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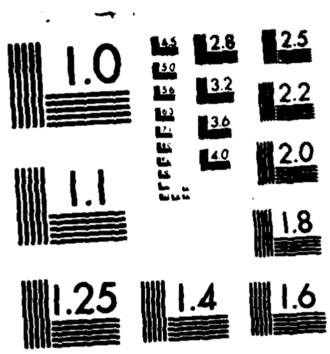
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TECHNICAL REPORT ARBRL-TR-02491

FLASH X-RAY CINERADIOGRAPHY AT 100,000 FPS

John J. Trimble
Clifford L. Aseltine

May 1983

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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flash x-ray	image intensification screen

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (dlc)

We have developed a cineradiography technique which will produce six pictures, each on a separate piece of film, with framing rates up to 100,000 frames/second. The system utilizes six 150 keV flash x-ray tubes mounted side by side in one head. X-rays are converted to light by a single x-ray image intensification screen with rapid phosphor decay. The x-ray screen is viewed through six individually adjustable lenses by six, gated image intensifier tubes with light amplification of 15,000. Output from the tubes is recorded on Polaroid film. The x-ray flash duration of 70 nanoseconds per tube determines exposure time.

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I. INTRODUCTION

In the past several decades, the field of detonation physics has made tremendous advances, due, in large measure, to the existence of high-speed framing cameras and streak photography. Flash radiography, although used extensively, has had less of an impact, due to the inability to obtain high framing rates. Because of a definite requirement for this capability for some of our projects, we have developed a flash x-ray cineradiography system.

Many x-ray cineradiography techniques have been proposed over the years. The objective of all such systems is to produce multiple, discrete images of a high-speed event with the shortest possible interframe time and with the least possible spatial separation of the x-ray sources. Systems proposed in the past have differed in the method used to generate the x-ray flashes and in the recording system. With respect to the x-ray source, Hunter[1] at Zenith Radio and Espejo[2] at Field Emission, Inc., suggested using multiple flash x-ray pulsers coupled to a single tube. This approach eliminated parallax, but anode heating severely limited the number of frames which could be taken. Bracher[3] used a steady state source with an image intensifier tube and high-speed framing camera. This system eliminates parallax but has low penetration capability and may be photon limited at high framing rates. In the work described here, we have used multiple flash x-ray tubes enclosed in a single tube head. This approach minimizes parallax while avoiding the difficulties mentioned above. With regard to recording techniques, Bracher and Swift[4] have suggested the use of a gated image converter camera which records successive images on different regions of the same piece of film. This system requires only one lens and image converter camera. We considered using a high-speed framing camera to view an image intensifier. This system requires an image intensifier with a fast decaying phosphor, an expensive high-speed framing camera, and may be photon limited due to the high f number (small effective aperture) and short exposure time of high-speed framing cameras. In the work described here, we overcame these problems by using a separate microchannel plate image intensifier for each frame.

II. EXPERIMENTAL SETUP

The block diagram of the cineradiography system is shown in Figure 1. This is a six-flash system capable of framing rates greater than 10^5 frames/second. The flash x-ray portion of the system consists of a six-channel

---

[1] *Hunter (1962) Zenith Radio Corporation, Menlo Park, California.*
[2] *Espejo, R. (1979) Hewlett-Packard, Field Emission Division, McMinnville, Oregon.*
[3] *Bracher, R. (1980) International Applied Physics, Inc., Dayton, Ohio.*
[4] *Swift, H. (1980) International Applied Physics, Inc., Dayton, Ohio.*

