June 17, 1941. 2,245,787

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EXAMINING BODIES BY MEANS OF NEUTRONS AND ELECTRON EMITTING MATERIAL

Filed April 27, 1939

Fig. 1

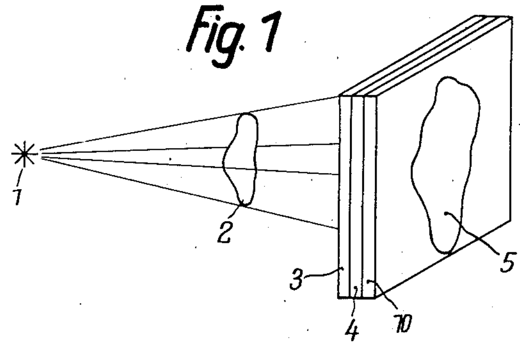


Fig. 2

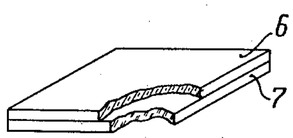


Fig. 3

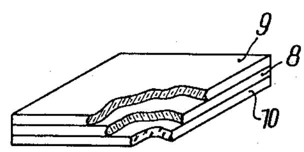


Fig. 4

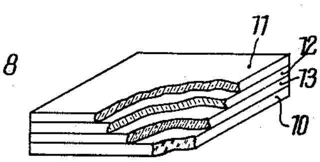


Fig. 5

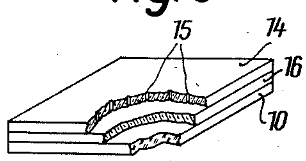


Fig. 6

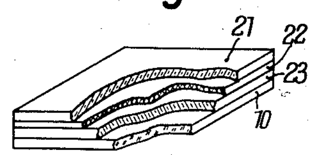


Fig. 7

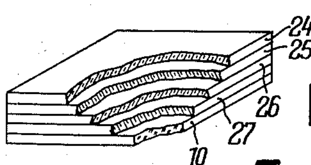


Fig. 8

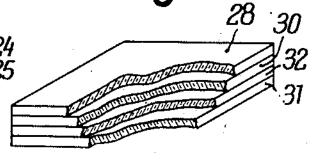


Fig. 9

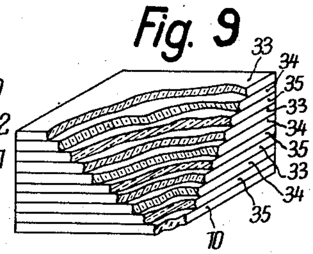
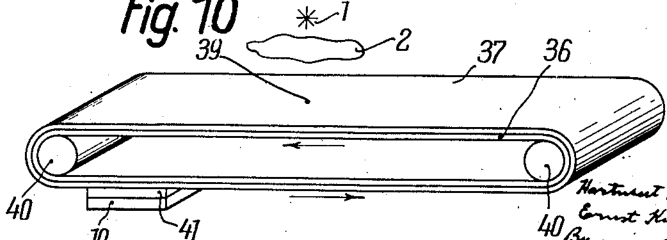


Fig. 10



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UNITED STATES PATENT OFFICE

2,245,787

EXAMINING BODIES BY MEANS OF NEUTRONS AND ELECTRON EMITTING MATERIAL

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24 Claims. (Cl. 250—65)

Bodies or substances which absorb or disperse neutrons, including for example living tissue, may be examined by means of neutrons, preferably slow neutrons, i. e. those of which the "de Broglie" wave is approximately equal to or is greater than the diameter of the nuclei of the atoms of the body or substance. This may be done by directing a beam of neutrons on to the body or substance and causing the neutrons that emerge from it to act upon a layer of material in which a reaction takes place in which heavy charged particles are produced and these particles are in turn caused to act either upon a fluorescent material or directly upon an adjacent photographically-sensitive layer. A disadvantage of this method is that the heavy particles have only a relatively short range in the material of the layer so that only a very thin surface layer is effective even of a thick layer of material, the thickness of this surface layer corresponding approximately to the range of the heavy particles in the material.

