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Some properties of six different types of dental x-ray unit

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Several types of x-ray machine are used in dental roentgenography. These machines differ with respect to kilovoltage, milliamperage, filtration, length of cone, etc. In addition to these factors, which can be changed as required, one must consider certain undesirable variations which are less controllable. These include (1) films as produced by the manufacturer, (2) line voltage, (3) timer, (4) changes in output of the x-ray unit (amount of radiation produced per second), and (5) darkroom technique. These variations result in roentgenograms that show different film densities under the same technique.

In the present article only the reliability of the mechanical timers and the variations in output are reported.

MATERIALS AND METHODS

Forty-four x-ray machines of six different types were examined with respect to reliability of timers and output.

A generally accepted method of measuring the time of exposure involves the use of a spinning top. This method is based on the fact that dental x-ray units, being self-rectified, produce radiation during only half the time of each line voltage cycle. If the frequency of the input current is 50 cycles per second, the tube will produce 50 emissions in each second. These different emissions can be recorded separately by moving a film during exposure under a lead screen in which there is a small hole. During each cycle, the radiation passes through the hole and exposes a different area of the film. The number of exposures that can be counted corresponds with the number of cycles (each of

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$\frac{1}{50}$ second) that occur during the exposure. Since the frequency of the line voltage is very stable (maximum variations do not exceed 0.5 per cent), this method of measuring exposure times is very reliable.

In the present study we used an apparatus (Fig. 1) which permitted the registration of twenty exposures on one film. The film was placed on a turntable, and the turntable was mounted in a box with lead cover. A small movable opening in the cover was used to expose the film. For each exposure setting, this opening was placed at a different distance from the center of rotation. In this way, the black spots on the film were recorded in concentric circles (Fig. 2).

A few black spots of reduced density are produced at the beginning of each exposure. There are two explanations for the reduced amount of radiation in the first few cycles:

1. The filament of the x-ray tube needs a certain time to reach its final temperature.
2. The manufacturer generally incorporates a resistor in the line voltage circuit to protect the tube from overloading at the start of the exposure. This resistor is shorted out after a few tenths of a second.

In this initial stage of exposure the amount of radiation output is reduced. Since we are interested in the blackening produced by a given exposure time, the number of exposure spots with reduced density are estimated to have been produced by one half the radiation that created spots of full density.

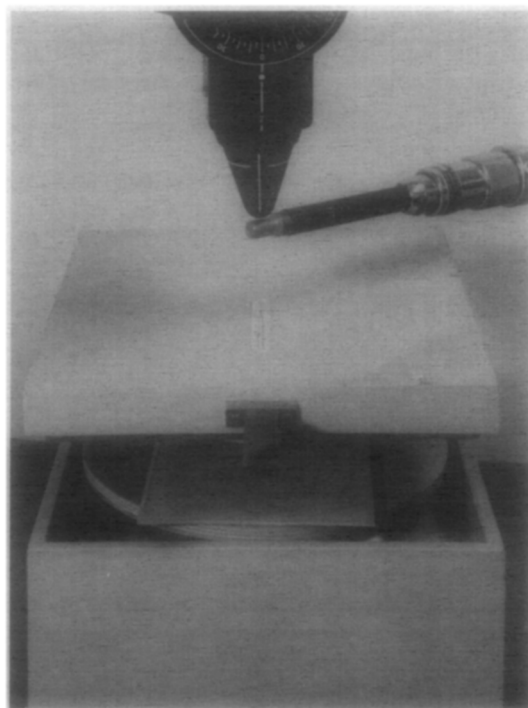


Fig. 1. Apparatus used to measure exposure time and dose.

