Dec. 22, 1964 JEAN-MARIE LAVIE 3,162,363
SLIDE-RULE FOR PERFORMING CALCULATION INVOLVING
SCREENS TO PROTECT PERSONNEL AGAINST RADIATIONS
Filed Sept. 8, 1959 5 Sheets-Sheet 1

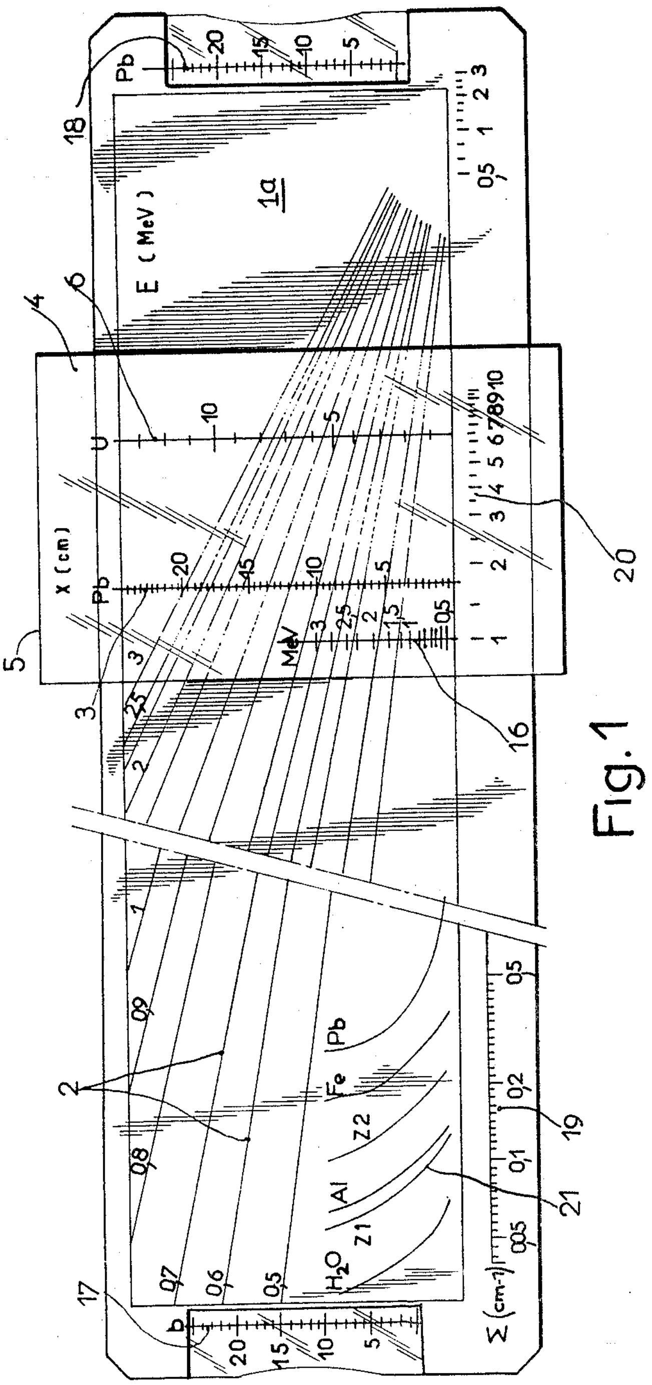


