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RB-105

IMPROVEMENTS IN THE PANEL LIGHT AMPLIFIER

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Improvements In The Panel Light Amplifier

The design characteristics and some of the properties of the grooved photoconductor light amplifier were first described in RB-14. Since that time the gain of the panel has been increased more than 10 times, and its threshold for light input reduced. These have been accomplished by modifying the structure to provide new modes of operation and by using a more sensitive photoconductive powder. A comparison between the new modes of operation and the earlier one is shown in terms of measured input-output characteristics of the amplifier. Although the decay time is of the order of seconds, as with earlier amplifiers, the shape of the decay curves and the rate of decay are determined by the method of operation. Data is also given on the time-integrated gain: the ratio of integrated light output to the integrated light input.

Introduction

The basic design of the original panel light amplifier is shown in Fig. 1 in cross section. The principle layers are the electroluminescent phosphor layer which produces the output image, and the thicker photoconductive layer whose resistance varies with the input radiation. Since in the dark the photoconductive layer must be many times higher in impedance than the electroluminescent layer, it is made much thicker. The thick photoconductor is grooved to increase the illumination efficiency. In operation the incident light is absorbed on the surfaces of the photoconductor so that photocurrents flow down the sides of the ridges and converge at the bottom of the grooves. To efficiently utilize the entire phosphor area a resistive current-diffusing layer is placed below the photoconductor. This spreads the photocurrents slightly; approximately one groove width. To prevent feedback of output light an opaque insulating layer is provided on the back surface of the phosphor layer.

Conventional Method of Operation

The photoconductive material employed is an improved cadmium sulphide powder bonded in plastic. The current-voltage characteristic of this material is very non-linear.[1] In Fig. 2 is shown a log-log plot of *d-c current* vs. *voltage* for a fixed light level. This curve indicates that the current varies approximately as the fourth power of the voltage over many orders of magnitude of current. One effect of the non-linearity is a reduction in amplifier gain when operated in the usual manner with a-c voltage. Fig. 3 shows a single amplifier element with sine wave excitation. Because of the non-linearity of the photoconductor most of the current flows during a small portion of the cycle when the voltage is near its peak.

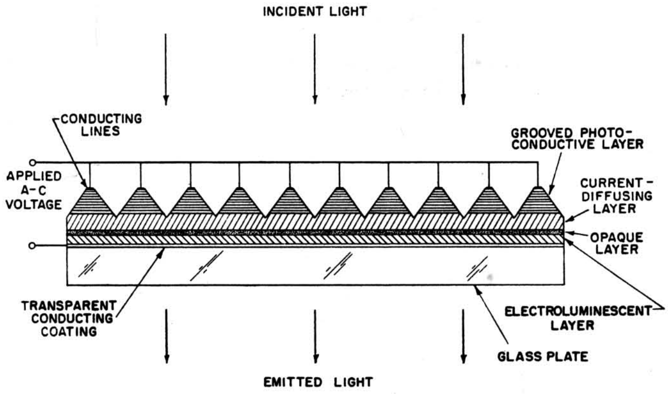

Fig. 1 – Cross section of the original design of the panel light amplifier.

Compared to a linear photoconductor with equal peak current, there is a reduction in average current for the non-linear cadmium sulphide powder with a corresponding reduction in output light from the phosphor layer. In operation the peak voltage which can be applied to the photoconductor is limited by breakdown. With a given peak voltage level some improvement in operation is possible with the non-linear cadmium sulphide by using rectangular wave shapes which increase the average a-c current. However, a much larger increase in current can be obtained by the following method.

