3.3 mA.

The anode heat unit input per second (kVp × mA × 1 sec) is essentially constant (500 HU) for all ratings.

As a first approximation of the leakage to be expected at 1 m from the focal spot at the various continuous tube unit ratings for a "diagnostic-type protective tube housing", the thickness of lead necessary to reduce the useful beam exposure rate to 100 mR/hr at 1 m was calculated for 150 kVp, 3.3 mA operation using the 150 kVp broad beam lead attenuation curve in NCRP Report No. 34, Appendix D, Fig. 1, and from our recent paper (Ke72). This lead thickness was determined to be 2.26 mm. The exposure rate at 1 m was then calculated for the other continuous tube unit ratings for 2.26 mm lead attenuation using the curves in the NCRP Report No. 34 (lead attenuation data at 85 kVp were interpolated). The results are shown in Table 1. The calculations are interesting in that there is approx 50% decrease in leakage when the kilovoltage

Table 1. Broad beam attenuation for 2.26 mm lead calculated from NCRP Report No. 34, Appendix D, Fig. 1

kVp	mA	mR/h at 1 m
150	3.3	100
125	4.0	55
100	5.0	25
85*	6.0	5.0

* Interpolated

is decreased from 150 to 125 kVp and 50% decrease from 125 to 100 kVp.

A tube housing leakage survey was then performed on the tube unit connected to the single-phase, 2-pulse generator using 35 ft (10.7 m) high-voltage cables. Measurement of leakage at 1 m from the focal spot was made using the Victoreen Radocon 555 operating the X-ray unit at 150 kVp, 3.3 mA. The results are shown in Figs. 1 and 2. The maximum leakage occurred at the front of the tube unit 10°–20° below a horizontal plane through the focal spot and was 55 mR/hr at 1 m. The tube voltage waveform at 150 kVp,

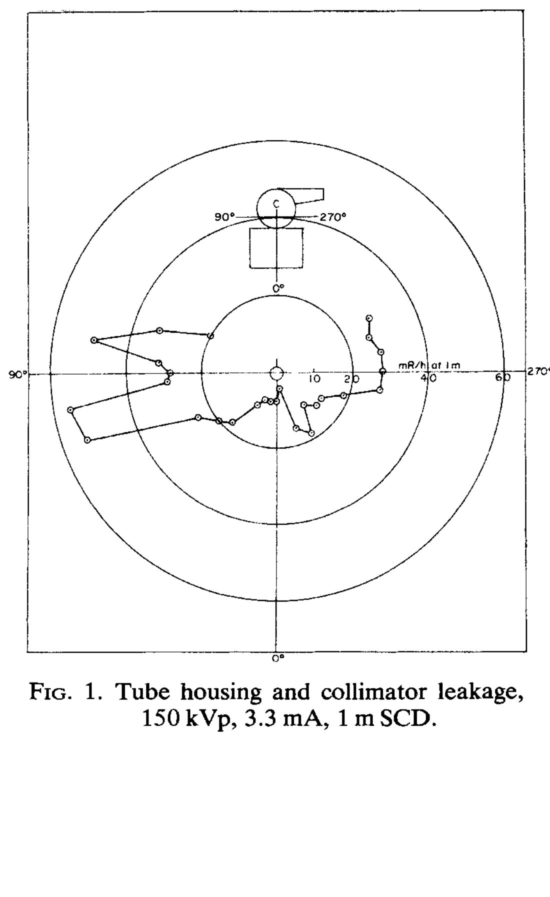


FIG. 1. Tube housing and collimator leakage, 150 kVp, 3.3 mA, 1 m SCD.

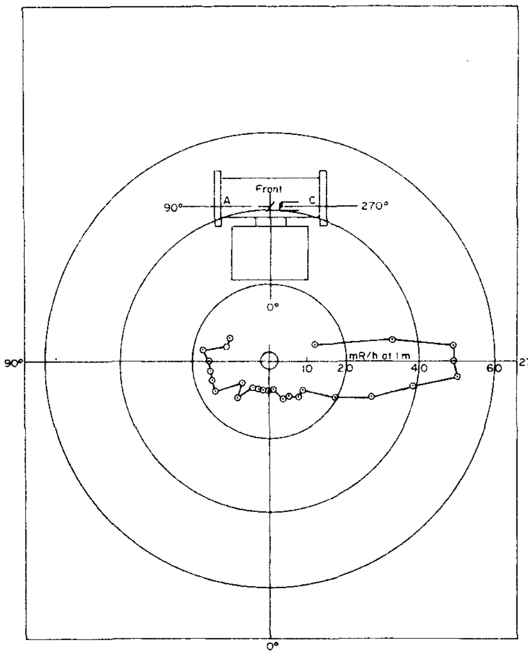


FIG. 2. Tube housing and collimator leakage, 150 kVp, 3.3 mA, 1 m SCD.

