High-Intensity Explosive Light Sources

PAPER A—13

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An explosive light source has been developed to produce daylight-quality illumination intense enough for reflected light color photography using ultra-high-speed cameras. Previously used explosive "candles" required much more high explosive and emitted rapidly fading light that was considerably less brilliant. Sheet explosives are combined with aluminized Mylar as a mirror-like reflector to make a highly efficient pyramid-shaped candle that can cover from 10 to 200 μsec according to need. The luminous intensity is maintained by a diverging explosive area as the detonation wave travels the length of the argon-filled container. In addition to increased time and brightness efficiency, this more compact design illuminates more uniformly and scatters less light outside the subject area.

The advantages of using various concentrations of argon as well as dilutions and admixtures with air, krypton and xenon were investigated. Methods are proposed whereby still more intense light can be obtained by substituting krypton and xenon, or adding these gases to the argon. The relative intensities of the various light sources were all compared and measured by photometric studies and calibration of films produced by photographing the light with a high-speed framing camera.

HIGH-SPEED PHOTOGRAPHY of subjects which have little or no self-luminosity requires a strong source of supplementary illumination. If the object to be photographed is itself destructive, then an expendable light source requiring no protective shielding must be used.

Light sources having extremely high levels of brightness can be produced by sending a shock wave, generated by a high-order detonation, through gases such as argon, krypton and xenon, which have a low ionization potential. Duration of the luminosity is controlled by the strength of the shock wave and the length of its path through the gases. These light sources, often called explosive light "candles," are assembled in standard and special designs and they operate reliably to illuminate many high-speed camera subjects.

Poulter Laboratories of Stanford Research Institute investigated the design and performance of a number of these devices for the Lawrence Radiation Laboratory, Livermore, Calif., under the auspices of the U.S. Atomic Energy Commission. Our object was to explore the possibility of making an efficient low-explosive-weight light source that would be at least as luminous as a standard LRL candle weighing more than 13 lb. A light source was desired which would produce enough light for normal exposure on color film for individual frame exposure times of about 2 μsec, and which would last more than 100 μsec. The weight of explosive was not to exceed 5 lb. The explosive charge and container configuration had to be combined with the best gas or gas mixture to produce maximum luminosity.

Our first step was to establish a consistent exposure and development procedure for measuring relative luminous flux photographed by a high-speed framing camera using panchromatic film. Sensitometric techniques adapted to the brief exposure required were used to calibrate films and light sources as a basis for evaluating the parameters of explosive candle design.

Density measurements were made of the photographic films which recorded the output of each light source tested; the results were plotted and analyzed. A highly reflective matte white target, conforming to the size of the intended subject, was used for the tests (Fig. 1). A Model 189 Beckman & Whitley framing camera recorded the light reflected from the targets. Other studies of the light sources were made directly with a streak camera so that time dimensions could be correlated precisely with luminosities. In addition, the effect of factors such as strength of shock wave, attenuation due to partition walls between explosive and gas, and gas composition were readily resolved in these streak pictures.

Gas Concentration

A series of experiments was made to study the production and reproducibility of high-intensity light from candles of varying argon concentration (argon in admixture with air). Identical charges and containers were used. Gas filling was controlled manometrically, and under these conditions a high degree of freedom from contamination was maintained. Glass cylinders were used as containers which had a thin $\frac{1}{16}$-in. glass partition between the explosive and the gas. It was found that a mixture of 10% air and 90% pure argon produced about half the luminosity of a similar candle

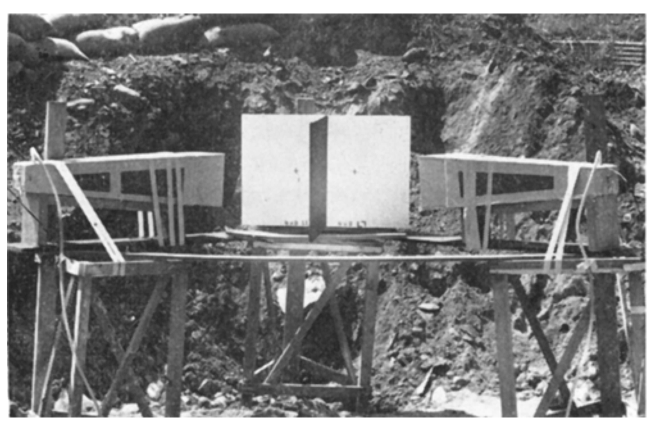


Fig. 1. Light source/target set-up.

