July 12, 1966 **I. FEUER** **3,260,846**

BETA RAY LIGHT SOURCE STRUCTURE

Filed April 9, 1963

Fig. 1.

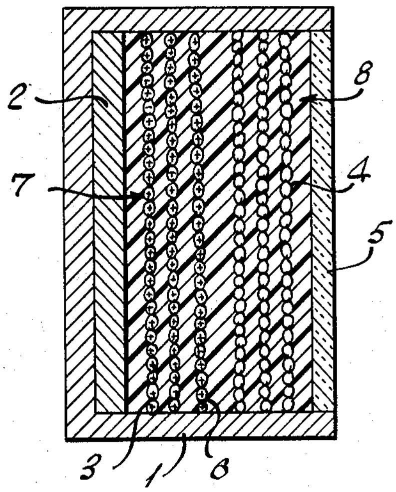


Fig. 2.

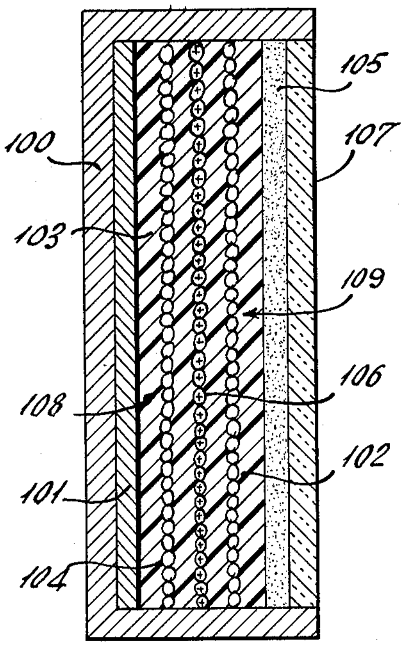
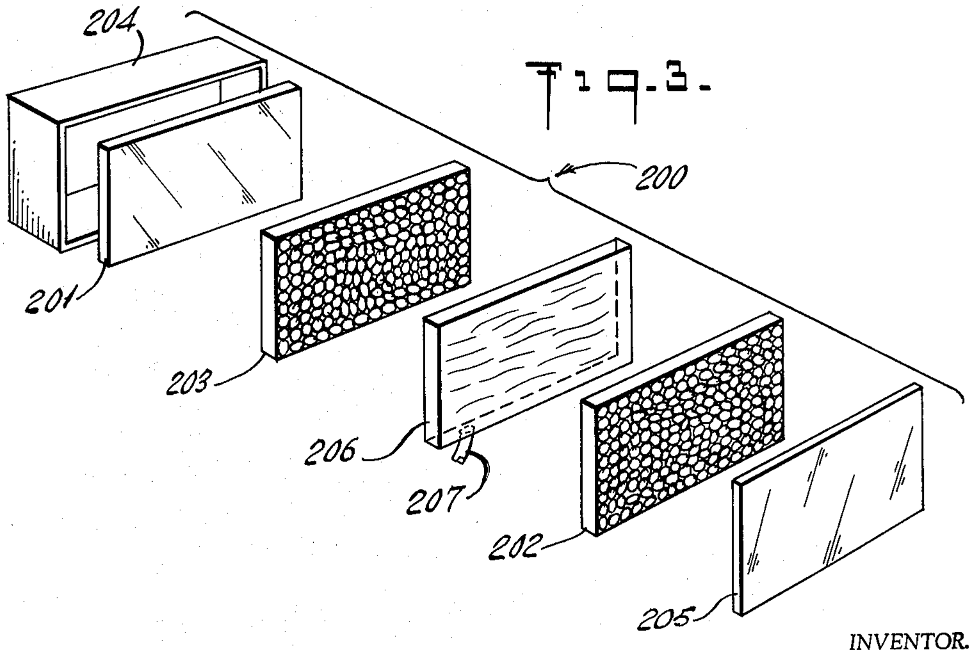


Fig. 3.