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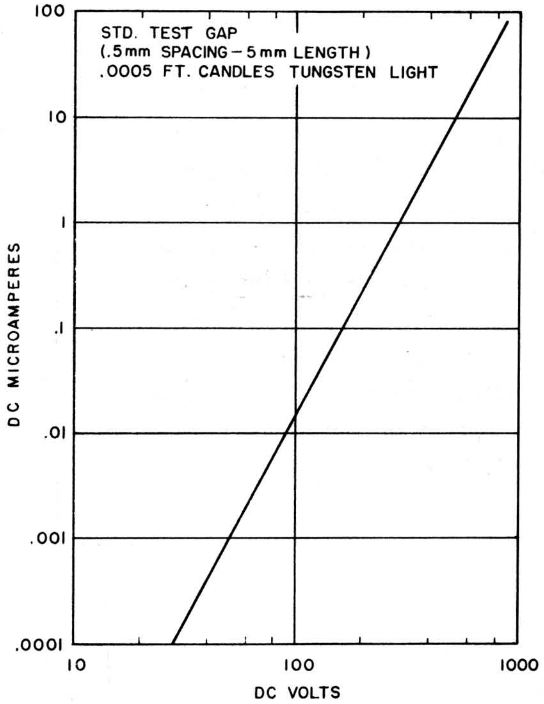
[1] *LB-967, Large Area High-Current Photoconductive Cells Using Cadmium Sulphide Powder,* by F. H. Nicoll and B. Kazan.



CURRENT VS. VOLTAGE WITH CONSTANT ILLUMINATION (CdS PHOTOCONDUCTIVE POWDER)

Fig. 2 – Current vs. voltage with constant illumination (CdS photoconductive powder).

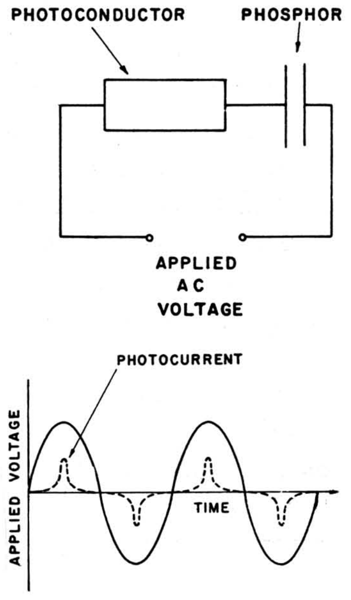


Fig. 3 – Amplifier element with a-c operation.

New Methods of Operation

If a d-c voltage equal to the peak a-c voltage is applied to the photoconductor, it is found that the d-c photocurrent is usually many times greater than the peak a-c photocurrent. This d-c increase of photocurrent is a particular property of the cadmium sulphide photoconductive powder. At the low light levels used with the amplifier the increase in photosensitivity may be as high as 10 times.[2]

While the photoconductor requires d-c voltage for best operation, the electroluminescent phosphor layer requires a-c voltage, being inoperative with d-c. This difference cannot be reconciled by the simple series circuit which has been the basis of light amplifier operation until now.

One method of overcoming the problem is shown in Fig. 4, representing a single amplifier element. Instead of a single photoconductive element, two smaller photoconductors are used, both of which are assumed to be equally illuminated. In series with each photoconductor is a diode so that a half-wave rectified voltage of opposite polarity and phase is applied to the two photoconductors. The voltage polarity and phase are shown by the solid lines to the right, with the photocurrent pulses as dashed lines. In operation during a positive half-cycle the current pulse through photoconductor "A" charges the phosphor layer positive. During the next half-cycle the current pulse of opposite direction through photoconductor "B" charges the phosphor layer negative, developing a-c voltage across the phosphor layer. Although pulsed d-c voltage is applied to the photoconductors instead of steady d-c, it is found that the peak photocurrent obtained is almost as great as with d-c. This type of operation produces a large increase in a-c voltage across the phosphor element for a given light flux in lumens falling on the photoconductive elements.

Using the basic principle of the rectified a-c operation, further improvement is obtained with the circuit of Fig. 5. Here, instead of diodes, d-c bias voltages of opposite polarity are inserted in series with the two photo-

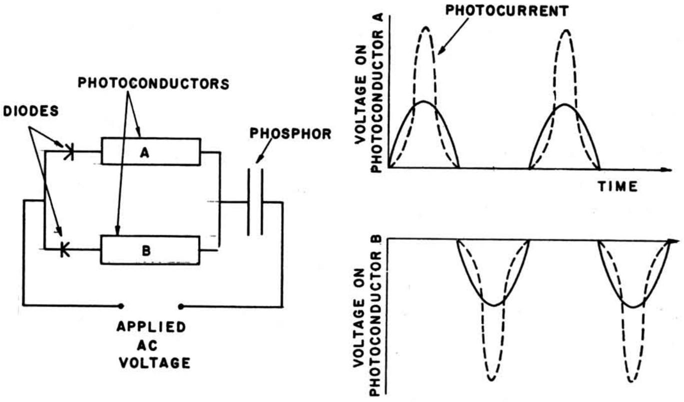


Fig. 4 – Amplifier element with rectified a-c operation.