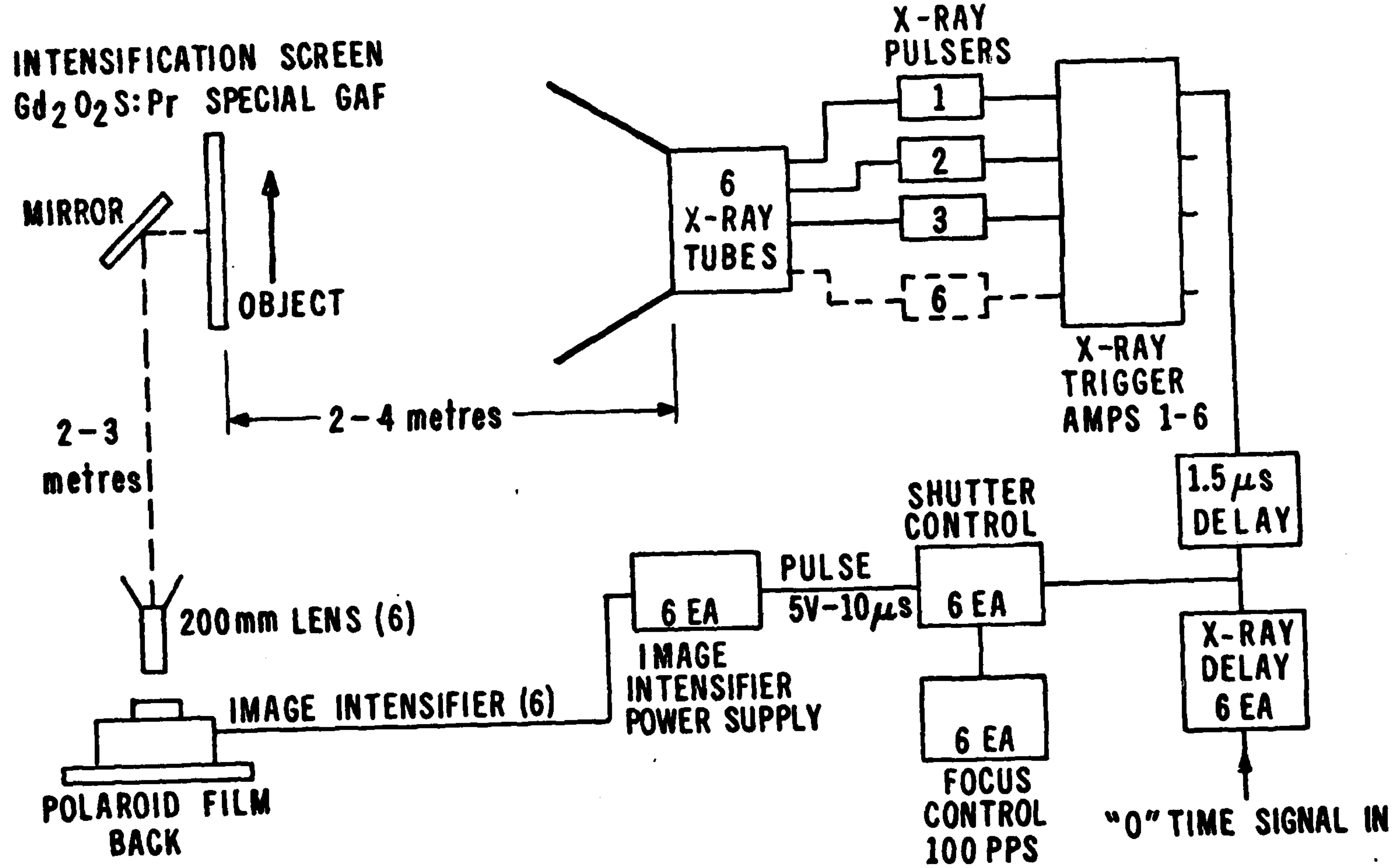


Figure 1 : Block diagram of Cineradiography System.

Hewlett-Packard 150 kv, 70 nanosecond pulse duration x-ray with six tubes contained in a single specially designed head and spaced 44.5 mm center to center (Figure 2). The exposure time of each frame is controlled by the pulse duration of the source. The x-ray photons are converted to visible light on a single 356 x 432 mm fast decay phosphor x-ray intensification screen. The choice of this screen will be discussed later. Six 200 mm F/2 lenses focus the image from the screen onto the input windows of six gated ITT microchannel plate image intensifier tubes (Figure 3) with gains adjustable up to 15,000. The image is recorded on Type 52 Polaroid film which is in direct contact with the output fiber-optics on each image intensifier tube.

A special pulsing circuit (Figure 4) for the gated image intensifier tube was developed to control the shutter "open" time. This time is adjustable from 3 to 100 μsec and is a function of framing rate. Built into the circuit is a novel pulse generator for static focusing of the optical system at a rate of 100 pulses/second.

III. SEQUENCE OF OPERATION

After a "0" time signal is supplied to the six delay units, a suitable delayed signal gates the first image intensifier and x-ray tube no. 1. The image tube is gated on for an adjustable period, determined by the framing rate. The moving object is shadowgraphed on the x-ray intensification screen, picked up by the image intensifier, amplified up to 15,000 times, and recorded on Polaroid ASA 400 film. This sequence continues for five additional flashes with adjustable preset intervals. A total of six individual flashes is recorded on six separate pieces of film.

The resolution of the image intensifier tube is nominally 22 line pairs/mm. When these images are enlarged to normal size, resolution becomes about 1.5 to 2 line pairs/mm, which is comparable to the resolution obtained in energetic ballistic events utilizing a standard x-ray film and intensifying screen package.

Prior to a decision on this approach to take cineradiographs, a study of x-ray intensification screens was undertaken. Light output and duration were measured with a photomultiplier tube and lens looking at several types of screens and phosphors. The results of our screen studies are shown in Figures 5-8. Phosphors tested and the principal results are as follows:

1. IAP-2000. A proprietary composition supplied to us by International Applied Physics who suggested its use for cineradiography applications.
2. Anthracine/Lucite. This phosphor was prepared by Gibbons in our laboratory as a possible fast decay scintillator. Results indicate this phosphor has definite possibilities for fast-framing-rate cineradiographs (10^6 FPS).
3. P-15. This phosphor was furnished by Sylvania. Excellent fast-decay characteristics.
4. P-24. Another Sylvania phosphor. Has very fast decay response.
5. $Gd_2O_2S:Pr$. From GAF. Very high light output with short decay.

