

May 14, 1968

F. B. SELLERS

3,383,510

ALPHA PARTICLE EXCITED MONOCHROMATIC X-RAY SOURCE

Filed Dec. 7, 1964

3 Sheets-Sheet 1

FIG. 1

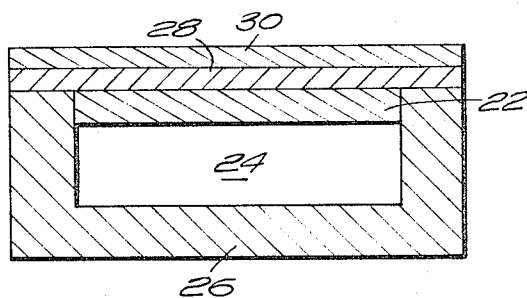
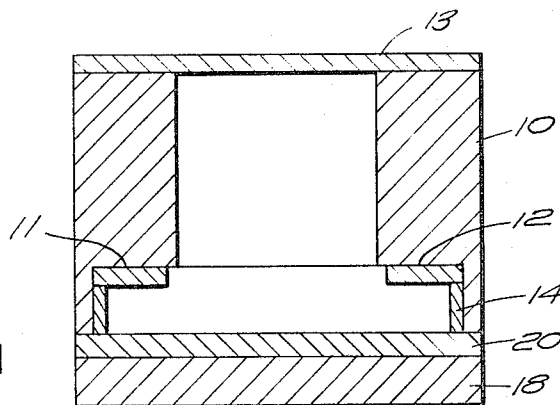


FIG. 2

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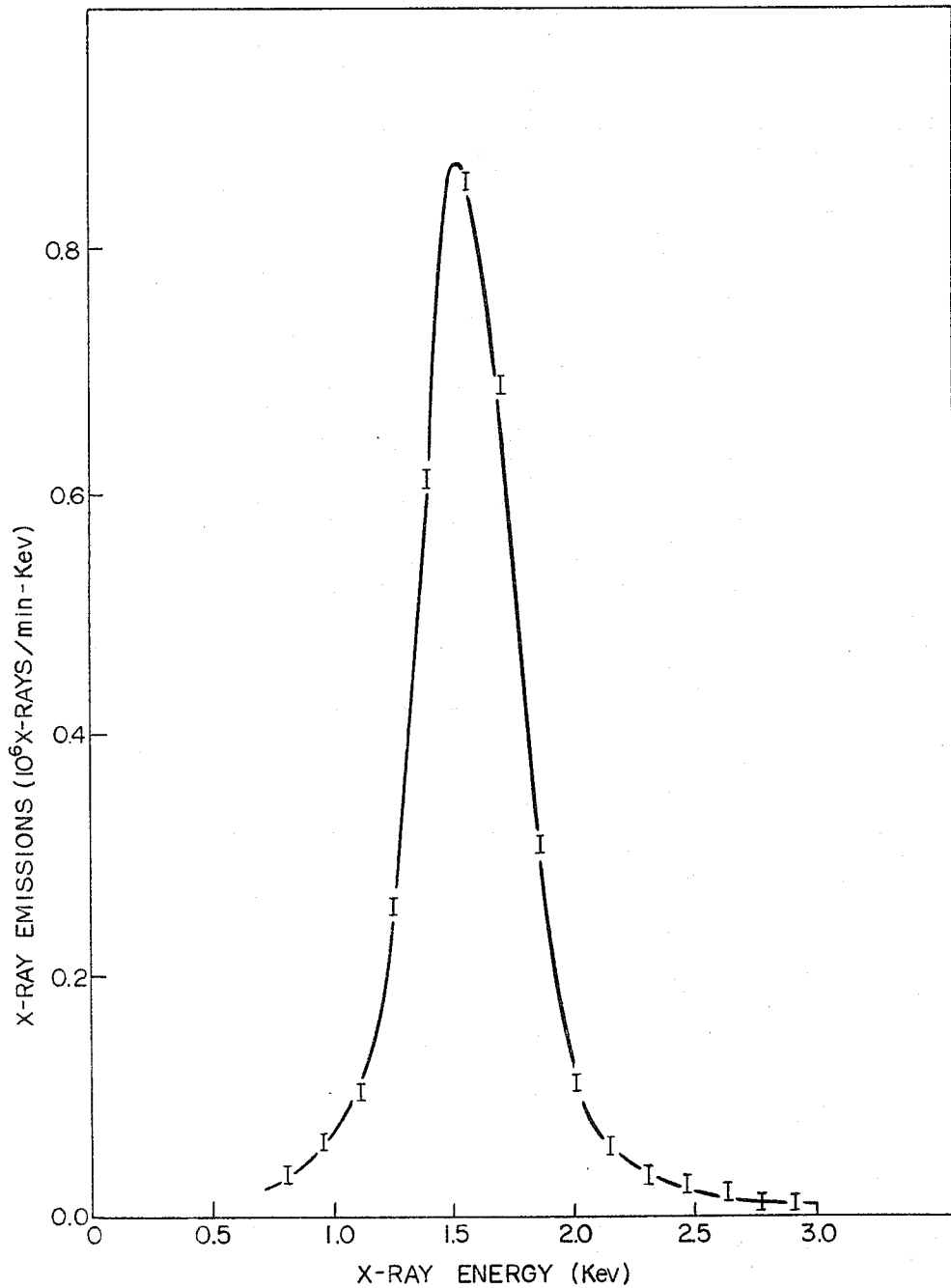