Fig. 1

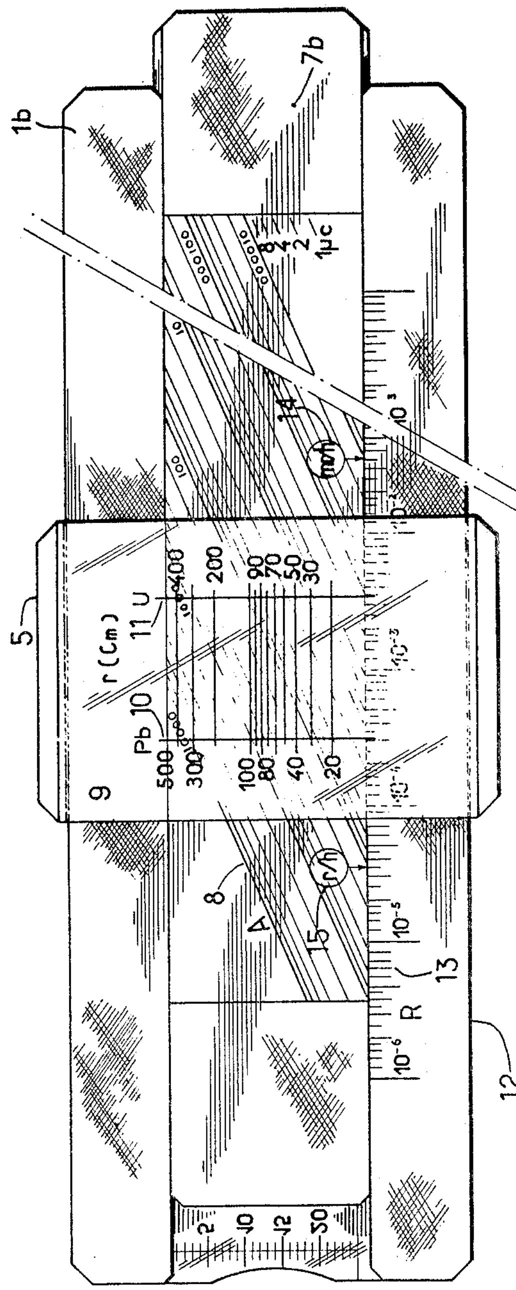


Fig. 2

Fig. 3

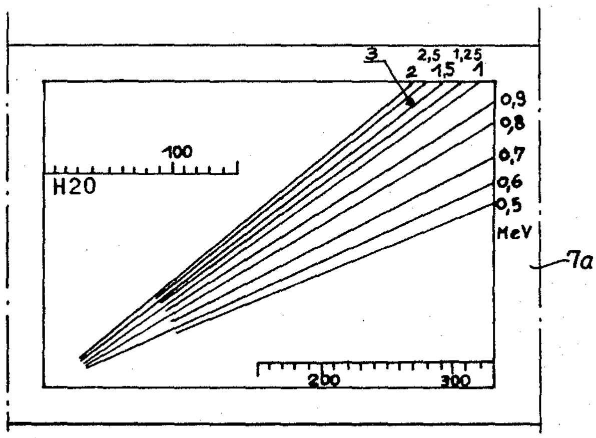


Fig. 4

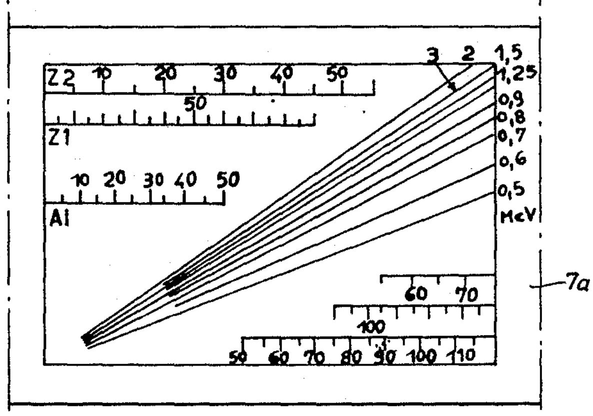
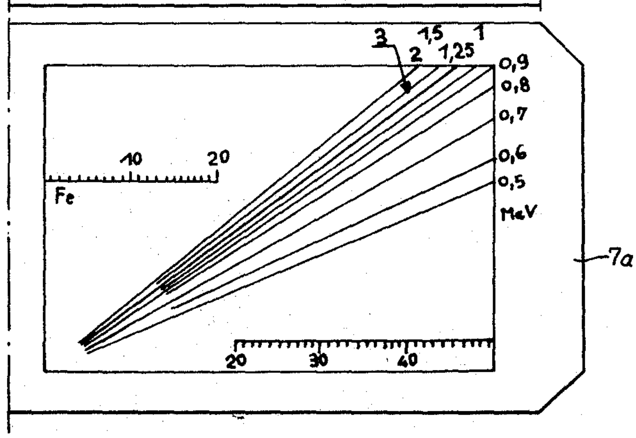