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[2] *RB-14, An Electroluminescent Light-Amplifying Picture Panel,* by B. Kazan and F. H. Nicoll.

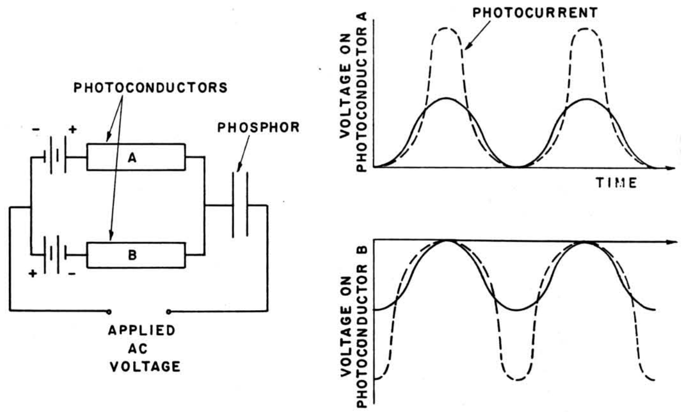

Fig. 5 – Amplifier element with biased a-c operation.

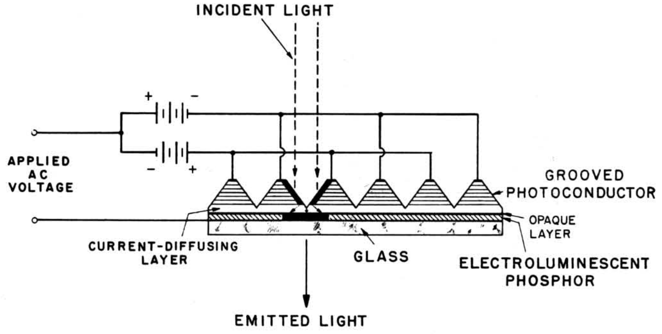

Fig. 6 – Biased a-c operation of light amplifier.

conductive elements. By setting the bias voltage equal to the peak a-c voltage, pulsating d-c voltages of opposite polarity and phase are applied to the photoconductors. Since the width of the voltage pulses between half-value points is greater than for the rectified a-c operation, the photocurrent pulses are wider than with rectified a-c. The average a-c current through the phosphor is therefore increased and more light output is produced. Although the voltage applied to one photoconductor rises before the voltage on the other photoconductor falls to zero, the current flow when the instantaneous voltage is low can be neglected for most input levels because of the non-linear property of the photoconductors.

To apply the rectified a-c, or biased a-c, method of operation to the light amplifier requires a modification of the electrode system. Fig. 6 shows the cross section of the modified amplifier operated with biased a-c. The conducting lines on the grooved photoconductor are separated into two interdigital sets, each set being connected to one of the two bias supplies. If light strikes the photoconductive layer, as shown, conductivity results on the surfaces of the grooves at the local area illuminated. The portions of the photoconductor and phosphor area corresponding to the single picture element of Fig. 5 are shown by the heavy lines.

Comparison of Operating Methods

The different modes of amplifier operation can be compared by means of the corresponding input-output characteristics. These cannot be measured, however, as static characteristics, because of the build-up properties of the photoconductor. Fig. 7 shows a log-log plot of d-c photocurrent vs. time for different light levels using the grooved photoconductive layer of the amplifier with interdigital electrodes as a photocell. Except for the very low light levels, a considerable portion of each curve is a straight line with a slope of about 2, indicating that the photocurrent rises as the *square of the time.* The time required for the individual curves to reach a specified fraction of their equilibrium levels depends on the input light level. This build-up time varies approximately *inversely* with the *light level.*