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BETA RAY LIGHT SOURCE STRUCTURE

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The present invention deals with light sources wherein phosphors are excited by a radioactive material. More specifically, the invention relates to a system wherein one or more regions or phosphor in combination with a heavy metal reflecting region serves to give a highly efficient means for converting radioactive energy into light.

It is well known that radioactive materials, i.e., beta ray emitters, can be employed to excite phosphors and cause the phosphor to give off light. A wide variety of systems have been taught for accomplishing this end. Thus, for example, flashlight or signs have been described which concentrate the light produced by the emitted radiation by the use of a parabolic mirror or straight forward aluminized reflector. The aluminum serves as a light reflector, thus tending to concentrate the useful light given off during the process. However, all of these prior art systems are relatively inefficient, e.g., exhibit efficiencies of the order of 1 to 4 percent (based on utilization of a minimal backscatter factor).

In accordance with the present invention, means are taught for making maximum use of radioactive energy in terms of providing a light source. Moreover this is accomplished in a manner, insuring safety and utilizing substances for dual roles.

As employed in the specification, the terms "forward" or "front" are used to denote the areas of regions between the radioactive source and the external environment to be illustrated. Similarly, the term "back" region is employed to denote the area behind the radioactive material and away from the area or surface from which light is directed to the external environment.

In accordance with the present invention, a light source which utilizes the beta ray energy of a radioactive material, preferably a weaker beta ray transmitter (emits beta rays of less than 1 mev. energy) is characterized by having a front phosphor region of sufficient depth to absorb beta rays given off by the source but not the light which is generated by the radioactive excitation of the phosphor particles, and a back heavy metal reflecting region which due to the high atomic number of the metal, i.e., greater than, or equal to, 45 preferably greater than 76, which serves to back scatter the beta particles, as well as reflect light. The reflected beta particles then further excite the forward phosphor regions and ultimately this energy is discharged from the system in the form of light energy. When employing weak beta emitters giving off less than 0.2 mev. beta rays a second phosphor region is preferably positioned between the radioactive source and the back heavy metal reflecting region so as to further convert beta rays which are reflected by the heavy metal region and convert the radioactive energy into light energy which is sent forwardly out of the structure.

It is essential that the backscattering region be characterized as a metal or metal composite having an atomic number greater or equal to 45 in order to reflect at least 60 percent of the back directed side rays. Materials of lower atomic number such as aluminum cannot serve to effectively backscatter the beta particles. By use of the heavy metal region beta particles which would normally be absorbed outside of the phosphor light producing material are now more efficiently utilized within the phosphor regions. Thus it is possible by the use of the present system to use merely the heavy metal back reflector region and a front phosphor region and get higher efficiencies in terms of light conversion than would be effected by the use of a two layer phosphor system with or without the use of an aluminum reflecting surface, as for example, shown in U.S. Patent 2,953,634 to MacHutchin et al.

The present invention is particularly more suited to the use of weaker beta ray emitters, i.e., materials giving off beta rays having an energy level of from 5 kev. to 1 mev. Examples of such beta ray emitters are carbon 14, nickel-63, cesium-134, krypton-85, tritium H–3, sulfur-35 or promethium-147. In one aspect of the present invention the radioactive material, e.g., tritium, may be deposited on an intermediate phosphor layer. This is desirable because the radiation from the tritium is maximally utilized and the upper non-activated phosphor layer serves as a protective barrier against radioactive contamination and mishandling. Through suitable modifications of the described structure, principally modifications of thickness of the various regions, the structure can be utilized for converting more energetic beta emitters such as RaE and Sr–90–Y90 into light energy.

In the high energetic emitter case it is preferable to have a high atomic reflector and only one phosphor layer (on the front) as there is minimum attenuation of the beta rays. There is however a higher light attenuation in the two equal layers of phosphor. A convenient indication of the energy levels of various beta emitters is set forth below.

