

Feb. 25, 1958

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2,824,970

SECONDARY DIAPHRAGMS FOR X-RAY RADIOGRAPHY

Filed March 30, 1953

3 Sheets-Sheet 1

Fig. 1.

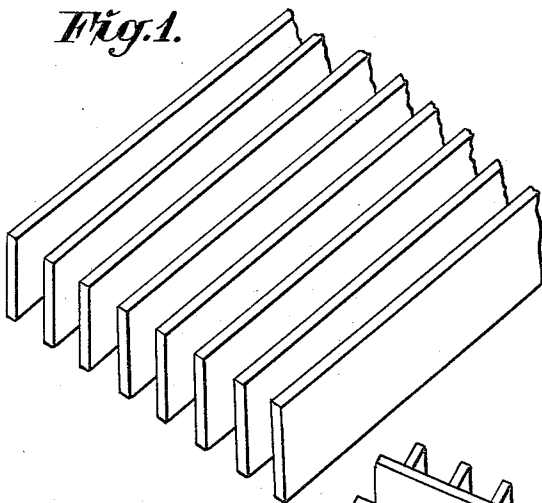


Fig. 2.

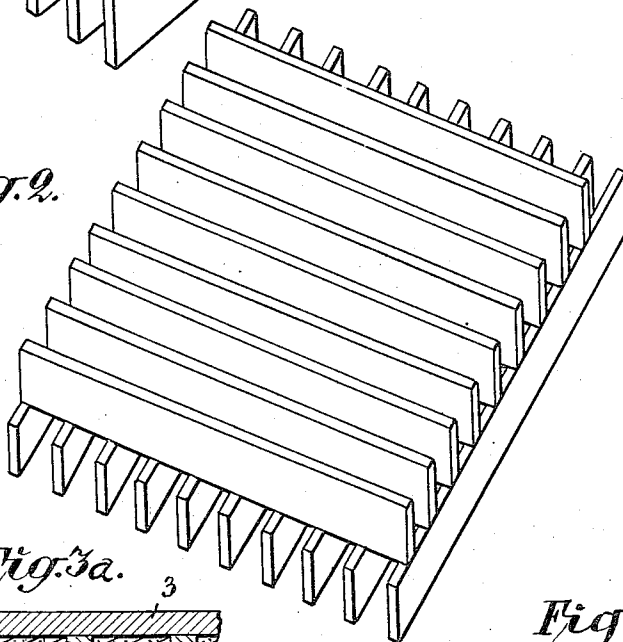


Fig. 3b.

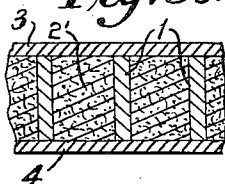


Fig. 3a.

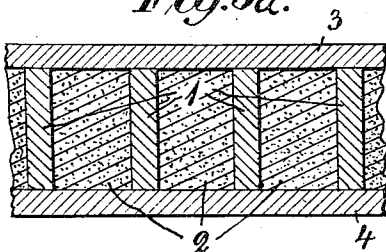
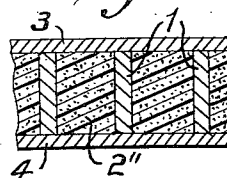


Fig. 3c.



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Fig. 4.

