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Investigation of the Use of a Stereo Cranz-Schardin Camera Having Video Image Sensors to Behind-Panel Fragmentation Studies

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A novel optical diagnostic apparatus for behind-target fragmentation studies was investigated. A simple concept was designed, constructed and tested using gun-fired projectiles. The goal of the work was to demonstrate that measurements of the fragment mass, velocity, and trajectory could be made with a system that requires an absolute minimum of operator intervention. The final report describes the system that was used and includes some data that was obtained from the experiments.

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PREFACE

This program was conducted by Special Illumination Systems, 444 Volusia Ave., Dayton, Ohio 45409, under Contract F08635-86-C-0226 with the Air Force Armament Laboratory, Eglin Air Force Base, Florida 32542-5000. George C. Crews, AFATL/SA managed the program for the Armament Laboratory. The program was conducted during the period from 11 August 1986 to 11 February 1987.

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LIST OF ABBREVIATIONS

Symbol	Meaning
AGC	Automatic Gain Control
AP	Armor-Piercing (round)
CCD	Charge-Coupled Device (image sensor)
CID	Charge-Injection Device (image sensor)
C-S	Cranz-Schardin (camera system)
HE	High Explosive (projectile)
KE	Kinetic Energy (projectile)
mm	Millimeters
nm	Nanometers
PRF	Pulse Repetition Frequency
SCR	Silicon Controlled Rectifier
SLR	Single-Lens Reflex (camera)
VCR	Video Cassette Recorder

SECTION I

INTRODUCTION

1. STATEMENT OF THE EXPERIMENTAL PROBLEM

The generation of behind-panel fragments is of interest to both survivability and vulnerability groups. Of course, the reasons for this interest are different; but, a knowledge of the fragments produced behind a panel when its front surface is struck by an HE or KE projectile is fundamental to the study of the effectiveness of a weapon or of the effectiveness of the armor designed to defeat it.

The environment behind a panel immediately after an impact on the front surface is filled with numerous high-velocity fragments and some may be pyrotechnic. A residual fragment of the original projectile may also pass through this region. Therefore, diagnostic equipment intended to study the fragments must be non contact, at least close to the rear surface of the target panel.

The conventional method of ruhning experiments designed to investigate the behind-panel fragments is to use two or more orthogonal flash x-ray systems to record the positions of the fragments at two points in time and a catch system to capture the fragments for the purposes of determining their masses. The problem with this technique is that it is very labor intensive and time consuming. Computer programs have been written to assist in the analysis of the flash x-ray data, but the execution of such an experiment still takes a long time. The processing and reading of the resultant radiographs is laborious. The fragmentation process is a statistical phenomenon so that a useful data base can be assembled only after a large number of experiments have been conducted. At present, this is not economically feasible.

While very suitable for in-bore and other types of imaging where no alternative technique is available, the flash x-ray technique suffers from several drawbacks when applied to the study of behind-panel fragmentation. First of all, x-rays cannot be usefully focused in the laboratory. This means that all radiographs must be unfocused shadowgraphs where resolution is limited and small particles cannot be easily detected even if they are of interest. The limited resolution of an x-ray system also places limits on the degree of accuracy of any velocity measurements made. Current x-ray systems are also expensive to use due to film processing and reading. In order to produce the amount of data required for behind-panel fragmentation studies, several sequential images of a given fragment are required. The data from these tracking images are used to determine the velocity and mass of the fragment. In fact, ten or more images would be desirable, but the cost of assembling such a large number of x-ray systems would be prohibitive even if it were possible to pack them in a sufficiently dense array. The radiographic film is always of large size--packing x-ray systems close together is nearly impossible. A better method of detecting and tracking behind-panel fragments would be helpful to generate a useful data base for such events.

2. THE CRANZ-SCHARDIN CAMERA AS A TOOL FOR BEHIND-PANEL DIAGNOSTICS

The Cranz-Schardin (C-S) camera was pioneered in Germany during the mid-1920's and was the first high-speed camera to be developed. In fact, even now it is capable of producing images as fast as any mechanical or electrical camera; and, the images are of much higher resolution since the camera has no moving parts, not even an electron beam as is present in an image-converter camera. The C-S camera is capable of recording images at any rate which might be desirable for behind-panel fragmentation studies. In addition, no resonant circuits, either mechanical or electronic, are present in a C-S camera so changing the time intervals between successive images is very easy to accomplish. This feature makes the C-S camera especially well adapted to ballistic-type experiments in which a system changes rapidly with time at the beginning of an event, but evolves more slowly later on. A C-S camera can be arranged so that the images it produces span both temporal regions, recording images rapidly at the beginning of an event, but more slowly as time proceeds.

As compared with other types of camera systems, the C-S camera has two disadvantages: it cannot record front-lit pictures; and, the images it records are from slightly different directions (parallax error). As will be shown below, neither of these are important in behind-panel diagnostic applications.

The C-S camera records only shadowgraphs of its subjects;

however, for fragmentation studies this is not a major disadvantage. All of the important data of fragment position, velocity, and eventually mass can be determined from a series of shadowgraphs. The fragments appear to be sharply defined black objects against a white background which makes them very visible. Surface detail (which is the only additional data which could be furnished by front-lit photography) is not of significance in fragmentation studies.

In fact, the shadow images which the C-S camera records are a positive benefit because such an imaging system has an immense depth-of-field; and, the images of objects which are widely separated in space will all be in sharp focus on the image plane. The reason for this is that the camera lenses of a C-S camera can be operated with large f/numbers. The light from the camera's sources can be coupled through a very small lens making the depth of field of the C-S camera very large and, consequently, it can be employed with large sample volumes. As an object moves toward or away from the camera lenses, its image will become larger or smaller, but its edges will remain sharp. In a stereo C-S camera system, corrections can be made for the apparent changes in object size.

The parallax errors which are introduced by the slightly differing observation angles in a C-S camera can be corrected without difficulty. Each fragment is imaged at every point in time by two different camera systems. One of these can record the apparent x and z coordinates of a fragment, while the orthogonal image records its apparent y and z coordinates. In most cases, the z coordinate will serve to uniquely define a fragment since it is very unlikely that two fragments will have exactly the same displacement in this direction. By means of a simple iterative procedure, the true x and y coordinates of a fragment can be generated from the image data. Also, the magnifications at which the two images were recorded can be calculated and the true fragment size measured.

There are two primary experimental difficulties which must be overcome when the C-S camera is applied to the study of behind-panel fragmentation: the bright flash of light (impact flash) which is produced whenever two solid metallic bodies strike one another at high velocities; and, the dense cloud of fine debris which is generated by the penetration of a projectile through a panel. We believe that the data gathered during the course of the present study indicates that both of these problems can be overcome with the use of a stereo laser-illuminated C-S camera.

SECTION II

EXPERIMENTAL EQUIPMENT AND TECHNIQUES

1. CRANZ-SCHARDIN CAMERA SYSTEM

A stereo Cranz-Schardin (C-S) camera system, illustrated schematically in Figure 1, was constructed for use in this project. The camera had two large field lenses of 11 3/4-inch diameter and 50-centimeter focal length. Six 370 watt pulsed semiconductor lasers (M/A COM Laser Diode type LD430)--three for each field lens--were mounted so that they all illuminated their corresponding field lens. The divergence angle of the laser beams produced by these lasers is highly assymmetric, being about 12 degrees in one direction and about 24 degrees in the other. Accordingly, small cylindrical lenses were used to correct the divergence of the laser beams in the larger direction so that each beam illuminated an approximately square area of the field lens. The field lens collected the light from each laser and focused it down to a small spot on the corresponding small camera lens. The camera lenses were simple biconvex, of 19-mm diameter and 50-mm focal length. Because of the physical limitations imposed by the placement of the gun range so close to one wall of the room in which it was housed, it was necessary to use two flat mirrors, one for each orthogonal direction, to bend the optical paths so that the six IR-sensitive video cameras could be mounted as illustrated in the figure. It was intended that the active volume (where both views can image the same fragment) should be about 10 inches in