Fig. 5



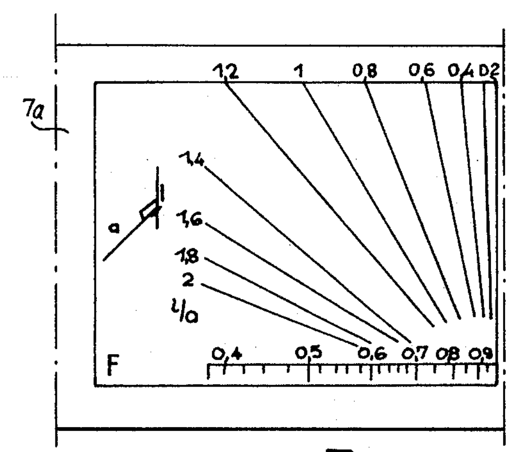


Fig. 7

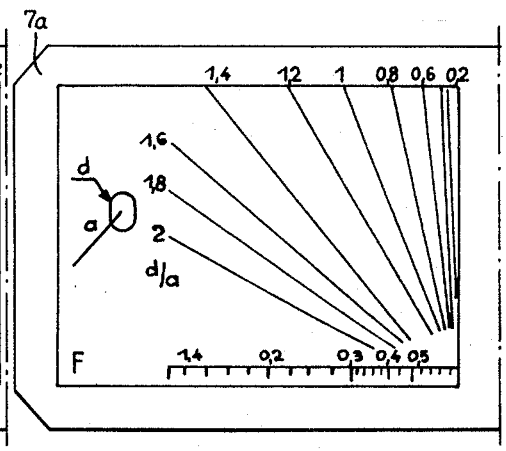


Fig. 6

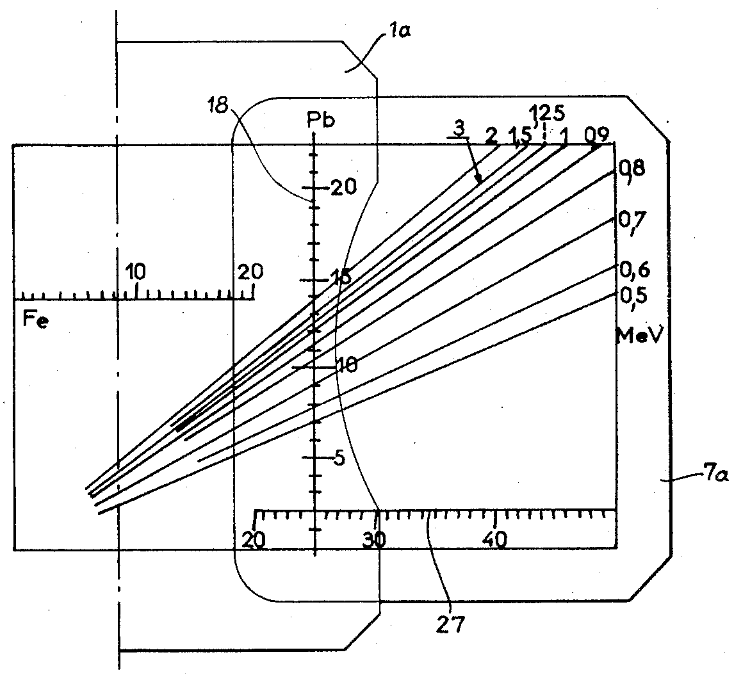


Fig. 8

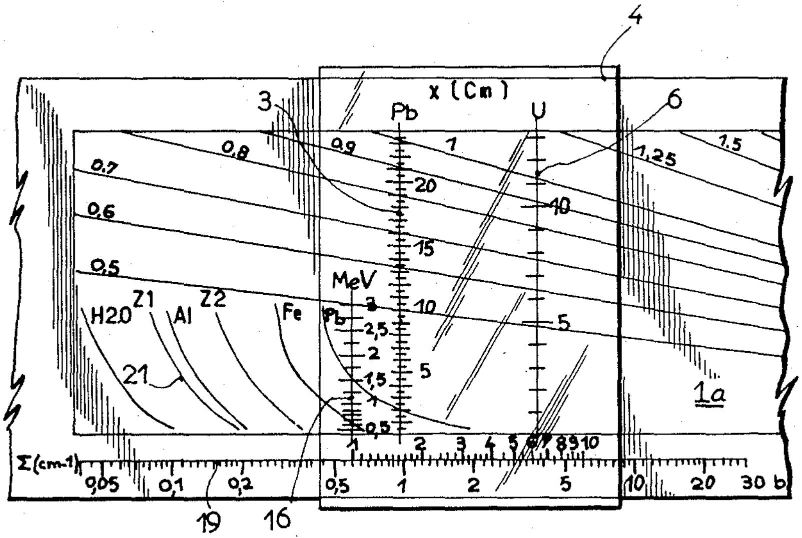


Fig. 9

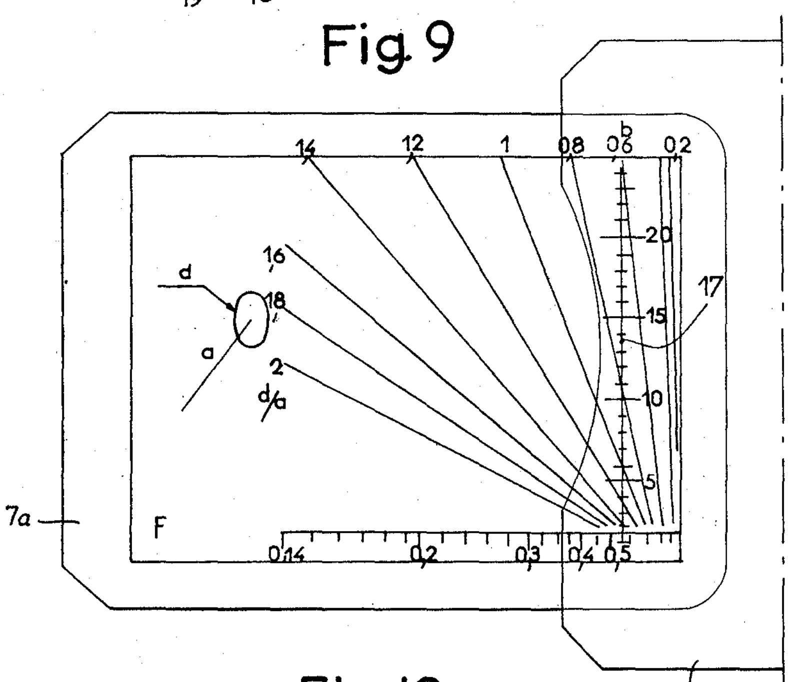


Fig. 10

1a

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SLIDE-RULE FOR PERFORMING CALCULATION INVOLVING SCREENS TO PROTECT PERSONNEL AGAINST RADIATIONS

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Claims priority, application France, Sept. 9, 1958, 774,037

6 Claims. (Cl. 235—70)

The present invention seeks to provide a slide-rule for performing, in accurate, rapid and easy fashion, calculations involving screens needed to protect personnel when radioactive substances emitting gamma radiation or X-rays are being handled.

The various problems to be solved, either in making such screens or in utilising a given screen, are:

Calculating screen thicknesses, using a given material, as a function of the operator's distance from a radioactive source, and of the intensity of gamma radiation emitted by the said source;

The minimum distance which the operator must keep, the intensity and energy of radiation emitted by the source being known, with or without a screen having a thickness sufficient to absorb the known gamma radiation;

The maximum source intensity which may be used with a given protection system.

Existing circular calculators do not enable such problems to be rapidly solved, except in specific cases, and only for a few common radioactive elements.

The basis of design of the slide-rule to which the present invention relates is the mathematical expression of intensity of radiation R at a given point, which involves the following parameters:

A, activity of the source of radiation;
B, so-called "build-up" factor, expressing the effect of diffusion of radiation;
I (E), irradiation intensity, due to a unit flux of photons of energy E;
μ, linear coefficient of absorption of the screen;
x, thickness of the screen;
r, distance of the source (assumed to be a point) from the operator.