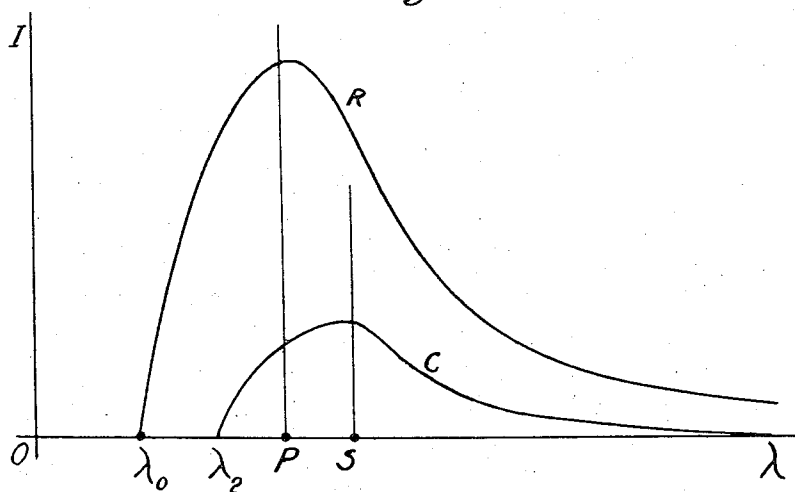
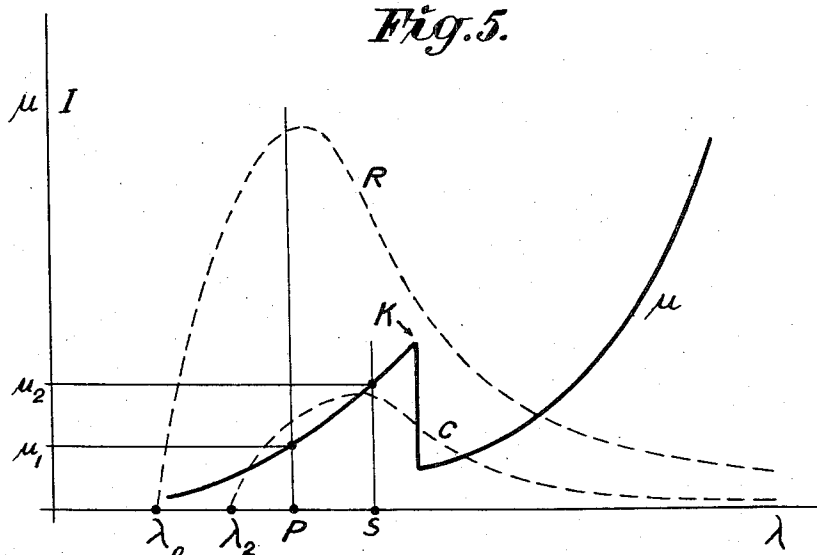


Fig. 5.



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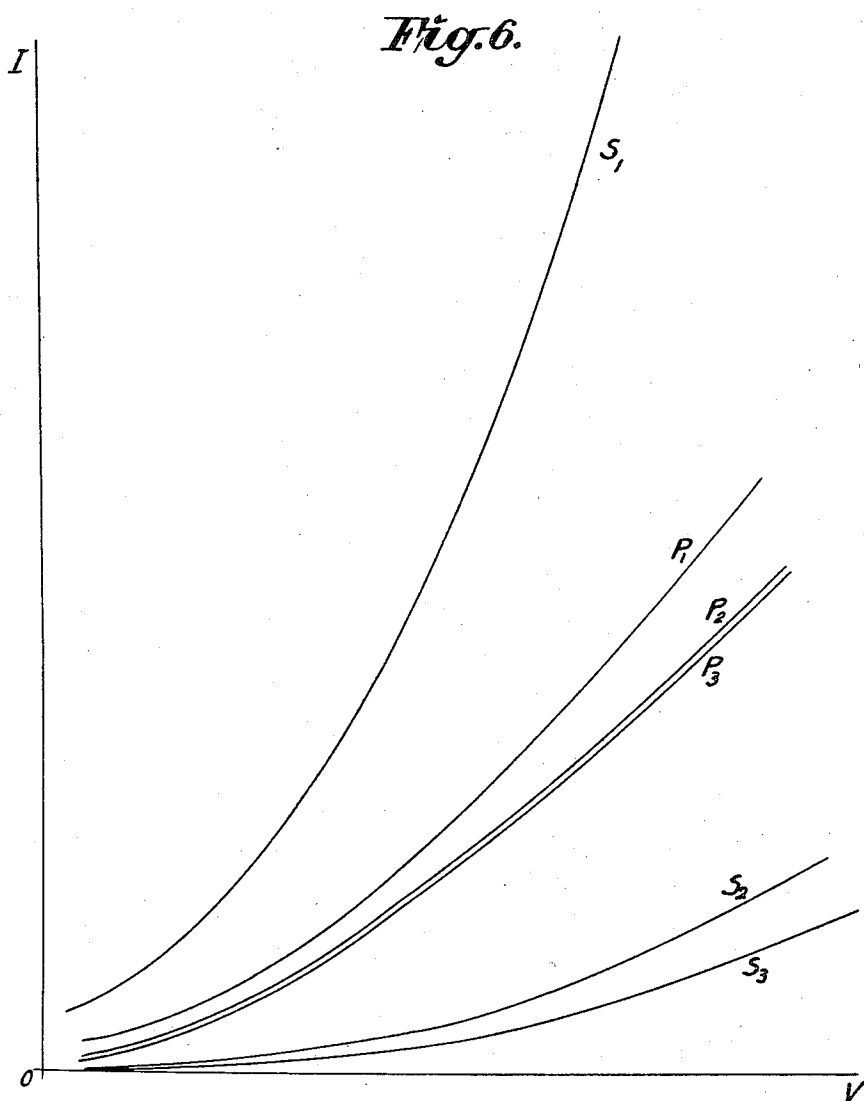
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SECONDARY DIAPHRAGMS FOR X-RAY RADIOGRAPHY

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Application March 30, 1953, Serial No. 345,662

Claims priority, application Sweden April 4, 1952

9 Claims. (Cl. 250—63)

The present invention relates to X-ray radiography and more particularly to secondary diaphragms in connection therewith.