3.3 mA, had 10 kV ripple. The ripple increased with decreasing voltage and increasing current and was 25 kV at 85 kVp, 6.0 mA. The voltage waveforms at the rated continuous currents at 150, 125, 100 and 85 kVp are shown in Fig. 3.

An ionization chamber was placed at the location of maximum leakage 1 m from the source and the leakage measured at the four

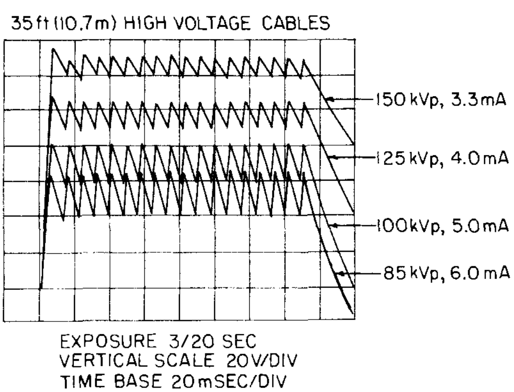


FIG. 3. Tube voltage waveforms, single-phase, 2-pulse system.

techniques for continuous operation. The measured data along with the leakage normalized to 100 mR/hr at 1 m at 150 kVp, 3.3 mA, are shown in Table 2. The normalized data are, in general, slightly lower than the calculated values due to the geometry being less than "broad beam" and the actual attenuation being greater than 2.26 mm lead equivalent, but are in good agreement with the calculated values.

The useful beam exposure rate using the single-phase, 2-pulse generator was measured at 150 kVp, 3.3 mA, with 2.26 mm lead added absorber to reduce the exposure rate to a nominal 100 mR/hr at 1 m using both 15 ft (4.57 m) and 35 ft (10.7 m) high-voltage cables. The results normalized to 100 mR/hr at 1 m are shown in Table 3. These data were taken using "broad beam" geometry. The decrease in normalized exposure rate with the 15 ft (4.57 m) high-voltage cables is due to the decreased capacitance of the shorter cables and corresponding increase in tube voltage ripple.

The three-phase, 12-pulse generator was operated at the minimum tube current control setting of 25 mA. The useful beam exposure

Table 2. Measured and normalized leakage single-phase, 2-pulse generator, 1 m source–chamber distance, 35 ft (10.7 m) high-voltage cables

		mR/h at 1 m	
kVp	mA	Measured	Normalized
150	3.3	55	100
125	4.0	27.5	50
100	5.0	12	22
85	6.0	2.8	5.0

Table 3. Useful beam exposure rate single-phase, 2-pulse generator 2.26 mm Pb attenuation, 1 m source–chamber distance

		High Voltage Cable Length	
kVp	mA	15 ft (4.57 m)	35 ft (10.7 m)
		Normalized mR/h at 1 m	
150	3.3	100	100
125	4.0	52	62
100	5.0	21	26
85	6.0	6.0	6.0

Table 4. Useful beam exposure rate three-phase, 12-pulse generator 2.26 mm Pb attenuation, 1 m source–chamber distance, 35 ft (10.7 m) high-voltage cables

kVp	mA	Normalized mR/h at 1 m
150	3.3	100
126	4.0	62
100	5.0	25
85	6.0	7.0

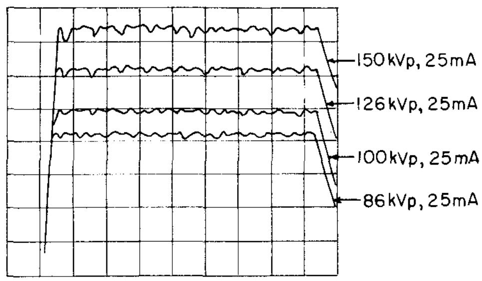


FIG. 4. Tube voltage waveforms, three-phase, 12-pulse system.

rate was measured at 86, 100, 126 and 150 kVp using "broad beam" geometry with 2.26 mm lead added absorber. The exposure rate normalized to 100 mR/hr at 1 m is shown in Table 4. These data are in good agreement with the single-phase, 2-pulse data with 35 ft (10.7 m) high-voltage cables shown in Table 2. Tube voltage waveforms are shown in Fig. 4. The ripple is approx 5 kV at 150 kVp and decreases as kilovoltage decreases.

DISCUSSION

The purpose of this investigation was to determine what effect, if any, there would be on the requirements for secondary barriers in medical diagnostic installations if a 150 kVp tube unit were to be installed but operated using a generator with a maximum kilovoltage rating less than 150 kVp, i.e. for the same number of exposures per week, as shown in NCRP Report No. 34, Appendix C, Table 2, would the reduced leakage at lower kilovoltages result in a lesser required thickness of lead in the secondary barriers of an X-ray room.

