PATENT SPECIFICATION

DRAWINGS ATTACHED

901,502

Date of Application and filing Complete Specification Sept. 8, 1959. No. 30571/59.

Application made in France (No. 774037) on Sept. 9, 1958.

Application made in France (No. 795315) on May 20, 1959.

Complete Specification Published July 18, 1962.

The inventor of this invention in the sense of being the actual deviser thereof within the meaning of Section 16 of the Patents Act 1949 is Jean Lavie, a French national, of 37 rue de Chartres, Massy, (Seine et Oise), France.

Index at acceptance:—Class **106(1)**, B3L, B5(B:F:GX).

International Classification: —**G06g.**

COMPLETE SPECIFICATION

A Slide-Rule for Calculations involving Protective Screens and Radioactive Sources

ERRATUM

SPECIFICATION NO. 901,502

Page 4, line 46, *after* "source" *delete* "full-stop" *insert* "?"

THE PATENT OFFICE,
24th August, 1962

DS 66778/1(25)/R.109 200 8/62 PL

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:—

Or again, by putting

$$k^1 = \frac{1}{4\pi} \quad \text{and} \quad C = \frac{1}{r}$$

$$R = k^1 \, A \, B \, C^2 \, I\,(E) \, e^{-\mu x} \qquad (2)$$

If the parameters are expressed in the following units:—

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

and if the following parameters are introduced:—

μ_a, coefficient of linear absorption in the air (cm^{-1})
P, specific gravity of air (g/cm^3)

then the expression $I\,(E) = \frac{E.\ \mu_a\ P}{187}$ may

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COMPLETE SPECIFICATION

A Slide-Rule for Calculations involving Protective Screens and Radioactive Sources

We, COMMISSARIAT A L'ENERGIE ATOMIQUE, an Organisation created in France by Ordonnance No. 45—2563, of 18th October, 1945, of 69, Rue de Varenne, Paris 7, France, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

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:—

$$R=\frac{A\,B\,I\,(E)\,e^{-\mu x}}{4\pi r^2} \qquad (1)$$

Or again, by putting

$$k^1=\frac{1}{4\,\pi} \quad \text{and} \quad C=\frac{1}{r}$$

$$R=k^1\;A\;B\;C^2\;I\;(E)\;e^{-\mu x} \qquad (2)$$

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 following parameters are introduced:—

μ_a, coefficient of linear absorption in the air (cm^{-1})

P, specific gravity of air (g/cm^3)

then the expression $I\;(E)=\frac{E.\;\mu_a\;P}{187}$ may be introduced into expression (1), which becomes:—

$$R=\frac{k\,\mu_a{}^{ABE\,e^{-\mu x}}}{r^2} \qquad (3)$$

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:—

$$\frac{Rr^2}{A}=\frac{k\mu_a\,B\,E}{e^{\mu x}} \qquad (4)$$

and may be broken up into two intermediate functions

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

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

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

$\text{Log}\ \gamma_1=\text{Log}\ k+\text{Log}\ \mu_a+\text{Log}\ B+\text{Log}\ E-\mu x$, 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 $\text{Log}\ y=2\ \text{Log}\ r-\text{Log}\ A$, 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 $\gamma_1=f\,(E, x)=\frac{k\mu_a\,B\,E}{e^{\mu x}}$, γ_1 being represented logarithmically along the abscissa, and x being read-off linearly on the ordinate, a scale for x being marked on one side of 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 irradiation intensity 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 a scale for r being marked 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 MeV; 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 $\frac{I_1}{I_2}$ 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 $\frac{l}{a}$; wherein l 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 $\frac{d}{a}$; 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, marked on the rear of the slider, 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, likewise marked on the rear of the slider, are graphs 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 rule 1 on one side of which is marked the family of curves 2 representing the variation in attenuation of the activity of gamma photons as a function of lead screen thickness, for different energies E of the said photons (0.5—0.6 etc. . . . —2.5—3 MeV).

The value of lead thickness x causing the said attenuation is read off on an axis 3 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:—

$$x_e=x_{Pb}\,.\,\frac{d_{Pb}}{d_e}$$

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 displaced with respect to the 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 facitate reading.