With this notation, the formula giving the intensity of radiation R may be written:

$$R=\frac{ABI(E)e^{-\mu x}}{4\pi r^2} \tag{1}$$

Or again, by putting

$$k'=\frac{1}{4\pi}$$

and

$$C=\frac{1}{r}$$

$$R=k'ABC^2I(E)e^{-\mu x} \tag{2}$$

If the parameters are expressed in the following units:

R in milliröntgens per hour
A in millicuries
E in megaelectron-volts
μ in (centimetre)$^{-1}$
r and x in centimetres

and if the coefficient of linear absorption of air μ_a, expressed in cm.$^{-1}$, is introduced, expression (1) then becomes:

$$R=k\frac{\mu_a ABEe^{-\mu x}}{r^2} \tag{3}$$

with $k=1.685.10^8$.

It will be seen that a system comprising five variables, R, x, r, A and E must thus be solved; if four of them are given it must be possible to determine the fifth. Consequently, the slide-rule to which the invention relates will allow of a solution to five types of problem, in each of which one of the variables is to be discovered, the other four being known.

Relationship (3) may be written:

$$\frac{Rr2}{A}=k\frac{\mu_a BE}{e^{\mu x}} \tag{4}$$

and may be broken up into two intermediate functions

$$\gamma_1=k\frac{\mu_a BE}{e^{\mu x}}=f(E,x)$$

and

$$\gamma_2=\frac{Rr^2}{A}=g(r,R,A)$$

The function $\gamma_2=g(r, R, A)$ being in its turn split into two by introduction of the function

$$y=\frac{r^2}{A}$$

The function

$$\gamma_1=k\frac{\mu_a BE}{e^{\mu x}}=f(E,x)$$

in which the terms k, E, μ, μ_a and even B (in the whole practical field of physical phenomena involved) are independent of x, represents the variation in attenuation of a given single-energy radiation as a function of the thickness x of the screen.

Graphical expansion of this function, which may be written:

$$\text{Log } \gamma_1=\log k+\log \mu_a+\log B+\log E-\mu x$$

results, in semi-logarithmic co-ordinates, in a series of very nearly rectilinear curves.

Likewise, the function

$$\gamma_2=\frac{Rr^2}{A}=g(r,R,A)$$

represents the variation in intensity of radiation as a function of the distance r from the source to the operator, and of the activity A of the source; and the function

$$y=\frac{r^2}{A}$$

which may be written $\log y=2 \log r-\log A$, results, in logarithmic co-ordinates, in marking out a series of parallel straight lines which are the straight lines of *isoactivity* (A=constant).

Thus, superimposing families of straight lines representing the functions γ_1 and y enables the four parameters x, r, A and E participating in the expression for radiation R to be determined.

This superimposition may be carried out by combining the conventional principles of intersecting graphs and the logarithmic slide-rule.

A slide-rule according to the invention is therefore characterised in that it comprises a rule bearing on one side the family of curves representing the function

$$\gamma_1=f(E,x)=\frac{k\mu_a BE}{e^{\mu x}}$$

γ_1 being represented logarithmically along the abscissa, and x being read off linearly on the ordinate, the said ordinate being marked on a transparent cursor extending on both sides of the rule and capable of moving parallel to the abscissa, the other side of the said rule being logarithmically divided in terms of the function R, and having mounted on it a moving slider bearing the family of curves, in logarithmic co-ordinates, representing the function

$$y=\frac{r^2}{A}$$

y being plotted as abscissa on the said slider, and r as ordinate on the other side of the movable cursor.

Preferably, the rear of the rule, the cursor and the slider bear respectively; on the rule, curves representing variations, as a function of energy, of the total effective macroscopic cross-section of various screen materials; on the cursor, an energy scale graduated in m.e.v.; and on the slider, a double series of curves giving, on the one hand, a direct reading, for different materials, of equivalent thicknesses of lead as a function of energy, and on the other hand enabling protection problems relating to non-point sources to be solved by graphs.

In a preferred embodiment, the materials for which curves of equivalent lead thickness are given are iron, aluminium, Z concrete (ordinary or heavy) and water. The corresponding curves, marked on the back of the slider, are groups each member of which is taken at a different photon energy.

In a variant of this embodiment, curves of isoenergy corresponding to a certain number of common radioactive elements are marked out on the rear of the rule.

Since concrete behaves in substantially the same manner as aluminium, the same family of curves may be used, the thickness scales being in the ratio of densities.