Table 1

Weak Beta Emitters		Medium Beta Emitters		Strong Beta Emitters	
Name	Energy, Mev.	Name	Mev.	Name	Mev.
C-14	.155	KR-85	.695	Y-90	2.18
H-3	.017	Thallium-204	.765	RaE	1.17
S-35	.167				
Ni-63	.067				

Numerous types of phosphors or phosphor combinations such as zinc sulfides, cadmium sulfides, zinc silicates, zinc beryllium silicates, zinc oxides, calcium tungstates, etc., are employed in the present structure. The depth of the front phosphor region will vary somewhat depending on the energy level of the radioactive source but will be of sufficient depth so as to absorb beta rays but not light rays. This is made possible by the fact that the attenuation thickness of optical transmission is substantially greater than the beta ray thickness for complete absorption of weak beta rays from the radioactive source, e.g., tritium. Thus the depth of the front phosphor region may be controlled to fall within a region giving at least 90 percent absorption of the weak beta rays, without absorbing substantial quantities of the light ray. Thus, for example, when employing zinc sulfide or cadmium sulfide phosphors in combination with a tritium beta ray source, a thickness of 1 mil allows 90 percent of the light rays to pass through unabsorbed while at least 90 percent of the weak beta rays are absorbed, since the absorption thickness for weak beta rays is of the order of 1.0–20 microns (depending upon the nature of the absorber).

The average particle size of the phosphor preferably lies in the micron range, e.g., 2 to 30, especially 10 to 30 microns. This is desirable because there is little self attenuation of the light in thin layers. However, if particle size is too small there are large light scatter losses.

As noted previously, it is essential that the back heavy metal region be of a metal or metal laminate having an atomic number greater than or equal to 45 in order to effectively return the beta rays to the forward part of the system and to effectively convert their energy into light. Simultaneously the heavy metal reflects light forwardly, thus giving a highly effective overall conversion of radioactive energy to light energy. It is particularly preferred to employ platinum, osmium, iridium, and their alloys, as the heavy metal back reflecting region. Alternatively, bismuth or lead or high atomic weight oxides such as lead oxide can be employed. Additionally, a bound laminate of aluminum deposited on a heavy metal such as platinum, bismuth, or lead can be utilized, the aluminum deposit serving to improve light reflection. It should be noted that the heavy metal region (compound of heavy metal with or without bound aluminum) is positioned closest to the back phosphor region (if one be employed) and is separated from the front phosphor region by the radioactive source. This is necessary since the back reflector region is employed to reflect both light and beta rays forwardly to the area where it is discharged from the structure in the form of light rays.

It is noted that since the front phosphor region is of sufficient depth so that at least some portions thereof are not radioactive, it serves as a protective cover absorbing the beta rays, as well as being a source of light and thus no additional protective covers are necessary. Normally, however, it will be desirable to use a front glass or plastic transparent cover such as one made of methyl methacrylate or mica. However, no distinct radio-active absorbing protecting structure is required. It is desirable, however, to coat the internal surface of the transparent cover with an anti-reflecting coating such as magnesium fluoride so as to minimize the internal reflection of the emitted light rays and thus maximize the effective light sent outwardly to the external environment. The various aspects and modifications of the present invention will be made more clearly apparent by reference to the following description and accompanying drawings.

FIGURE 1 illustrates a system characterized by the use of a single front phosphor region in combination with a heavy metal back reflecting region.

FIGURE 2 illustrates the use of multiple phosphor regions in combination with a solid radioactive source.

FIGURE 3 depicts a system amendable to the utilization of a gaseous radioactive material.

With reference to FIGURE 1, shown therein is a system characterized by the use of a front phosphor region and solid radioactive materials imbedded in a phosphor layer, there being no distinct back phosphor region employed in the illustrated system. The entire system is enclosed in casing **1** which may be made of any of a wide variety of materials such as glass, plastics, methacrylates, epoxies and metals, such as aluminum or iron. Casing **1** in combination with transparent glass or plastic cover **5** provides an enclosure for containing the system of the present invention whereby beta rays are converted into light. The source of radioactivity in region **7** are radioactive particles imbedded in or on phosphor grains. The actual impregnation of the phosphor particle with the radioactive solid can be done by a wide variety of conventional techniques, as for example, (a) sedimentation and evaporation, (b) vacuum evaporation, (c) slush milling and evaporation, (d) spray coating, etc. The radioactive solid is a stearic type solid and a ZnS phosphor is employed. The radioactive material gives off beta rays having energy levels of approximately 3 kev. to 17.9 kev. The phosphor particles are approximately 1 to 24 microns in size and the radioactive material comprises about 10^{-6} to 10^{-3} percent (by weight) of the phosphor. Region **7** is approximately 5–18 microns in depth.