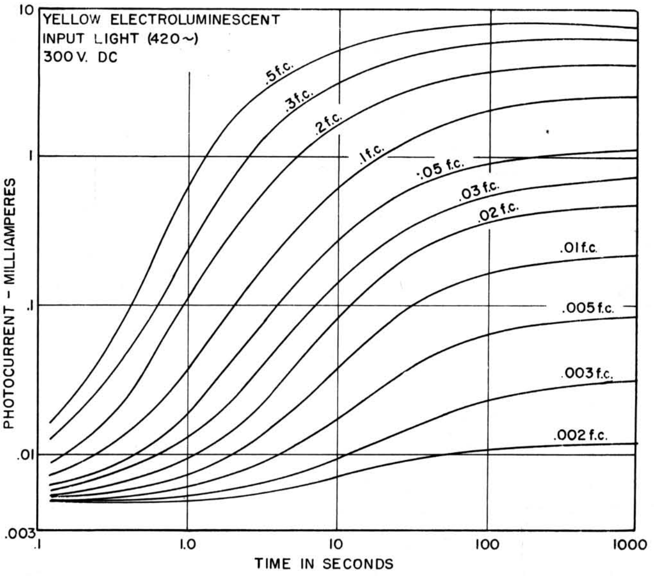

Fig. 7 – Photocurrent vs. time for various light levels.

In measuring the output of the light amplifier it is necessary to specify both the input light level and the time of excitation. Fig. 8 shows log-log curves for the three methods of operation indicating *output* vs. *input light* for a fixed excitation time of 10 seconds. All of the curves have high slopes with a gamma of about 3. For low-level light input the rectified a-c operation gives about 20 times as much light output as the conventional a-c operation. Using biased a-c operation, more than 50 times as much light output is obtained compared to the conventional a-c operation. Alternatively, with biased a-c about 5 times less light input is required to produce a given light output compared to conventional a-c, thus lowering the threshold of operation.

At the higher output levels the curve of conventional a-c operation exhibits only slight saturation. The recti-

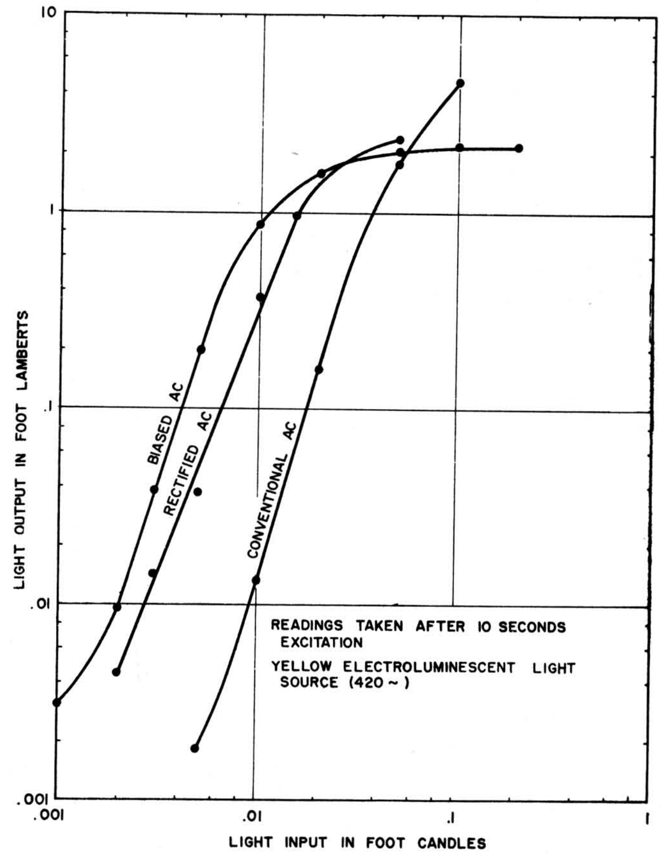

Fig. 8 – Comparison of input-output characteristics of amplifier.