According to the invention this disadvantage is obviated by employing a layer of a material in which the neutrons produce, not heavy charged particles, but positively or negatively charged electrons. The shorter terms "electrons" and "positrons" respectively are sometimes used to denote these two different forms of electrons. In what follows, however, the single term "electrons" is employed to denote positive or negative electrons. Moreover the layer of material in which the reaction is caused by the neutrons will hereinafter be referred to as "the neutron-reactive layer," although the material need not be in the form of a layer but may be finely distributed in another substance. In this neutron-reactive layer, radio-active nuclei are thus artificially formed, which nuclei, when they disintegrate, give off electrons. These have the property of causing certain substances to fluoresce in the same way as the heavy particles. They are also able to darken a photographic plate. The range of the electrons is however considerably greater than that of the heavy particles. A relatively thick neutron-reactive layer may therefore be used according to the invention so that the effect on fluorescent substance or on a photographic plate is greater, with the same intensity of the incident neutrons, than it is in the case of the heavy particles.

The neutron-reactive layer may be applied to the side of the fluorescent substance which is adjacent to the source of neutrons. A non-transparent material may then be used for the neutron-reactive layer. The substance that gives off the electrons may however be mixed with the fluorescent substance. In certain circumstances it is even of advantage to apply it to the side of the fluorescent substance which is on the far side of the source of neutrons during the exposure. However, in this case, the neutron-reactive layer must either consist of a material which is permeable to the rays emitted by the fluorescent substance or it must be applied in such a thin layer that undue absorption does not take place in the substance forming the neutron-reactive layer. In many cases, especially when a non-transparent substance is used for the neutron-reactive layer, it is of advantage to provide openings in the neutron-reactive layer so as to allow the passage of the radiation from the fluorescent substance, for example to make it in the form of a screen or grid, or to apply the substance forming the neutron-reactive layer in the form of finely-distributed grains.

Any substance which emits electrons under the influence of neutrons may in general be employed for the neutron-reactive layer. Such substances are for example silver and its compounds, more especially silver chloride, rhodium, indium and yttrium and their compounds. Moreover any substances which, under the influence of electrons, emit rays which are visible to the eye or act upon a photographic plate, may be employed as the fluorescent material. Fluorescent zinc sulphide is especially suitable for this purpose. The fluorescent substance may in certain circumstances be mixed with advantage with the substance which gives off electrons. It is especially advantageous to use a substance which, under the influence of neutrons, emits electrons and is itself caused by them to become luminous.

The visible radiation which proceeds from the fluorescent mass may either be observed by the eye or may be made to act, together with the invisible radiation, upon photographic material, for example on a photographic plate or a film. In order to increase the effect, the photographic layer may be embedded between two layers of fluorescent material at least one of which is covered with a layer of material which gives off electrons or is mixed with such a material.

The substances which give off electrons under the influence of the neutrons have for the greater part the property of giving off electrons not only directly after being exposed to the neutrons but also for a certain time after being exposed. The manner in which the emission of electrons gradually ceases is determined by the mean life of the radioactive nuclei which are formed in the neutron-reactive layer by the bombardment with neutrons. The mean life varies according to the substance, between a very small fraction of a second and many days.

In order to obtain the maximum possible effect upon the eye and a really effective action on the photographic material, it is advisable to extend the time of observation or the time of exposure of the photographic layer by the fluorescent material and the substance emitting electrons as far as possible beyond the mean life of the artificial radioactive nuclei which are formed. For observation with the eye, therefore, substances are usually to be preferred of which the life is short, whereas in the case of the photographic layer substances having a longer life may be used.

These substances having a long life may in certain cases be of particular advantage. As a rule Roentgen rays and gamma rays are produced at the same time as neutrons. These rays also act upon the photographic layer if the latter, during the exposure to neutrons of the neutron-reactive layer, is arranged in the immediate vicinity of the neutron-reactive layer. When a substance is used for emitting electrons in which artificial radioactive nuclei of relatively long life are formed, it is possible to delay bringing the photographic material into the vicinity of the neutron-reactive layer, or the combination of fluorescent material and substance emitting electrons, until after the exposure of the neutron-reactive layer to the neutrons. When this is done the possibility of the gamma or Roentgen rays acting upon the photographic material is excluded. The photographic material serves to retain the latent image which is present in the intermediate layer in the form of radioactive nuclei and which has been produced there during the exposure to the slow neutrons. The interval between the exposure to neutrons and the action upon the photographic material must be made shorter, the shorter the mean life of the artificial radioactive nuclei.