For X-ray equipment operating in the 85–150 kVp range, the preceding data show that the leakage from a 150 kVp diagnostic-type protective tube housing is reduced by a factor between 0.50 and 0.62 when the voltage is decreased from 150 to 125 kVp, by a factor between 0.21 and 0.26 when the voltage is decreased from 150 to 100 kVp and by a factor between 0.05 and 0.07 when the voltage is decreased from 150 to 85 kVp. The reduction factor is not constant but varies as shown due to cable length and type of energizing system.

The data necessary to calculate shielding for medical diagnostic X-ray installations are given in NCRP Report No. 34 for operation at 100, 125 and 150 kVp. The shielding thicknesses in lead and concrete for secondary protective barriers were calculated for operation at these voltages with the workloads, distances and types of areas given in NCRP Report No. 34, Appendix C, Table V, assuming:

(1) leakage of 100 mR in 1 hr at 1 m at 100, 125 and 150 kVp,

(2) leakage of 62 mR in 1 hr at 1 m at 125 kVp and,

(3) leakage of 26 mR in 1 hr at 1 m at 100 kVp.

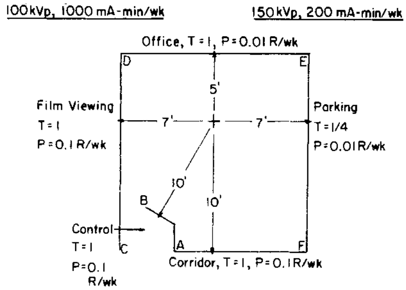
For scattered radiation a 1 m source–film distance (0.8 m source–skin distance) was assumed with a 14 × 17 in. (35.6 × 43.2 cm) field at 1 m resulting in a 1000 cm^2 field area at 0.8 m. The ratio of scatter to incident exposure was taken from a recent paper from our laboratory (Tr72).

The calculated minimum secondary protective barrier thicknesses in lead for a typical medical diagnostic radiographic installation are shown in Fig. 5. The assumptions used in calculating the required shielding are shown in the figure. Lead thicknesses are tabulated for three conditions:

(1) A 150 kVp tube in a 150 kVp diagnostic-type protective tube housing operating at 150 kVp.

(2) A 100 kVp tube in a 100 kVp diagnostic-type protective tube housing operating at 100 kVp.

(3) A 150 kVp tube in a 150 kVp



Wall Section	150 kVp Operation 150 kVp Tube Unit Leakage 100 mR/h at 1 m	100 kVp Operation 100 kVp Tube Unit Leakage 100 mR/h at 1 m	100 kVp Operation 150 kVp Tube Unit Leakage 26 mR/h at 1 m
	Minimum Lead Secondary Barrier Thickness-mm		
A-B	0.03	0.31	0.07
C-D	0.40	0.38	0.43
D-E	1.16	1.17	1.04
E-F	0.61	0.52	0.52
F-A	0.03	0.31	0.07

FIG. 5. Calculated lead secondary barrier thickness for a typical medical diagnostic radiographic installation.

diagnostic-type protective tube housing operating at 100 kVp.

It will be noted that there is little difference in the shielding required for the 150 kVp tube in a 150 kVp diagnostic-type protective tube housing whether operated at 150 or 100 kVp. The increase in shielding for operation of the 100 kVp tube in a 100 kVp diagnostic-type protective tube housing for two of the locations is a result of leakage and scatter barrier thicknesses differing by less than 3 HVLs requiring one half-value layer additional shielding at these locations.

The controlling factor for the barrier thickness for controlled areas was shown to be scattered radiation and not leakage radiation. For noncontrolled areas the barrier for scattered radiation was the controlling factor except at short (less than 10 ft—3.1 m) source-barrier distances and only at 100 kVp. For this one situation, the barrier thickness for leakage radiation exceeded that for scattered radiation by less than $\frac{1}{2}$ of one half-value layer. The use of reduced values for the leakage radiation when operating a 150 kVp tube unit at 100 or 125 kVp does not, therefore, reduce the required secondary barrier thickness by more than one half-value layer (0.24–0.29 mm Pb).

SUMMARY

Calculated and measured data are presented for the leakage from a 150 kVp tube in a 150 kVp diagnostic-type protective tube housing when operated at its maximum continuous rated current at 85, 100, 125 and 150 kVp. When the tube is operated at its maximum continuous rated current at less than its maximum rated voltage, the decrease in thickness of the secondary barriers as a result of the reduced tube housing leakage will not be more than one half-value layer. In most cases the lead thickness specified for an installation will be the commercially available sheet lead thickness greater than the calculated value. Where lead is specially rolled for a calculated thickness it may be advisable to use the lower leakage in calculating the barrier thickness providing the roller thickness tolerance is less than one half-value layer.

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