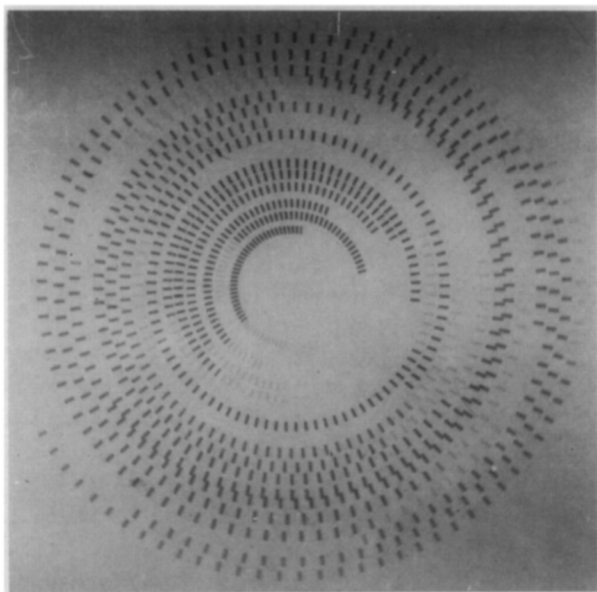


Fig. 2. Recording of sixteen different exposure times on one film.

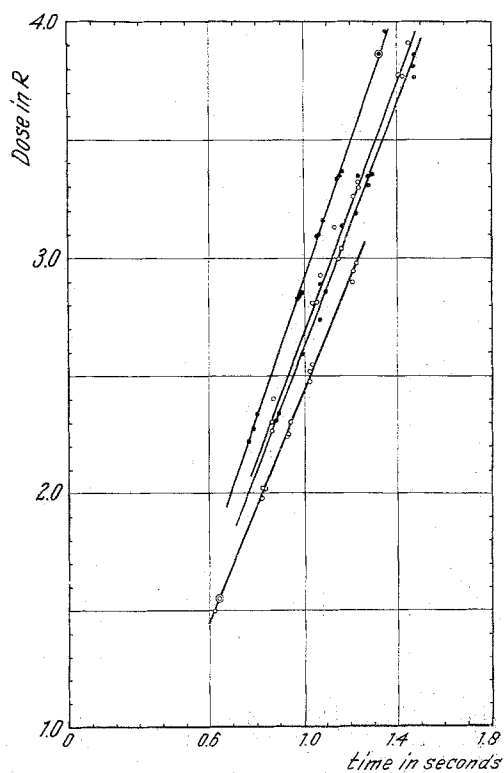


Fig. 3. Example of curves showing relation between dose (in r) and time of exposure (machines E) used to measure the output at 1 second.

Some of the timers could not be set exactly at a certain time interval, and in these cases the next closest setting was used.

The exposure settings tested were 0.1, 0.2, 0.4, 0.75 or 0.8, and 1.5 seconds. Each exposure was repeated five times.

Timer

In this study the setting of the timer is called the *exposure setting* and the time that the film is actually exposed is called the *time of exposure*. The ratio of these two values (time of exposure/exposure setting) is used as the *error in the exposure*.

For a series of exposures of the same subject, it is desirable that timer errors be so small that any variation in film blackening is negligible. This variation is called the *error within the machines* and is symbolized by S_w .