When the fluorescent screen is observed visually, there is also the danger that the Roentgen or gamma rays which are produced together with the neutrons will have a damaging or disturbing action upon the observer. If a substance having an adequate mean life is used for the electron-emitting substance, it is possible to effect the exposure to neutrons in a part of the apparatus from which no gamma or Roentgen rays or neutrons may leave in the direction of the observer, and to examine the fluorescent screen at a point of the apparatus at which no undesirable Roentgen or gamma radiation is present.

The neutron-reactive layer and the fluorescent substance may be used repeatedly because, when the emission of electrons dies away, the original condition is restored. Accordingly, it is in certain circumstances of advantage to make the neutron-reactive layer in the form of an endless band different parts of which are exposed to neutrons successively. The fluorescent substance may be applied to this band-like carrier but in certain circumstances it is more advantageous to cause the intermediate layer to act upon a fluorescent screen which is not adjacent to it during exposure. It is then possible in the first place to prevent the fluorescent screen from being damaged by the neutrons, gamma and Roentgen rays, and secondly the fluorescent substance is not caused to fluoresce or subsequently to fluoresce by the gamma and Roentgen rays, and thirdly it is possible to use one fluorescent screen for observing latent images in the intermediate layer which have been formed successively. In the last case it is advisable, in order to increase the speed of changing the images, to use a fluorescent substance which when excited by electrons does not continue to fluoresce for very long.

As already mentioned, the neutron-reactive layer may be in the form of an endless band. The substance forming the neutron-reactive layer may however be applied to an inactive support. The fluorescent substance may also be arranged on this support or on a separate support. The photographic material may also be applied to a separate support which may have any desired length. Pictures of moving objects may also be taken by proceeding in accordance with the invention. In this case it is convenient either to produce the neutrons intermittently or to expose the neutron-reactive layer to them only intermittently with an intermittent forward movement of the neutron-reactive layer.

The neutron-reactive layer may also be caused to act directly on the photographic material. If the intensity is adequate, a photographic image may be obtained in this manner without the interposition of a fluorescent substance.

If the neutron-reactive layer is applied to the photographic layer of emulsion in the form of a liquid coating which subsequently solidifies, it is of advantage to apply it by means of a binding agent which dissolves in a solvent which does not attack the photographic layer or in the liquids which are necessary for development.

In order to increase the action of the visible or invisible radiation from the fluorescent material there may in certain circumstances first be arranged near it a substance which emits heavy particles under the influence of slow neutrons, for example, a layer of boron or lithium or a substance containing boron or lithium. This layer is then covered with a layer which emits electrons under the influence of neutrons. As the electrons have in general a wide range of penetration, the arrangement may be such that the electrons pass through the layer of boron or lithium without undue hindrance so that the fluorescent material is caused to become luminous both by the heavy particles and by the electrons. The fluorescent material and the substance which emits heavy particles may be applied on one side of the photographic layer and the substance which emits electrons on the other side. The electrons are able to penetrate the photographic layer if it is thin enough.

As a further expedient for increasing the intensity or for reducing the duration of exposure that is necessary, it may be of advantage in certain cases to make the layer which emits electrons of such a thickness that the neutrons are practically entirely absorbed in it. However, in such a thick neutron-reactive layer a large proportion of the electrons which are released by the absorbed neutrons in the neutron-reactive layer would be absorbed, because often the layer would be substantially thicker than the range of penetration of the electrons. The neutron-reactive layer may therefore be composed of a number of thin neutron-reactive layers which are of such mechanical strength that after the exposure to the neutrons they may be applied individually to one, or between two, photographic layers, upon which they act directly by the electrons which are emitted or by means of the fluorescent material. In this manner the latent image of a thick neutron-reactive layer composed of n-sub-layers is reproduced upon n or $2n$ photographic layers. The thickness of the individual sub-layers is, in general, advantageously such that only a moderate, for example 10%, absorption of electrons takes place in it. The time of exposure is selected so that it is of the order of magnitude of the mean lives of the radioactive neuclei of the neutron-reactive layer. In photographing one object, several thick neutron-reactive layers may be exposed successively and their sub-layers after separation may be caused to act upon the same or different photographic layers in the manner described. Upon the repetition of this process the same neutron-reactive layers may be used if in the meantime their artificial radio-activity has decreased to an adequate extent.