As may be seen in Figure 2, the other side of the rule has mounted on it a moving slider 7 bearing 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 other side 9 of the cursor 5, along one of the two axes 10 or 11 corresponding to lead and uranium, as on the side 4 of the cursor.

The lower edge 12 of the slide-rule bears a logarithmic scale 13 (used also on constructing the sets of curves $\gamma_1=f\ (E, x)$ and $y=\frac{r^2}{A}$) giving the values of intensity of irradiation R in milliröntgens per hour (reference mark 14) or röntgens per hour (reference mark 15).

Moreover, on the side 4 of the cursor 5 (Figure 1) there is an energy scale 16 extending, in this particular example, from 0.5 to 3 MeV; two scales 17 and 18 are likewise engraved on transparent parts of the rule, the scale 17 being graduated in mean free paths, and the scale 18 in centimetres of lead. The rule also has engraved on it the logarithmic scale 19 graduated in total effective macroscopic screen cross-section, to which corresponds the logarithmic scale 20 graduated in thicknesses on the side 4 of the cursor. Finally, the set of curves 21 on the side 1 of the rule represents variations, as a function of energy, in total effective macroscopic cross-section Σ of the various screen materials to which consideration is given; 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 MeV 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 the rule intersects the division 25 on a horizontal scale graduated in iron thickness on the back of the slider 7. Scale referred to as . . . Fe . . . in Figure 8. The result, i.e., 12 cm. of lead, is read off at the intersection of the 1 MeV energy straight line and the lead reference scale. Irradiation intensity with a 12 cm. lead screen is then calculated as follows:—

The cursor is moved on side 1 in such a manner as to make the value x=12 on the axis 3 engraved on the side 4 of the cursor intersect with the energy E=1 MeV of the gamma photons on the corresponding curve in the group 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 operate) on the axis 10 engraved on the side 9 of the cursor and the value A=100 Curies (source activity) on the slider are caused to correspond. 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.

The second example of use of the slide-rule concerns calculation of irradiation intensity on the axis of symmetry of a mono-kinetic 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 MeV 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, the cursor is moved on the rear of the rule so that the energy scale 16 intersects the lead curve 21 at the 1.5 MeV 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 slide-rule is used so that the curve $\frac{d}{a}=1$ intersects the scale 17 at division 6. 0.63 is read off at the intersection of the scale 17 and the scale "F" (Figure 10). The irradiation intensity due to the circular source is equal to $65\times0.63:40$ mr./h., a multiplication which is carried out with the aid of the logarithmic scales 19 and 20 on the rule and the cursor.

WHAT WE CLAIM IS:—

1. Slide-rule for calculations involving protective screens and radioactive sources, characterised in that it comprises a rule bearing on one side the family of curves repre-

senting the function $\gamma_1 = f(E, x) = \frac{k E B \mu_a}{e^{\mu x}}$, where k is a numerical co-efficient depending on the units chosen, E represents the energy of the photons, B is the so-called "build-up" factor, and μ_a and μ are the co-efficients of linear absorption of air and the material of which the screen is made respectively, γ_1 being represented logarithmically along the abscissa, and x being read off linearly on the ordinate, a scale for x being marked on one side of 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 irradiation intensity R, and having mounted on it a moving slider bearing the family of curves, in logarithmic co-ordinates, representing the function $y = \frac{r^2}{A}$, where r is the distance from the source to the operator, and A is the activity of the source, y being plotted as abscissa on the said slider, and r as ordinate, a scale for r being marked on the other side of the movable cursor.

2. Slide-rule according to Claim 1, having inscribed thereon curves representing variations, as a function of photon energy, in the total effective macroscopic cross-section of various screen materials.

3. Slide-rule according to Claim 1 or Claim 2, in which the cursor bears an energy scale graduated linearly in megaelectron-volts, and a thickness scale graduated logarithmically in centimetres.