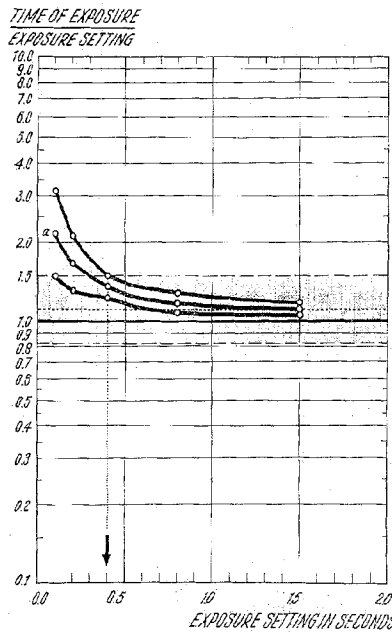
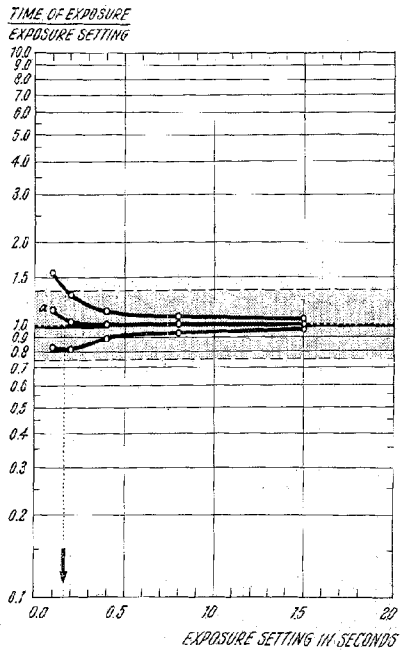
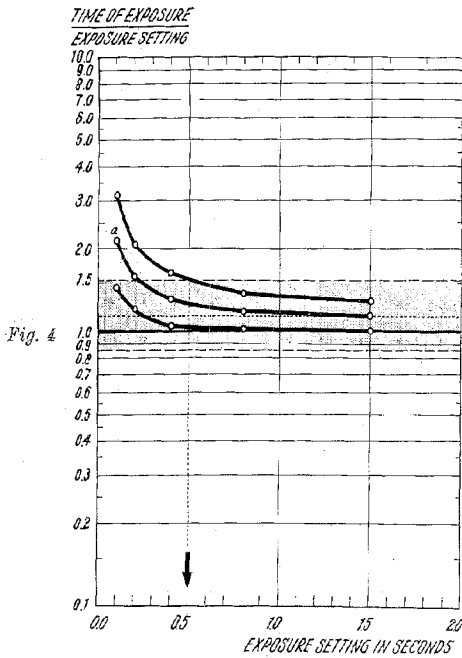
For a complete x-ray examination of the mouth, a table of exposure times is used for the different areas. It would be most convenient if the same exposure table could be used for different x-ray machines of the same type (all other factors being equal). This requires a minimal difference between the timers. These differences are called the *error between the machines* and are symbolized by S_b .

When x-ray machines of different types are evaluated, the errors both between and within the machines must be considered. For this reason, the combination of the above variations was also calculated. This is called the *total error* and is symbolized by S_t . Its significance can be explained as follows: If there are available a large number of timers of the same type and one timer is selected and used only once, there is a probability of 0.95 that the error found will be smaller than twice the standard deviation (S_t).