Presented on October 17, 1960, at the Fifth International Congress on High-Speed Photography in Washington, D.C., by Zev Pressman, Poulter Laboratories, Stanford Research Institute, Menlo Park, Calif.

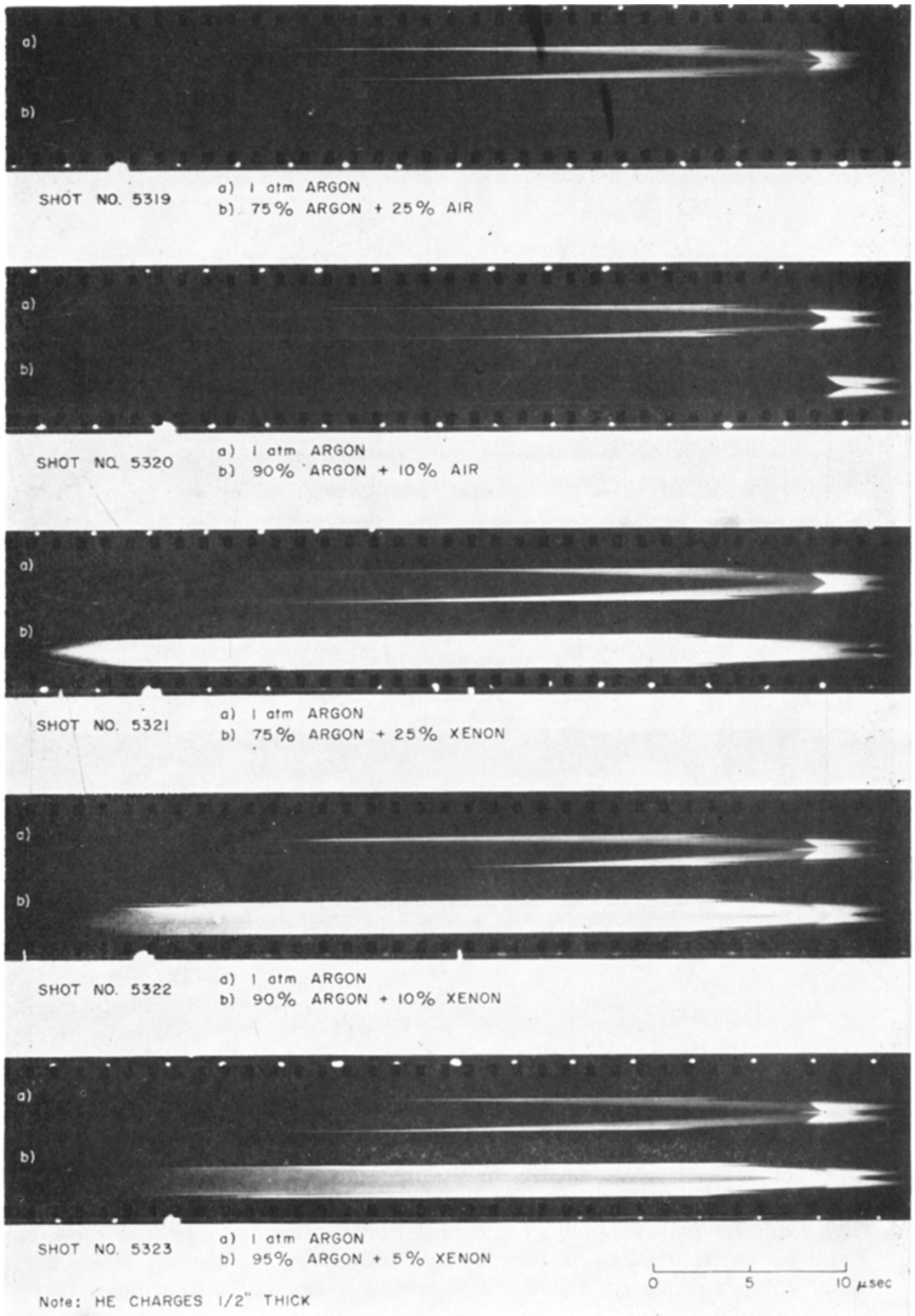


Fig. 2. Effects of argon mixtures on luminosity.

with 100% pure argon. Further dilution—75% argon, 25% air—caused a loss of nearly all luminosity (Fig. 2).