4. Slide-rule according to any one of the preceding claims, in which the rear of the slider bears a double series of curves, giving on the one hand a direct reading of equivalent lead thicknesses for different materials as a function of energy, and on the other hand graphs enabling protection problems relating to non-point sources to be solved.

5. Slide-rule according to any one of the preceding claims, in which one side bears isoenergy curves for certain common radioactive elements.

6. Slide-rule substantially as described with reference to the accompanying drawings.

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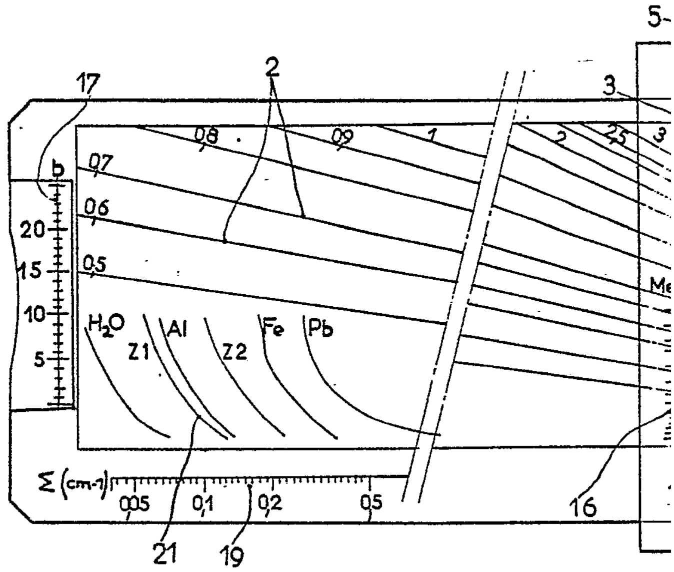
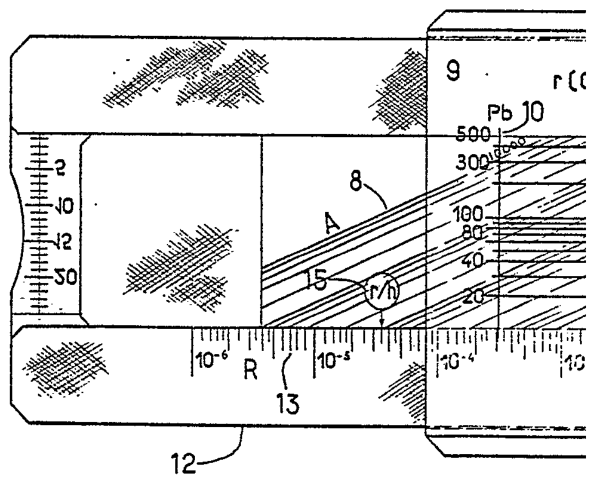


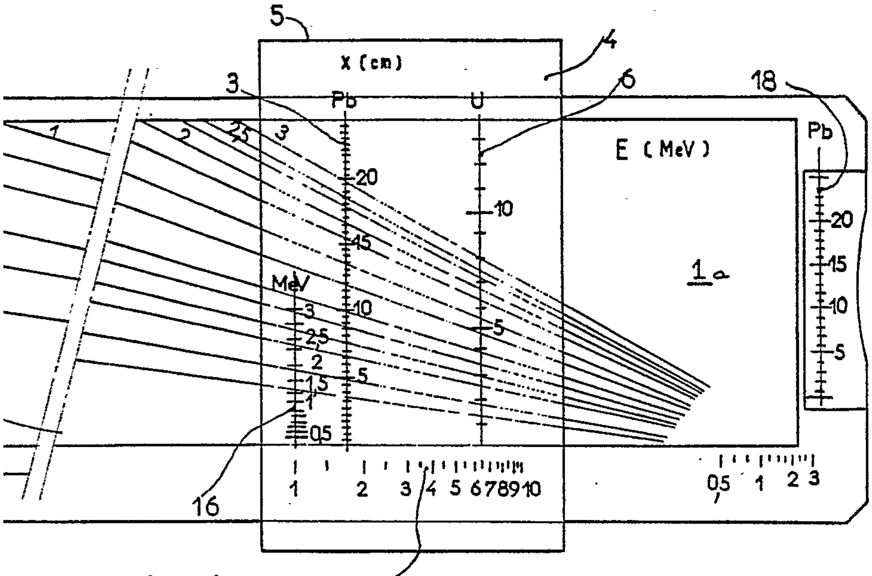
5
2
3
17
b
20
15
10
5
0,7
0,6
0,5
0,8
0,9
1
2
2,5
3
H2O
Z1
Al
Z2
Fe
Pb
Σ (cm-1)
0,05
0,1
0,2
0,5
16
21
19