Utilizing these results, it appears the special GAF $Gd_2O_2S:Pr$

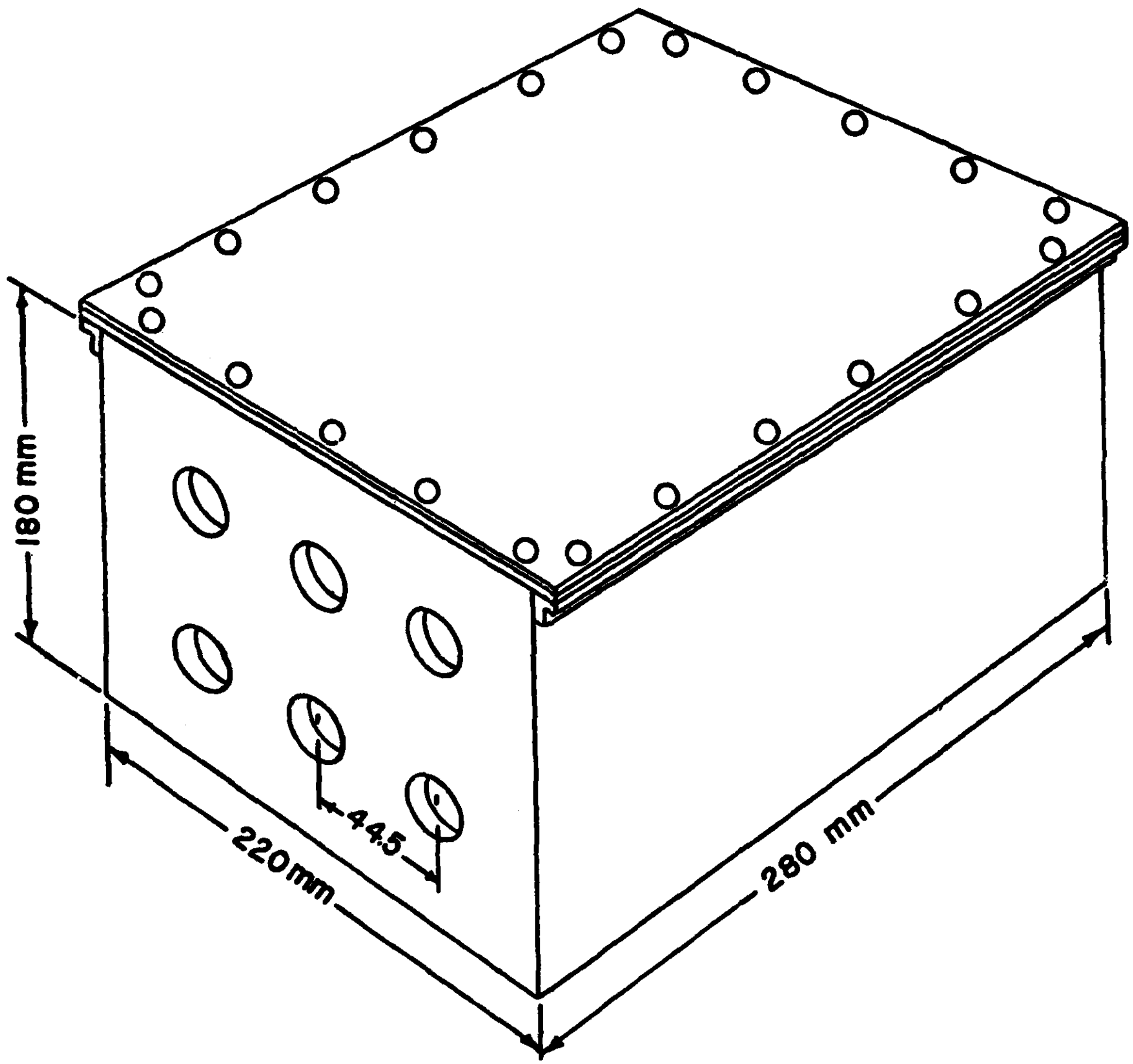


Figure 2: Single head containing six tubes.

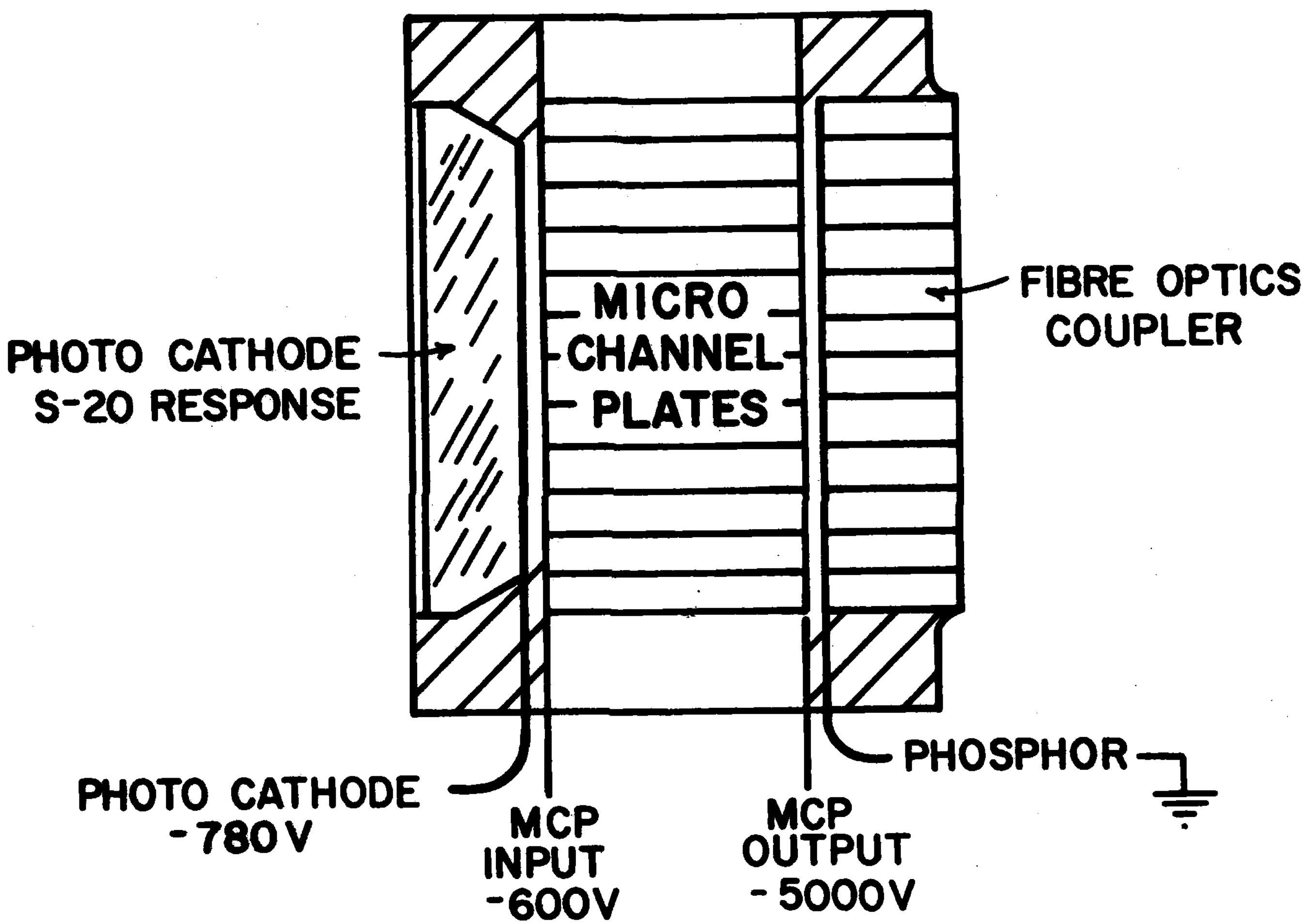


Figure 3: ITT Micro Channel Plate Image Intensifier Tube.