FIG. 3

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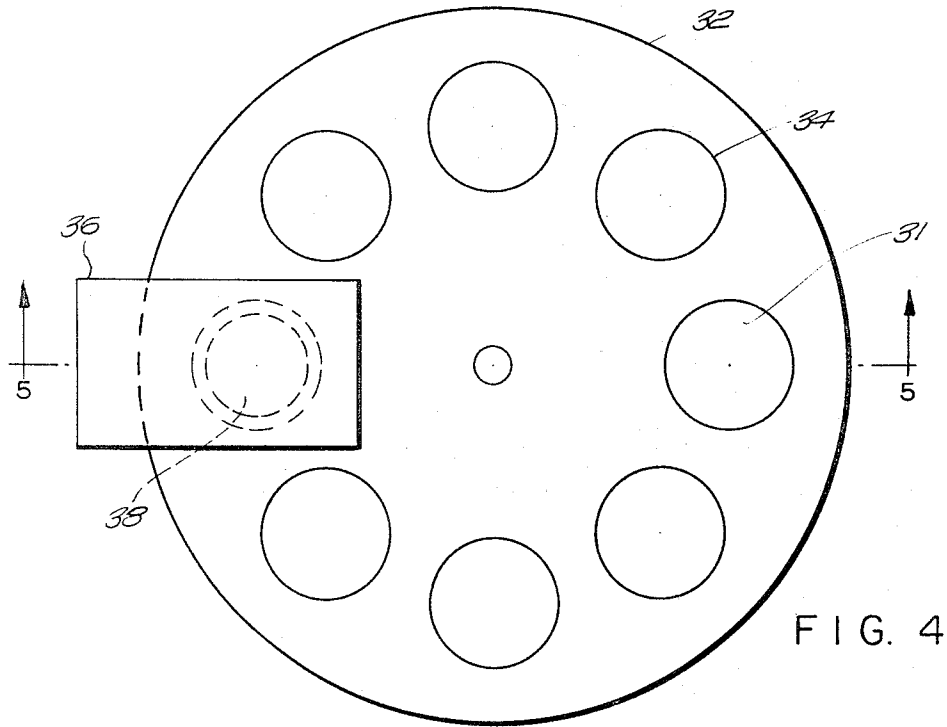


FIG. 4

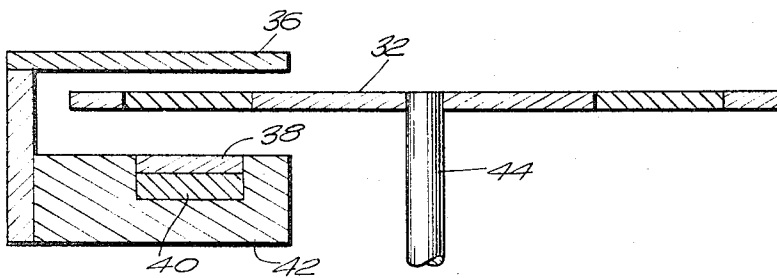


FIG. 5

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ALPHA PARTICLE EXCITED MONOCHROMATIC X-RAY SOURCE

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ABSTRACT OF THE DISCLOSURE

A substantially monochromatic X-ray source in which an alpha particle emitter is used to bombard a target material to produce X-rays characteristic of the target material. A narrow band filter is used to further narrow the spectrum of X-rays produced. The filter, target and alpha emitter are arranged on a base so that only the characteristic X-rays from the target are allowed to strike the filter.