Any problem concerning these materials is dealt with using lead as a reference.

If the screen thickness is given, it is transformed into equivalent lead thickness, and calculations are carried out as with lead.

If, on the contrary, it is required to find the screen thickness, the equivalent lead screen thickness is first of all determined, and conversion into thickness of the selected material is then carried out.

As regards using the slide-rule for calculating radiation due to non-point sources, this is made possible by reference to the idea of a non-point source having the same activity.

In fact, if I_1 designates the intensity of irradiation corresponding to a non-point source whereof the activity is uniformly distributed, and I_2 the intensity of irradiation, under the same conditions of protection, due to a point source having the same activity, the ratio I_1/I_2 defines a correction factor, knowledge of which enables protection problems relevant to extended sources to be dealt with using a point source as reference.

The slide-rule may be constructed to enable such problems to be solved in the case of sources which may be considered, as regards protection, either as linear sources or as plane circular sources.

For this purpose, curves are marked on the back of the slider representing variations in the correction factor

$$\frac{I_1}{I_2}=F$$

as a function of screen thickness expressed in mean free paths, and of apparent source diameter.

Apparent source diameter must be understood to mean:

(*a*) For linear sources the ratio $1/a$; wherein 1 is the length of the source, and a is the distance from the source to the measurement point, taken on a perpendicular to the middle of the source;

(*b*) For plane circular sources the ratio d/a; wherein d is the diameter of the source, and a is the distance from the source to the measurement point, taken on the perpendicular to the plane of the source at its centre.

Under these conditions, screen thickness must be calculated in mean free paths. This is the non-dimensional parameter $b=\Sigma x$, an expression wherein:

Σ is the total effective macroscopic cross-section of the screen, and x is the thickness of the same screen.

In order to determine the total effective macroscopic cross-section, the photon energy and nature of the screen material being known, Σ is determined by the process of intersection. The scale graduated in energy on the front of the cursor and the curves on the front of the rule are used for this purpose, the said curves representing variations in Σ as a function of photon energy for each of the screen materials under consideration.

The product $b=\Sigma x$ is calculated on the front of the rule. To this end, there are two logarithmic scales, one on the rule and the other on the cursor, and they enable the product Σx to be worked out by simply adding scale lengths. b is read off on the scale on the rule opposite to x on the corresponding scale on the cursor. However, the position of the decimal point is not specified, and the division "1" may, for example, represent 1, 10 or 100.

A non-limitative example of a slide-rule for calculations involving protective screens and radioactive sources in accordance with the invention will be described hereinafter with reference to the appended diagrammatic FIGURES 1 to 10.

FIGURE 1 illustrates the rear of the slide-rule, equipped with its cursor;

FIGURE 2 illustrates the front of the slide-rule, equipped with the cursor and the slider;

FIGURES 3, 4 and 5, are scales marked on the rear of the slider, to give a direct reading, as a function of energy, of lead thicknesses equivalent to a given thickness of iron, aluminium, Z concrete or water.

FIGURES 6 and 7, are graphs likewise marked on the rear of the slider, enabling protection problems relating to non-point sources to be solved (plane circular sources for FIGURE 6 and linear sources for FIGURE 7).

FIGURES 8, 9 and 10 are views of part of the rear of the slide-rule while various calculations explained hereinafter are being carried out.

As may be seen in FIGURE 1, the slide-rule includes a base plate of opaque material **1** on face **1***a* of which is marked the family of curves **2** (shown inside a rectangular line frame printed on the body **1**) representing the variation in attenuation of the activity of gamma photons as a function of screen thickness if it is lead, for different energies E of the said photons (0.5–0.6 etc. . . . –2.5–3 m.e.v.).

The value of lead thickness x causing the said attenuation is read off on an axis **3** printed on the side **4** of a transparent cursor **5** capable of being displaced parallel to the length of the rule.

In order to extend the field of use of these curves, which are worked out for lead, to other possible protective materials, such as uranium, the following approximate law of equivalent thicknesses is used:

$$x_e=x_{Pb}\cdot\frac{d_{Pb}}{d_e}$$

where x_{Pb} and d_{Pb} designate lead screen thickness and lead density respectively, and x_e and d_e designate screen thickness and density respectively of a material other than lead.

