Film-Tech

Projection Light Sources

EARLY LIGHT SOURCES

The very first use of light to *deliberately* produce images was undoubtedly prehistoric. You can easily imagine our early ancestors making movements in the presence of the sun or a fire to cause predictable silhouettes or shadows, a fact probably capitalized on by the local shaman or witch doctor! In fact, some of the earliest available historical illustrations depict just such a process: the formation of silhouette images on surfaces using the sun as the light source. Later experiments in the 17th century used the sun to reflect an image onto a wall or screen from a mirror containing sketches on its surface. As surprising as it may sound, some of Edison's early experiments with motion pictures (in the late 1800's) included a rotating theatre in which the light source for projection was the sun! The contraption was nicknamed the "black maria" because the entire installation was covered with black material to seal out the daylight.

Number of Feature Films Started by U.S. Companies *(MPAV-MI)*		
	1980	*265*
	1981	*273*
	1982	*257*
	1983	*262*

Number of Feature Films Released in the U.S. (including reissues, etc) *(MPAV-MI)*		
	1980	*316*
	1981	*331*
	1982	*362*
	1983	*468*

The Only Posthumous Oscar for Acting*—Peter Finch—Best Actor in* Network *(1975)*

The "Magic Lantern"

With the coming of oil lamps and candles, predictable and easily adaptable light sources were available for experimentation. Although short on brightness, they led to the development of the "magic lantern" in the 17th century. One could speculate that the sheer amazement at seeing an enlarged sketch or silhouette reproduced on a wall prompted the word "magic." Refinements in the design of oil lamps, as well as in magic lanterns, eventually made the viewing of commercially made, hand-colored slides a popular pastime. Unfortunately, these oil lamps were in no way capable of producing the light required for motion pictures.

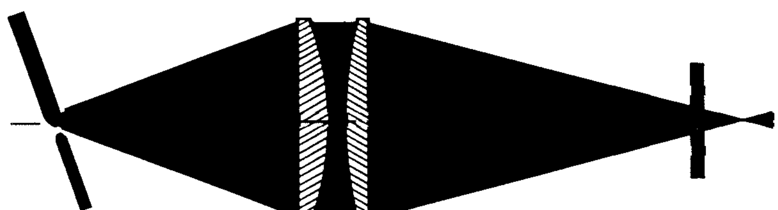

Figure 1

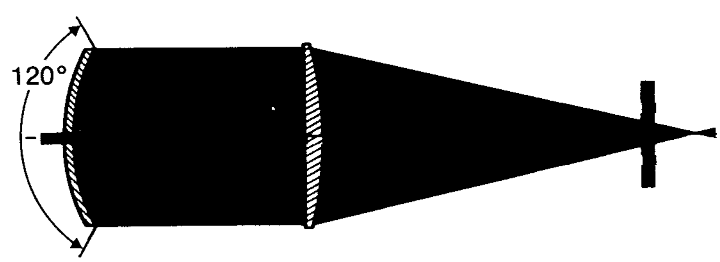

Figure 2a

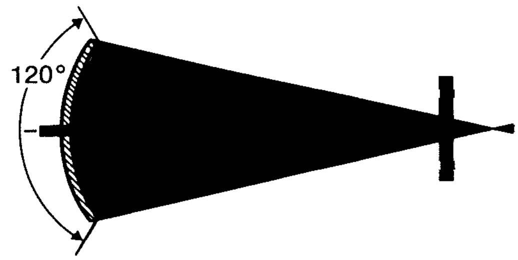

Figure 2b

Enter the Carbon Arc

The commercial success of motion pictures did not become a reality until late in the 19th century when the carbon arc, first produced by Sir Humphrey Davey early in the century, was adopted as the light source.

The carbon arc provided the very small bright light source needed for acceptable motion picture projection. Not until 30 to 40 years later were suitable *incandescent* lamps available that would satisfy the same projection requirements.

The first carbon arc lamps used in motion picture projection burned two carbons (positive and negative) in a nearly vertical position with the positive carbon at the top. This inclined position exposed the brilliant positive-crater light to the condenser lens that picked up a light cone measuring about 45° and focused it on the projector aperture shown in Figure 1. To provide the greatest direct exposure of the positive crater to the condenser lens, the negative carbon position was adjusted so that the tip of the positive carbon more nearly faced the condenser lens.