If an object is examined by means of a mixture of neutrons of different velocities, radioactive nuclei having different durations of life are in certain circumstances formed in the neutron-reactive layer. Accordingly immediately after exposure both the electrons which are derived from radioactive nuclei having a short life and the electrons which originate from nuclei having a long life act upon the fluorescent material or upon the photographic plate. When some time has elapsed after exposure only the electrons which originate from radioactive nuclei having a long life act upon the fluorescent material or the photographic plate. Separation of the effect of the long-life latent image from the short-life image may be effected by appropriate choice of the time of exposure to neutrons, of the instant at which copying begins and of the duration of copying. As, owing to the isolation of the effect of the long-life latent image, a certain weakening inevitably occurs, in some circumstances a repetition or several repetitions of the exposure or photograph may be necessary such repetitions being made with the elements in like geometrical relationship. That is, the electron-emitting layer and the fluorescent layer or the photosensitive layer must be at the same relative positions in the successive exposures. Also if the time of exposure and the time of copying are shortened as is necessary for isolating the effect of the short-life latent image it is necessary in many cases to repeat the process.

When a mixture of neutrons of different velocity is used, there are obtained separable latent images which are produced by neutrons of different velocity. These images or the copies corresponding to them will in general differ from one another because the absorption of the neutrons in the substances to be examined depends greatly upon the velocity of the neutrons.

The principles of the invention are illustrated in the accompanying drawing in which:

Fig. 1 is a diagrammatic representation of the method and device of the invention;

Figs. 2–9 are diagrammatic representations in partial section of nine different embodiments of the image-forming device of the invention; and

Fig. 10 is a diagrammatic representation in perspective of a modified embodiment of the method of the invention.

In Fig. 1, **1** represents a source of neutrons, and **2** represents the body of which an image is to be obtained by means of the neutron beam which is partially absorbed in the body. The neutrons passing body **2** impinge on the substance **3** which reacts with the neutrons with the emission of electrons. The electrons emitted by substance **3** act upon an electron-sensitive substance **4**, for example, a fluorescent substance or a photographic layer. The layer of neutron-sensitive substance **3** and the layer of electron-sensitive substance **4** are carried on supporting layer **10** which, if layer **4** is a fluorescent substance, is preferably transparent. **5** indicates the image of object **2** which would be visible if layer **4** is a fluorescent substance or which could be made visible by development if layer **4** is a photographic material.

In the device shown in Fig. 2, **6** is a layer of substance which reacts with neutrons with emission of electrons mixed with fluorescent material and supported on supporting member **7**. When this device is used in the relation shown in Fig. 1, an image of the irradiated body appears on the face of layer **6** and if the supporting layer is transparent the image may be seen on both sides of the device.

In the device shown in Fig. 3, an electron-sensitive layer **8** is carried upon a support **9** and a layer of substance which reacts with neutrons with the emission of electrons is applied at **9**. The electron-sensitive layer **8** can consist, for example, of a fluorescent material or of a photosensitive material. When the electron-sensitive layer **8** is a photosensitive material, fluorescent material may be mixed with the electron-emitting substance in layer **9**. When the electron-sensitive substance of layer **8** is a fluorescent substance, it is advantageous to use a transparent substance for the electron-emitting substance **9**. The electron-emitting substance **9** may consist of a substance which becomes radio-active under the influence of the impinging neutrons. Layer **8** may consist of a mixture of a substance sensitive to charged particles with a substance containing boron or lithium or a substance containing boron or lithium may be mixed with the neutron-sensitive substance in layer **9** and layer **8** may be a substance sensitive to charged particles.

The device shown in Fig. 4 comprises three active layers carried on a supporting layer **10**. Layer **11** consists of a neutron-sensitive substance, layer **12** is an electron-sensitive substance, preferably a fluorescent material, layer **13** is a photosensitive substance.