Positioned forwardly from said radioactive source is front phosphor region **8**. Region **8** may contain 1 or more layers of phosphor particles which are excited by the beta rays given off from region **7** and thus convert the radioactive energy into light energy which passes outwardly through transparent cover **5**. At least a substantial portion of region **8** is free of radioactive materials so as to serve as a shield layer, preventing the weak beta rays from passing out through transparent cover **5**. By the same measure the width of phosphor layer **8** is such that the light produced therein is not absorbed to a substantial degree and thus passes out to the external source. Phospor particles **4** may be the same type of phosphor containing material employed in the radioactive region or alternatively can be a different phosphor containing material, as for example, in the present illustration, calcium tungstate. In general, there is no purpose for another phosphor in the coverage light source as another phosphor would yield another color.

Numeral **6** in the drawing represents the radioactive substance deposited on or impregnated in phosphor particles **3**.

Since the beta rays are being given off in a variety of directions, normally only those passing forwardly would be "seen" by light producing phosphor region **4**. However, in accordance with the present invention, region **2** containing a heavy metal, i.e., a platinum layer, is positioned behind the radioactive region **7** and serves to reflect both beta rays and light which may be directed inwardly from phosphor regions **7** and **8**. The reflected light and backscattered beta rays are reflected forwardly into phosphor region **8** and are effectively made use of, the latter being converted to light energy upon impinging the phosphor particles, and the former passing substantially unabsorbed out through transparent cover **5**. In general, heavy metal reflecting region **2** will have a thickness of approximately 0.1 mil to 10 mils, preferably 0.1 to 2 mils, so as to effectively serve to reflect beta ray particles. Thus, in the present example, region **2** will have a depth of about 0.5 mil; region **7**, a depth of about 15 microns and region **8**, a depth of about 15–30 microns. Substantially no beta rays thus pass out of the system through cover **5** while converting the beta rays of the radioactive solid source material to light rays.

In general, it is desired that the various regions, e.g., phosphor regions, heavy metal reflecting regions be disposed in parallel relation in order to obtain uniformity of light discharged from the structure. While parallel curved surfaces can be employed, in general it is desirable to employ relatively flat regions.

Turning to FIGURE 2, shown therein is a particularly preferred embodiment of the present invention employing a plurality of phosphor regions in combination with a heavy metal reflecting region. The source of beta rays are zinc sulfide particles having a tritiated center (about 10^{-7} to 10^{-3} weight percent tritium based in zinc sulfide). The central radioactive solid source region is shown as a single layer of tritiated zinc sulfide particles although a plurality of layers could, of course, be employed. Throughout the structure various binders, plasticizers, etc., can be employed to bind the various particles to each other or to surfaces of the composite structure. Inorganic adhesives, such as sodium silicate and potassium silicate are particularly desirable because of their stability. Additionally, various resins such as epoxy resins or ethylcellulose can be employed. The binders, plasticizers, etc., are indicated by the numeral **103** in the drawing.

A front phosphor particle region **109** is positioned between radioactive materials **106** and the light discharging portion of the overall structure. The present example phosphor region **109** contains one or more layers of zinc sulfide phosphor particles **102**. Particles **102** are 18 microns, average, in size. The depth of region **109** is about 18 microns.