It is an object of the invention to provide such secondary diaphragms which are more effective in providing sharp X-ray images than diaphragms hitherto known. Another object is to obtain the increased effectivity with reasonable thick diaphragms and without the necessity of too exact orientation of the diaphragm.

In the reproduction of an image by means of X-ray radiation a source of radiation with as nearly as possible a pin-point focal spot throws a shadow-image of the object upon either a fluorescent screen or a photographic film, possibly with intensifying screens. The contrast and definition in the shadow-image are dependent in the first place upon a very small source of radiation; i. e., a small radiating focal spot on the anode of the X-ray tube. For practical reasons, however, the focal spot must have a certain areal extent and must therefore introduce some lack of definition into the image. Another well-known and serious source of poor contrast and definition is the so called Compton effect which is a result of the secondary radiation of the object to be radiographed. The primary X-ray radiation penetrating the object gives rise to such secondary radiation, which is not directed from the focal spot of the X-ray tube but radiates instead from various points of the object in all directions. Consequently, the secondary radiation contributes extensively to the deterioration of the image.

In the art this injurious effect of the secondary radiation upon the image has long been suppressed, to a certain degree, by the use of a secondary diaphragm immediately in front of the fluorescent screen or photographic film. This diaphragm consists of screening strips of heavy material, usually lead, placed on edge, and having such dimensions that the direct radiation is obstructed as little as possible while the secondary radiation, which deviates from the direction of the primary radiation, to a great extent is absorbed by the grid strips and is thus prevented from striking the screen or film. Such secondary diaphragms are constructed with screening strips of lead placed on edge and, as a rule, joined by separating strips of a material having only a slight capacity of absorption for the X-ray radiation passing through. The use of such secondary diaphragms affords a notable improvement in contrast and definition in the image. Unfortunately, the aforementioned diaphragms can not sufficiently prevent the image-destroying effect of the secondary radiation, because secondary radiation of almost the same direction as that of the primary radiation and of a considerable intensity is nevertheless able to pass between the screening grid strips. Investigations have demonstrated that the remaining secondary radiation is of sufficient intensity to cause an appreciable deterioration of the image and, in many instances, make the reproduction of small degrees of contrast and fine structures in the object impossible.

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The present invention relates to such an improvement in secondary diaphragms of the type described that more satisfactory results may be obtained than heretofore in respect to contrast and finer structures in the reproductions. As in the constructions known in the art, the secondary diaphragm of this invention consists of a screening grid in the form of strips put on edge of highly absorbent material, such as lead, for the absorption of the greater part of the injurious secondary radiation. The characteristic feature of this invention lies in the fact that in the interstices of the screening grid of the secondary diaphragm, in the path of the radiation is introduced an absorbing material hereinafter denoted as discriminating material, of such nature that its K-absorption wavelength limit lies at a shorter wavelength than 7 A. The secondary radiation, which due to the Compton effect has obtained a greater wavelength than the image-producing primary radiation, will therefore be absorbed to a greater extent than the primary radiation. Inasmuch as secondary radiation is absorbed to a greater extent than the primary radiation by such material, the ratio between the useful radiation and the detrimental radiation will be improved, resulting in sharper contrast in the image. The denomination discriminating material has been selected because the material serves as a kind of discriminator through extensively obstructing the passage of the detrimental secondary radiation without obstructing the passage of the primary radiation to a disturbing degree, although the intensity of the primary radiation may be decreased to a certain extent.

The discriminating material may be introduced into the interstices of the screening grid or as a superficial layer over the edges of the strips of the screening grid on one or both sides of the grid. Or, it may be applied in one or both of the plates which frequently cover the screening grid proper.

The invention will now be described in greater detail, with reference to the accompanying drawings in which:

Figs. 1 and 2 show the orientation and dimensioning of the screening grid strips. Fig. 1 illustrating a series of screening strips converging toward the focal spot and Fig. 2 representing a series of crossing strips.