Layer **12** may also consist of a neutron-sensitive substance and layers **11** and **13** of a photosensitive substance, preferably mixed with a fluorescent substance. Layer **11** may consist of a fluorescent substance, layer **12** of a transparent neutron-sensitive substance and layer **13** of a photographic material, in which case the fluorescent radiation from layer **11** passing through transparent layer **12** produces a latent image in layer **13**.

Layer **11** may consist of an electron-emitting neutron-sensitive substance and layer **12** of an electron-sensitive substance, and layer **13** can include an additional neutron-sensitive substance containing boron or lithium in order to increase the effect. The electron-sensitive layer can consist either of fluorescent substance or photosensitive substance.

In the device shown in Fig. 5, the neutron-sensitive substance in layer **14** is opaque and is provided with a plurality of perforations **15** through which the radiation issuing from fluorescent layer **16** can pass. This arrangement is of importance when the supporting layer **10** is opaque and when it is desirable not to apply the fluorescent layer on the side of the neutron-sensitive layer available to the observer.

In Fig. 6, a layer **21** of neutron-sensitive substance is attached to a layer of photosensitive material by means of a soluble binding agent **22**, the photosensitive layer being supported by support **10**.

In the embodiment of Fig. 7, a layer **24** of neutron-sensitive substance, a layer **25** containing boron or lithium, a fluorescent layer **26**, and a photosensitive layer **27** are carried on support **10**. The sequence of the layers may be varied.

In the device of Fig. 8, two fluorescent layers **30** and **31** and a layer of photosensitive material **32** are provided together with a neutron-sensitive layer **28**. Since the photosensitive layer **32** is sensitive to the electrons issuing from the neutron-sensitive layer **28**, the fluorescent layers **30** and **31** can be omitted if the intensity of the neutron radiation is great enough.

In the device of Fig. 9, there are a plurality of groups of layers, each group consisting of a layer of electron-emitting, neutron-sensitive substance **33**, fluorescent layers **34**, and a photosensitive layer **35**. Three groups of such layers in the example shown are carried by a common support **10**. If the neutron radiation is intensive enough, the fluorescent layers **34** may be omitted as explained in connection with Fig. 8.

In the device of Fig. 10, an endless strip **36** carried on rollers **40** bears a layer **37** of electron-emitting, neutron-sensitive substance. In this form of the invention, the neutron-sensitive substance **39** is exposed to a beam of neutrons from source **1** passing through the object **2** to be examined and impinging on the neutron-sensitive layer at **39**. The layer is then advanced by rotation of the rollers **40** to bring area **39** adjacent a layer of electron-sensitive substance **41** carried on support **10**. The electron-sensitive substance may consist either of fluorescent material or of photosensitive material or a mixture of two such materials. An electron-sensitive material, for example, fluorescent material, may be mixed with the neutron-sensitive substance in layer **37** or a layer of fluorescent substance may be applied on the endless strip in addition to the neutron-sensitive layer.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:

1. A method for obtaining an image of an object by means of neutrons which comprises directing a beam of neutrons upon the object and causing the emergent beam of neutrons to impinge upon a layer comprising a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a substance sensitive to the emitted electrons.

2. A method for obtaining an image of an object by means of neutrons which comprises directing a beam of neutrons upon the object and causing the emergent beam of neutrons to impinge upon a layer comprising a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a fluorescent material.

3. A method for obtaining an image of an object by means of neutrons which comprises directing a beam of neutrons upon the object and causing the emergent beam of neutrons to impinge upon a layer comprising a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a photosensitive material.

4. A method for obtaining an image of an object by means of neutrons which comprises directing a beam of neutrons upon the object and causing the emergent beam of neutrons to impinge upon a layer comprising a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a fluorescent substance, and a photosensitive material.

5. A method for obtaining an image of an object by means of neutrons which comprises directing a beam of neutrons upon the object and causing the emergent beam of neutrons to impinge upon a layer comprising a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a substance selected from the group consisting of boron, lithium and compounds thereof, and a substance sensitive to the emitted particles.

6. A method for obtaining an image of an object by means of neutrons which comprises directing a beam of neutrons upon the object and causing the emergent beam of neutrons to impinge upon a layer comprising a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a substance selected from the group consisting of boron, lithium and compounds thereof, and a photosensitive material.