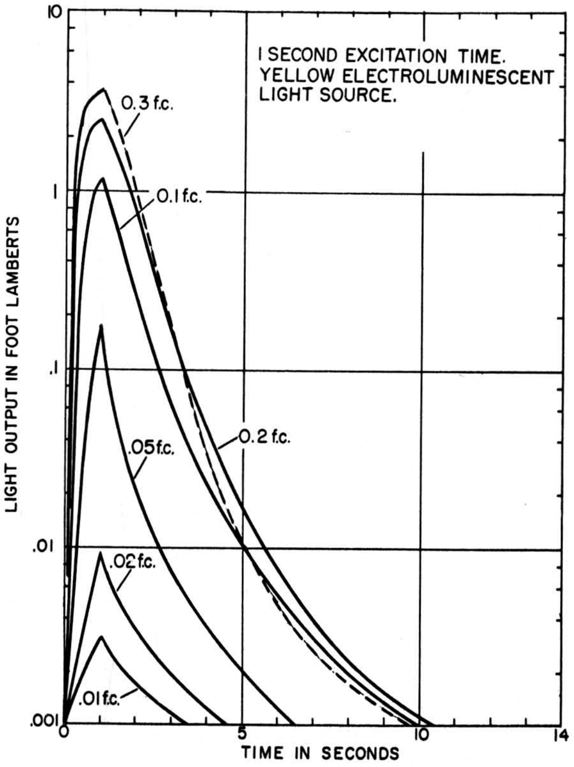

Fig. 9 – Build-up and decay for various input levels.

fied a-c curve shows considerable saturation and the biased a-c curve shows almost complete saturation, as evidenced by the flatness of the curve. The saturating effects of the rectified and biased a-c are not due to a saturation of the photoconductor but caused by a leakage of charge through the photoconductive elements during the half-cycle when they are assumed to be non-conducting. The clipping action of the biased a-c is of practical advantage in protecting the phosphor layer from breakdown. If the amplifier is accidentally excited with high input lights this limits the voltage which can be applied to the phosphor.

For longer or shorter excitation times than the 10 seconds shown, sets of similar-shaped characteristics are obtained, displaced to the left or right respectively. Using a light input obtained from a yellow electroluminescent source of identical spectral distribution as the amplifier output, light gains of about 400 times are obtained with an excitation time of about a minute. Since the photoconductor has its peak in the red at about 750 millimicrons, it is not efficiently excited by the yellow electroluminescent light input used here. Other measurements with tungsten light input of about 2800° K indicate a gain in lumens of more than 1000 times with one minute excitation time.

Decay Characteristics and Integrated Gain

In addition to its build-up properties the present cadmium sulphide photoconductor has a decay time of the order of seconds. Fig. 9 shows decay curves of the amplifier with a-c operation for different levels of input excitation. Each curve was obtained by applying the input for one second and then allowing the amplifier to decay for the remaining time. About 2 to 5 seconds are required for the output to fall to *one-tenth* its value, with the rate of decay greater for the higher input levels. At the highest light input level of 0.3 foot-candles, the decay curve, shown as a dashed line, crosses below the lower curves. The increased rate of decay is caused by a temperature rise in the photoconductor due to power dissipated by the high photocurrents. Fig. 10 shows a similar set of build-up and decay curves for biased a-c operation. The decay curves here are almost straight lines, indicating an exponential decay with about 8 seconds required for the output light to fall to *one-tenth* its value. Here again, the curve for the highest input light level, shown as a dashed line, crosses the lower curves due to the temperature rise in the photoconductor.

From the curves of this figure the time-integrated light output can be obtained for each light input level. Fig. 11 shows the integrated light output corresponding to the different integrated light input values. This curve

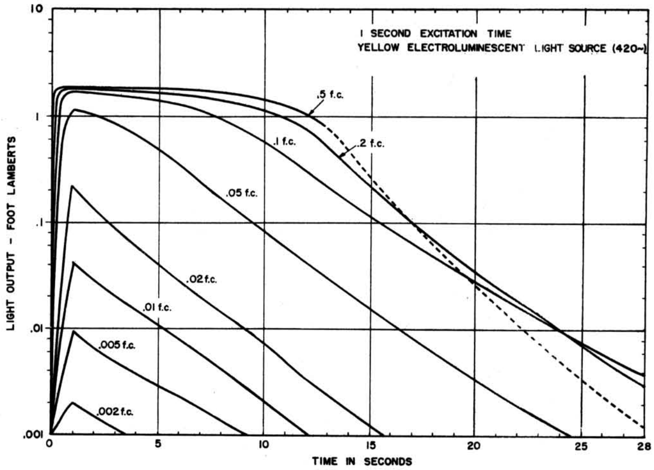

Fig. 10 – Build-up and decay for various input levels.

also has a high slope, indicating a gamma of about 2. The maximum integrated gain is about 100 times, using the yellow electroluminescent light input. With proper spectral match to the photoconductor, an integrated energy gain of about 200 is possible.