Similar tests were run with candles containing xenon–argon, krypton–argon, pure xenon, and pure krypton. Even with thin glass partitions between the explosive and the gas, as little as 5% xenon (95% argon) produced luminosity noticeably greater than the 100% pure argon. 10% xenon was more than twice as luminous as the 5% mixture; and the 25% xenon mixture, more than twice that of the 10% mixture. Crude or impure xenon contained too many hydrocarbons to be useful as a light-producing medium. Pure xenon responded best. It produced more than twice as much luminosity as the 25% xenon–argon mixture (Fig. 3).

Later tests without any partition between the explosive and the gas indicated that although the differences in luminosities for the above gases were less, the brightness order remained the same. Even under these conditions, the luminosity produced by pure xenon was more than twice that of pure argon.

Krypton also proved to be extremely useful in explosive candles. Pure krypton produced almost as much luminosity as pure xenon; a mixture of 10% krypton–90% argon increased the luminosity above that for pure argon by more than 50%. As the cost of krypton is approximately $\frac{1}{5}$ that of xenon, the advantage of krypton is obvious.

Luminosities produced by a shock wave sent through argon in greater than, and in less than, 1-atm concentration were studied. Argon produced nearly as much light at $\frac{1}{2}$-atm concentration as at normal atmospheric pressure. A small gain in luminosity was achieved when

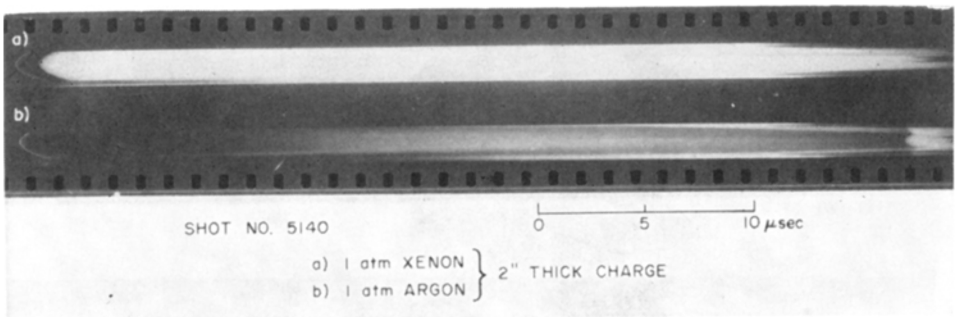


Fig. 3. Comparison of luminosity produced by shock wave in xenon vs. argon.

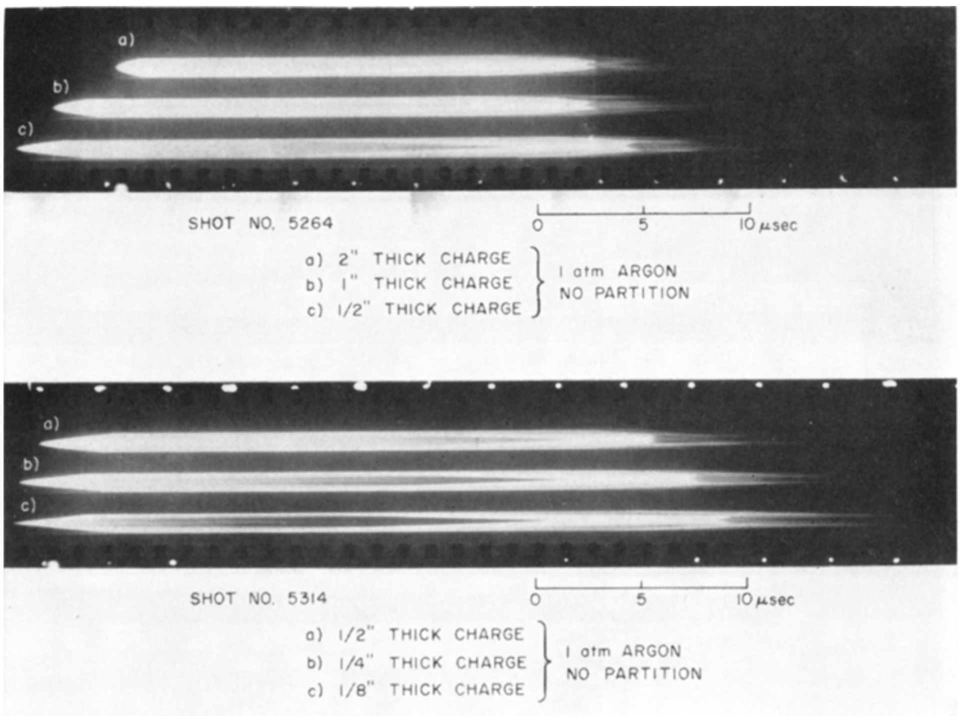


Fig. 4. Effects of HE charge thickness.

argon was used at 2-atm pressure. Two-atmosphere pressure of krypton gave nearly the same effective luminosity as 1 atm of pure krypton.