This invention relates in general to monochromatic X-ray sources and more particularly to a monochromatic X-ray source in which the X-rays are produced by impinging alpha rays on a selected target.

There are many applications of X-rays in which it is desirable to use a monochromatic source. Such applications include microradiography, composition analysis and some specific material and density gauging techniques. In many of these techniques a portable X-ray source is highly desirable and to this end portable sources have been used in which beta radiation emitted from a radioisotope was allowed to impinge upon a target material thereby producing the characteristic fluorescent X-rays from that material. Such sources produced, however, not a line monochromatic emission but rather a relatively broad spectrum of energies. This broadening of the energy spectrum resulted from the generation of Bremsstrahlung caused by deceleration of the beta particles in the target material. The resultant spectrum was essentially a superposition of the fluorescent characteristic X-radiation from the target upon this Bremsstrahlung radiation.

One technique developed for overcoming these difficulties was the utilization of an alpha emitting radioisotope to excite the characteristic X-rays from the target. Such an X-ray source is described in U.S. Patent No. 2,998,524. Since, as a practical matter, no Bremsstrahlung radiation is generated as the result of bombardment of the target material with alpha rays, then this source of dilution of the monochromaticity of the emitted X-rays is eliminated. There are, however, problems connected with X-ray sources of the type described in the above-referenced patent. One such problem arises from interaction of the alpha particles with the filter material with the resultant production of characteristic X-rays from the filter material thereby producing a spectrum including X-rays from both the target and the filter material. Another limitation of that device arises from the nature of some alpha ray emitters. Thus, most alpha ray emitters produce not only alpha particles but also some concurrent gamma radiation. Much of the gamma radiation emitted by certain alpha sources is in the energy region in which characteristic K X-rays from low atomic number elements lie and in which L X-rays from high atomic number elements lie. Since both X-rays and gamma rays are electromagnetic radiation, differing only in their origin, then the emission from this source presents an energy spectrum considerably broader than the monochromatic line source repre-

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sented by characteristic K X-rays from the selected target.

The problem associated with this emission of gamma rays from the alpha emitting isotope is particularly severe when it is desirable to use alpha emitters of significantly long half-lives such as Pu-239 (half life about 24,000 years) or Po-209 (half life about 109 years). In the case of Pu-239, 100% of the alpha emissions are accompanied by gamma radiation and, in the case of Po-209, approximately 1% of the alpha emissions are accompanied by gamma radiation. In the case of Pu-239 approximately 90% of the gamma emission is at an energy below 13 kev. and about 73% of the emitted gammas have an energy below 1 kev. The use of conventional filters on the output of the X-ray source does not eliminate the problem since these filters are incapable of inhibiting the passage of the 13 kev. gamma rays from Pu-239, for example, without at the same time eliminating essentially all of the characteristic radiation from the target element.

It is, therefore, the primary object of the present invention to produce a substantially monochromatic X-ray source using alpha ray bombardment of the X-ray producing target.

It is another object of the present invention to provide alpha excited X-ray sources producing X-rays at a selected number of sharply defined energies.

It is still another object of the present invention to provide an alpha excited X-ray source in a configuration which permits interchanging of target and filter elements thereby allowing the energy of the X-ray output from the source to be selected at any one of a number of convenient energy values.

Broadly speaking, the X-ray source of the present invention employs an arrangement of an alpha particle emitter, a target material, and a filter within a source holder such that there is no interaction between the alpha particles and the filter, thereby eliminating the emission of X-rays characteristic of the filter elements. Additionally, in one embodiment the arrangement of these elements is such that gamma radiation emitted from the alpha particle emitter is substantially eliminated from the output beam of X-rays from the source. In still another embodiment the arrangement of these elements permits ready interchanging of the target and filter elements so that the characteristic X-ray emitted from the source may be changed without the requirement of recoating an alpha emitter on a target material.