Fig.1



9
Pb 10
500
300
100
80
40
20
8
A
15
r/h
2
10
12
30
R
13
12

Fig.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Pb
U
E (MeV)
1a
MeV
Pb
5
4
3
6
18
16
20

Fig. 1

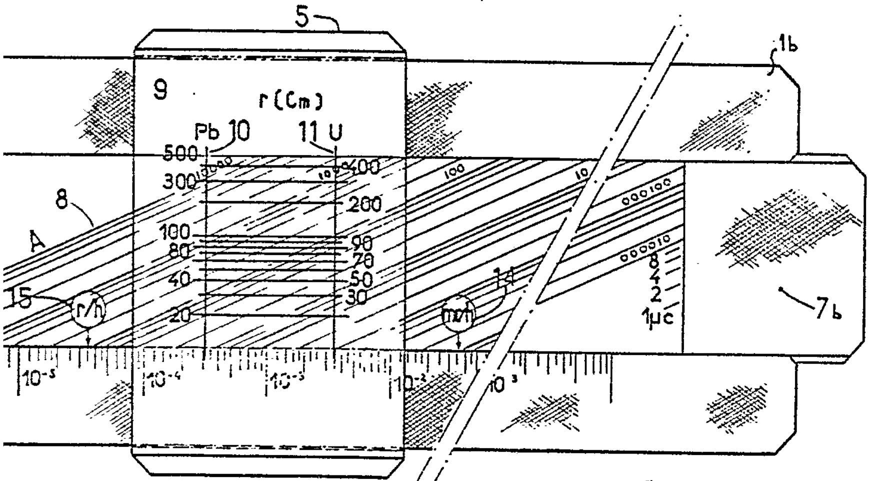

r (Cm)
Pb 10
11 U
9
5
8
A
15
14
1b
7b
1μc

Fig. 2

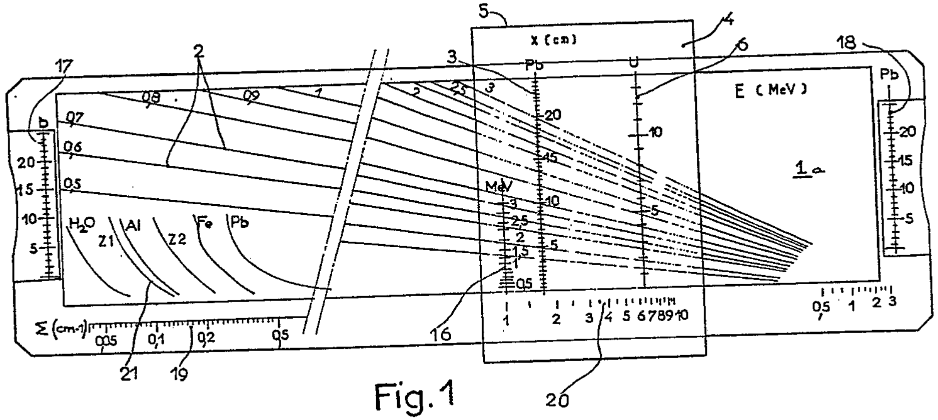