Fig. 3a shows a cross section through a part of a screening grid, provided with two cover plates and wherein the discriminating material is constituted as an alloy.

Fig. 3b is a view similar to Fig. 3a and wherein the discriminating material is absorbed in a fibrous carrier material;

Fig. 3c is a view similar to Fig. 3a and wherein the discriminating material is included as filler in a carrier material consisting of a plastic;

Fig. 4 is a diagram showing the intensity of the X-ray radiation as a function of the wavelength.

Fig. 5 presents curves corresponding to those in Fig. 4, but with an absorption curve for a discriminating material plotted in.

Fig. 6, finally, shows the variation in the relative intensity of the radiation, with a diaphragm of the type in common use heretofore and with a diaphragm including discriminating material according to the invention.

In Fig. 3a, strips of lead or a similar heavy material placed on edge in spaced relation are denoted by 1. Parallel spaced cover plates 3 and 4 are placed across the opposite edges of the strips 1 and, in accordance with the invention as illustrated in this figure, the spaces between the strips 1, which spaces form passageways for the X-rays, are filled with the discriminating material constituted as an alloy 2. It is also possible to apply the discriminating material as a sheet on the surface of at least one of the cover plates 3 and 4.

An X-ray tube usually emits a heterogeneous radiation, with only the lower limit of its wavelength controlled by

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the operating voltage of the tube. In a study of the X-ray radiation generally used in radiography, it is observed that the wavelength distribution and the intensity may be illustrated by curves such as shown in Fig. 4. The abscissa in Fig. 4 represents the wavelength of the X-ray radiation and the ordinate its intensity. Curve R shows the intensity of the primary radiation as a function of the wavelength. Point λ_0 on the wavelength scale indicates the shortest wavelength, determined by the voltage of the X-ray tube, which the tube emits. Investigations and experiments have shown that, in regard to image-producing properties, such an intensity-wavelength curve can be replaced by a given intensity at a definite wavelength; i. e., monochromatic radiation. This may also be expressed so that the intensity-wavelength curve has an average point, denoted P in Fig. 4. It should be obvious that in such a comparison variations in hardness or penetrating capacity must be taken into consideration for the different wavelengths. The present intention is to describe, only with respect to image-producing, such a heterogeneous radiation of a particular intensity as equal to a monochromatic radiation of a definite wavelength (effective wavelength λ_e) and equal intensity. When the primary radiation passes through the object, secondary radiation arises, and because of the Compton effect, the wavelength of this secondary radiation is increased.

A short review of the Compton effect must be included. The Compton effect is obtained when a photon meets an electron at a low energy level. This collision results in a change in direction and a loss of the energy for the photon, while the electron receives an impulse concurrently. The loss of the energy of the photon also means an increase in wavelength. If the change in direction in relation to the direction of the primary radiation is denoted by the angle θ , the increase in the wavelength will be

$$0.0242(1 - \cos \theta) \text{ A.}$$

In the case of a directional change of 90° , the increase in the wavelength will be 0.0242 A. and with a change of 180° , it will be 0.0484 A. In a measurement of the Compton effect after the passage of the X-ray radiation through the object, the intensity of the radiation appearing with Compton effect (i. e., with increased wavelength) proves to be considerably greater than indicated by the foregoing expression. The reason for this lies in the occurrence of many reflexes with exchanges of energy within the object. Inasmuch as the change in wavelength due to simple Compton effect is constant and independent of the wavelength of the primary radiation, the shorter the wavelength of the primary radiation, the more clearly it appears.

Curve C in Fig. 4 shows the intensity and wavelength distribution of the secondary or scattered radiation after penetration of the object. Point S indicates the average point of the scattered radiation curve. The displacement between the average points of the two curves, P and S, denotes the change in the wavelength of the radiation due to the Compton effect. The advantages of the new diaphragm are obtained through providing the screening grid with a discriminating material A having the property highly absorbing the secondary radiation having the longer effective wavelength, according to curve C in Fig. 4, while immaterially affecting the primary radiation, according to curve R in Fig. 4. By means of selecting suitable discriminating material with regard, among other factors, to the operating voltage of the X-ray tube, the absorption wavelength band of the material can be exploited. It is primarily the K-absorption wavelength band which is used. The solid-line curve in Fig. 5 shows the absorption of one discriminating material. The dashed curves are the same intensity-wavelength curves for X-ray radiation as shown in Fig. 4. It is clearly evident from Fig. 5 how much less the absorption μ_1 for the average point P is than the absorption μ_1 for the average point S for the secondary radiation. Investigations and tests have shown that one or more of the ele-