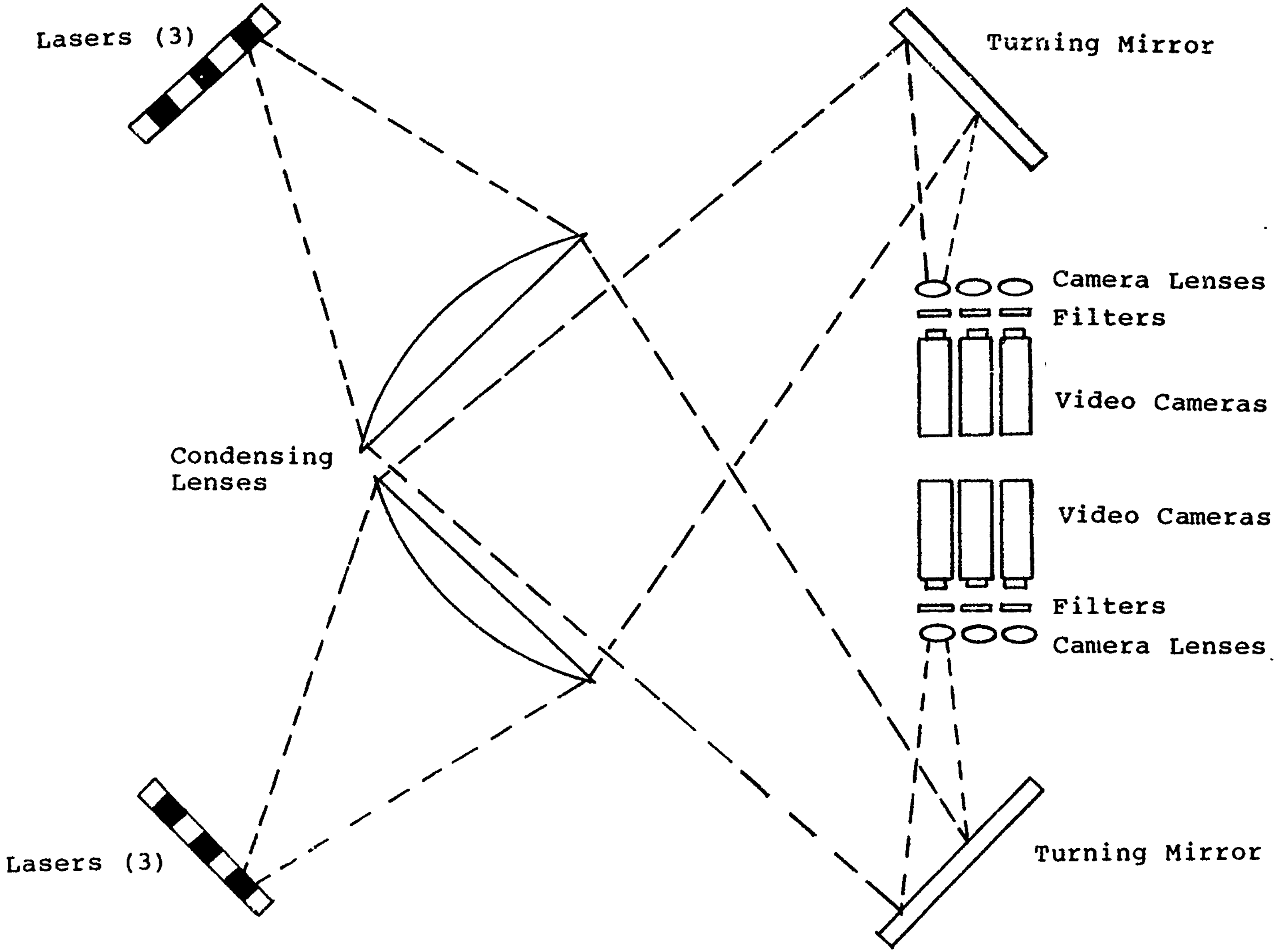

Figure 1. Schematic Diagram of C-S Camera System

diameter, but the spherical aberration of the large lenses reduced this to only about 5 inches. This problem can be overcome, but was not recognized until it was too late to be corrected. (The correction method is described in Section V.)

Figure 2 illustrates the phenomenon of on-axis spherical aberration. A thick spherical lens, as is illustrated in the figure, will not diffract all the rays originating at a point on one side of the lens to a single point on the other side. Light rays which strike the lens at a large distance from its center will be bent so that they cross the optic axis of the lens behind the classical focal point. The camera lens of a C-S camera cannot collect these rays and, therefore, the outer portion of the field of view appears to be black. Thus, it appears that the whole of the large condensing lens is not illuminated and the field over which the C-S camera can record back-lit images is restricted.

The M/A COM laser diodes emitted at 904 nm and produced a peak output power of about 370 W with a pulse duration of about 100 ns. Each laser was independently driven by discharging a .01 mFd-capacitor charged to 600 volts through it by means of a type S3700M silicon-controlled rectifier (SCR). The lasers were fired in pairs--one for each orthogonal direction--whereby two images were recorded simultaneously. In all, six images were recorded per impact in three pairs.

The time differences between the firings of the pairs of lasers were set using a Commodore SX-64 portable microcomputer. The C-S camera was equipped with a counting board which consisted of three sets of five counters each. The counters

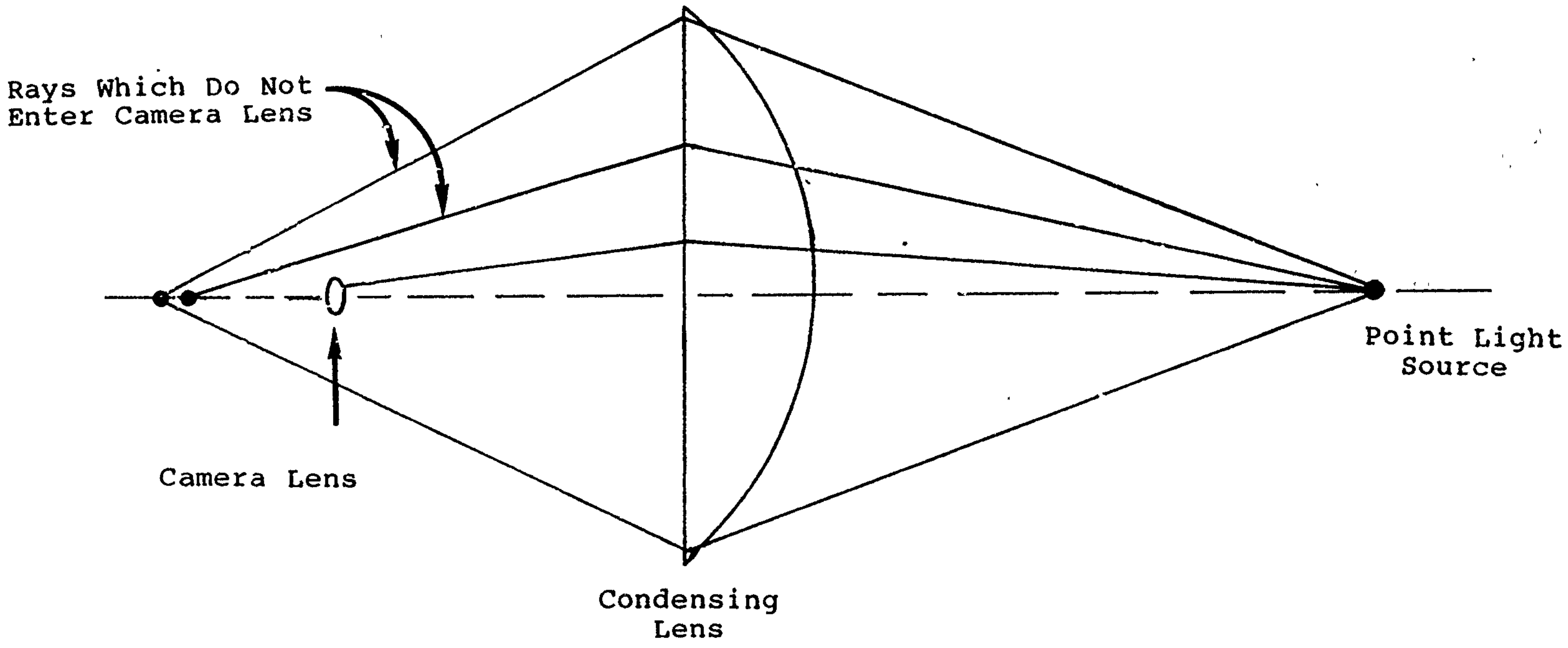

Figure 2. Influence of Spherical Aberration on the Field of View of a C-S Camera

were loaded with data prior to the beginning of each experiment. Then, upon the receipt of a trigger signal, all three sets of counters would begin to count down simultaneously. The clock frequency for the countdown was only 1 MHz. The counting circuitry was actually capable of operating at rates 20 times as high as this, but since time intervals measuring tens or hundreds of microseconds were involved in the ballistic experiments, there was no need to run the clock faster. Each set of five counters was loaded with a different number. Therefore, during the countdown sequence, one set would reach terminal count first and the corresponding pair of lasers would fire. As the countdown proceeded, the next set of counters would reach zero, the next pair of lasers would fire, and the process continued through the third set of counters. Three intervals were used to control the times:

a. the time between impact and the firing of the first pair of lasers,

b. the time between the firing of the first pair of lasers and the second pair of lasers,

c. the time between the firing of the second pair of lasers and the third pair of lasers.

The program employed was adapted from one normally used by the contractor in conjunction with its commercial line of C-S cameras.

Video cameras (Model 7282) were purchased. Their resolution is relatively low. Their image is 660 by 495 pixels, but they are relatively inexpensive and appear to be more sensitive than charge-coupled device or charge-injection device cameras. Also, the CCD camera with which we have had experience displayed all the symptoms of having a sharply-defined threshold. Below this level, the camera does not appear to produce any image at all; however, above the threshold, the image is quite bright. As we were not certain of the cause of this effect, vidicon video cameras having a larger gray scale were used. The lenses with which these cameras are normally equipped were removed and replaced by the simple lenses mentioned above. The Cranz-Schardin does not favor the use of multi-element, complex lenses--simple ones work better. The cameras were allowed to free-run, and their outputs were fed into six independent video cassette recorders (VCR's). The image data written onto the video cassette was recovered later. The method for doing this is described below.

The VCR's recording the images from the video cameras were labeled 1 to 6, and the tapes recorded by them were labeled by shot number and VCR number. Because of the VCR numbering scheme employed, the images recorded were paired as follows: Tape 1 and Tape 6 recorded the lasers which fired first, then Tape 2 and Tape 5 recorded the images from the second pair of lasers to fire and, finally, Tape 3 and Tape 4 recorded the images produced by the last pair of lasers to fire.

The light output from the lasers is many decades higher than that required by the video cameras to produce an image. Therefore, the light reaching the faceplates of the cameras was attenuated by passage through a number of attenuator layers. The primary attenuator was an interference filter having a nominal bandwidth of 5 nm and centered at 904 nm. This reduced the intensity of the laser light by about 50 percent and, for all practical purposes, completely eliminated any extraneous light with wavelengths shorter than about 900 nm or longer than about 910 nm. In addition, three layers of neutral density filters were used. The total attenuation at 904 nm was about a factor of 400,000 or 56 dB. At all other wavelengths it was very much higher. The lasers employed were obviously very much more intense than required. In fact, pulsed light-emitting diodes (LED's) would have worked in this application were it not for the high level of impact flash which had to be discriminated against. By starting with a high power laser, it was possible to employ filters of a very high optical density and, thereby, eliminate the effects of the impact flash.

The video signal outputs from the six video cameras were fed into inputs of six Realistic Model 16 video cassette recorders (VCR's). The VCR's were all activated simultaneously by a remote IR hand-held control. The tapes in the VCR's were all rewound and the VCR's were all set to record, but not turned on. After the gun was set to fire, the last action before closing the door to the room in which the gun range was housed was to activate the VCR's to begin recording. They were set to run at the speed normally designated long play, or the middle speed range. Usually the time required to charge up the capacitor employed to fire the gun solenoid allowed the VCR's to run the tape for a distance of about 10 feet, so the recorded images were always close to the beginning of the tapes.