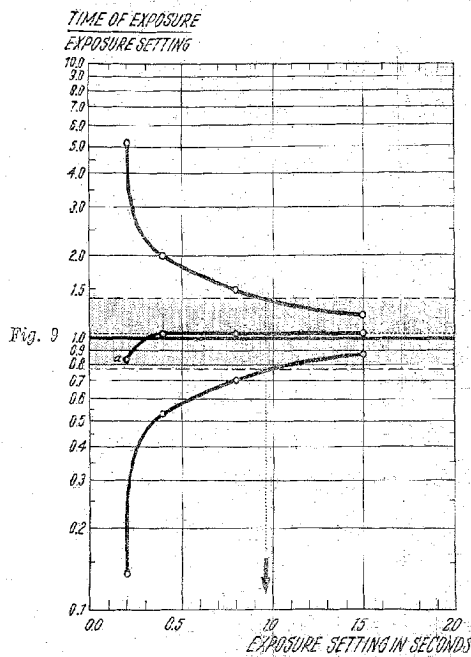
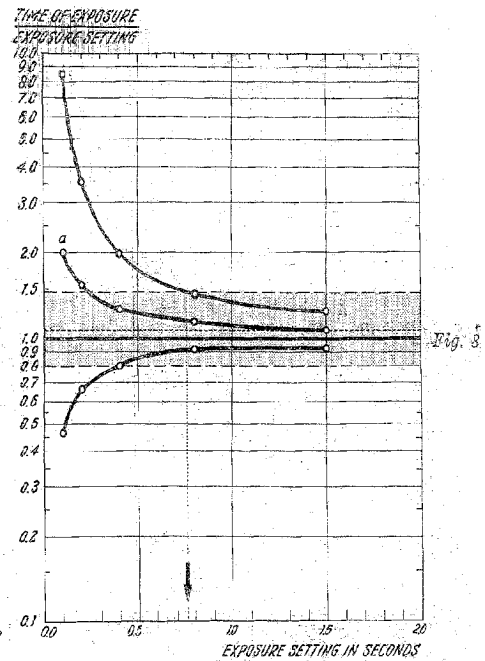
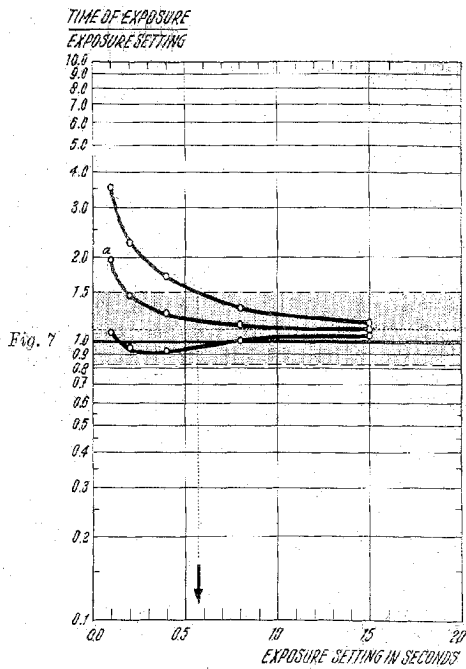
When a change is made from one type of apparatus to another, one can convert the exposure table for the first type into a table for the other machine by multiplying the exposure times by a certain factor. This procedure is justified only when the ratio between the exposure times for the different areas is maintained. This means that the timer must operate in such a way that when the setting on the timer scale is doubled the exposure actually made is also doubled. In other words, the exposure times produced should be proportional to the calibration. The deviation from linearity is called the *error of linearity*. This effect was studied by comparing the average error of each exposure setting. To visualize the findings, we made graphs showing the average errors for the different exposure settings (Figs. 4 to 9, lines labeled *a*). The error of linearity is absent if the averages (time of exposure divided by exposure settings) are equal for all exposure settings. Equal averages are shown by a horizontal line *a* in the graph; any deviation means an error of linearity.

The shortest exposure time that can be used with an exposure table depends on the error of linearity and also on the total error. For this reason, the total error was also incorporated in the graphs showing the error of linearity. Two lines were drawn at distances of two times the standard deviation from the average error.

From these two curves the exposure setting at which a certain error is not



Figs. 4, 5, and 6. Error in the exposure (time of exposure/exposure setting) for different exposure settings in machines A, B, and C.



Figs. 7, 8, and 9. Error in the exposure (time of exposure/exposure setting) for different exposure settings in machines D, E, and F.

exceeded can be read. A limit for this error should be derived from practical applications. In general, the ratio in the exposure for the same area in adults and children is approximately 1:0.5. From this point of view, a *maximum acceptable error* of $\frac{3}{4}$ and $\frac{4}{3}$ was used. In the graphs these limits are shown by broken lines. There are two intersections of these limits with the curves. The arrow indicates the *minimal reliable time*; that is, the shortest exposure time that can be used without exceeding the maximum acceptable error.

Output

For the reasons explained above, it is important that the differences in output between the machines and within the machines be small.

To study these differences, we measured the output in roentgens per second at the tip of the cone. The dose measurement is reliable only if the power supply to which the x-ray unit is connected is exactly 220 volts. Moreover, the exposure time should be exactly 1 second. The line voltage may change with time and drop during exposure. To avoid any influence of these factors on the output, we used a variable autotransformer in connection with an accurate voltmeter. The drop in line voltage was recorded. Prior to each exposure the voltage was adjusted to 220 volts plus any anticipated drop in line voltage in order to produce exactly 220 volts at the moment of exposure. Because the timer switch cannot be used to terminate the exposure after exactly 1 second, we used a series of exposures with different timer settings (0.7, 0.9, 1.0, 1.1, and 1.3 seconds) and repeated them three times. At each exposure the output and exposure time were measured.