These and other features of the present invention will become more fully understood from the following description when taken in conjunction with the accompanying drawing in which:

FIG. 1 is an illustration in cross-sectional view of one preferred embodiment of the source of this invention;

FIG. 2 is an illustration in cross-sectional view of a second preferred embodiment of the source of this invention;

FIG. 3 is a plot of the X-ray spectrum emitted from an alpha excited aluminum target;

FIG. 4 is a plan view of an embodiment of this invention providing for interchangeable target materials; and

FIG. 5 is a vertical cross-sectional view taken along the line 5—5 of FIG. 4.

With reference to FIG. 1, the device illustrated includes a generally cylindrical hollow body 10 having an internal annular step 11 formed by materially reducing the wall thickness of the cylindrical body 10. Disposed on this annular step 11 is an annular source 12 of alpha radiation. The source of alpha radiation may be formed

from any number of suitable radioisotopes such as, Po-209, Po-210, Pu-239, Pa-227, Bi-197 or At-217. The alpha emitting isotope is preferably sealed within a very thin layer of material such as gold foil, beryllium, carbon or molybdenum which emits, in response to alpha bombardment, very little undesirable radiation. As a practical matter, the alpha emitting isotope is usually deposited on a backing of similar material which is itself formed in the shape of an annular ring conforming to the step 11. Across the open portion of the cylinder 10 at the end opposite to the annular step 11 there is fixed a circular filter plate 13. The opposite end of the cylinder is closed by a circular plate 18 which has disposed between it and the walls of the cylinder 10 a disc target element 20. The filter element 13, the target disc 20 and the retaining plate 18 may be fixed to the cylindrical body 10 by any convenient fastening such as screws or the like.

The cylinder 10 is formed of a material which is generally opaque to gamma rays of the energy expected to be emitted by the alpha emitting radioisotopes. The target 20 is formed of a suitable element to produce X-rays at the desired energy in the form of characteristic X-rays and the filter element 13 is a conventional "clean-up" filter which passes the characteristic X-rays produced by the target element at the desired energy but tends to inhibit strongly X-rays of energies different from this characteristic energy. Such filters may generally be formed of elements whose atomic number is one or two less than that of the target element. In addition to the above elements, the inner walls of the widened portion of the container 10 are preferably lined with a cylindrical liner 14 formed either of the target material or of a material that emits a radiation not within the same energy region as the target characteristic X-ray, such as beryllium whose characteristic X-ray emission at .110 kev. can easily be attenuated by the filter. In those instances in which it is particularly desirable to inhibit the emission of gamma radiation, the liner can be composed of gold. It is apparent that in a device such as that illustrated in FIG. 1, the filter element 13, the liner 14 and the target and retaining elements 20 and 18, respectively, can be readily replaced with similar elements formed of different materials in order to produce any one of a number of desired energies from the X-ray source.

The arrangement of elements forming the X-ray source of FIG. 1 is very advantageous since alpha particles emitted from the isotope 12 are not incident upon and, therefore, do not interact with the filter 13. Thus, no X-rays characteristic of filter 13 are produced by the source. Additionally, because of the configuration of the shielding material of the body 10 and the placement of the alpha emitting isotope 12, this source may utilize long-lived alpha emitters such as Pu-239 without the output beam of X-rays including an undesirably high proportion of gamma radiation. In those instances where the isotope 12 itself produces substantial quantities of gamma radiation the retaining plate 18 should be selected of a material which has a low probability of reflecting the emitted gamma rays back in the direction of the filter plate 13. For the gamma rays emitted from Pu-239, a suitable material for the retaining plate 18 would be almost any low atomic number material, for instance, carbon or beryllium. The alpha rays emitted from the radioisotope 12 are, of course, incident upon the target 20 and those X-rays emitted from the target 20 in the direction of the filter element 13 pass through this filter element and form the output X-ray beam from the source.