2. GUN RANGE DESCRIPTION

A Mann barrel about 5 feet long and rifled for 0.50 caliber rounds was used as the launcher. Armor-piercing (AP) 0.50-caliber rounds were used in all tests. The launch velocity in all tests was nominally 3000 ft/sec. The gun fired into a 6-inch (inside) diameter steel drift tube approximately 6.5 feet long which ran between the muzzle of the gun and the target tank. (A drift tube is simply a hollow tube which the bullet "drifts" through.) The target tank was constructed specifically for this project and had external dimensions of 14 inches wide by 14 inches high by 24 inches long. At a distance of 10 inches into the tank, provisions were made for attaching the steel target plates. The sample volume, in which the images of the fragments were recorded, was located approximately 1.5 inches further downrange. This volume was bounded on the four lateral sides by apertures covered by plastic windows. The apertures were 11 by 11 inches and the windows were 14 by 14 inches. The windows were made of methacrylate plastic and consisted of two layers: a 0.25-inch thick layer on the inside and a 0.50-inch thick layer on the outside. The double-layer construction was used because it was anticipated that the windows might be struck by small fragments which the thinner inner layer could stop without damaging the more expensive outer layer. However, experience showed that this precaution was unnecessary since very little damage was done to the inner surfaces of the windows, at least during the short shooting sequence of this program. The idea is a good one since a thin inner layer of plastic can protect the thick outer plastic in the event that a small fragment is launched at a peculiar angle. When a dynamite cap was detonated into the target tank, the thin plastic inner layer did stop its fragments.

A stopping tank, about 36 inches on a side, was attached to the target tank on its downrange side. This tank contained a large steel block to capture the fragments and the residue of the steel core of the 0.50 caliber armor-piercing round.

Figures 3 to 6 illustrate several views of the C-S camera, the gun range, and the target tank.

A trigger signal was generated by a foil switch attached to the steel target plates. The foil switches were located on the uprange side of the target plates so that the switch was closed as soon as a projectile impacted the target. The output pulse from this switch was suitably processed to provide the TTL-level (+5 VDC) trigger pulse used to initiate the firing of the laser sequence.

3. IMAGE ANALYSIS

The video cameras and VCR's were allowed to run freely. That is, there was no correlation between the impact of the projectile against the target plate (and hence the firing of the lasers) and the scanning of the faceplate of the vidicon tube. Therefore, in most instances a laser fired when its corresponding video camera was in the middle of a field scan. The first part of this field was black since the laser had not fired when that portion of the face was scanned; later on the field would become bright since the laser had fired. The next

Figure 3. Target Tank and C-S Camera System, Camera Pulled Uprange to Reveal Target Tank

Figure 4. C-S Camera in Position Around Target Tank, Downrange View

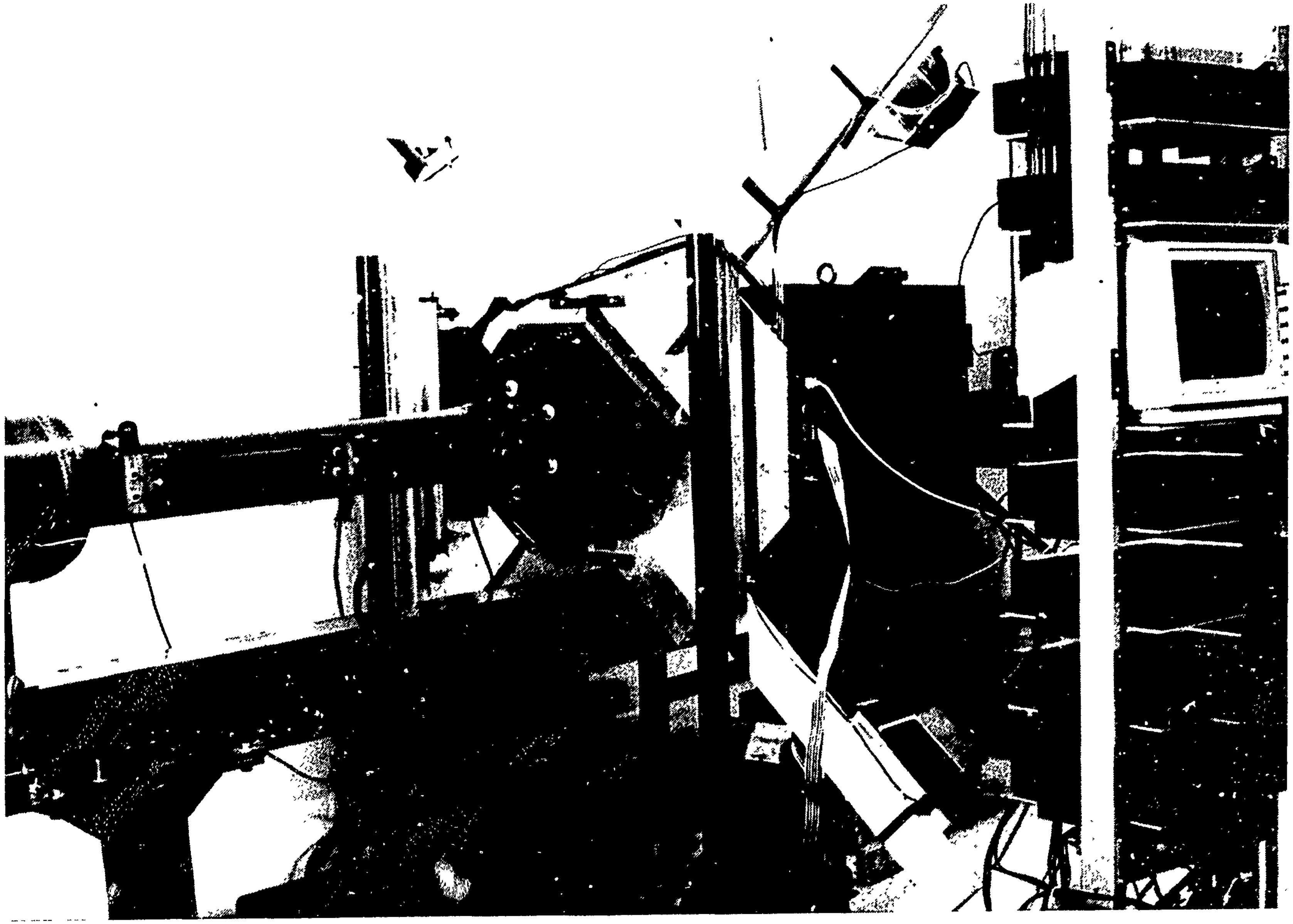

Figure 5. C-S Camera in Position Around Target Tank, Uprange View

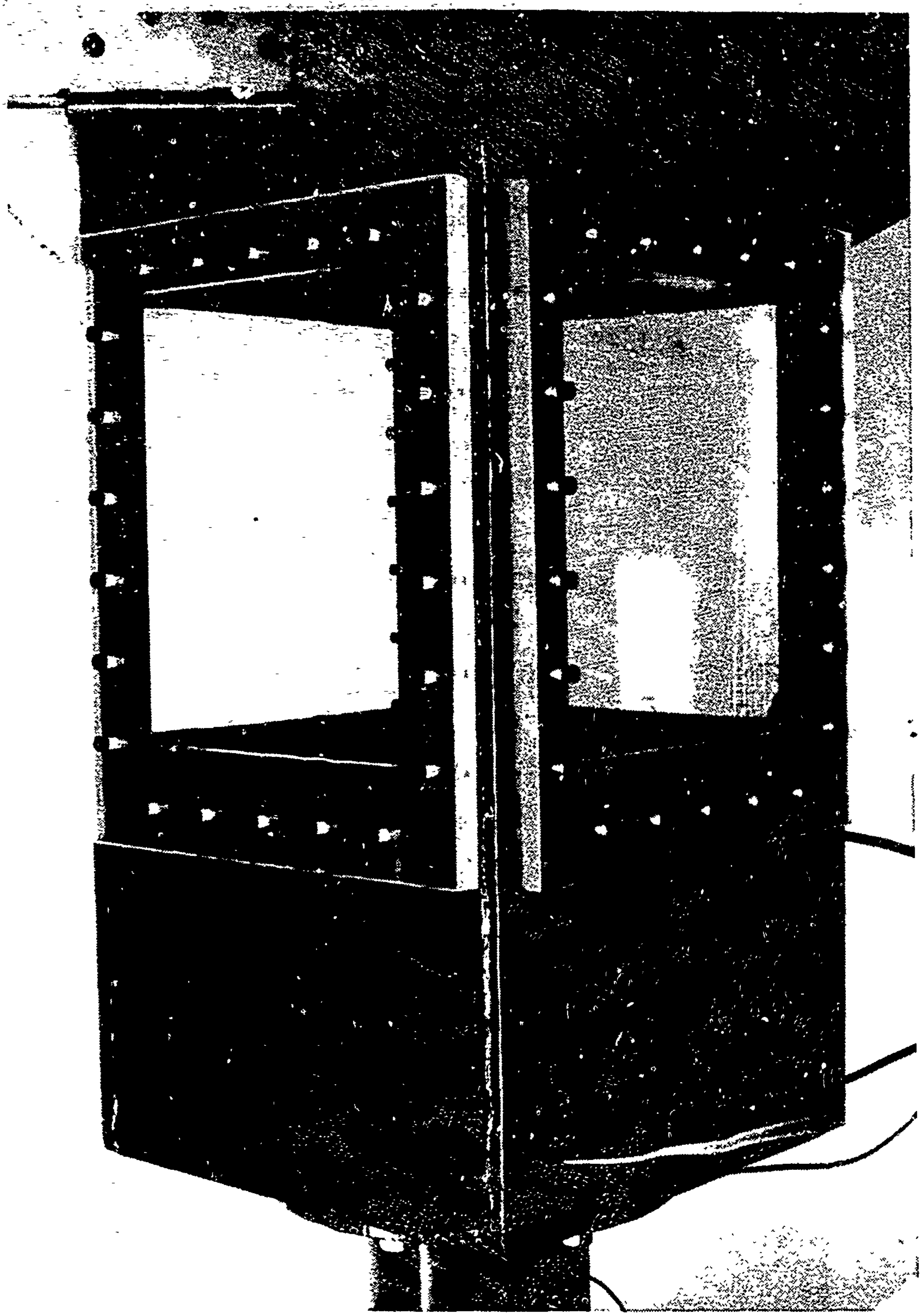

Figure 6. Target Tank

full field was also bright because it was scanned after the laser fired. Finally, the next field was a partial one being bright at the beginning (where it had not been scanned before), and dark again where it had been scanned earlier after the laser fired. This produced a rather confused set of images, and it was found that freeze-framing the resultant tape record was not useful. This was due to two causes: the VCR will display only one field in the still frame mode; and, the large amount of noise on the video signal produced by the overlap of the audio channel on the Realistic VCR's.