Picture Quality

Fig. 12 shows a photograph of the output picture produced on a 12-inch light amplifier with a low-level image projected from behind. By means of a double exposure the external frame of the amplifier is also shown. In operation, biased a-c was used. The resolution of the amplifier, determined by the number of photoconductive grooves is about 500 lines.

Conclusions

The high light gains and long persistence of the present amplifier are potentially useful in slow TV and radar applications. In the case of slow TV it is desired to scan a single frame in a period as long as a minute, using low-frequency video information. For viewing the picture, storage is necessary for a frame period or longer. One relatively simple method is to use a cathode ray tube with a long persistence phosphor. The available light during persistence, however, is very low, and the image must be viewed in completely darkened surroundings. Utilizing the long decay and integrated energy gain of the amplifier, a much brighter picture can be obtained with long storage by projecting a cathode ray tube image on the amplifier.

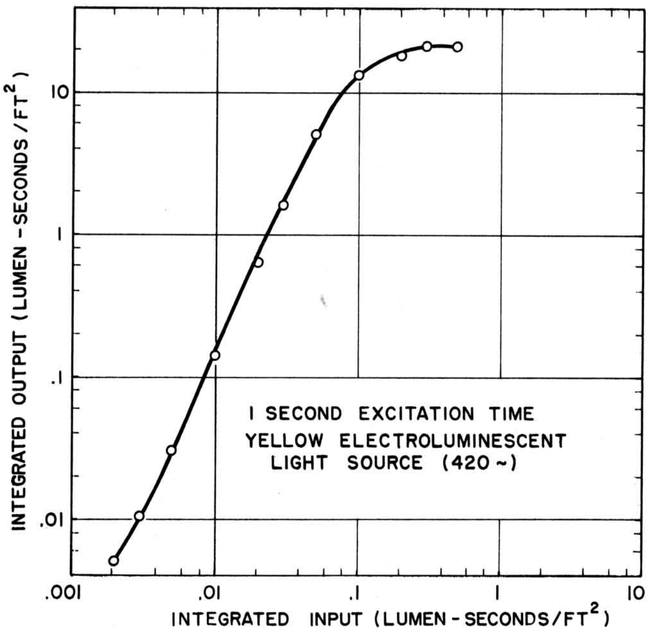

Fig. 11 – Input-output characteristic (integrated light).

The problem of inadequate light level also occurs with the conventional P-7 radar screen where the decaying target traces require a darkened room for viewing. Here again the light amplifier is potentially useful for producing a bright, long-decay output picture from a projected cathode ray tube image. Since the light amplifier has build-up properties similar to the P-7 phosphor, successive input pulses at short intervals cause an increase in the light output.

The present light amplifier is also sensitive to radiation in the near infrared, extending to about 900 millimicrons. For stationary scenes it can convert a low-level infrared image to a visible picture of much higher level. Alternatively, with a pulsed infrared source, an instantaneous image may be temporarily recorded for direct viewing.

The cadmium sulphide photoconductor used in the amplifier is also highly sensitive to X-rays. The panel can thus directly convert an X-ray image to a visible picture. Until now, the fluoroscope screen has been the primary means for the direct viewing of X-ray images in medical and industrial applications. As is well known, the image on the fluoroscope screen is frequently very dim, particularly in medical applications, requiring a darkened room for viewing and dark adaptation of the observer's eyes for many minutes. Because of the very low light levels and poor image contrast, details can be perceived with difficulty or not at all. By comparison, the light amplifier with its high gain can convert an X-ray image into a visible picture 100 times brighter than the fluoroscope screen, using the same X-ray levels. The resultant intensified image can be viewed in moderate

Fig. 12 – Photograph of the output picture produced on a 12" light amplifier with a low-level image projected from behind.

room light without dark adaptation. In addition, the high gamma of the amplifier greatly enhances the contrast of the output image so that details which might be overlooked on the fluoroscope screen can be easily observed on the amplifier.

With its long decay properties, the amplifier is expected to be of use in industrial X-ray applications involving stationary objects and in special medical applications where a temporary photograph or bright image is desired for viewing after the X-rays have been cut off.

James E. Berkeyheiser Jr.

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Benjamin Kazan

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