Fig. 1

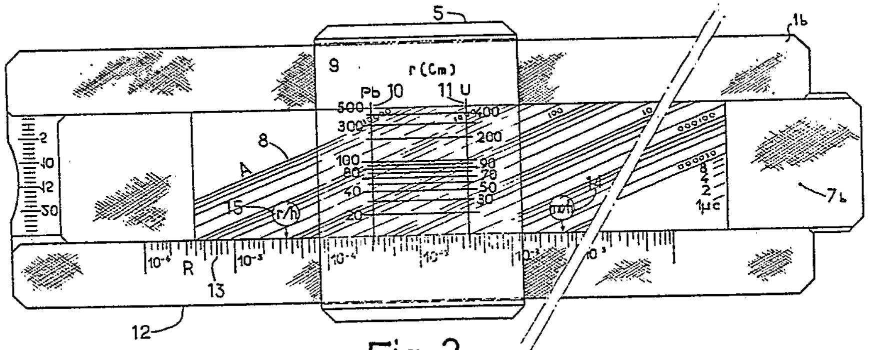


Fig. 2

Fig. 3

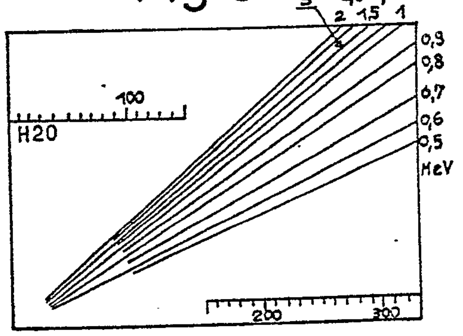


Fig.4

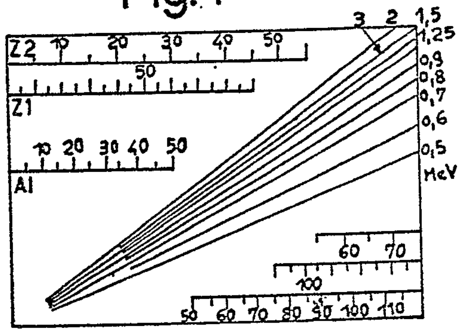
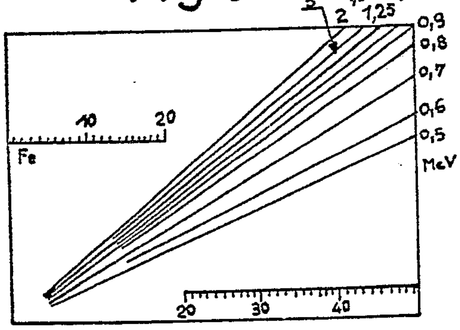
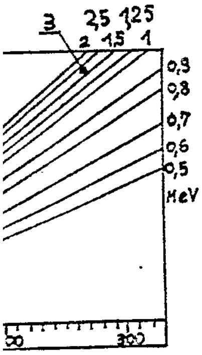
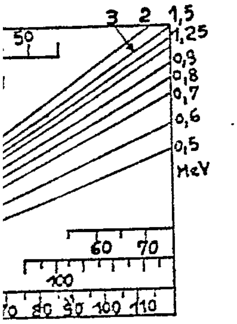