In order to generate permanent images which could be examined easily, it was decided to integrate the video image using ordinary photographic processing. This was accomplished by replaying the tapes through a Samsung Model CD-1451D152GA color monitor. This monitor has a resolution of about 320 pixels (H) and 200 pixels (V) and, therefore, had a resolution only slightly smaller than the video cameras themselves. To conduct a survey of all the images recorded on all the tapes, image integration was first accomplished using a 4-inch by 5-inch view camera outfitted with a Polaroid back. The view camera was focused on the faceplate of the monitor. The VCR was allowed to play back the tape until it reached a distance of about 12 inches in front of where the actual laser image was recorded. At the time, the shutter on the view camera was opened, allowing light from the monitor to enter the camera. The monitor screen was observed, and when the laser image flashed on the monitor screen, the camera shutter was allowed to close. In this way, both the video fields were superimposed in the recorded image, and the fact that the first and third fields were only partial was not evident. There was, however, always evidence as to this field-splitting because a horizontal line which indicated where the field-splitting occurred was almost always present on the Polaroid film images. This caused no problem as it did not obscure any important detail. We believe that the line at the junction between the split fields is caused by the decay of the vidicon. Its signal decays to practically zero after 50 ms and during the time required for two full field scans (33ms), its response would have been considerably reduced.

Two types of Polaroid film, type 667 (high contrast) and type 612 (low contrast) were used to record the images from the video tape. It was found in some instances that the detectability of particles was a strong function of the display intensity of the monitor screen and the type of Polaroid film employed. Figure 7 illustrates a case in which fragments are visible in one Polaroid print, but not in another. Since this was the case, several Polaroid prints of many video images were made using both types of film in order to ensure that no important results were overlooked.

After surveying all the video images as recorded on Polaroid film, some were selected as being worth more detailed examination. These were re-photographed using the same setup as above, except that a 35-mm single-lens-reflex (SLR) camera was employed to capture the images which were recorded on Tri-X film. A large number of exposures of each video image were made, and then the best image was printed in an 8-inch by 10-inch format on ordinary polycontrast photographic paper. In

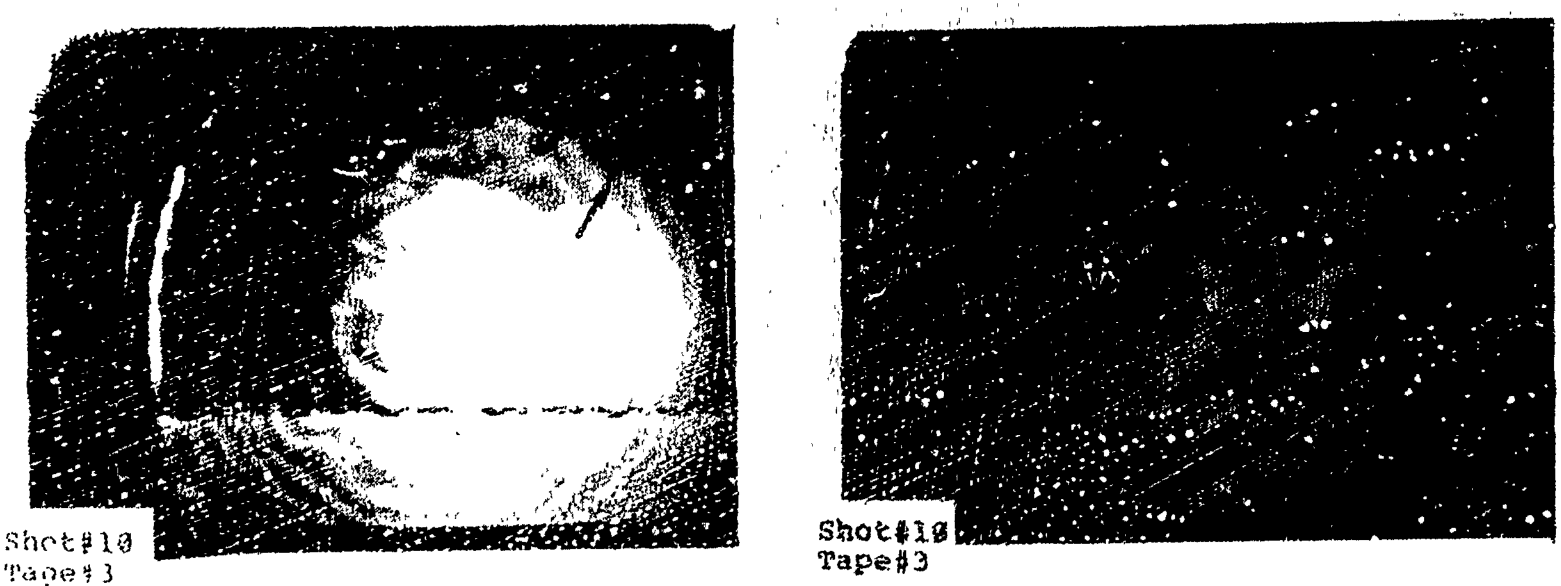

Figure 7. Video Tape Images Recorded Using Different Polaroid Films

this way, all the detail which was recorded by the video camera and VCR could be recovered.

Experimentation with tapes recorded on the VCRs illustrated the fact that a considerable amount of detail could be lost due to their low frequency response. A simple calculation will show how this comes about:

a. The RS-170 video standard has a horizontal sweep frequency of approximately 15,750/sec. If a horizontal resolution of 320 pixels is to be achieved, the pixels must have a pulse repetition frequency of 320 X 15,750/sec or 5.04 MHz.

b. A somewhat more accurate method of estimating the required video bandwidth is to consider what the rise time of each video pixel signal must be. Each pixel has a temporal width of 1/5.04 MHz or about 200 ns. The rise time of the signal must therefore be about 100 ns, and its fall time must be about the same. As a rule of thumb, the bandwidth in megahertz is equal to 350 divided by the rise time in nanoseconds. Therefore, this calculation yields a required bandwidth of 3.5 MHz.

Regardless of the value chosen for the necessary bandwidth, the frequency response of the VCR's needed to be high, above 3 MHz. Tests were made to observe the effects of the limited recording bandwidth of the VCRs. The simpliest method to use was to employ a small, inexpensive microcomputer, a Commodore PLUS/4, as a video signal generator. The computer was programmed to cover the whole monitor screen with a set of signs. When fed directly into the color monitor, these appeared to be crisp and very distinct. When fed into a VCR and back out again (no recording), it was observed that even this simple arrangement degraded the quality of the signal slightly. However, when the video output of the computer was recorded on the VCR and then played back, the images were extremely degraded--the equals signs were no longer distinct and they were merged together to form continuous lines running completely across the monitor screen.

To overcome the frequency limitations imposed by a VCR, a device called a video enhancer was employed. It was attached between the VCR and the monitor. This type of device is intended to restore the leading and trailing edges of video signals which have been degraded by the limited frequency response of a VCR. Such a unit, Archer Model 15-1272 (very inexpensive), was purchased. It was demonstrated that this enhancer could very easily restore the images of the equals signs to their original resolution with the enhancement control set at about one-half its maximum range. With the enhancement set to too low a value, the trailing edges of the equals signs were not distinct, with the enhancement set to too high a value, a strong white reversal region would follow the black equals signs.

In order to increase the contrast between the fragments, the background, and the dense cloud of very fine particles created by the breakup of the jacket of the AP projectiles and the target plate, the video tape images were always re-recorded on film with the enhancement set at its maximum value. This made the right-hand side of the recorded video image always quite bright wherever there was a sharp edge in the image. The edge had to be sharp or else the enhancement would not produce the white region. Several images illustrate this effect, having white regions next to fragments while the edges of the cloud (since the edge is not sharp) are not delineated by such a white region. Any region (such as the edge of the fine particle cloud) which does not have a sharply-defined edge, does not exhibit the white region.

SECTION III

EXPERIMENTAL RESULTS

1. SHOT MATRIX

Eleven experimentals were conducted using the stereo C-S camera mounted in the gun range. These are described in Table 1. The figures given under the heading Laser Timing are the times after impact that the laser-illuminated images were recorded.

TABLE 1. EXPERIMENTAL SHOT MATRIX

Shot #	Target Thickness (inch)	Laser Timing (Microsec.)	Comments
1	Ø.25	11Ø,27Ø,48Ø	Image at 27Ø microseconds shows projectile and cloud. 48Ø microseconds far too long a delay. Late-time fragments are visible on tapes 3 and 4 (48Ø microseconds)
2	Ø.25	None	Lasers were not fired. No impact flash could be detected.
3	Ø.25	6Ø,11Ø,16Ø	Images recorded too early.
4	Ø.25	17Ø,22Ø,27Ø	Good sequence showing projectile advancing across field of view. Projectile visible from only one direction. Fragments clearly

			discernible on leading edge. Some evidence of cloud penetration.
5	None	None	Press-25 Flashbulb only--test to determine effectiveness of 100:1 reduction in intensity with crossed polarizing filters. This attenuation is not sufficient for such a bright, stationary object.
6	0.50	170,220,270	Times too early. Projectile not in field of view of both sections. Evidence for early-time (spall) fragments. Projectile must have been moving slower than in earlier tests.
7	0.25	260,270,280	Early-time fragments visible in one image taken at 270 microseconds.
8	0.25	220,230,240	No useful results.
9	0.25	300,310,320	Fragments on leading edge clearly visible. Some evidence for cloud penetration.
10	0.25	270,280,290	Fragments visible on tape 1 (270 microseconds) and tape 3 (290 microseconds).

			Projectile not visible.
11	None	None	Test of detectability of detonation flash from #8 dynamite cap. No light emission observed.

2. GENERAL OBSERVATIONS

The set of images recorded showed that two distinct types of fragments could be recorded. The first of these, which we believe to be spall fragments, arrived in the view of the camera at early time, i.e., at least 100 microseconds ahead of the projectile. These were not observed in many cases because they were out of the field of view too soon. However, these fragments appeared in at least two shots (6 and 7). They were well ahead of the projectile and apparently moving rapidly, probably driven off the target plate by the impacting projectile.

The second type of fragments observed were those created by the breakup of the jacket of the 0.50 caliber AP round and from the target plate. These were always slightly behind and to the sides of the residue of the projectile. This residue consists of the hardened steel core of the projectile. All the photographic evidence suggests that the core remained intact during the penetration because the images of it always showed a sharp, well-defined object.