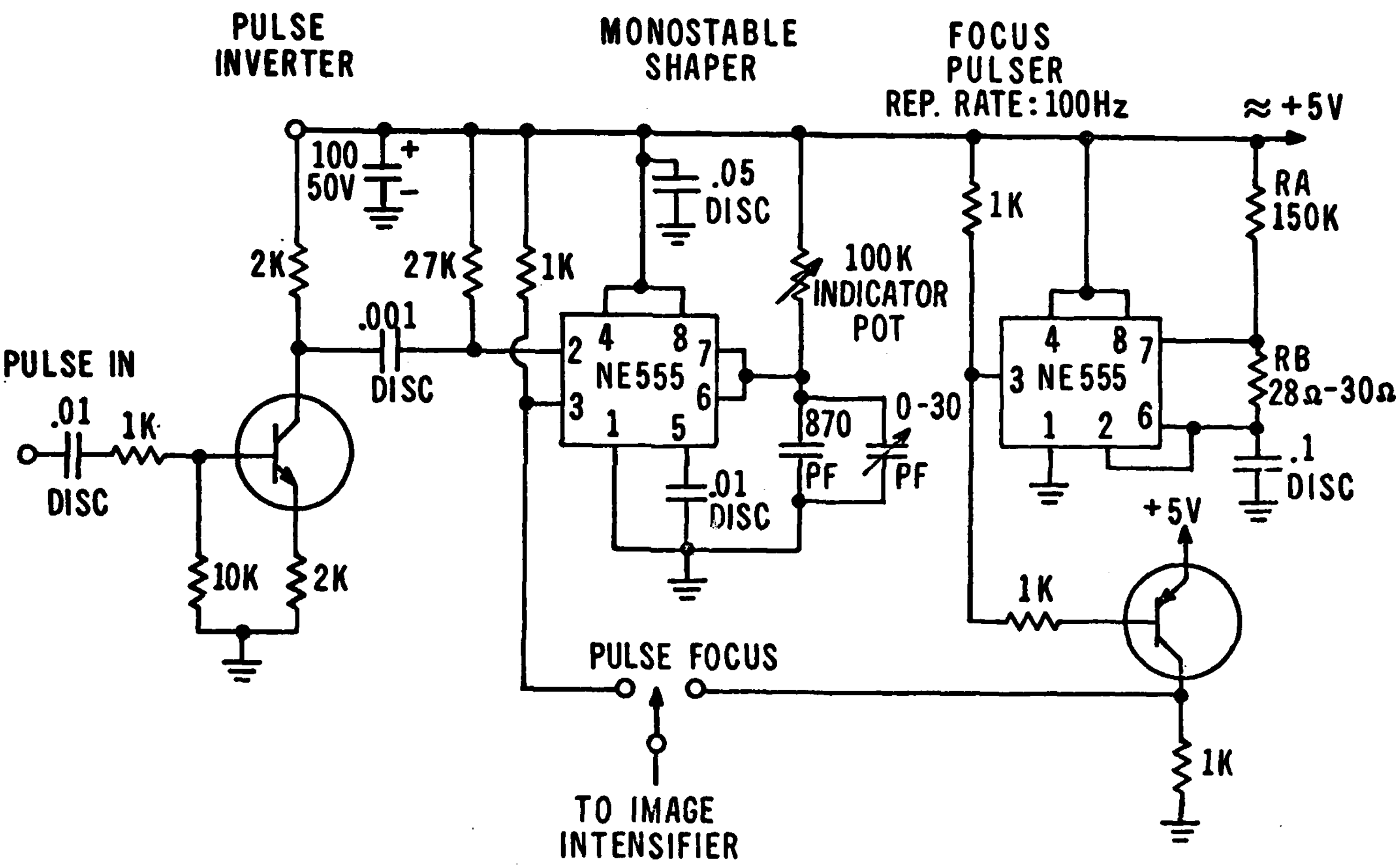


Figure 4: Diagram of electronic focusing and pulsing circuit.