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ments of the periodic system with atomic numbers (Z) higher than 13 and without strong inherent radiation are suitable for use as discriminating material. Elements with atomic numbers lower than 13 have their K-absorption wavelength limit at over 7 A. Therefore, they lie so far from the wavelength range in which the secondary radiation substantially affects the contrast in the image that they are without significance for this diaphragm. In the selection of suitable discriminating material, it is important that the K-absorption wavelength band for the various elements occur at different wavelengths according to the equation.

$$\lambda_K = k(Z-1)^{-2}$$

where

λ_K = the wavelength of the X-ray radiation

k = a constant

Z = the atomic number of the discriminating material in material in the periodic system

As has already been shown in connection with the discussion of the curves in Figs. 4 and 5 it is possible to obtain especially good effects with the new diaphragm through selecting a suitable discriminating material in relation to the particular radiation wavelength which is otherwise adapted to the radiography of a particular object. In the majority of cases, a diaphragm with discriminating material selected with regard to a wider wavelength range can fulfill its purpose entirely satisfactorily. However, in the radiography of special objects and extensive serial radiography, there may be reasons for the selection of the particular discriminating material which affords the most advantageous relation between image-producing and image-destroying radiation striking the film. In such cases, the discriminating material that should be selected has proven to be an element with the atomic number

$$Z^{1.2} = \frac{7}{\lambda_e}$$

where λ_e is the effective wavelength of the secondary radiation. As regards the quantity of discriminating material expediently used, it may be mentioned that a greater proportion of the lighter elements with low atomic numbers is required than of the heavier elements with higher atomic numbers. Experiments have shown that the proportion of discriminating material, which because of the properties of absorption of the material are inversely proportional to the third power of the atomic number, should be at least

$$Q = 22,500Z^{-3}$$

Q = quantity of the active element or elements of the discriminating material in the passageways for the X-rays through the diaphragm in percent of the non-discriminating material in said passageways. Z = the atomic number in the periodic system of the discriminating material.

The upper limit for the proportion of discriminating material is that which affords the same absorption in the discriminator plus its carrier as in the screening grid itself; i. e., that which eliminates the screening effect of the device. In practice, one should operate in the lower half of this proportion range in order to avoid unnecessarily increasing the exposure time and/or the requisite voltage of the X-ray tube used.

Fig. 6 presents a further example illustrating the advantage of the new secondary diaphragm. The curves show the radiation intensities after penetration of a diaphragm of the type usual heretofore, on the one hand, and after a diaphragm containing discriminating material according to the invention, on the other hand. The abscissa in the figure represents the operating voltage V of the X-ray tube. The ordinate represents the intensity I of the X-ray radiation. Curve P₁ represents the primary X-ray radiation after passage through a water phantom, and curve S₁ shows the secondary radiation which arose in the object. The latter is even more intense than the primary radiation. Without any secondary diaphragm, both these radiations would strike the photo-

graphic film to their full extent and, in the familiar manner, the secondary radiation would obliterate even strong contrast which is essential to the evaluation of the image. Through a secondary diaphragm of the type usual heretofore, introduced into the path of the radiation in front of the film, radiation intensities are obtained after penetration of the diaphragm as shown in curves P_2 and S_2 , corresponding respectively to primary and secondary radiation. As mentioned earlier, and as is evident from correlation of the intensities of the two curves, considerably better images are obtained with than without these diaphragms. The two curves P_3 and S_3 in the same figure are intensity curves recorded under the same conditions and with a screening grid of the same construction as used for curves P_2 and S_2 . Curve P_3 shows the intensity of the primary radiation and curve S_3 that of the secondary radiation after the total radiation having penetrated the object has passed through a secondary diaphragm containing discriminating material according to the invention. A comparison of the ratio between the intensities of primary and secondary radiation P/S after penetration of the two different diaphragms, indicates that the ratio is considerably improved by the new diaphragm. The ratio P/S is essentially improved by the addition of discriminating material to the screening grid system. The great improvement in the reproduction of the image with the new secondary diaphragm appears even more clearly when the density of the photographic film is considered in relation to the radiation intensity.