The introduction of the reflector lamp, equipped with an elliptical mirror, increased the efficiency of the carbon arc considerably. As shown in Figure 2a (with a relay condenser lens) and 2b (a later version without the lens), the light cone was increased to about 120°. This fact alone permitted the use of smaller carbons, burning horizontally, and at lower amperages, to achieve the same light output as some of the earlier and larger condenser lamps.

MORE LIGHT EFFICIENCY

As mentioned earlier, successful motion picture projection depends on a concentrated light source that can be conveniently imaged on the projector aperture at the film plane. Whether the imaging is done with *lenses* (condensers) or *mirrors* is of little consequence, although the most important difference between the two alternatives is light efficiency. Current carbon arc lamps, using large-diameter mirrors, have generally replaced the less efficient condenser lamps.

From the very first use of the carbon arc in projection, there was steady progress towards more efficient production and use of projection light. Developments in carbon manufacture adapted the arc to the more efficient optical systems; and when combined with better lamps, these new designs provided the source of projection light which is still in common use today. The need for increased screen brightness to meet the demands of larger theatres resulted in the use of higher arc currents and larger carbons. Steadiness of the light output was improved by using cored positive carbons and metal-coated negative carbons, smaller in diameter than the positive.

By this time, motion picture theatres were emerging from the limited capacities imposed by the audible range of the human voice on the stage. Theatres that seated 3,000 or more patrons were being built and the screens were being enlarged to accommodate those patrons in the rear seats, making the need for more screen light imperative. Coincidentally, new developments in carbon arc technology evolved with the introduction of the "high-intensity" arc. Before this point, carbon arcs were regarded as "low intensity" and produced a yellow-white light.

HIGH-INTENSITY CARBON ARCS

The light source of the carbon arc comes from the incandescent plasma ball in the crater of the positive carbon as shown in Figure 3. The new high-intensity carbon arc went considerably beyond the upper limit of crater brilliancy offered by the low-intensity arc and also produced a snow-white light, vital to the proper presentation of color films.

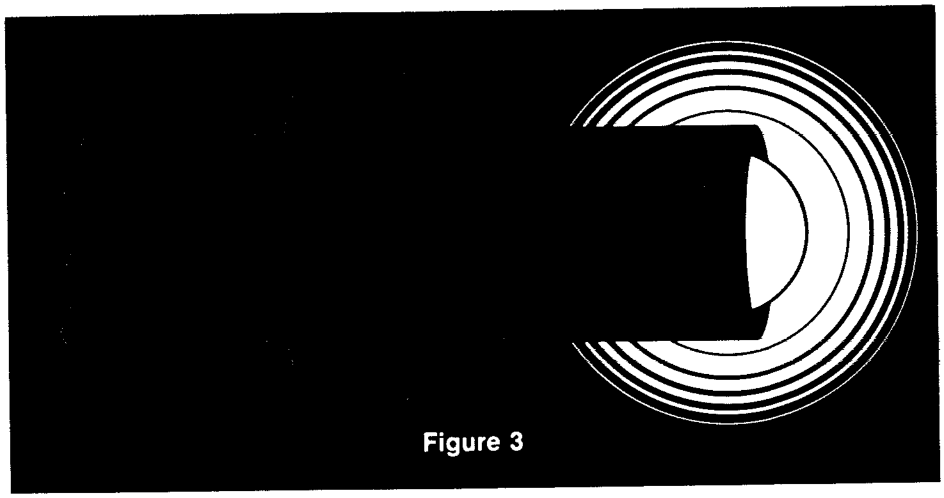

Figure 3

The high-intensity arc is produced by a positive carbon that has a larger core than the low-intensity carbon and contains rare earth materials, such as compounds of cerium, that become highly luminescent under the high concentration of electrons in the arc stream. The current density in the positive carbon can exceed 1,500 amperes per square inch. At these high current densities, the core material vaporizes more quickly than the surrounding carbon shell and produces a deep crater in the face of the carbon. Within this crater, vapors of carbon and core materials are excited to a very high temperature and radiating efficiency. The effect of this action produces a brightness within the crater several times greater than possible in a low-intensity carbon arc. In these original high-intensity lamps, the negative carbon was inclined to the horizontal positive carbon that rotated to maintain a symmetrical crater form. This method of operation is still used in the large carbon arc lamps.