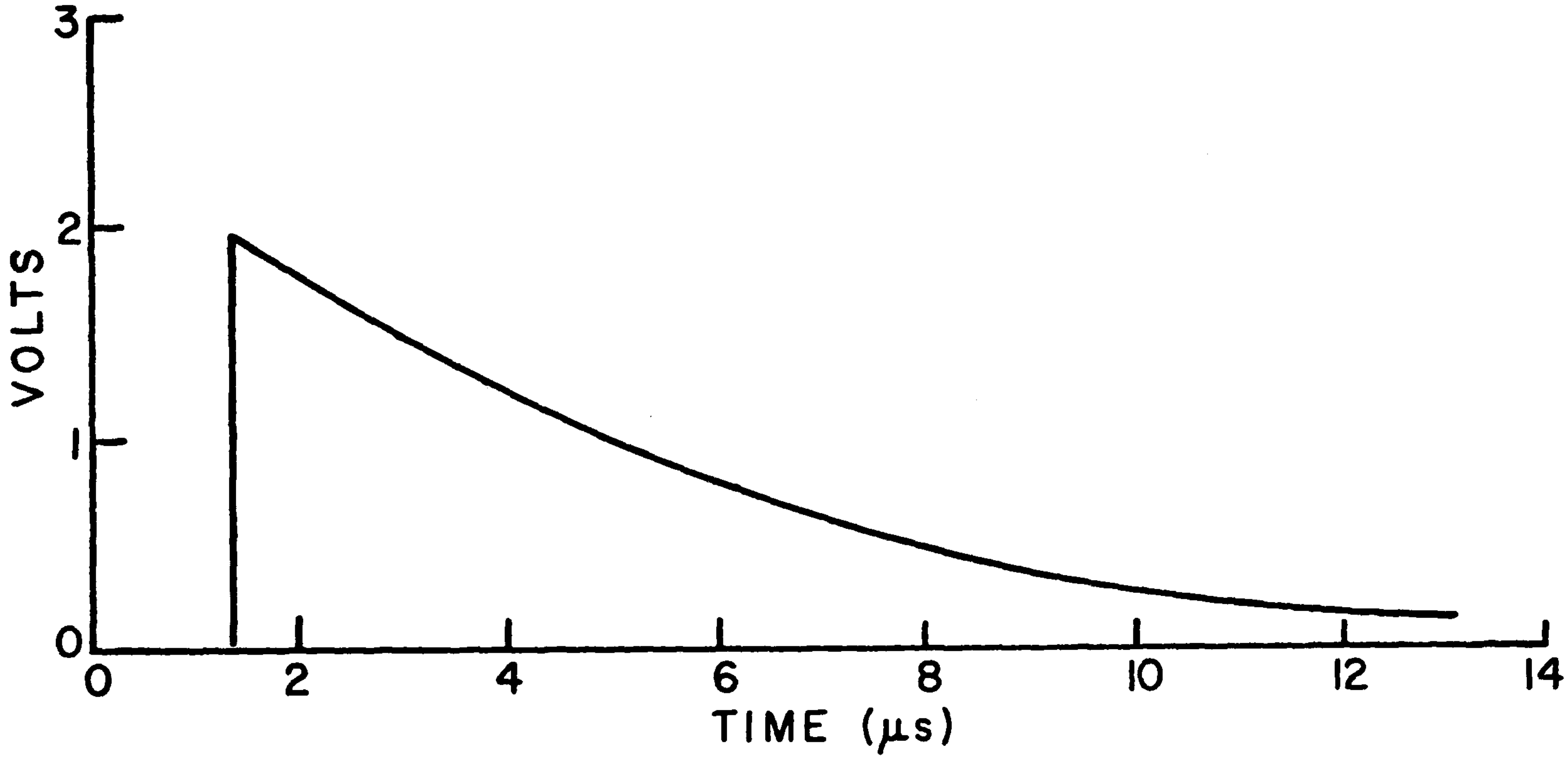


Figure 5 : Result of study of GAF Gd_2O_2S:Pr Screen (August 1980).

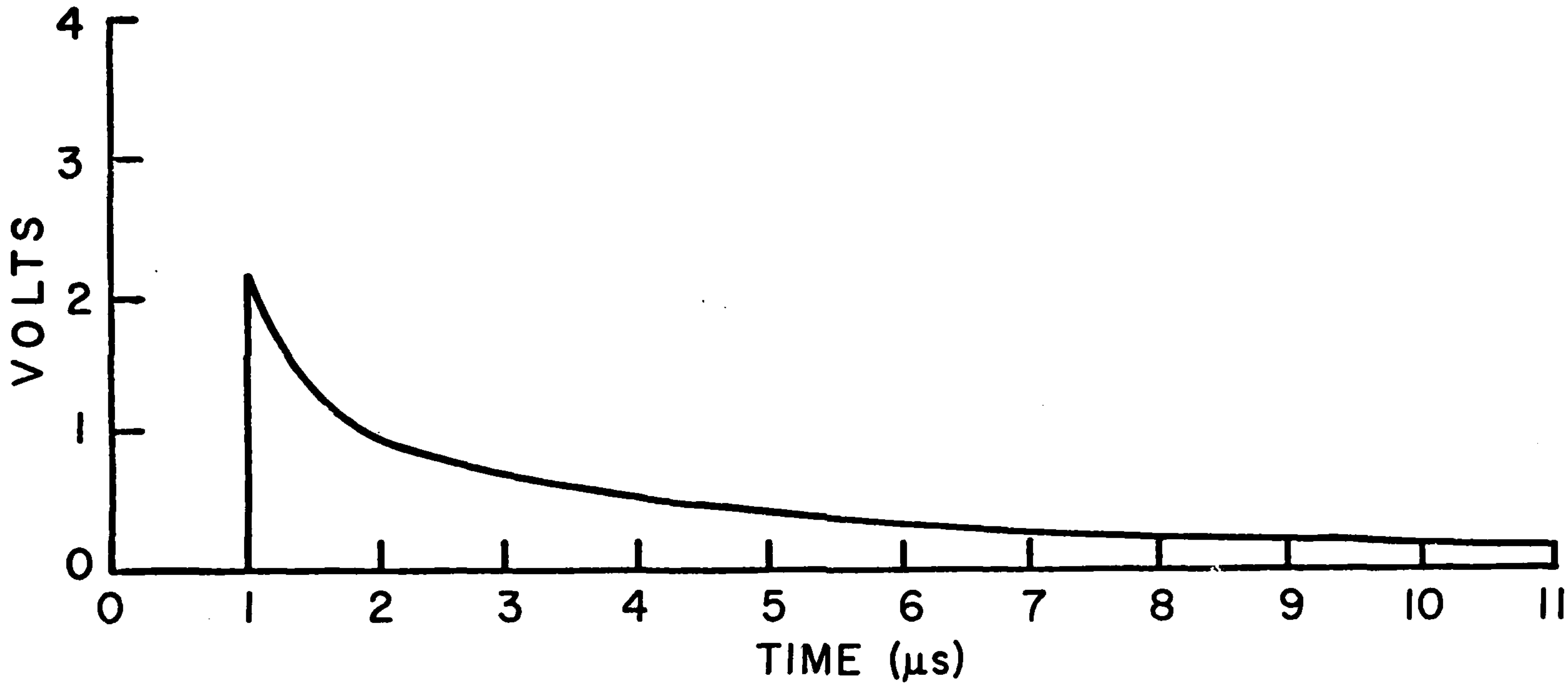


Figure 6: Result of study of P-15 phosphor screen.