A completely unexpected phenomenon was observed: all the images recorded showed a very strong, and apparently random, modulation pattern. Each image had a modulation which was characteristic of that particular image and which was distinctly different from that of the other images. This phenomenon has never been observed by us in any camera we have built which uses film as a detection medium. It was concluded that these patterns must be due to some characteristic of the video cameras, not the lasers or optical components. We believe that these patterns are caused by interference between the front and rear surfaces of the glass face of the vidicon tube of the video cameras. The glass surface on which the photocathode of the vidicon tube is deposited is certainly not a piece of optical glass, but rather just ordinary glass, probably molded. Therefore, this glass is of non-uniform thickness and fully capable of producing the random interference patterns we have observed. Because the coherence lengths of the semiconductor lasers are so short (a few millimeters at best), we know that the interference phenomenon must be caused by surfaces which are in close proximity. The irregular nature of the observed patterns and the fact that they have only been seen when vidicon tubes are used almost dictates that the faceplates of the vidicon tubes must be responsible for them. Fortunately, this phenomenon is easy to overcome, as described in Section V.

To prove that the orthogonal C-S technique is useful in analyzing behind-panel fragmentation, two primary facts must be demonstrated: that the C-S camera images are not affected by the impact flash; and, that the cloud of fine debris which is generated during the impact can be penetrated so that fragments lying within the cloud can be detected.

The first of these has been demonstrated beyond a shadow of a doubt. Shot #2, in which the lasers were not fired and where the only light present was due to impact flash, produced no images on the video tapes whatsoever. It is impossible to demonstrate this negative result by means of images, because all that could be shown would be a blank (or black) print. However, the tapes were scanned very carefully and there is simply no visible image on them. (Three video tapes were recorded during Shot #2.) Also, Shot #11, where a dynamite cap was detonated in the field of view of the camera, produced similar blank tapes. We know that certain very bright and stationary light sources will penetrate the very dense optical filters used during the course of this work. A stationary magnesium-filled Press-25 flashbulb is an example. Because this light source was stationary, produced light for a very long time, and was so bright, it could write a very bright image on the video tapes. However, impact flash cannot do this because it evidently must be several decades weaker than a Press-25 flashbulb. The suppression of the impact flash is due to two causes:

a. The light emitted during and after the impact process has a very wide emission bandwidth. This light is due to two different types of phenomenon. The first is blackbody radiation from small, hot fragments created by the breakup of the projectile and target plate. These particles, heated to incandescence during the impact, radiate the broad band radiation characteristic of any hot body. This radiation is very broad band so that the fraction of it which can get through the narrow-band interference filters covering the video cameras is very small. For a very hot body, the emission band will extend from the near ultraviolet (say 350 nm to the far infrared, say 10,000 nm). The narrow band around 904 nm which the interference filter would allow to pass covers but a minute fraction of the total emission from a hot body. A conventional photograph taken of an impact flash would lead one to believe that a large amount of light is emitted during such a process. This is because a conventional photograph will see a broad band of light emitted during the flash. If the wavelength band of observation is restricted by the use of an interference filter and a strong neutral density filter is also used, the image recorded by conventional photography will rapidly disappear.

The major source of light during an impact flash appears to be caused by the combustion of small, hot fragments of metal. These are burning and converting chemical energy into light. This can be an intense source of light (the most familiar system which exhibits the same characteristic is the conventional magnesium-oxygen flashbulb), but its emission is also very broad band. Therefore, its presence also cannot be detected by a system having a narrow wavelength acceptance bandwidth.

b. The light-emitting fragments are moving rapidly, regardless of what the source of light emission is. Therefore, in contrast to the stationary flashbulb (which can penetrate the filter system employed in this work), the light from an incandescent fragment is dispersed over a wide area of the image. The light energy per unit area is therefore very low, and decreases linearly with the velocity of the fragment. High velocity fragments, although they may be strongly emitting light, simply do not lie in the field of view of the C-S camera long enough to produce visible images. Although it may be many times shorter than the duration of the light emission from an incandescent fragment, the intensity of the laser light is many tens of thousands of times higher. Thus, the image created by the laser light can be recorded while the light from a fragment leaves no record.

The second condition which must be met in order to show that the C-S camera technique will be useful in behind-panel fragmentation studies, is that the laser light can penetrate the cloud under certain circumstances. This has not been definitely demonstrated. This is primarily because the C-S camera used in this study was operated in a fashion designed to record images of clear fragments, i.e., those lying in a region separate from the cloud. Very strong attenuation (by a factor of 400,000) was used when the images were recorded. Such a high level of attenuation was not required to suppress the light from the impact flash since it was completely undetectable. (A small amount of light from the flash would have been acceptable because the images of fragments could still have been detected even in the presence of a small amount of extraneous light.) Several of the images recorded gave evidence that the cloud was not too dense to be penetrated, and it would have been a simple matter to have removed some of the attenuators in front of the vidicon tubes and produce brighter images illustrating deeper cloud penetration. However, this was not considered until after the program was concluded. The images which illustrate partial cloud penetration are described below. The methods for producing images having greater cloud penetration are described in Section V.

3. POLAROID IMAGE OBSERVATIONS

As described earlier, the video tape images were recorded on Polaroid film by playing back the tapes and holding the Polaroid camera shutter open until the flash indicating where the laser image was on the film passed by. Then, the Polaroid print was developed and preserved for later examination.

It was found that what could be seen on these polaroid prints was a strong function of several parameters which could only be semi-quantitatively controlled. These were:

a. The contrast setting of the video monitor.

b. The brightness setting of the video monitor.

c. The type of Polaroid film employed (sensitive, high-contrast or less sensitive, low-contrast).

d. The lens aperture of the 4-by 5-inch view camera holding the Polaroid film back.

Figure 7 illustrates how the visibility of the fragment images is affected by the type of Polaroid film used to record the images from one of the video tapes. In one case, low sensitivity, low contrast film (type 612) was used to record the image. In the other case, high sensitivity, high contrast film (type 667) was used. In one image, the fragments are clearly visible, but in the other, they are not and could have been completely overlooked.

From observations illustrated in Figure 7, it was concluded that the Polaroid prints were too variable to be used as a basis for the analysis of the video images. They were therefore used to survey the entire set of video images, but only for the purpose of determining which images should be further photographed using our 35-mm single-lens-reflex (SLR) camera. This second method of extracting the video images was more time consuming and was restricted to those video images having interesting features.

4. 35-MM SLR IMAGE OBSERVATIONS.

Fifty-seven video tapes were recorded during the course of this program. Of these, 48 were recorded during the course of impact experiments involving fragmentation and 9 were recorded during experiments designed to test the C-S camera's sensitivity to extraneous light.

Two tests, that of an AP projectile penetrating through a Ø.25-inch thick steel panel (Shot #2) and of a detonating #8 dynamite cap (Shot #11) showed that no light was detected by the sensors of the C-S camera. The test using a Press-25 flashbulb (Shot #5) showed that this source of light is so intense that not even the filters employed during this study were sufficient to block its light. Fortunately, the behind-panel impact flash is not nearly as intense as one of these flashbulbs.

Of the 48 video tapes surveyed by recording Polaroid print images of their display on a video monitor, a total of eight were selected for further examination by the recording of images using a 35 mm SLR camera. The reasons for rejecting the rest of the images was primarily due to two causes: either the image did not show any interesting details; or, the image recorded by the video camera was too dark and the modulation pattern was too intense to discern any useful images. One of the set of six images (Tape #6) was almost always bad--it apparently was knocked out of alignment early in the shooting program and this fact was not noted. Mostly, the video tapes were rejected because they did not contain any useful information.

The video images which were selected for further examination were the following:

a. Shot #1, Tape #2, 270 microseconds after impact.

b. Shot #4, tape #2, 220 microseconds after impact.

c. Shot #4, Tape #3, 270 microseconds after impact.

d. Shot #6, Tape #3, 270 microseconds after impact.

e. Shot #7, Tape #3, 270 microseconds after impact.

f. Shot #9, Tape #2, 310 microseconds after impact.

g. Shot #9, Tape #3, 320 microseconds after impact.

h. Shot #10, Tape #1, 270 microseconds after impact.

These video images were displayed upon the monitor and recorded on the 35-mm SLR camera using Kodak Tri-X Reversal Film. A wide variety of lens apertures were used for the SLR camera, ranging from f/2 to f/32 to ensure that the proper exposure range for the film was spanned. The resultant films were developed and then delivered to a photographic technician with the instructions to select the best recorded image and to print it so that one of two conditions prevailed: either the fragment images were clearest; or, the extent to which the dense debris cloud had been penetrated to reveal internal fragments was emphasized. The resulting prints are illustrated in Figures 8 through 15. Each of these images are discussed below.

a. Figure 8, Shot #1, Tape #2, (270 microseconds after impact.)

The cloud behind the projectile can be seen to be penetrated by the laser light, although the very dense cloud immediately adjacent to the projectile is not. This suggests that late-time fragments will be much easier to detect than those in close proximity to the projectile.

b. Figure 9, Shot #4, Tape #2. (220 microseconds after impact.)

Pre-projectile (spall) fragments are clearly visible.

c. Figure 10, Shot #4, Tape #2. (270 microseconds after impact.)

The interference pattern is missing in this image. The cause for this is unknown, but the brightness of this print indicates that the film (or print paper) is completely saturated. No evidence for cloud penetration is detectable.

d. Figure 11, Shot #6, Tape #3. (270 microseconds after impact.)