High-explosive pads ranging in thickness from $\frac{1}{8}$ in. to 2 in. were tested to determine the effect on luminosity. Thinner charges produced a longer lasting and somewhat more uniform luminosity because of the slower shock-wave travel; however, when the explosive charge was less than $\frac{1}{2}$-in. thick, luminosity was substantially reduced. High-explosive Composition B-3 was used in these tests. The cylindrical pads of explosive measured 3 in. in diameter and were taped to 3-in.-diameter cardboard tubes closed at the other end with lantern slide cover glass. Argon at 1-atm pressure was allowed to flow until all air was flushed from the tubes. Detonator caps and boosters were cemented to the explosive charges and the test candles were fired, for comparison purposes, in groups of three while being observed by the streak camera (Fig. 4). Because of noticeable wall effects caused by reflections of shock waves from the tube walls in the form of crisscrossing and irregular nodes of luminosity, it was necessary to examine the integrated luminosity by studying reflected light with the framing camera. The desirability of using explosive pads 1-in. and 2-in. thick was clearly demonstrated.

Candle Configuration

The configuration of explosive light candles proved to be the most important single factor of design. A number of *bench experiments* were made on mock-ups of light candles using matched opal enlarger bulbs; and the results were incorporated into the candles field tested at the Poulter Laboratories Test Site. Conventional reflector designs obviously were not suited to explosive candles. The moving plane of luminosity eliminated any consideration of parabolic or spherical configuration in reflector arrangements, or of lens systems such as those in spotlights which depend on a fixed small light source to achieve any real efficiency. Fresnel lenses (see Table I) proved to be inefficient when any considerable area was to be illuminated.

Photometer measurements on mock-ups as shown in Fig. 5, followed by actual explosive candle tests, showed conclusively that the mirror-like surface of thin aluminized Mylar was far more efficient than aluminum paint, white paper, or any diffuse reflecting material. Luminosity produced by the aluminized Mylar-lined candles averaged more than twice the intensity and varied less than 10% through the entire distance traveled for certain desirable configurations.

Table I. Fresnel lenses used with cylindrical and pyramidal reflectors.

Type of configuration	Position of light source: At back of reflector — Area illuminated, in.	At back of reflector — Relative foot-candles	Halfway advanced — Area illuminated, in.	Halfway advanced — Relative foot-candles
(a) 13A; 4"; 24"; F	2 1/2"	100	5"	125
(b) 13B; 4"; 10", 24"; F	2"	80	3 1/2"	200
(c) 14A, ground glass; 4"; 10", 24"; F	4"	10	5"	32
(d) 15A; 4"; 24", 10"; F	1"	360	1 1/2"	400
(e) 16A, white matte paper; 3", 8"; 24"; F	2 1/2"	250	5 1/2"	400
(f) 16B, aluminized mylar; 3", 8"; 24"; F	6"	300	5"	460
(g) 17A (4A), aluminized mylar; 3", 8"; 24"; no Fresnel	12"	180	16"	180

Table II. Preliminary comparison of reflectors. (Lining materials and configurations).

Type of configuration (Distance to target: 30", 21")	Position of light plane in reflector	Relative foot-candles	Diameter of area illuminated, in.	Comment
Plain cardboard (4")	back	29	8	Low level illumination due to absorption by cardboard
	halfway	50	10	
Sprayed aluminum paint (diffuse reflector) (4")	back	25	7	
	halfway	70	9	
Aluminized mylar (mirror-like reflector) (4")	back	125	6	Almost 4× gain in illumination over plain cardboard and useful light outside of main illuminated area
	halfway	135	8	
White matte paper (3", 8")	back	40	13	Covers square area; area coverage improved; reflection better than plain cardboard
	halfway	70	16	
Aluminized mylar (3", 8")	back	180	12	Illumination level and area coverage most promising
	halfway	180	16	
Aluminized mylar (3", 8")	back	180	10	Other tests indicated that as light advanced, area coverage continued to be smaller than square pyramid shape
	halfway	—	—	
Aluminized mylar (8")	back	250	3	Mirror-like lining reflects maximum illumination; tube shape restricts area coverage
	halfway	180	6	
Dull foil (8")	back	180	3	
	halfway	125	6	
Dull foil (10")	back	200	3	
	halfway	135	5	
Dull foil (6")	back	160	3	
	halfway	125	5	