With reference now to FIG. 2, there is shown an X-ray source in which the radioisotope 22 is deposited on a backing plate 24, both of which are inserted within a generally cup-shaped housing 26, enclosed at its open

end with a target element 28 and a filter 30. The alpha emitter 22 is disposed between the backing plate 24 and the target element 28. The target materials and the filter materials may, in this embodiment, be formed of the same materials as in the preceding embodiments. It is, however, necessary in this configuration that the target material 28 have a thickness approximately equal to the maximum range of alpha particles emitted from the particular radioisotope used. The range of a 5 mev. alpha particle in a typical material can be readily determined from data presently available in a number of well-known sources. Typically, a thickness of aluminum of 6.6 milligrams per square centimeter would be required. For nickel this value would be 9.8 milligrams per square centimeter and for copper 9.2 milligrams per square centimeter. Target disc elements of this thickness of these materials can be readily obtained from commercial sources.

In this embodiment, radiation, generated within the target material 28 in response to the impinging alpha rays, passes out through the filter element 30 disposed on the upper surface of the target. By appropriate selection of the target thickness in accordance with the discussion above, the number of alpha particles which pass completely through the target and, therefore, interact with the filter can be minimized while still permitting a significant quantity of the characteristic radiation produced in the target element to be passed through the filter and emitted as the output X-ray beam. It should be noted that the configuration illustrated in FIG. 2 permits for extremely easy interchangeability of the target and source materials thereby permitting, by selection of appropriate materials, any one of a number of selected characteristic X-ray energies to be generated by this source. The material of the backer in this embodiment should be carefully chosen so that any X-rays generated within this backer as a result of the interaction of the alpha rays with the backing material will be readily filtered by the filter element. Thus, if the backing element is formed of beryllium, then the resultant beryllium characteristic X-rays would be easily attenuated by the use of a filter fabricated from any higher atomic number material. A second suitable material for forming this backing plate 24 is LiH, since the only X-ray generated from this material is the characteristic lithium X-ray which has an energy of .052 kev. This energy X-ray is even more severely attenuated by the filter than the X-ray generated from beryllium.

Turning now to FIG. 3, the K X-ray spectrum produced from aluminum excited by Po-210 alpha particles is shown. The vertical coordinate gives the number of X-rays emitted per minute/kev. while the horizontal coordinate gives the X-ray energy in kev. In this instance the alpha ray emitter was covered with a foil such that the average energy of the alpha rays striking the aluminum was approximately 1 mev. The curve shown represents the spectrum as measured by a detector with a 30% resolution. Hence the actual emitted X-rays were essentially monochromatic at 1.5 kev. It can be shown that for alpha rays of approximately 1 mev. striking aluminum with a geometry which permits a coupling efficiency of 0.5 between the alpha and aluminum, the equivalent source strength of X-rays is 35 microcuries per millicurie of alpha emitter. The coupling efficiency is defined as the solid angle of the target as viewed from the source divided by 4π steradians. The source configuration illustrated in FIG. 2 would have a coupling efficiency of approximately 0.5. The coupling efficiency of the source configuration illustrated in FIG. 1 will depend upon the ratio r to h where r is the radius of the smaller portion of the cylinder and h is the distance of separation between the annular lip and the target material. It can be shown that the maximum output will occur at approximately $h=r$ and that the coupling efficiency for these conditions will be approximately 0.05. Thus the ratio of

equivalent X-ray strength for this source configuration with an aluminum target is approximately 3.5 microcuries per millicurie. The efficiency of these sources can be drastically increased by utilizing alpha emitters which have an effective output at a higher energy, for example near their maximum energy of 5 to 6 mev. Such alpha sources may be obtained by using an evaporated coating rather than a foil cover on the alpha source. If the alpha ray incident energy were in the order of 5 to 6 mev., then the equivalent yield from an aluminum target for a 0.5 coupling efficiency would be 88 microcuries per millicurie and of course with a coupling efficiency of 0.05 the yield would be 8.8 microcuries per millicurie.

The configuration of the source illustrated in FIG. 2, by use of an appropriately selected target element, can be made to generate X-rays at a number of selected energies thus providing simultaneously a number of monochromatic X-rays at different energy levels. Such a source would be extremely useful in many calibration situations, for example, as a device for calibrating a multi-channel analyzer which could be simultaneously calibrated for several energies ranging over perhaps three decades. One way in which this could be accomplished is to construct the target 28 of a homogeneous mixture of a number of elements, each having a characteristic X-ray at a particular energy value separate from the others and suitable for calibration purposes. Such a device provides for simultaneous calibrating X-rays at a number of different energies. Another approach is illustrated in the device of FIG. 4 which permits any one of a number of selected energies to be "dial" selected from the source.