The position of the scanning beam is clearly visible in this print. Below the line indicated on the figure, where the photocathode of the vidicon was scanned immediately after the

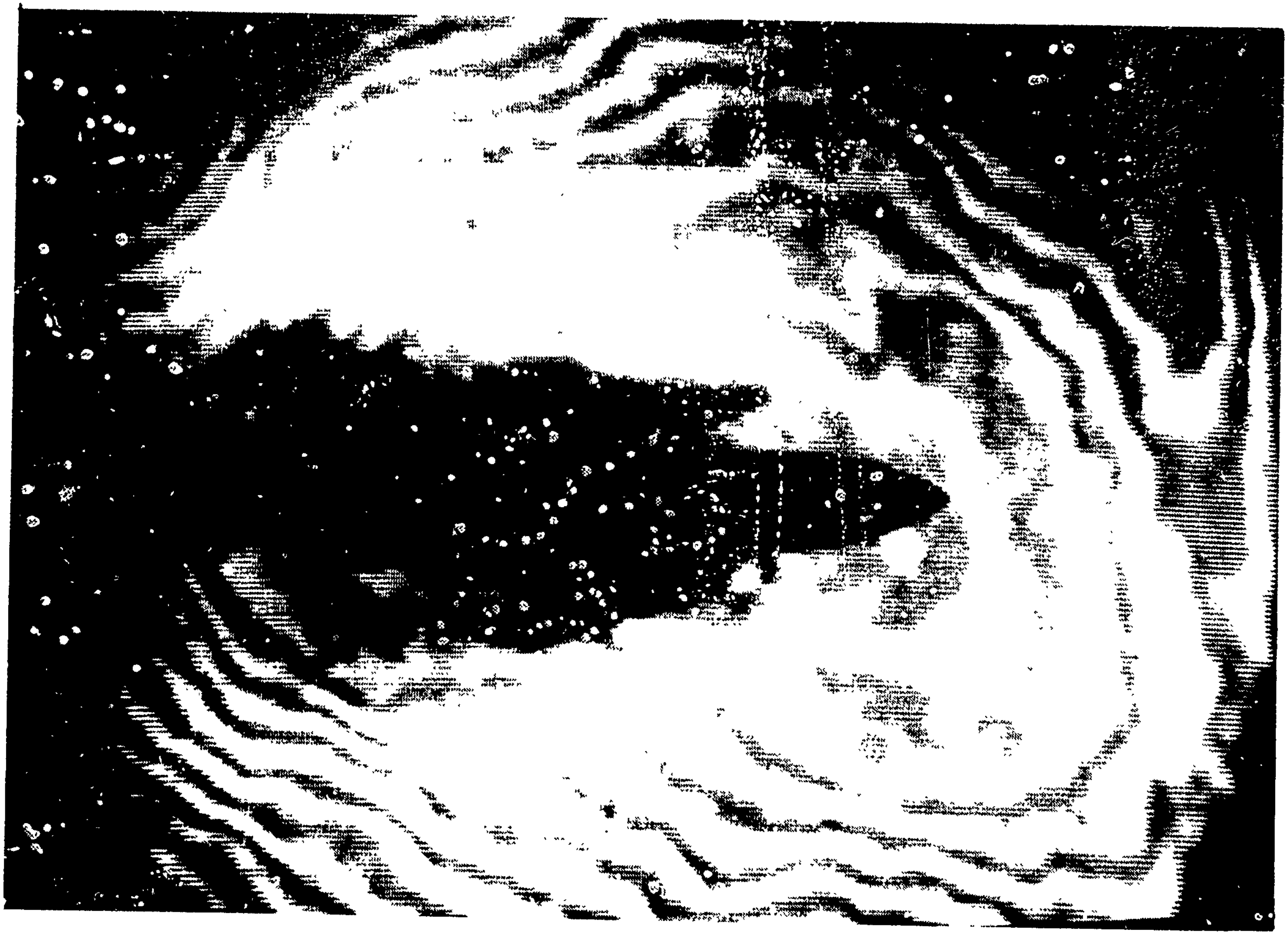

Figure 8. 35-mm SLR Camera Reconstruction of Video Image, Shot #1, Tape #2

Figure 9. 35-mm SLR Camera Reconstruction of Video Image, Shot #4, Tape #2

Figure 10. 35-mm SLR Camera Reconstruction of Video Image, Shot #4, Tape #3

Figure 11. 35-mm SLR Camera Reconstruction of Video Image, Shot #6, Tape #3

laser fired, a good penetration of the cloud was achieved and some fragments are observable. Above this line (scanned later) the cloud appears to be much more dense. This is taken to indicate that the image on the vidicon face may decay much more rapidly than we were lead to expect--apparently even a short delay in reading the vidicon photocathode makes the cloud appear to be more dense than it really is.

e. Figure 12, Shot #7, Tape #3. (270 microseconds after impact.)

Fragments are clearly visible in the upper right-hand corner of the image. Others may be present in the lower right-hand corner. Over-enhancement of the video signal causes a white region to lie to the right of each fragment with a well-defined edge,

f. Figure 13, Shot #9, Tape #2. (310 microseconds after impact.)

The cloud here appears to be very impenetrable. This is believed to be an artifact since the camera saw through the cloud immediately after the laser fired. This is verified by the sharp difference in the image above and below the position of the scanning beam when the laser fired. Above this line the cloud appears dense since the image on the camera tube had time to decay before it was read. The projectile is seen to be pulling ahead of the dense cloud of debris as compared to the images recorded at earlier times. (Figures 9, 10, and 11.)

g. Figure 14, Shot #9, Tape #3. (320 microseconds after impact.)