A large addition of discriminating material produces a better effect but may also introduce disadvantages such as long exposure times or exposure of the object to excessive irradiation. The discriminating material can be applied to the screening grid in several different ways; alone or in the form of a chemical compound, an alloy as shown in Fig. 3a or in combination with other carrier materials. These latter having, of course, lower absorption capacity (greater radiopacity) than the discriminating material. A suitable carrier material, which may be organic or inorganic, may be combined with the discriminating material or its compounds, for example, and subsequently applied to the screening grid in various ways. The carrier material may also advantageously be comprised of a fiber material, e. g., textile material or paper, such as in laminated form, soaked in a suitable solution or suspension of the discriminating material or a compound thereof and dried as shown at 2' in Fig. 3b. Moreover, various plastic materials could be used as carriers with the discriminating material mixed therein as shown at 2' in Fig. 3c, possibly together with other fillers. Light metals can be alloyed with discriminating material and applied to the screening grid. It may even be expedient that two or more basic elements, suitable as discriminating material, be combined. It should be pointed out that the salts of discriminating materials act in a particular manner. The salts usually give a curve with the K-absorption wavelength band immediately beside the K-absorption wavelength band of the salt-forming substance. Accordingly, this should be taken into consideration in the selection of a discriminating material. In addition, several layers containing different discriminating materials and combined with the screening grid in various manners could be used. The essential feature is the fact that the new screen grid system of the scattered radiation diaphragm is equipped with one or more elements of the kind and quantity set forth herein above; meaning that the kind and quantity be so adapted that the scattered radiation undergoes a greater absorption than the primary radiation.

In practice, the most important wavelength range in radiography corresponds to a wavelength λ_e for secondary radiation of less than 1 A. In the following table, the K-absorption edges are given for some of the more common elements which are suitable as discriminating

material for the radiation range below the limit 1 A.

Table

	Ti	2.5
5	Mn	1.89
	Ni	1.48
	As	1.04
	Sr	0.77
	Mo	0.62
10	Sb	0.41
	Te	0.39
	Ta	0.18
	Au	0.15
	Pb	0.14
15	Bi	0.13
	V	2.26
	Fe	1.73
	Cu	1.37
	Se	0.97
20	Zr	0.69
	Ag	0.48
	Ba	0.33
	W	0.18
	Hg	0.15
25	U	0.11
	Cr	2.06
	Co	1.60
	Zn	1.28
	Br	0.91
30	Sn	0.42

As previously mentioned, it is possible to combine two or more of the elements listed or to use compounds containing several of them, in order to attain as steep an absorption curve as possible within the wavelength range in question.

What is claimed is:

1. Secondary diaphragm for X-ray radiography comprising screening strips of an X-ray absorbing material placed on edge to form a screening grid and define passageways for X-rays extending between said strips, and discriminating material of less absorptive capacity for primary radiation than said screening strips evenly distributed over the entire cross section of said passageways and containing at least one element having atomic number (Z) higher than 13 in the periodic system and a K-absorption edge at a wavelength shorter than 7 angstrom units, the proportion of said discriminating material being at least $22,500Z^{-3}$ percent by weight of the total material between the screening strips.
2. Secondary diaphragm as claimed in claim 1 in which the discriminating material contains an element, the effective absorption edge of which lies at a longer wavelength than the effective wavelength of the secondary radiation.
3. Secondary diaphragm as claimed in claim 2 in which the discriminating material contains an element having an absorption curve having a steep part ending at said absorption edge, the effective wavelength of the secondary radiation lying on said steep part.
4. Secondary diaphragm as claimed in claim 1, comprising a carrier material for the discriminating material, said carrier material having a K-absorption edge at a longer wavelength than 7 angstrom units.
5. Secondary diaphragm as claimed in claim 4 in which the discriminating material is absorbed in a fibrous carrier material.
6. Secondary diaphragm as claimed in claim 4 in which the discriminating material is absorbed in a fibrous carrier material of the group consisting of textile material and paper.
7. Secondary diaphragm as claimed in claim 4 in which the discriminating material is included as filler in a carrier material consisting of a plastic.
8. Secondary diaphragm as claimed in claim 4 in which the discriminating material is alloyed with at least one

metal having a lower atomic number than that of the discriminating material.

9. Secondary diaphragm as claimed in claim 1 in which the discriminating material contains an element the atomic number of which is not less than

$$\left(\frac{7}{\lambda_e}\right)^{\frac{1}{1.2}}$$

where λ_e is the effective wavelength of the secondary radiation. 10

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