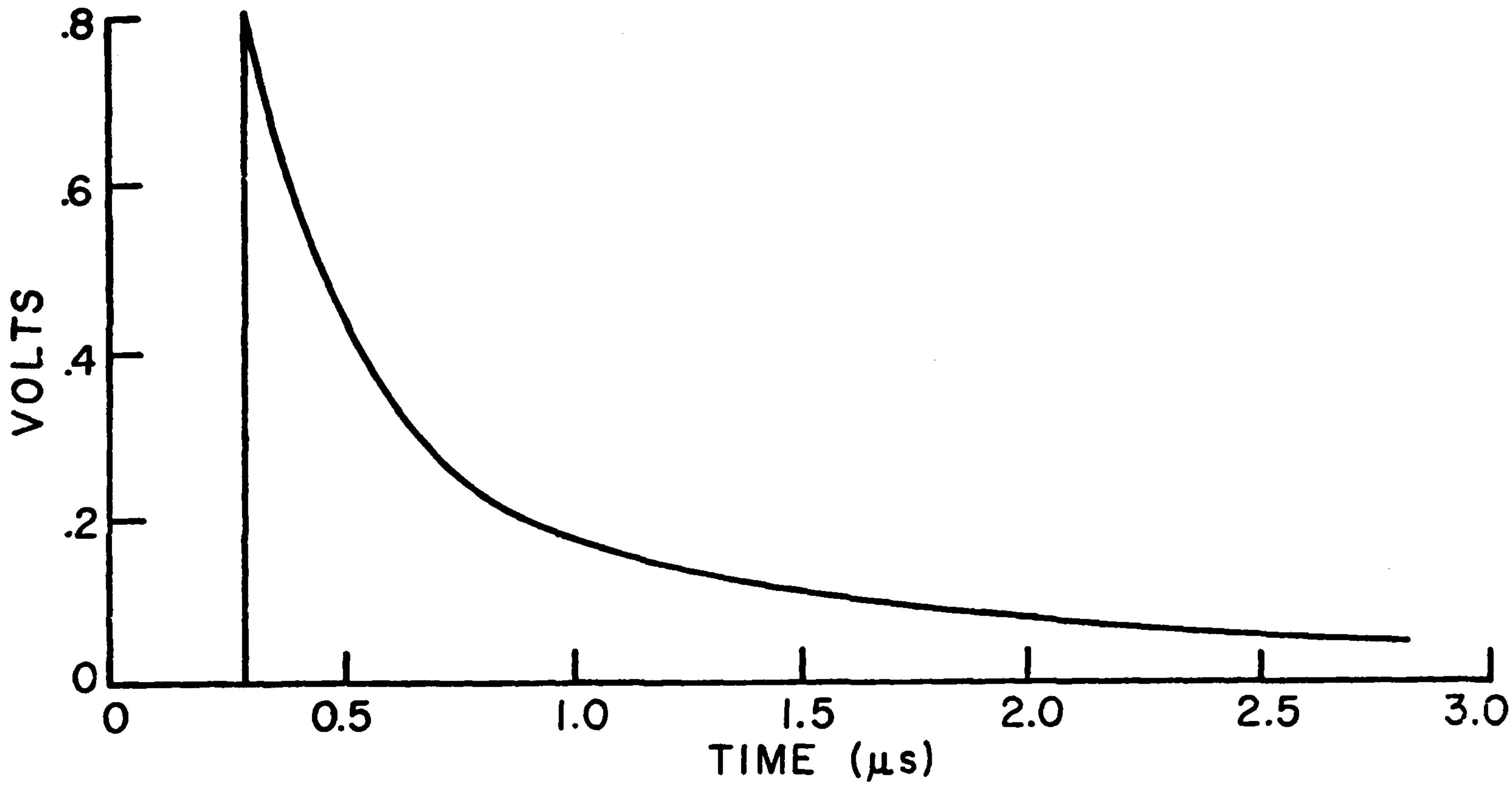


Figure 7: Result of study of P-24 phosphor screen.