The projectile has pulled even further ahead of the dense

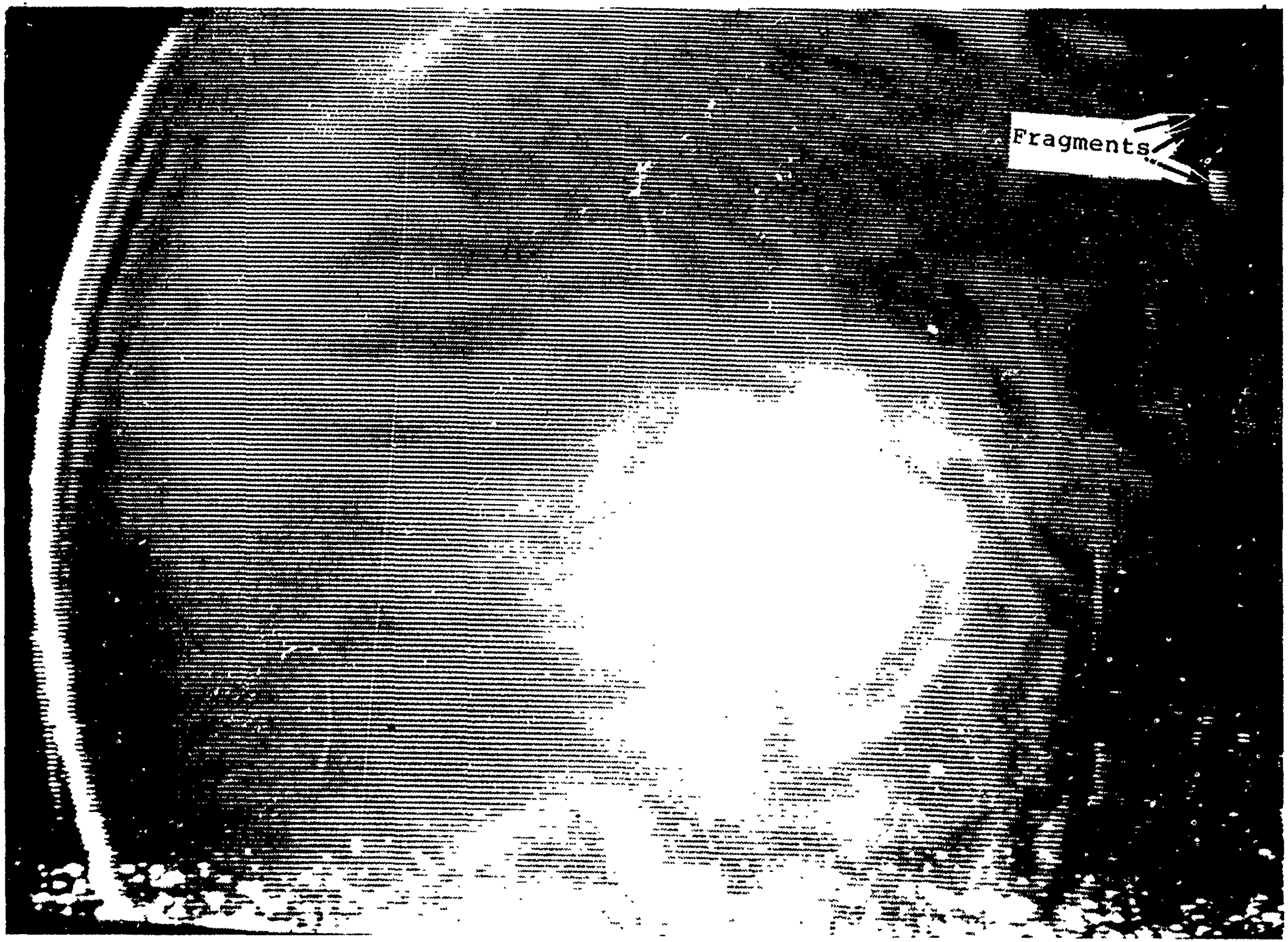

Figure 12. 35-mm SLR Camera Reconstruction of Videc Image, Shot #7, Tape #5

Figure 13. 35-mm SLR Camera Reconstruction of Video Image, Shot #9, Tape #2

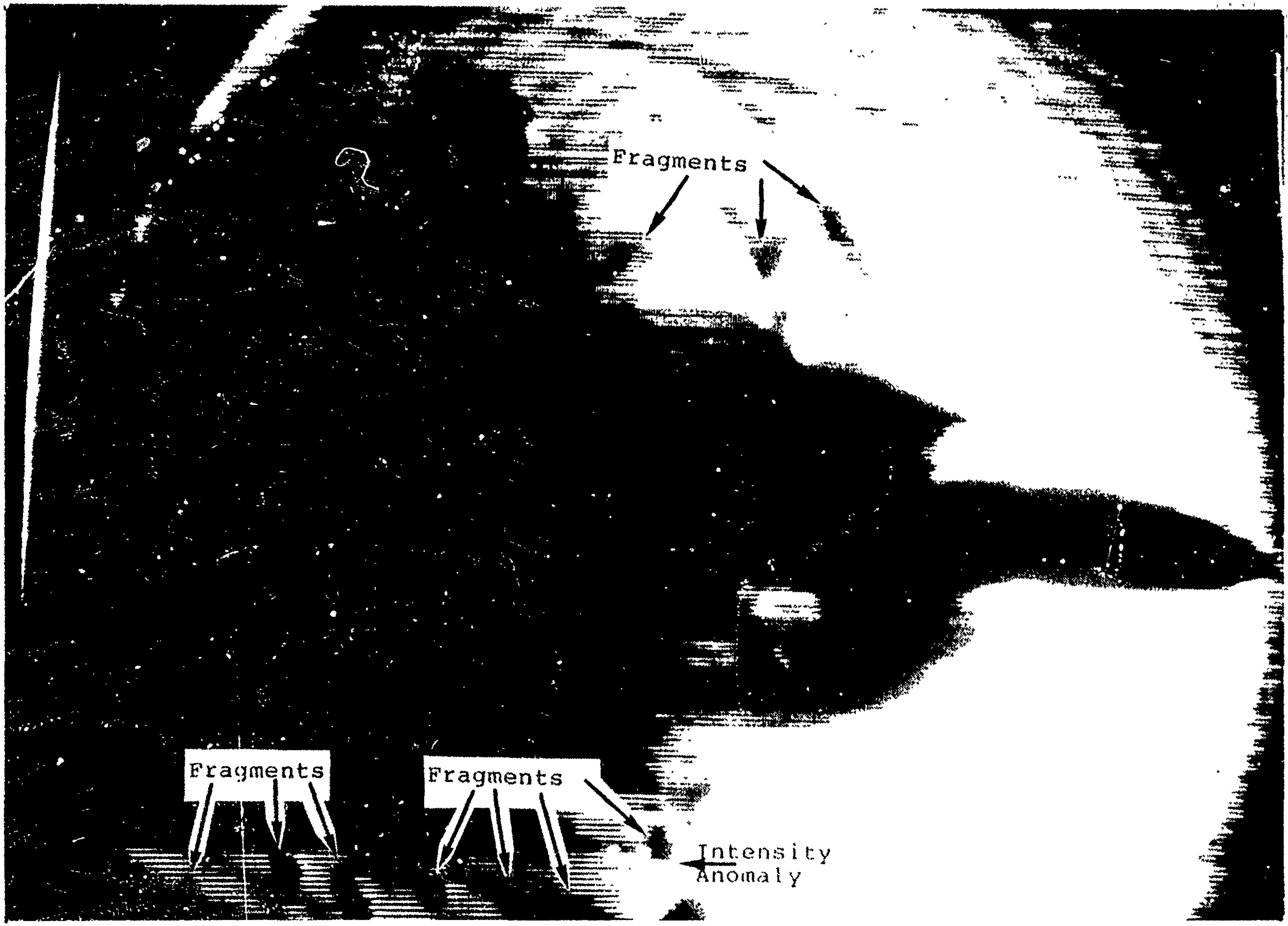

Figure 14. 35-mm SLR Camera Reconstruction of Video Image, Shot #9, Tape #3

debris cloud. The effect of the image decay is very evident in the lower portion of this image. Below the sharp line of demarcation, the cloud is clearly penetrated (as in Figure 11). Above this line, the cloud appears to be extremely dense, but this is not real, the image on the vidicon has simply decayed so much that it appears to be much more dense than it really is.

h. Figure 15, Shot #10, Tape #1. (270 microseconds after impact.)

Fragments are clearly visible. These must be spall fragments because no projectile image was visible on any tapes recorded on this impact. It is believed that the projectile was going inordinately slow during this shot.

5. EVIDENCE FOR CLOUD PENETRATION

We have discovered that the vidicon tubes in the IR-sensitive video cameras were exhibiting a completely inexplicable behavior-- a very rapid decay in sensitivity. According to the published specifications, the image on the vidicons will decay fairly rapidly-- from the maximum response at zero time to essentially zero response at about 50 ms later. The decay curve is more-or-less linear with time. Since a full frame scan requires a total of 1/30 second, it was expected that a decay in the image would be observed, but that it would not be severe enough to obscure the essential details of the images. To our astonishment, this was not the case.

The first indication that the vidicon tubes were

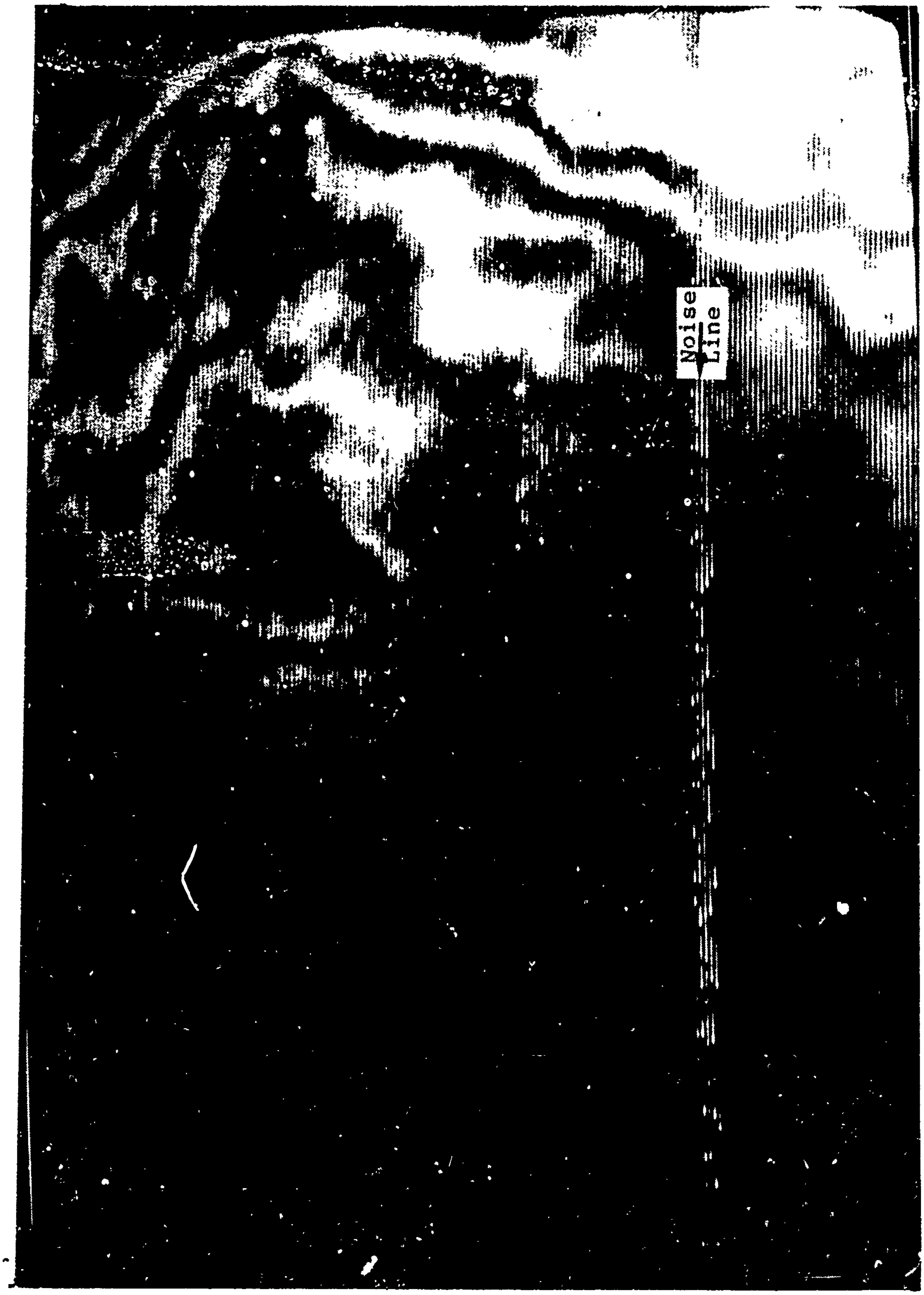

Figure 15. 35-mm SLR Camera Reconstruction of Video Image, Shot #1Ø, Tape #1

displaying an anomalous behavior was given when the image illustrated in Figure 11 was examined closely. It will be noted that in the lower left-hand corner, there is a sharp line of demarcation (indicated by an arrow in the figure). Above this sharp line, the cloud of fine debris appears to be completely black; but, below the line it can be seen that an appreciable amount of light actually penetrated the debris cloud at some distance from the trajectory. This does not appear (at first) to be very significant, but the examination of other images illustrated that a strange phenomenon was occurring.

Once the significance of the potential implications of this observation began to be appreciated, other images were more closely examined. Figure 14 revealed an even more startling fact: in its lower left-hand corner there were definite fragment images, clear evidence that the fine debris cloud had at least been partially penetrated. The results were even clearer than in Figure 11--above the sharp line of demarcation, the debris cloud appeared to be absolutely black, but below it the laser light had clearly penetrated the cloud to reveal the presence of fragments which otherwise would have been completely invisible. The debris cloud would apparently have masked them completely.

One anomaly which had been observed, but not fully appreciated, was the fact that one of the first images recorded (Figure 8) showed an image of the projectile remnant and the debris cloud in which the cloud behind the projectile was penetrated by the laser light. The anomaly lies in the fact that all the other images of the cloud indicate that it is exceedingly dense (as conventional wisdom dictates that it must be). Nonetheless, there is no reason to expect that the cloud in Figure 8 is really any different than the clouds in the other figures, only that our perception of it is different. Nearly all the experimental conditions of all the shots were the same: projectile type, target panel composition and thickness, impact velocity, and so on were the same when the image illustrated in Figure 8 was recorded as they were in the other images which indicated that the cloud was impenetrable.

The question is therefore: Why was the cloud penetrated fairly well in Figure 8 and in certain portions of Figures 11 and 14? We believe that the answer lies in the relationship between where the lasers fired and where the vidicon tube happened to be scanning. In most images, the video camera happened to be scanning near the bottom of the tube face when the laser fired. In Figures 11 and 14 this is clearly the case: the cloud is penetrated for a short portion of the image immediately after the laser fired, but the rest of the image is scanned at a later time at appears to be much darker. The explanation for the unusual results illustrated in Figure 8 is the fact that the electron beam just happened to be scanning the upper portion of the vidicon cube face when the laser went off. Therefore, when the image of the projectile and the debris cloud was scanned, the cloud appeared to be much less dense than in the other images. Capturing the images illustrating cloud penetration was entirely fortuitous, depending upon the entirely random relationship between the scanning of the vidicon face and the time at which the lasers fired (which was determined by the impact of the projectile).

When it was realized that the vidicon tube images might be decaying very much faster than anticipated, all the video images recorded on Polaroid film were re-examined for evidence of this occuring. It was, and is illustrated in Figure 16.