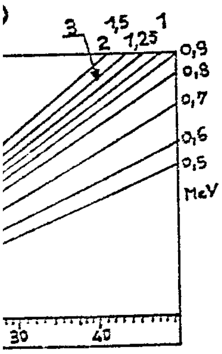
Fig. 5



901502 COMPLETE SPECIFICATION
5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheets 2 & 3







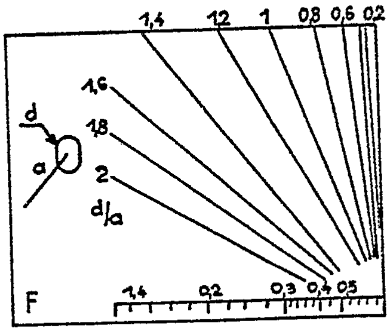


Fig. 6

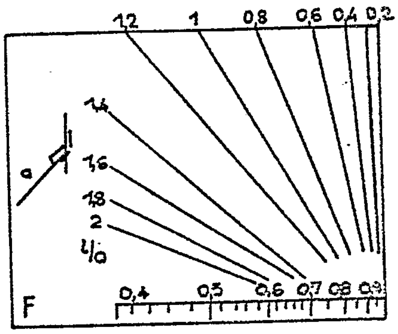


Fig. 7

Fig. 3

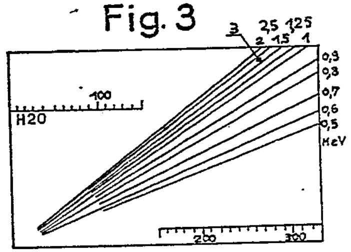


Fig. 4

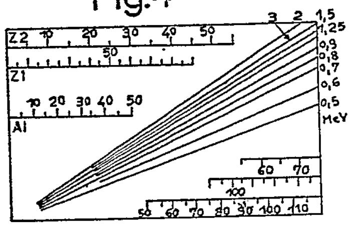
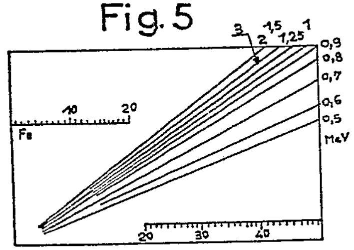


Fig. 5



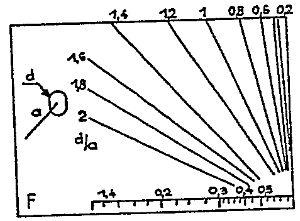


Fig. 6

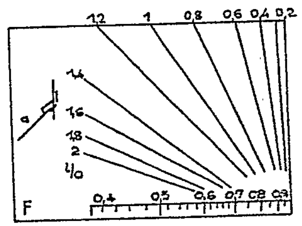
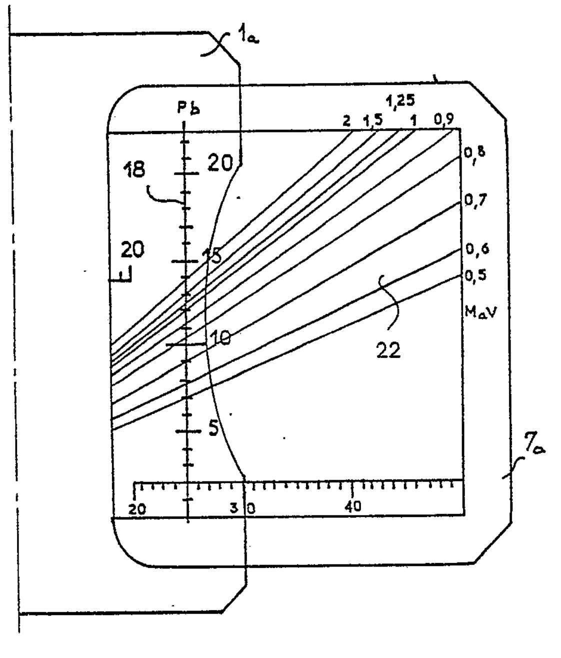


Fig. 7

Fig.8



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5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 4 & 5

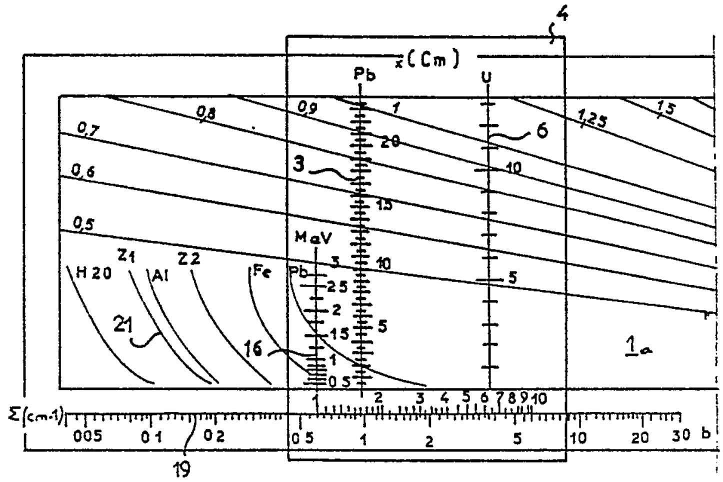
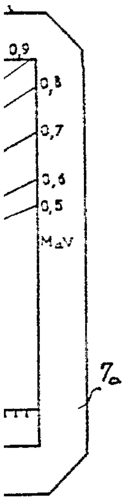