These findings were used to plot a graph from which the output at exactly 1 second could be read. The differences in output within the machine can also be observed (Fig. 3).

Finally, the timer and the output of the machine may change with use. This effect is called *effect of aging*. The machines investigated were of different ages, and there was a substantial difference in the frequency of their use. For these reasons, the effects of aging and the different errors could not be separated.

Table I shows machines tested.

Table I

Code letter	Manufacturer	Type	Technical data	Number of machines investigated	Age of machines (year of purchase)
A	Philips	Oralix	45 kv. 5 Ma.	10	1949 to 1960
B	Philips	Oralix	50 kv. 7.5 Ma.	10	1960 to 1963
C	Ritter	D9	50 kv. 10 Ma.	5	1958 to 1963
D	Siemens	Heliodent	50 kv. 7 Ma. 100 r/minute	5	1959 to 1963
E	Siemens	Heliodent	50 kv. 7 Ma. 200 r/minute	5*	1958 to 1959
F	Siemens	Kugel	60 kv. 10 Ma.	9	1939 to 1954

*One of these machines became comparable to the machines listed under code letter D because an additional filter of 1 mm. aluminum was incorporated.

RESULTS**Timer**

For each different type of x-ray unit, the errors between and within the machines were calculated (Figs. 10 to 15). It can be observed that the error between the machines (S_b) is always larger than the error within the machines (S_w), although the differences vary considerably. From these findings, it is clear that the variations in blackening produced by one particular x-ray machine are considerably smaller than the differences that occur when one exposure table is used for different machines.

The total error and the error of linearity are shown in Figs. 4 to 9. In these graphs horizontal lines illustrate the limits of the errors which are acceptable ($\frac{1}{2}$ and $\frac{3}{4}$ times the average at 1.5 seconds). At the intersection of these lines with the curves, a vertical arrow indicates the "minimal reliable time." Table II shows the results for the different products.

Large differences between the products are found. Some machines require better timers when newer, faster x-ray films are used.

In general, it can be concluded that mechanical timers cannot be used for exposures shorter than a few tenths of a second. In view of the fact that the error within the machines is smaller than the error between the machines, it can be concluded that when different exposure tables are used for different machines the minimal reliable time will be smaller. A good electronic timer or a synchronous motor-operated timer is recommended for the shorter exposure times.

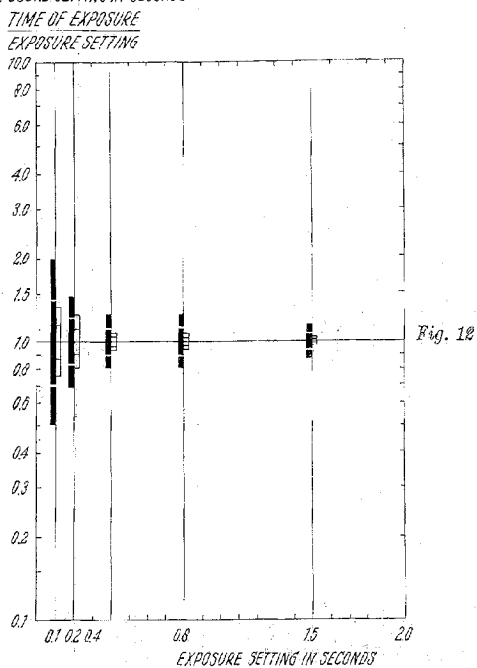
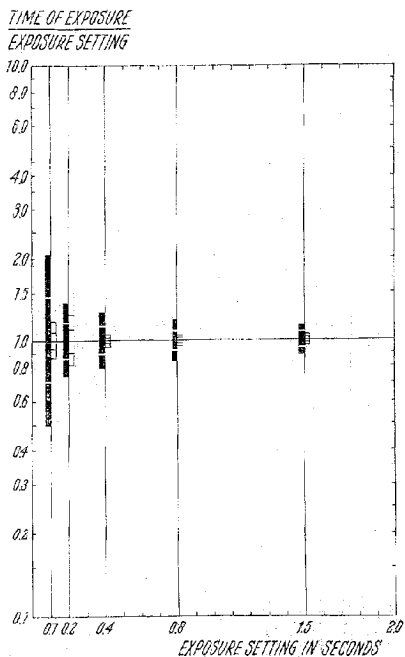
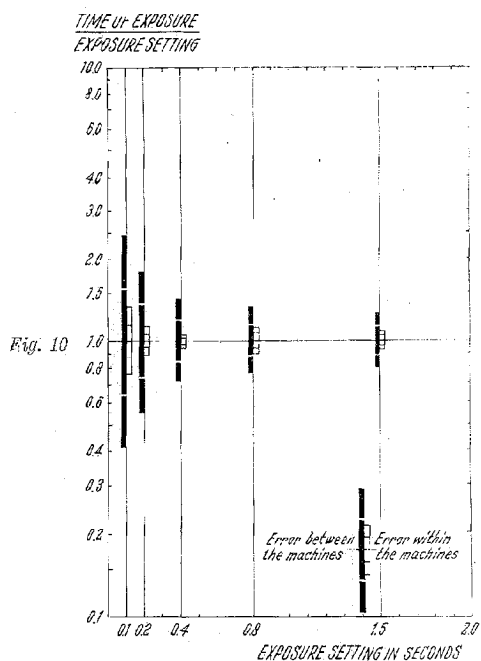
Output