Positioned behind the radioactive source is a second phosphor region **108** similarly containing zinc sulfide particles. Beta rays given off by the tritium pass randomly and thus the presence of back phosphor layer **108** serve to convert beta rays passed backwardly into light energy. Light from regions **108** and **109**, together with beta rays which are not emitted in a forward direction strike heavy metal reflecting region **101** which in the present example is a platinum reflector having a thickness of 0.5 mil. The heavy metal serves to reflect both the light and the beta particles forwardly. The reflected beta particles then come into contact with the phosphor in region **108** or **109** and are converted into light energy which passes out directly, or through reflection, through the front surface of the light producing system. Instead of platinum, lead oxide, platinum-iridium alloy rhodium, etc., could be employed for region **101**.

A glass or a plastic, e.g., methyl methacrylate, cover **107** is normally employed at the front surface of the structure. Preferably the glass has an internal anti-reflecting region **105** which may take the form of magnesium fluoride which has been previously deposited on the internal portions of the glass. The magnesium fluoride insures that emitted light is not internally reflected into the central portions of the structure, but rather passes out through the glass covering plate. Enclosure **100** surrounding the light source may be made of Lucite or any of a wide variety of conventional materials.

The relative dimensions of the system are as follows:

Approximate depth of front phosphor region	18 microns.
Approximate depth of back phosphor region	18 microns.
Approximate depth of heavy metal reflection region	0.5 mil.
Overall depth of light source	1.5 cm.
Overall length of light source	5.0 cm.–25 cm.
Overall width of light source	5.0 cm.–10 cm.

The tritium radioactive material has a radioactivity ranging from 2.5 millicurie/cm.^{2} to a few hundred millicurie/cm.^{2}. By operating in accordance with the present invention, a light brightness level (having a higher efficiency as previously stated) ranging from 5 microlamberts to a few hundred microlamberts is obtained. The efficiency of converting the beta rays into light energy can be better than 2 microlamberts per millicurie of solid tritiated compound in the low level light range. This is based on photometric measurements using an Aminco photomultiplier photometer and tritiated luminous standards.

FIGURE 3 illustrates a structure particularly suitable for use in systems wherein a gaseous radioactive material, such as krypton-85 or tritium (H-3) are employed. The system of FIGURE 3 is quite similar to FIGURE 2 in that it contains two phosphor particle regions, **202** and **203** positioned on each side of radioactive region **206**. Normally region **206** is evacuated through port **207** and thereafter radioactive gas is injected through inlet **207** to reach the pressure desired. Normally atmospheric or somewhat less than atmospheric pressure is utilized. Light source **200** similarly contains a heavy metal back reflecting layer **201** which serves to reflect both light and beta rays forwardly, light ultimately passing through transparent cover **205**. The phosphor particles may be of any of a wide variety, e.g., zinc sulfide, cadmium tungstate, etc. The thickness of the front phosphor region in particular is chosen so as to absorb substantially all the beta rays emitted from region **206** in a forward direction while allowing the light generated by the excitement of the phosphor particles to pass outwardly. Structure **200** may be enclosed by walls **204** which may be made of aluminum.

Cell **200** is gas tight and may possess a dehydrating agent such as silica gel therein. In the present example, the space between phosphor regions **203** and **202**, i.e., the depth of the radioactive region **206** is of the order of 1 centimeter, and the phosphor regions have an approximate depth of about 18 microns. It is also to be noted that the overall depth of the cell, i.e., 1.5–3 centimeters is only a fraction of the other dimensions of the cell, e.g., length, 25 cm.; width, 7.5 cm.; and thus maximum efficiency may be approached from the geometrical and reflective properties of the configuration.

It should be clearly understood that the present light sources can be employed in a variety of manners. They can be employed for railway and signaling purposes. They find application as a lantern or as a marker or sign; when employing it for the latter purpose a portion of the covering plate may be made opaque and so the transparent portion is illuminated and produces a self-luminous form such as a traffic speed indicator or directional signal, portable map reader or negative X-ray copier or reader.

Various modifications may be made to the present invention. For the more energetic medium energy beta emitter such as KR-85 (gaseous type) and Thallium-204 (solid type) one may employ the basic combination of a heavy metal backscatterer and light reflector coupled with a single phosphor layer on the front face to produce a more effective light source. In this case the light attenuation produced by both a front and back phosphor can be appreciable; hence one would want maximum reflection of the beta rays.