Using the high-intensity arc for projection along with a condenser-lens optical system (Figure 4) gave three to four times more light on the screen than the low-intensity arc and made further improvements to the efficiency of light production. Subsequent improvements in the condenser-lens system, to provide a larger light cone angle, raised the efficiency of the optical system to more than *five* times that obtained from the earliest projection lamps. Thus improved, these lamps produced about 40 times the amount of light projected on the screens of the first theatres. This figure was more than doubled by later improvements in high-intensity carbons and optical systems.

The Benefits of Screen Luminance

One of the most important benefits realized from the increase in screen luminance was the improvement in general illumination in the theatre. Prior to the screen luminance improvements, early theatres operated in almost complete darkness except for the dull red glow of exit lights. The tremendous increase in screen light, however, permitted an acceptable picture to be shown in the presence of a comfortable level of general illumination in theatres seating many hundreds . . . and even thousands of patrons!

Smaller theatres did not have the need for that much light. The development of the reflector-type low-intensity lamp gave the small theatre a considerable measure of improvement in screen light and permitted the installation of some general illumination. Somewhat larger theatres that needed more light, but did not require the high-intensity condenser-type lamps, used the mirror principle with the high-intensity arc, commonly called the "Hi-Low" lamp. As shown in Figure 5, the negative carbon was inclined to the rotating positive, but at a much smaller angle than in the condenser high-intensity lamp.

Further improvements in carbons and lamps increased lamp efficiency considerably up to the current large mirror, rotating positive-carbon lamps that are capable of light outputs equal to or exceeding the large condenser arc lamps. With today's trend toward large-capacity film-transport systems, however, the limitations of the uninterrupted burning time of large carbon arc lamphouses (about 45-50 minutes) has greatly increased the need for alternative light sources.

Figure 4

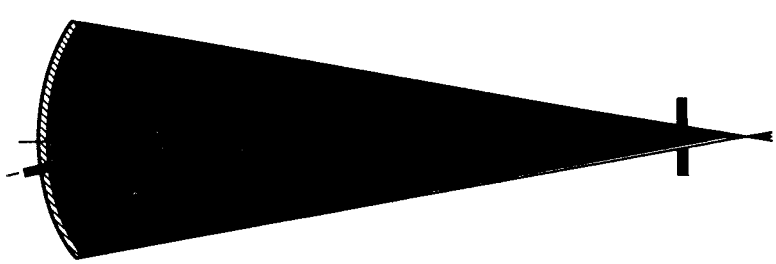

Figure 5

INCANDESCENT LAMPS

Parallel to the progress in carbon arc development, work was also being done in the development of concentrated filaments for incandescent projection lamps. While none of these lamps could equal the output of arc lamps, their convenience and size were ideally suited for home, education, and to a limited degree for preview and conference rooms and small theatres. Further development provided several important refinements in concentrated filament lamps, particularly the metal halide lamp which requires only a small quartz envelope that remains essentially free of blackening throughout its life. The miniaturization of incandescent projection lamps has greatly influenced the reduction of projector size and improved reliability and performance in the home consumer market.

XENON SHORT-ARC LAMPS

Around 1951, the xenon short-arc lamp was introduced. While there are several types of zenon arcs, the short-arc, adopted for motion picture projection, has the unique properties that have made it the currently preferred light source for professional motion picture projection in theatres. Important factors include economy, stability during operation, and a continuous light source which is necessary when projecting with large-capacity film equipment.

A typical xenon short-arc bulb consists of two parallel tungsten electrodes enclosed in an envelope of fused silica that is filled with xenon gas at a pressure of 8-20 bar (see Figure 6). The bulb is ignited by a short, high-current surge produced by an ignitor circuit within the lamphouse. Thereafter, the bulb continues to burn at its rated ampere/voltage level. The current level from the power supply can be varied to some extent and allows the light output to be adjusted without changing the color temperature of the light on the screen. Bulb life varies, but when used as directed, the warranted life usually exceeds 1,000 hours for the large bulbs and 2,000 hours for some of the smaller bulbs.