The side **4** of the cursor consequently bears a second axis **6** printed thereon and spaced from axis **3**, the latter axis being for lead screens and the axis **6** for uranium screens; in this embodiment, only these two axes are used in order to facilitate reading.

As may be seen in FIGURE 2, face **1***b* of the front of the rule has mounted on it a moving slider **7** of opaque material having printed on face **7***b* thereof a group **8** of straight lines of isoactivity μ for activities A from 10 microcuries to 10^4 curies.

The value of the distance r from the source to the operator is read off on the front **9** of the cursor **5**, along one of the two axes **10** or **11** printed thereon and corresponding to lead and uranium, as on side **4** of the cursor.

The lower edge **12** of front of the slide-rule has a logarithmic scale 13 printed thereon (used also in constructing the sets of curves

$$\gamma_1 = f(E,x) \text{ and } y = \frac{r^2}{A})$$

giving the values of intensity of irradiation R in milliröntgens per hour (at reference mark 14) or röntgens per hour (at reference mark 15).

On the rear face 4 of cursor 5 (FIGURE 1) there is printed an energy scale 16 extending, in this particular example, from 0.5 to 3 m.e.v.; two scales 17 and 18 are likewise engraved on transparent inserts at the end of the base plate 1, the scale 17 being graduated in mean free paths, and the scale 18 in centimetres of lead. The face 1*a* of base plate 1 also has engraved on it adjacent the left end thereof in FIG. 1*a* logarithmic scale 19 graduated in total effective macroscopic screen cross-section which corresponds to a logarithmic scale 20 graduated in thicknesses and engraved or printed at the bottom of rear face 4 of the cursor. A set of curves 21 is face 1*a* of engraved or printed at the lower left of base 1 represents variations, as a function of energy, in total effective macroscopic cross-section Σ of the various screen materials to which consideration is given such as water, light Z_1 concrete, aluminium, heavy Z_2 concrete, iron, lead, uranium.

The manner in which the slide-rule is used will be described hereinafter by way of example for two different problems.

Let it be assumed that a 100-curie point source emits 1 m.e.v. of gamma radiation, what is the irradiation intensity at 1 m. from the source when an iron screen 25 cm. thick is interposed in front of the source? The following operations then have to be carried out; to determine the thickness of lead equivalent to that of the iron screen, the slider 7 is placed in such a position that the lead reference scale 18 on insert in face 1*a* of base plate 1 intersects the division 25 on the horizontal scale 27 graduated in centimeters of iron thickness on the back 7*a* of the slider 7 (FIGURE 8). The result, i.e. 12 cm. of lead, is read off at the intersection of the 1 m.e.v. energy straight line of scale 22 and the lead reference scale 18. Irradiation intensity with a 12 cm. lead screen is then calculated as follows:

The cursor is moved on side 1*a* of base plate 1 so the value $x=12$ on scale 3 on the side 4 of the cursor intersects the line for $E=1$ m.e.v. of the gamma photons on the corresponding curve on scale 2. The co-ordinates of the point found verify the equation:

$$\gamma_1 = f(E, x)$$

The slide-rule is then turned over, and the slider 7 is moved without touching the cursor, so that the value $r=100$ cm. (distance from source to operator) on scale 10 on side 9 of the cursor and the line for the value $A=100$ curies (source activity) on scale 8 on face 7*b* of the slider 7 are made to intersect. The co-ordinates of the point found verify the equation:

$$y = \frac{r^2}{A}$$

The value of irradiation intensity R is then read off on scale 13 in milliröntgens per hour opposite to the reference mark 14 (or in röntgens per hour opposite to the reference mark 15), i.e. 14 mr./h. in the example chosen. If the screen in the example above had been concrete then scale 23 would have been used in place of scale 22. If the screen had been aluminium scale 23 would again be used and scale 24 would be used had the screen been water.

The second example of use of the slide-rule is the calculation of irradiation intensity on the axis of symmetry of a monokinetic non-point source.