With reference to the gas systems; one may utilize solely a single thick phosphor front screen especially for the more energetic emitters coupled with a heavy reflective scatterer as in this case the total light attenuation produced in a front and back phosphor system becomes significant.

In general it will be desired for the present invention to take the form of a radioactive light source employing a weak beta ray source in which substantially planar regions of heavy metal reflector, phosphor particles, and radioactive particles are utilized. The heavy metal region serves both as an electron and light reflector. A minimal number of layers of a phosphorized material containing a radioactive source, i.e., tritiated phosphors can be employed with a front non-radioactive phosphor region serving as a source of light through excitement by beta rays as well as substantially absorbing all forwardly directed beta rays and insuring safety of the overall device.

Having described the present invention, that which is sought to be protected is set forth in the following claims.

I claim:

1. An improved radioactive light source which comprises a casing having disposed therein a radioactive region containing a material giving off beta rays, a phosphor region positioned in front of said radioactive region in the direction of light discharged from said source, said phosphor region being of sufficient thickness to absorb a substantial portion of beta rays without substantial absorption of light rays, a light reflective and beta ray-reflective heavy metal reflecting region positioned behind and enclosing the back portion of said radio-active region, said heavy metal having an atomic number of at least 45 and having a thickness sufficient to reflect beta rays, said metal being positioned adjacent to said radioactive region and in direct contact with the beta rays given off by said radioactive region and having a front facing light reflecting surface so that said reflecting region serves to reflect both light and beta rays forwardly, said forwardly directed beta rays exciting said phosphor region and being converted into light.

2. A radioactive light source structure comprising a casing having disposed therein a radioactive region containing beta emitters, a phosphor region positioned between said radioactive region and the area wherein light is discharged from said structure, said phosphor region being of sufficient depth to absorb at least 90% of the weak beta rays emitted from said radioactive region without substantially absorbing light rays, a light reflective and beta ray reflective heavy metal reflecting region positioned behind and enclosing the portion of said radioactive region away from the area of light discharged from said structure, said heavy metal region comprising a metal having an atomic number of at least 45 and being of a thickness sufficient to back-scatter a major portion of the beta rays contacting its structure, said metal portion being adjacent said radioactive region and in direct contact with the beta rays given off by said radioactive region and having a forward-facing light reflective surface so as to reflect both light and beta rays forwardly, said reflective beta rays and beta rays emanating from said radioactive region serving to excite the phosphor region and be converted into light energy.

3. The structure of claim 1 wherein a transparent cover is positioned between said front phosphor region and the exterior area to be illuminated, said transparent cover being coated on its internal surface with a non-reflecting agent.

4. The structure of claim 1 wherein said heavy metal region comprises platinum.

5. A self-luminous light source structure comprising in combination therein a phosphor region in the area wherein said light source structure discharges light into the environment proximate thereto and further removed from the area where light is discharged from said structure a region which contains a substance emanating weak beta rays, a second phosphor region positioned behind said region containing weak beta ray source, a light reflective and beta ray reflective heavy metal reflective region positioned behind and enclosing the back portion of said second phosphor region, said heavy metal region being in direct contact with the beta rays emitted by said substance so as to be capable of reflecting light and beta rays forwardly, said heavy metal reflecting region comprising a metal having an atomic number of at least 45, said heavy metal reflecting region having a thickness sufficient to reflect beta rays and said reflective region having a front facing light reflecting surface so that said reflecting region serves to reflect both light and beta rays forwardly in the direction of said front phosphor region, thus converting said beta rays to light energy, as well as directing light to the front part of said structure, said phosphor region being of a sufficient depth to absorb at least 90% of the weak beta rays without absorbing a substantial portion of the light emitted by said light source structure, light from said structure passing through said front phosphor region and being directed outwardly from said structure therethrough.

6. The structure of claim 5 wherein said heavy metal region comprises platinum.

7. The structure of claim 5 wherein said weak beta ray source is tritium impregnated upon phosphor particles.

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