In the device of FIG. 4 a number of interchangeable targets 34 are mounted on a wheel 32 for passage over the source material 38. In FIG. 5 a vertical cross-sectional view of the same device is shown. A filter 36 is arranged on one side of the wheel 32 and the source material 38 backed up by a backing plate 40 is mounted within a holder 42 on the other side of the wheel. Typically the wheel 32 would be mounted to rotate on a shaft 44 so that any selected one of the targets 34 may be positioned over the alpha emitting source 38. Modifications of this arrangement can readily be conceived by anyone skilled in the art. Typical of such modifications would be the employment of wedge-shaped or pie-shaped segments rather than the circular segments shown as targets in FIG. 4, or of separate filters attached to each target element such that the filter is rotated into place along with the target. Additionally, convenient mechanical adaptations such as indents and the like for exact positioning of the target may readily be provided on this device.

The invention having been described, various modifications and improvements will now occur to those skilled in the art and the invention described should be construed as limited only by the spirit and scope of the appended claims.

What is claimed is:

1. A source emitting an X-ray beam characterized by a specific quantum energy spectrum comprising, a base member, an alpha particle emitter, a target element mounted on said base member and formed of a material having a characteristic X-ray emission spectrum, said alpha emitter being positioned on said base member with respect to said target element such that alpha rays incident upon said target element result in the emission of said characteristic X-rays; a filter element selectively transparent to X-rays of said specific quantum energy spectrum; said filter element being positioned on said base member with respect to said target element such that a substantial portion of characteristic X-rays emitted

from said target element are transmitted therethrough, said target element, said filter element and said alpha particle emitter being positioned relative to one another such that alpha particles from said emitter are not incident upon said filter element.

2. Apparatus in accordance with claim 1 wherein said target element is formed of a homogeneous mixture of materials adapted to emit a series of substantially monochromatic X-rays at separated energy levels, each of said energy levels corresponding to a characteristic X-ray energy of one of the elements of said mixture.

3. A source emitting an X-ray beam characterized by a specific quantum energy spectrum comprising, a base member formed generally as a hollow cylinder, said cylinder having a reduced wall thickness at one end thereof forming thereby an annular ledge, said base member being formed of a material substantially opaque to electromagnetic radiation of energies in the region of said specific quantum energy spectrum, an alpha ray emitter mounted on said ledge, said alpha emitter extending only as far as the radial dimension of said ledge, a target element fixed to the end of said cylinder adjacent to said ledge, said target element being formed of a material which, upon excitation by alpha particles from said alpha emitter, emits characteristic X-rays having said specific quantum energy spectrum.

4. A source emitting an X-ray beam characterized by a specific quantum energy spectrum comprising, a base member, an alpha particle emitter mounted on said base member; a target element mounted on said base member and formed of a material which emits, upon excitation by impinging alpha particles, characteristic X-rays having said specific quantum energy spectrum; a filter element mounted on said base member, said filter element being selectively transparent to X-rays of said specific quantum energy spectrum, said target element being interposed between said alpha particle emitter and said filter element, said target element being sufficiently thick to prevent substantially any alpha particles from said alpha emitter from reaching said filter element.

5. A source emitting an X-ray beam characterized by a specific quantum energy spectrum comprising, a base member formed generally as a hollow cylinder, said cylinder having a reduced wall thickness at one end thereof forming thereby an annular ledge, said base member being formed of a material substantially opaque to electromagnetic radiation of energies in the region of said specific quantum energy spectrum, an alpha ray emitter mounted on said ledge, said alpha emitter extending only as far as the radial dimensions of said ledge, a target element fixed to the end of said cylinder adjacent to said ledge, said target element being formed of a material which, upon excitation by alpha particles from said alpha emitter, emits characteristic X-rays having said specific quantum energy spectrum, a filter element fixed to the opposite end of said cylinder enclosing the hollow portion of said cylinder, said filter element being formed of a material selectively transparent to X-rays at the levels of said specific quantum energy spectrum.

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