Fig. 3 shows how the output per second was determined graphically. From the curves, it can be observed that the error within the machines is very small. All of the different types tested showed this same effect. The errors between the machines, however, are rather large, as illustrated in Fig. 16, which shows the range in output per second of the machines. In addition to the large range that was found, one series of identical machines (A) could be subdivided in two categories having a large difference in output. After inspecting the type A machines, it was observed that the three machines with reduced output had an additional nonremovable aluminum filter.

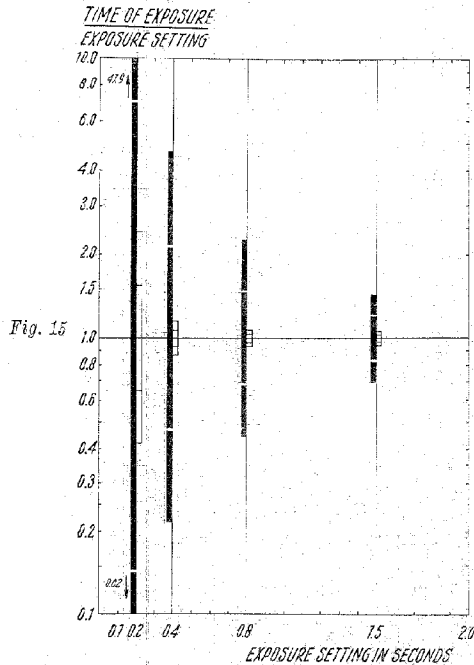
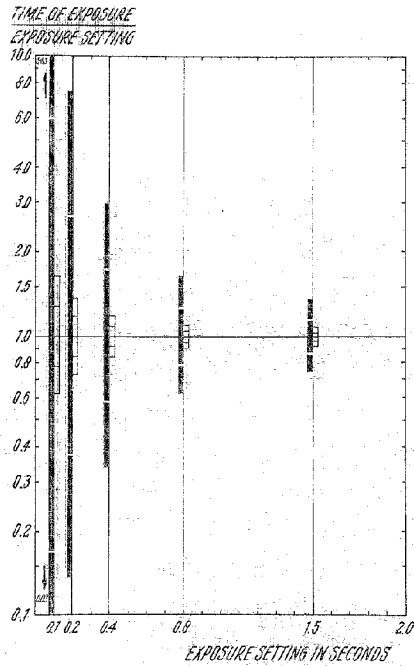
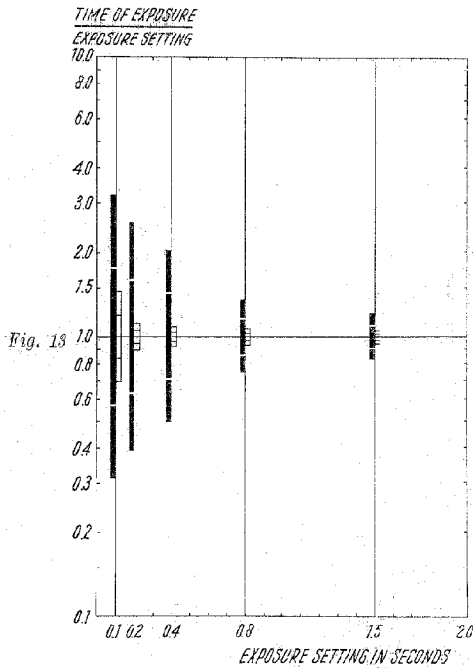
As a result of these findings, seven groups of machines can be distinguished. The number of machines in each group becomes too small to be used for a statistical analysis.