The basic gas container shapes studied (see Table II) were cylinders, truncated cones and truncated pyramids. The latter two emitted more light than the cylinder and permitted a larger area to be illuminated. In addition, hexagonal as well as square base pyramids were tested. The hexagonal pyramids were slightly better in some respects but less convenient to fabricate and to store than the square pyramid design which was finally selected. A triangular pyramid was measured on the photometer but was considered not suitable for field testing (Table III).

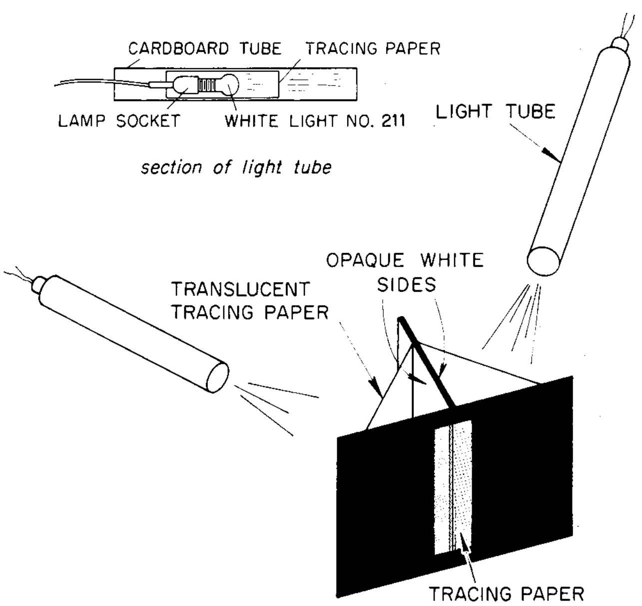


Fig. 5. Comparison photometer arrangement.

Confirming these bench tests on mock-ups, subsequent field testing with explosive charges showed that a square pyramid was about as efficient as a hexagon having the same end area; also, the square pyramid illuminated a larger target area more uniformly. The cone-shaped candle tended to concentrate the light in either a ring of light or a relatively small spot of brightly lighted area on the target, depending on the target distance from the light source. Figure 6 shows the basic configurations that were *field tested.*

The final and most satisfactory explosive candle (Fig. 6(d)) produced in this series of experiments was a 30-in.-long truncated square-base pyramid tapering from the narrow end (which measured 4 by 4 in.) to the front end which was sealed by 8 by 8 by $\frac{1}{8}$-in. Plexiglas. The back end had a 4 by 4 by 1-in. pad of Comp. B-3 taped to it. Two sheets of 0.200-in. thick Du Pont type D sheet explosive, each measuring 4 by 30 by 8 in., were folded along their length to fit into diagonally opposed angles along the length of the pyramid. These two sheets of explosive were butted tightly against the initiating high-explosive pad at their narrow ends and were cemented to the thin fiber-board housing of the candle with Pliobond cement. The folded sheet configuration caused strong interacting shock waves which produced