7. A method for obtaining an image of an object by means of neutrons which comprises directing a beam of neutrons upon the object, causing the emergent beam of neutrons to impinge upon a layer containing a substance which reacts with neutrons to form an electron-emitting radioactive substance, and exposing a layer of a substance sensitive to the emitted electrons, to said first-named layer after the latter has been exposed to said emergent beam of neutrons.

8. A method for obtaining an image of an object by means of neutrons which comprises directing a beam of neutrons upon the object, causing the emergent beam of neutrons to impinge upon a layer containing a substance which reacts with neutrons to form an electron-emitting radioactive substance, said layer also comprising a fluorescent substance, and exposing a photosensitive layer to said first-named layer after the latter has been exposed to said emergent beam of neutrons.

9. A method for obtaining an image of an object by means of neutrons which comprises directing a beam of neutrons upon the object, causing the emergent beam of neutrons to impinge upon a plurality of separable adjacent layers, each containing a substance which reacts with neutrons to form an electron-emitting radioactive substance, and thereafter exposing a separate layer of a substance sensitive to the emitted electrons to each of said first-named layers.

10. A method for obtaining an image of an object by means of neutrons which comprises directing a beam of neutrons upon the object, causing the emergent beam of neutrons to impinge upon a layer containing a substance which reacts with neutrons to form a plurality of electron-emitting substances of different mean lives, and thereafter exposing a plurality of separate photosensitive layers to said first-named layer, the time of each successive exposure being of the order of the mean life of one of the radioactive components of said first-named layer in

the order of increasing mean life periods of said components.

11. A device for forming an image of the distribution of the intensity of a beam of neutrons comprising a layer containing a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a substance sensitive to the emitted electrons.

12. A device for forming an image of the distribution of the intensity of a beam of neutrons comprising a layer containing a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a fluorescent material.

13. A device for forming an image of the distribution of the intensity of a beam of neutrons comprising a layer containing a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a photosensitive material.

14. A device for forming an image of the distribution of the intensity of a beam of neutrons comprising a layer containing a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a fluorescent material, and a photosensitive material.

15. A device for forming an image of the distribution of the intensity of a beam of neutrons comprising a layer containing a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a substance selected from the group consisting of boron, lithium and compounds thereof, and a substance sensitive to the emitted electrons.

16. A device for forming an image of the distribution of the intensity of a beam of neutrons comprising a layer containing a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a substance selected from the group consisting of boron, lithium and compounds thereof, and a photosensitive material.

17. A device for forming an image of the distribution of the intensity of a beam of neutrons comprising a layer containing a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a substance selected from the group consisting of boron, lithium and compounds thereof, and a fluorescent material.

18. A device for forming an image of the distribution of the intensity of a beam of neutrons comprising a layer containing a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a substance selected from the group consisting of boron, lithium and compounds thereof, a fluorescent material, and a photosensitive material.

19. A device as defined in claim 11 in which the neutron-reactive substance is arranged in layers on both sides of a layer of the electron-sensitive substance.

20. A device for forming an image of the distribution of the intensity of a beam of neutrons comprising a layer containing a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a fluorescent material, said neutron-reactive substance being permeable to the radiation emanating from the fluorescent material.

21. A device for forming an image of the distribution of the intensity of a beam of neutrons comprising a layer containing a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a fluorescent material, said neutron-reactive substance being impermeable to the radiation emanating from the fluorescent material and being perforated to allow the passage of said radiation.

22. A device for forming an image of the distribution of the intensity of a beam of neutrons comprising a layer of photosensitive material, and a substance which reacts with neutrons to form an electron-emitting substance bound to said layer of photosensitive material by means of a binder composition soluble in a solvent which does not affect the photosensitive material.

23. A device for forming an image of the distribution of the intensity of a beam of neutrons comprising a layer of photosensitive material, and a substance which reacts with neutrons to form an electron-emitting substance, said layer also comprising a fluorescent material bound to said layer of photosensitive material by means of a binder composition soluble in a solvent which does not affect the photosensitive material.

24. A device for forming an image of the distribution of the intensity of a beam of neutrons comprising a layer of photosensitive material, a substance which reacts with neutrons to form an electron-emitting substance on one side of said layer of photo-sensitive material, and a fluorescent material and a substance selected from the group consisting of boron, lithium and compounds thereof on the other side of said layer of photosensitive material.

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