Table II

<i>Apparatus</i>	<i>Minimal reliable time (seconds)</i>
A	0.5
B	0.2
C	0.4
D	0.6
E	0.8
F	1.0



Figs. 10, 11, and 12. Graphs showing the error within the machines (S_w) and the error between the machines (S_b) at the five investigated times for machines A, B, and C. Column length two times the standard deviation to both sides.



Figs. 13, 14, 15. Graphs showing the error within the machines (S_2) and the error between the machines (S_3) at the five investigated times for machines D, E, and F. Column length two times the standard deviation to both sides.

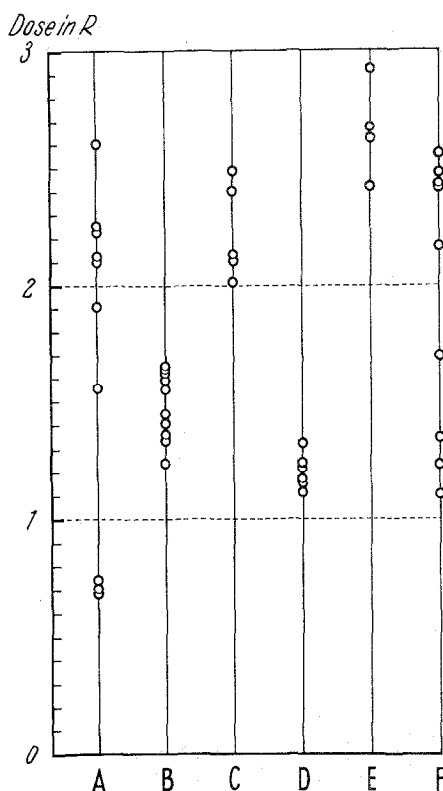


Fig. 16. Range in output per second of the different products.

DISCUSSION

In the exposure of x-ray films, the blackening depends on the product of the exposure time and the output per second. In this study an excess in time with a factor of $\frac{4}{3}$ and a reduction in time with a factor of $\frac{3}{4}$ were used as the maximum acceptable limits. If these limits are also used for variations in the output, the final deviation that can occur during exposure is equal to the product of these two limits. This means a variation with a factor of $\frac{9}{16}$ and $\frac{16}{9}$. These limits are much too large to be acceptable for use with an exposure table. If the acceptable limits for the final error are fixed at $\frac{3}{4}$ and $\frac{4}{3}$, the errors in exposure and output should not exceed $\sqrt{\frac{4}{3}}$ and $\sqrt{\frac{3}{4}}$, or 1.15 and 0.86, each. Since the error in the timer is probably larger than the error in output, one is not justified in dividing the total error into two equal parts. For this reason, it is not possible to set up separate requirements for the timer and for the output.

SUMMARY

Forty-four x-ray machines were tested for reliability of timer and for output. A distinction was made between different types of errors, and large differences between these categories of errors were found.

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