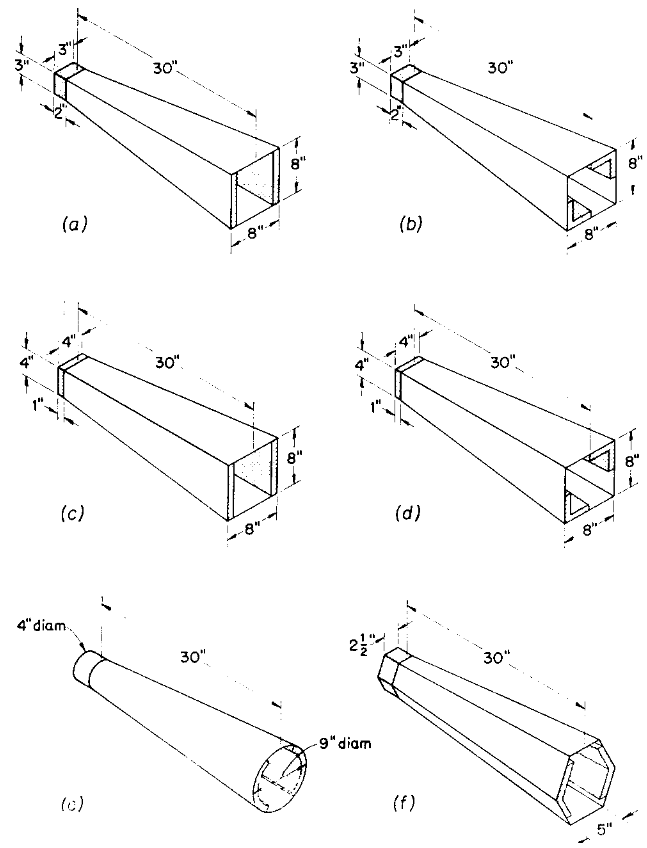
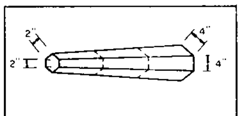
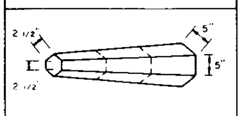
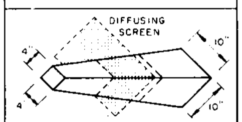
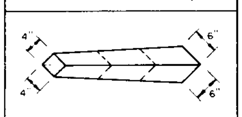
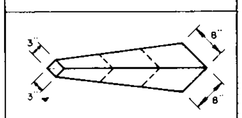
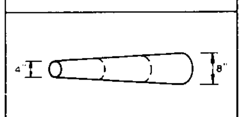
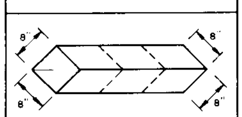
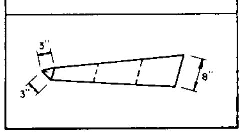
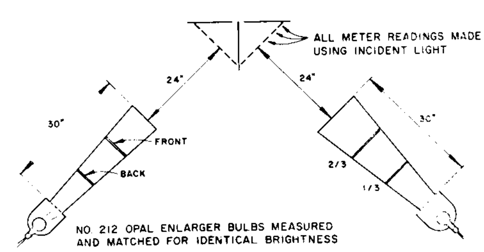


Fig. 6. Basic candles tested showing use of HE pad and sheet explosives.

Table III. Photometer arrangement for measuring and comparing relative intensities versus area distribution of mock-up light candle configurations.

Type of configuration	Light at back end (no diffuser)		One-third advanced (diffused light)		Two-thirds advanced (diffused light)	
	Relative foot-candles	Area illuminated, in.	Relative foot-candles	Area illuminated, in.	Relative foot-candles	Area illuminated, in.
	200	9 × 9	40	11 × 11	25	12 × 12
	300	10 × 10	64	12 × 12	40	14 × 14
	250	12 × 12	64	13 × 13	40	15 × 15
	200	9 × 9	40	12 × 12	25	13 × 13
	225	12 × 12	45	14 × 14	32	15 × 15
	320	7 × 7	160	9 × 9	80	11 × 11
	125	15 × 15	32	15 × 15	32	15 × 15
	125	8 × 8	20	10 × 10	11	13 × 13



uniform high luminosity for better than 100 μsec. All four inner walls had aluminized Mylar cemented to the explosive-covered and bare areas of the sides. This provided a highly reflecting surface ahead of the shock wave as it traveled the length of the candle. An extension hood taped outside the Plexiglas window served to extend the walls of the candle toward the target. This 6-in.-long hood, made of cardboard with aluminized Mylar cemented to the inner surfaces, restricted the luminosity to the target area and extended the useful duration of the luminosity by approximately 10%.

A small hole was drilled near the back end of the candle for the argon hose; air was flushed out through a similar hole near the window or front end. Argon was allowed to flow continuously to be sure of thorough flushing of air up to the actual detonation.

It was found that this configuration, when lined with folded sheet explosive and a highly reflecting surface, produced a reasonably constant light output for more than 100 μsec with an intensity as great as that for the peak of the 13-lb standard LRL candle. Undoubtedly, more luminosity can be gained by making the candle's outside structure of steel plate, which would concentrate more energy by reflecting the shock wave back into the gas-filled interior. This, combined with krypton or xenon and more powerful explosives such as HMX, would produce maximum luminosity from a given weight of explosive.