Let it be assumed that a plane circular source 100 cm. in diameter, and having a total gamma activity of 10 curies, emits 1.5 m.e.v. of gamma radiation energy. If this source is placed behind a lead screen 10 cm. thick, parallel to the plane of the source, what is the irradiation intensity at 1 m. from the source on the perpendicular passing through its centre?

The operation of the slide-rule is as follows:

The problem is first solved assuming that the source is a point and has a total activity of 10 curies. Proceeding as before, the irradiation intensity is found to be 65 mr./h. The screen thickness *b*, expressed in mean free paths, is determined in a second operation. To do this, face 4 of cursor 5 is moved to the left on the base plate 1 (FIG. 1), so that the energy scale 16 intersects the lead curve 21 at the 1.5 m.e.v. division (FIGURE 9). $b=6$ on the scale 19 on the rule is read off opposite to division 10 on the logarithmic scale 20 on the cursor. Finally, to find the correction factor, the slider is moved so that the curve

$$\frac{d}{a} = 1$$

of the family of curves 26 on slider 7 intersects the scale 17 at division 6. 0.63 is read off at the intersection of the scale 17 and the scale "F" on slider 7 (FIGURE 10). The irradiation density due to the circular source is equal to 65×0.63:40 mr./h., a multiplication which is carried out with the aid of the logarithmic scales 19 and 20 on faces 1*a* of base plate 1 and on face 4 of cursor 5.

The calculation of irradiation intensity for a linear source is determined as in the second example above but using scale 25 (FIG. 7) on slider 7 rather than scale 26.

I claim:

1. In a slide-rule for calculations involving protective screens and radioactive sources, a base, a movable slider and a transparent cursor on said base, a family of curves on one face of said base for the function

$$Y_1 = f(Ex) = \frac{kERμ_a}{e^{\mu x}}$$

where *k* is a numerical, coefficient dependent upon the chosen units, E is the energy of the photons, B is the build-up factor, *x* is the thickness of the screen and μ_a and μx are the linear coefficients respectively of absorption of air and of the material of the screen, Y_1 being shown logarithmically on the abscissa of the family of curves, a linearly graduated ordinate on said cursor for and movable over said family of curves for the values of the thickness of the screen *x*, a logarithmic scale on the opposite face of said base for the function R of intensity of irradiation and a system of logarithmic coordinates on the face of said slider movable over and cooperating with the scale for R for the family of curves representing the function

$$y = \frac{r^2}{A}$$

where *r* is the distance to the operator from the source and A is the activity of the source, *y* being shown as the abscissa on said slider, an ordinate scale graduated logarithmically on the other side of said cursor for the values of *r* beneath which ordinate scale said system of logarithmic coordinates are moved and reference marks on said slider cooperating with said scale for the function R providing values from said scale for the function R in milliröntgens per hour and in röntgens per hour.

2. In a slide-rule as described in claim 1, a pair of ordinates graduated linearly on the first of said sides of said cursor corresponding to the values of the thickness of the screens calculated respectively for a lead screen and for a uranium screen.

3. A slide-rule as described in claim 1, two ordinates graduated logarithmically on the other of the faces of said cursor corresponding to the distances from the source to

the operator respectively for a lead screen and a uranium screen.

4. A slide-rule as described in claim 1, curves on the first face of said base for variations, in function of the energy of photons, in the total effective macroscopic cross-section of various screen materials.

5. A slide-rule as described in claim 1 including an energy scale graduated linearly in megaelectron-volts and a scale of thicknesses graduated logarithmically in centimeters on the first face of said cursor.

6. In a slide-rule as described in claim 1, a double series of curves on said slider one series giving by direct reading the equivalent thicknesses in lead for different materials in function of energy and the other series solving protection problems for non-point sources.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,162,363 December 22, 1964

Jean-Marie Lavie

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 6, lines 40 to 42, the formula should appear as shown below instead of as in the patent:

$$Y_1 = f(Ex) = \frac{kEB\mu_a}{e^{\mu x}}$$

line 69, after "ordinates" insert -- movable over and cooperating with said family of curves --; line 73, after "ordinates" insert -- movable over said system of logarithnimic co-ordinates --; column 7, line 6, after "materials" insert -- cooperating with said energy scale --.

Signed and sealed this 29th day of June 1965.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents

UNITED STATES PATENT OFFICE
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