Vertical vs. Horizontal

Until the early 1970's, xenon short-arc lamps were generally operated in a vertical position. The bulb was mounted between a main elliptical mirror and a spherical auxiliary mirror. The function of the auxiliary mirror was to focus the arc back into itself to increase the efficiency of the system. Alignment of these systems was critical and required trained personnel.

In the early 1970's the present concept of horizontal lamps was accepted. The lamp is mounted horizontally in the center line of a deep-dish elliptical reflector as shown in Figure 7. The cathode (small tip) points towards the projector to decrease the amount of shadow falling on the reflector. Because of the large pickup angle permitted by the reflector (up to 235°), these systems produce about 50% more light than the vertical design and are more uniform in screen brightness. And the alignment procedure is much easier. A newer design has reverted to placing the bulb and mirror vertically and directing the light horizontally to the projector aperture with the mirror tilted at 45°.

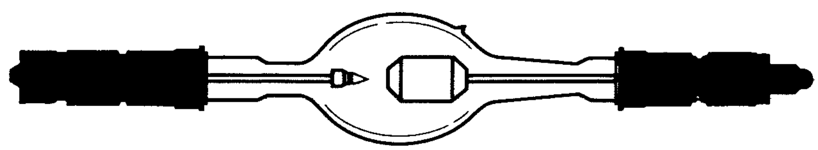

Figure 6

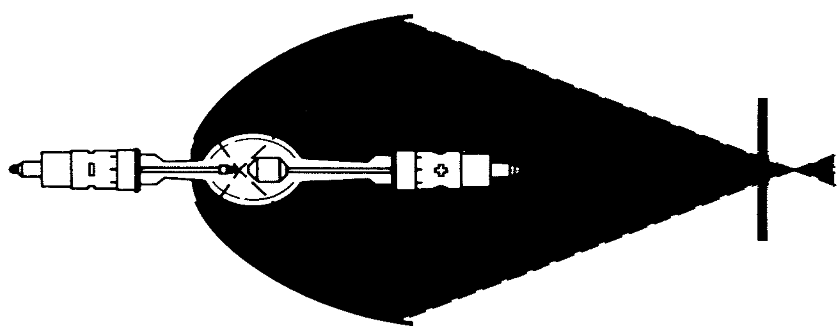

Figure 7

The adaptations of the xenon short-arc to projection lamphouses bypassed the condenser lens and went directly to reflectors. The xenon arc is not formed partially in a crater, as in a carbon arc, but rather between two electrodes in the open. As a result, most of the total incandescent plasma is accessible to the mirror, or mirrors, and directed to the projector aperture, providing a greater efficiency and light output than was possible with other light sources. Because the xenon arc is very concentrated, however, great care is necessary in the design of the special mirrors and in the alignment of the lamphouses, so that "hot spots" will not be produced at the projector aperture.

LIMITATIONS IN PROJECTION LIGHT SOURCES

Regardless of the methods used to produce a light source, there are strict limitations in both the light intensity and incident radiant flux that can be used and tolerated by current films.

Having progressed from the dim "flickers" to the large, well-lighted screens of today, there might be a tendency to continue seeking still higher levels of illuminance for even larger presentations. There is a restricting influence, however, and that is the film. When you consider the rigors that thin motion picture film must undergo during projection, it is understandable to expect that a limit exists somewhere. And that limit is radiant energy!

A typical black-and-white film contains images made up of metallic silver. As with any metal, silver absorbs radiant energy and therefore affects the stability of the frame position in the projector aperture. Under average theatrical projection conditions, the frame in the aperture expands towards the light source (called negative drift) as heat is absorbed by the silver image. When the frame leaves the aperture, it recovers to nearly its original position and the process is repeated for each successive frame. This is considered normal in theatrical projection and the resultant screen image is acceptable.