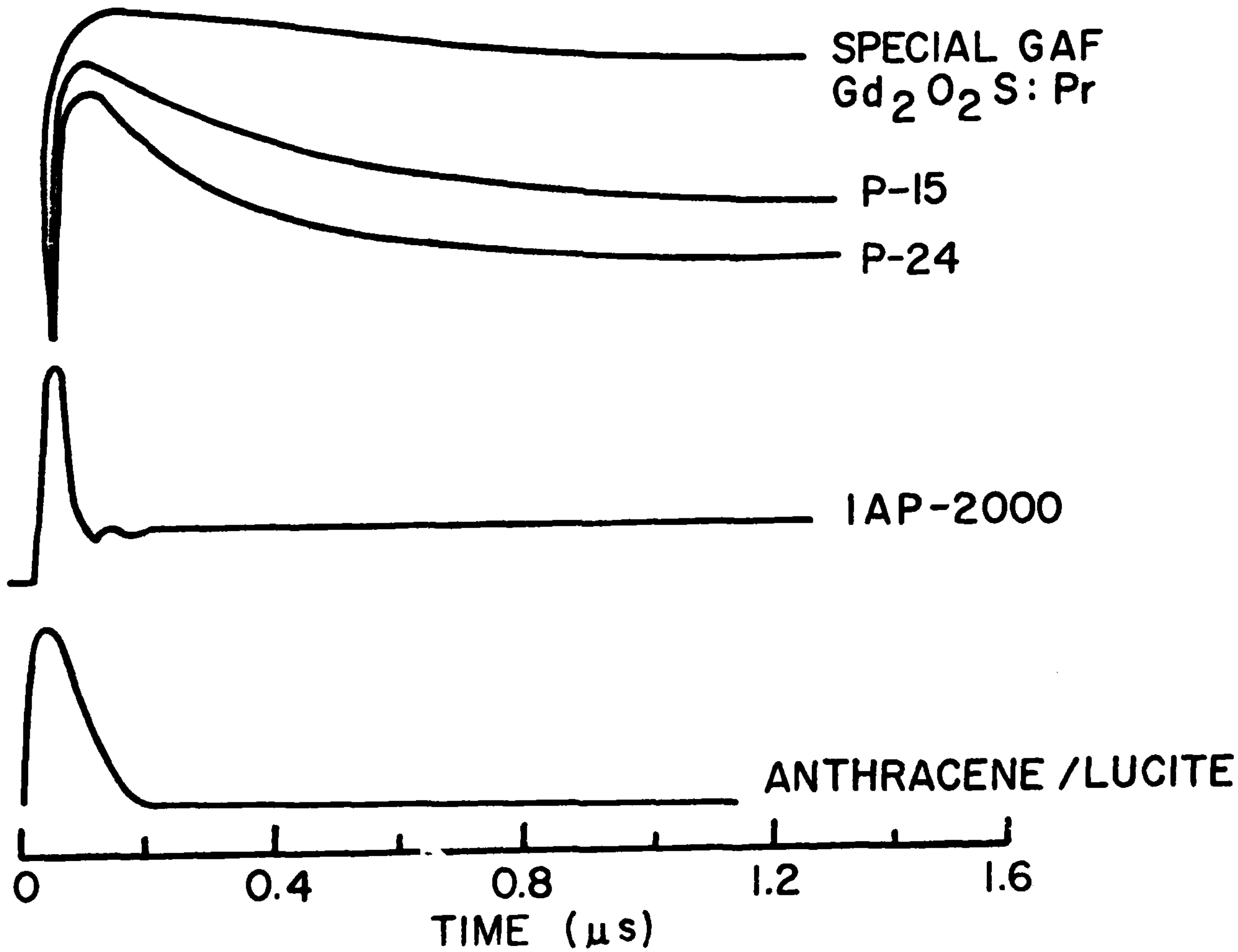


Figure 8: Comparison of fast decay intensification screens.

(gadolinium-oxy-sulfide with praseodymium doping) provides the most light over a 10 μsec interval. This screen decays to the baseline in approximately 14 μsec, but at the 10 μsec point is sufficiently decayed that it does not interfere with subsequent pictures. Gadolinium-oxy-sulfide screens are widely used as x-ray intensifiers. When the rare earth element praseodymium is added, the phosphor decay time is greatly reduced. Light emission from our screen falls in the blue-green region. Higher frame rates can be obtained by using faster decay phosphors such as P-15 or P-24. Work is continuing on phosphors for these higher frame rates.

IV. RESULTS

With the Gd_2OS_2:Pr screen and system components shown in Figure 1, a three-channel system was assembled and tested (Figure 9). The first sequence of pictures shows a 25 mm diameter x 6 mm thick disc being propelled from a stick of explosive. The delay between each picture is 175 μsec, producing a framing rate of 5700 FPS. Using the 50 mm fiducial marks located on the intensification screen, the measured velocity is approximately .63 mm/μsec (Figure 10).

The second series of pictures are shadowgraphs of a much faster event. Sheet explosive, 1.6 mm thick, is sandwiched between two 3.2 mm x 25 mm x 300 mm aluminum plates and detonated. The delay between pictures is 10 μsec giving a framing rate of 10^5 FPS. The detonation velocity measured from the film is approximately 7 mm/μsec (Figure 11).

V. CONCLUSIONS

We have demonstrated the capabilities of the cineradiography system with a sequence of three pictures. Three more channels will be incorporated when additional image intensifier tubes and flash x-ray pulsers are delivered. No problems are anticipated with the additional channels. We feel any reasonable number could be added, possibly 9 to 12 without any degradation in performance.

The system described here offers the following features, many of which are not available on existing cineradiography systems:

a. High penetration capability through dense materials

b. High framing rate > (10^5 FPS)

c. Good resolution

d. Short exposure time (70 nanoseconds)