Fig. 9



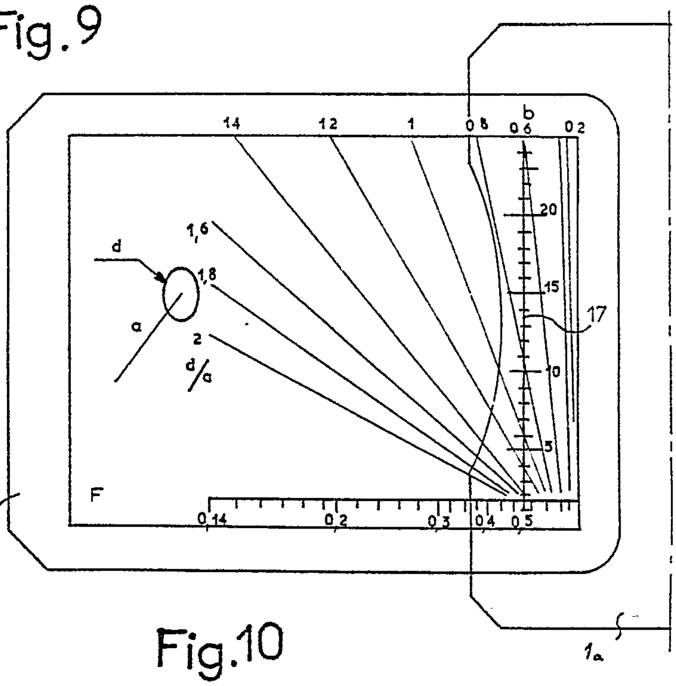
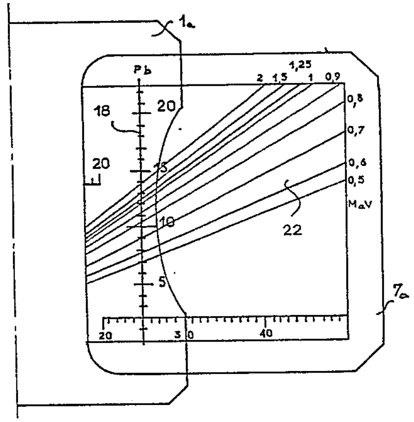


Fig.10

901502 COMPLETE SPECIFICATION
5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheets 4 & 5

Fig.8



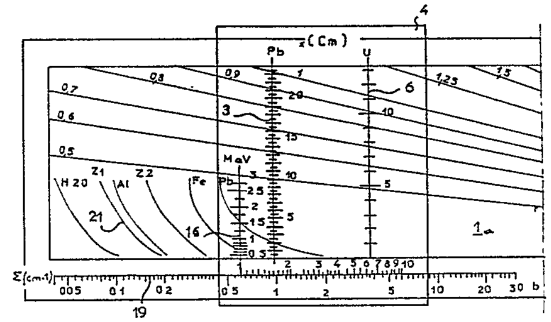


Fig. 9

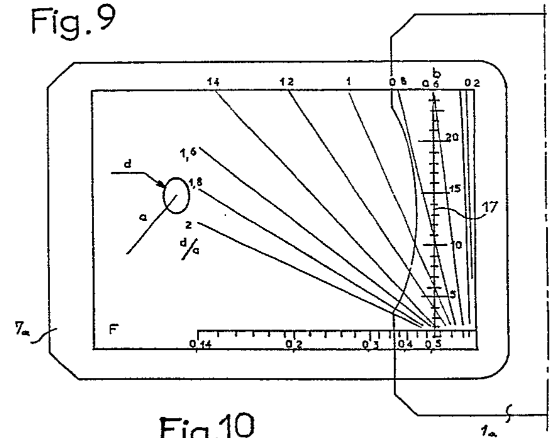


Fig.10