As the heat energy increases, however, the negative drift becomes erratic and all of the frames do not position in the same plane in the aperture. When this behavior exceeds the nominal depth of focus of the projection lens, the screen image appears soft, a condition generally referred to as flutter. Adjusting the focus will not correct the situation. Further increase in radiant energy causes the individual frames to drift randomly and more violently in either direction beyond the ability of any lens or manual focusing to compensate. The resultant screen image appears alternately and randomly in-and-out of focus and cannot be corrected by focusing. Continued projection will eventually stabilize the film behavior but, now, each successive frame drifts in the opposite direction towards the lens, or drifts positive. Although the screen image appears very sharp in the center, the edges are considerably out of focus. The condition does not improve with continued projection. There are varying degrees of flutter and in-and-out of focus and the radiant-energy levels listed in the table are those that can cause objectionable screen image quality. If the radiant energy is increased even further, blistering will occur, particularly in the dense, low-key scenes. At this point, the film is useless for further projection.

Other Film Behavior Characteristics

Among these most noticeable projection problems are other less important film behavior characteristics, such as embossing, change in reflected image tone, and focus drift. The first two may affect the cosmetic appearance of the film, but have not been observed to cause screen-image problems. However, the third item, focus drift, can produce a gradual softening of the screen image during projection if focus is not checked regularly. This usually occurs during conventional projection with 2000-foot reels and is the result of the film having been wound tightly, emulsion side out, on small plastic cores at the laboratory.

Color films contain images composed of dyes rather than metallic silver. Because these dyes are essentially transparent to infrared radiation, most harmful and nonimage producing infrared radiation passes through the film without causing any problem. Caution is still necessary, however, because it is possible to "misadjust" large arc lamps to produce a radiant-energy flux that can cause the same types of problems usually associated with silver image films.

To ensure proper and safe projection conditions with current arc lamps, it is important not to circumvent the safeguards incorporated in the lamps. Dichroic heat filters and/or mirrors should be neither removed nor substituted. Operating currents in xenon arc lamps should not exceed the manufacturer's recommendations, nor should any lamphouse be adjusted to produce a "hot spot" in the center screen . . . a common practice in drive-ins in an attempt to get more light on the screen.

Incident radiant energy at the projector aperture is measured directly with a specially designed radiometer. The values are expressed as watts per square millimetre. With the newer, and larger xenon arc lamps, the omission of a recommended heat filter, or intentional misadjustment of the lamp to create more center screen light (hot spot), can produce radiant-energy levels in excess of 1.0 W/mm^2. By contrast, a properly adjusted 4000 W xenon arc lamp, with a proper heat filter, and burning at the recommended current, will rarely exceed about 0.5 W/mm^2 . . . a safe level with today's films. The table above lists the incident energy levels at which screen-image problems can occur. Absolute values are not possible because of the many variables such as image density, film type and thickness, energy fluctuations, and ambient humidity conditions.

Intensity Threshold
Mean Net Watts/mm^2

Condition	Acetate Base	
	B&W	Color
1. Embossing	These film behavior characteristics are common to all theatrical projection in varying degrees and, except for focus drift, require no attention or concern.	
2. Change in reflected image tone (B&W only)		
3. Focus drift		
4. Image flutter	0.55–0.65	0.60–0.70
5. In-and-out of focus	0.65–0.70	0.80–0.90
6. Blistering	0.70–0.75	1.15*

*Under aggravated laboratory conditions it is possible to produce scorching (not blistering) on some films. Most films run under these high-radiant-energy levels will show a considerable amount of permanent distortion, however. Isolated trade samples have shown blistering caused by conditions not yet determined. Limited tests on polyester base films showed similar performance characteristics.

WHAT ABOUT THE FUTURE?

One can only speculate as to the requirements for future screen presentations. Will multiple units with smaller screens prevail or will there be a switch to huge screens, or possibly the same smaller screens with a high level of ambient light for greater adaptability, comfort, safety, and easier control of distracting patron behavior? Electronic imagery cannot fulfill the stringent requirements of small theatres, much less a change to large screens, so the challenge remains with film projection.

Methods are known that can enable film to withstand higher incident-radiant-energy levels safely, such as pulsed air jets and a liquid gate, but the commercial adaptation of such techniques has not yet been motivated by need. Great care must be exercised, therefore, in the installation and adjustment of arc lamps or any other concentrated light source to care for and protect your motion picture film properly during projection.

Thanks to Union Carbide Corporation, Carbon Products Division, for research information relating to carbon arcs.