e. Minimal parallax

f. Immediate film processing

g. No superimposed images from multiple flashes

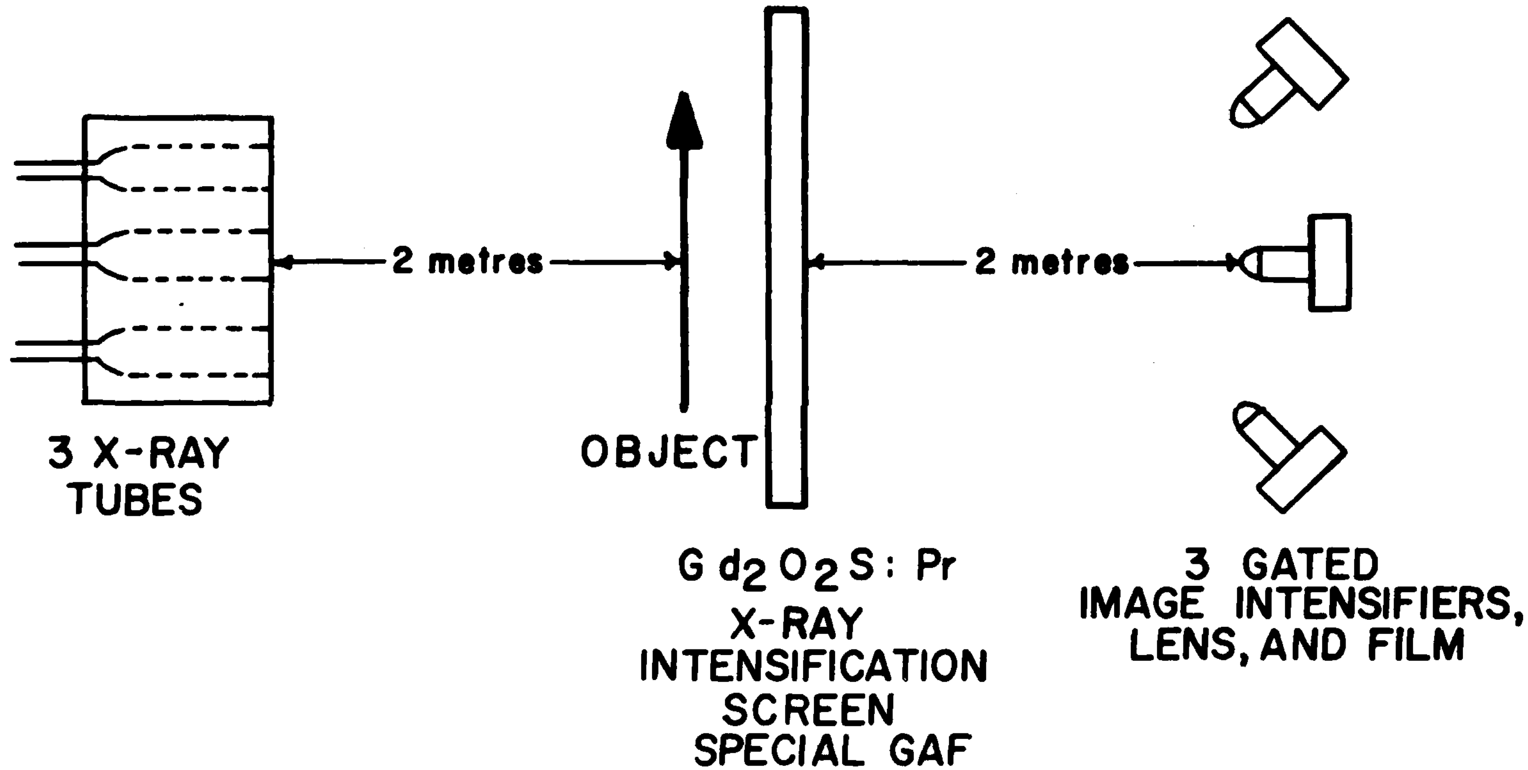
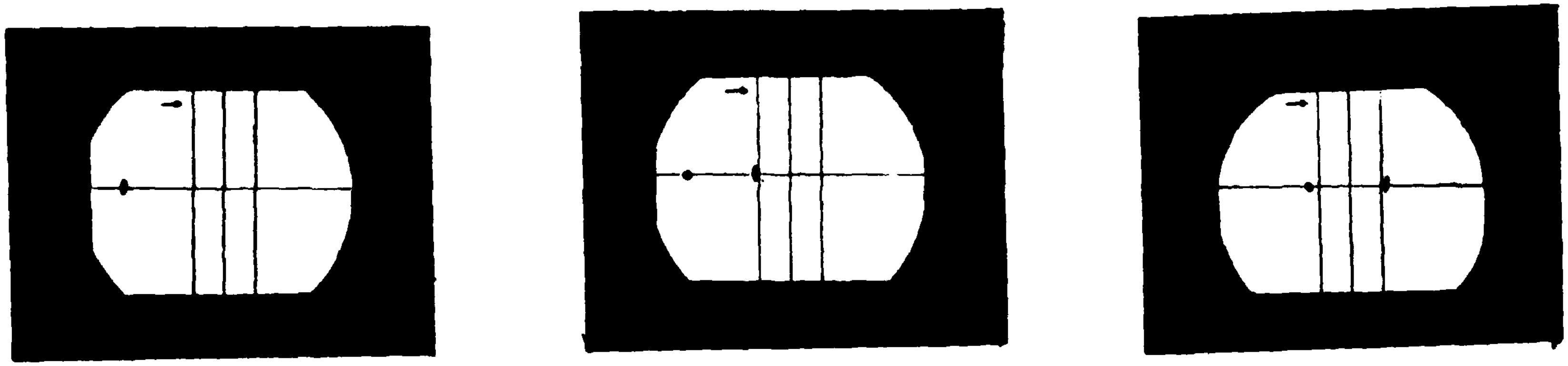
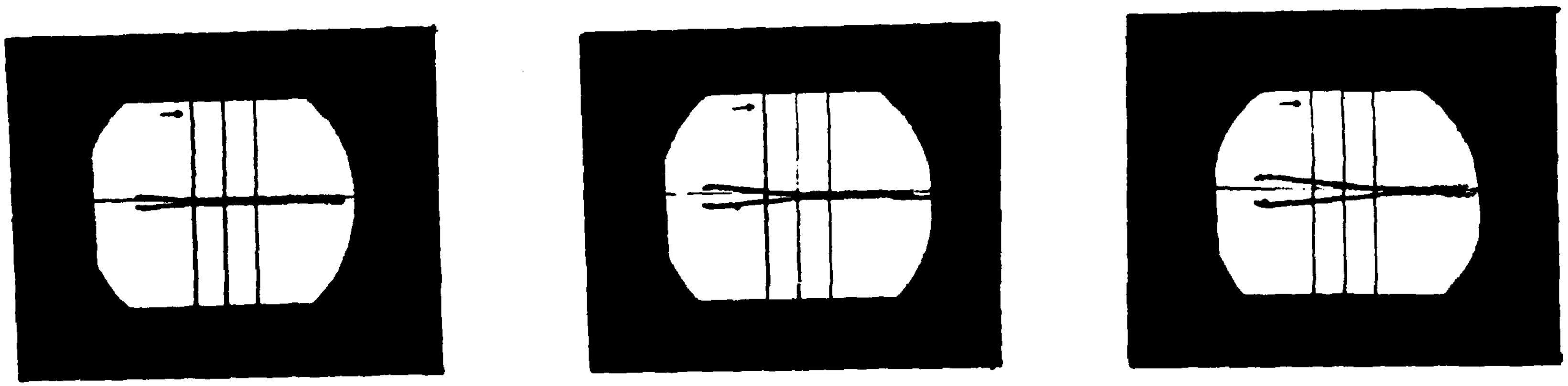


Figure 9: Set-up for Three-Flash Cineradiography.



CHANNEL 1 CHANNEL 2 CHANNEL 3

FIGURE 10 -LOW FRAMING RATE SEQUENCE (5700 FPS)



CHANNEL 1 CHANNEL 2 CHANNEL 3

FIGURE 11 -FAST FRAMING RATE SEQUENCE (100,000 FPS)

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