The images illustrated in Figure 16 clearly illustrate the image brightness decay phenomenon. Each has a clearly-defined split-field line in the upper portion of the image. Below this line, the image appears to be very bright for a short distance, but decays to a uniform gray level quite rapidly. By counting the number of horizontal scan lines between the split-field line and the first line where the apparently constant gray level is reached, we estimate that only 500 microseconds are required for the vidicon tube to decay. This does not appear to be artifact of the Polaroid film or the fact that these images were over-enhanced on the video monitor when these images were recorded. Almost every image shows this effect to some extent or another, it is just especially clear in these two. This phenomenon cannot be due to the over-enhancement because the white area which this processing creates never extends very far from the leading edge of a fragment. Therefore, it cannot cause a bright area to extend over the whole width of the image. It also seems very unlikely that any of the laser or laser-firing circuitry can be responsible for this brightened region because the

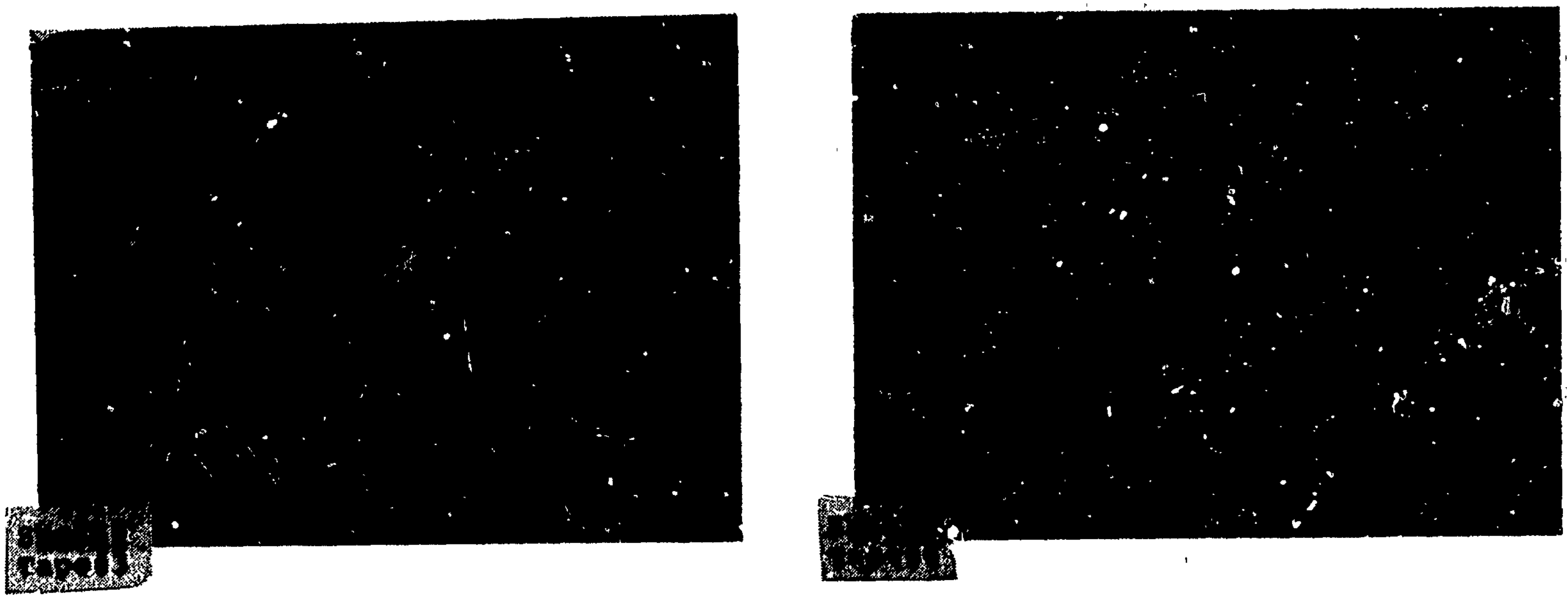

Figure 16. Polaroid Images Illustrating the Rapid Decay of a Vidicon Signal

laser discharge was so brief (100 ns) and any recharge of the laser discharge capacitor and other portions of the discharge circuitry also required only a short time, perhaps a few microseconds.

We presently believe that the variations in image brightness observed in Figure 16 was caused by the automatic gain control (AGC) circuitry in the video cameras. We had expected that the AGC Circutry would react rather slowly and therefore would not influence the output from the cameras during the time required to scan a single frame. This hypothesis has not been tested, however. The fact that this brightening falls off rapidly precludes its being responsible for the cloud behind the projectile being so well penetrated in the image illustrated in Figure 8, but it certainly was responsible for the very rapid changes in the apparent density of the cloud in Figures 11 and 14. Therefore, we believe that almost all of the cloud images which were recorded are misleading and that the cloud, while not very transparent and certainly an important subject of concern, is not as dense as formerly supposed. Improvements in technique such as are suggested in Section V will allow data on the position, velocity, and mass of the fragments to be gathered, even when they are initially located close to the projectile remnant. Allowing the cloud to disperse more and using multiple image sensors for a particular image are especially important.

SECTION IV

CONCLUSIONS

Although the data gathered during the course of this work were less esthetically pleasing than we had hoped, it definitely indicates that a Cranz-Schardin Camera System can be a useful tool for the investigation of behind-panel fragmentation.

There has been one unqualified success--the demonstration that the C-S camera images are completely immune to interference from the behind-panel impact flash. No evidence for any light originating from such a flash has ever been detected on any of the images that have been recorded. If light due to a flash were to be detected, it would appear in two forms: as bright traces across the images due to a pyrotechnic fragment; or, as a general wash-out or decrease in contrast of the laser-illuminated images. Neither of these has ever been observed on any images. Bright traces are particularly easy to detect, but none has ever appeared, either in the test where the lasers were not fired, or during any of the projectile-impact tests where the lasers were fired. A general decrease in the contrast of the images has never been observed, either. The lasers employed were so powerful that their output could be attenuated by a factor of 400,000 and still it was intense enough to write images on the vidicon tubes. Only an incredibly bright, long-lived, stationary incandescent object, such as a flashbulb, can produce a sufficient amount of total light so that it can effectively penetrate the stack of neutral density and interference filters which were employed to discriminate against ambient light in these tests. Neither impact flash nor the light created by a small detonation can produce a detectable image.

Conclusive evidence has been gathered which indicates that it was possible to penetrate the dense cloud consisting of small fragments which is produced by the impact. Images were recorded which showed that the cloud had been penetrated both behind the projectile and at some distance beside it. However, these results were not reproducible since no method of controlling the scanning of the video cameras was available. At least two images show that the apparent optical density of the cloud is strongly influenced by the time delay between the firing of the lasers and the time at which a particular portion of the photocathode of the vidicon tube was scanned. Immediately after the laser fired, good peripheral penetration of the cloud was seen in some cases, but those portions of the image which were scanned at later times had evidently decayed to the point where the cloud appeared absolutely black. This rapid decay of the vidicon image was completely unexpected. The instances where good cloud penetration was achieved and fragments revealed cannot be taken to indicate that the cloud will not be too dense to penetrate (at least, very close to the projectile); but, they do show that the images recorded during the course of this program were strongly influenced by the image decay of the vidicons. Such decay always tends to show the cloud as being more dense than it really is.

The images recorded during this program were less satisfactory than expected for a number of unforeseen reasons. These were:

a. The images were strongly modulated by what is believed to be an interference pattern. In many cases, images were so strongly modulated by a pseudo-random set of black bands that they had to be discarded. These bands make the identification of fragments (which are also black) very difficult.

b. The fields of view of the two sections of the C-S camera were very much smaller than expected due to the spherical aberration of the main condensing lenses. This can be easily remedied, but was not recognized as being important in the present camera until it was too late to remedy it. This reduction on the size of the field of view made it difficult to track a small particle from one frame to another although large objects such as the core of the projectile could be seen if the timing of the firing of the lasers was precisely correct.

c. The images deposited on the photocathodes of the vidicon tubes decayed too rapidly, making it appear that little cloud penetration was achieved. Evidence suggests that the cloud was penetrated to a much greater extent than the available images indicate. The equipment and techniques by means of which these problems can be overcome are described in Section V.

SECTION V

SUGGESTIONS FOR FURTHER WORK

Since one of the major problems involved with behind-panel fragmentation studies, that of impact flash, has been successfully solved through the use of high-peak-power lasers, the second major problem, penetration of the dense, fine fragment cloud generated during the impact can be exclusively addressed. The following is a list of modifications in apparatus or technique which should be made in any future work.

a. The array of fragments and the fine-particle cloud should be sampled at distances which are a little farther down-range than was done during the present program. This will have two beneficial effects: the fine-particle cloud will dispense and become much less dense than it was in the present tests; and, aerodynamic drag will be much more effective at retarding the cloud relative to the projectile remnant and the large fragments traveling at high velocity. In the present program, the projectile could only be tracked for a distance of about 15 inches from the target panel, but even at this short distance it can be seen to be pulling out of the fine debris cloud. At larger distances downrange, both the projectile and the higher velocity fragments will emerge from inside the cloud. At least two images indicated that the present system was close to penetrating the outer edges of the cloud to reveal fragments within it. Allowing the cloud to expand still further will allow deeper cloud penetration to be achieved.

b. The field-of-view of the Cranz-Schardin Camera System should be enlarged. This will partly satisfy the condition suggested in a. above, but is very desirable in itself to reduce the sensitivity of the imaging to the exact timing of the lasers. At a launch velocity of 3000 ft/sec, it took only about 160 microseconds for the projectile core to cross the field of view of the present camera, assuming that the velocity of the core was not decreased very much during the penetration process. In any event, the projectile core and the fragments were moving at nearly the same velocities and required very little time to cross the field of view of the camera. If the field of view were larger, much less care would be needed in setting the timing intervals for the lasers and the results would have been much less sensitive to the actual projectile velocity.

c. The vidicon-type video cameras should be replaced by charge-coupled-device (CCD) or charge-injection-device (CID) image sensors whose images do not decay so rapidly. Not only are these much easier to control, but they can also retain an image virtually forever. Their only limitation is due to the integration of their dark current if the read out is delayed for too long a period of time. However, this can be a period of several tenths of a second in contrast to the rapid decay of a vidicon image.

d. The video cassette recorders should be replaced by inexpensive video frame-grabbers. These devices considerably simplify the playing back of video images and store the image data in a form which is amenable to computer-assisted modification and analysis.

e. Methods for stripping the fine particle cloud from the projectile remnant and the larger fragments should be investigated. Two possible methods are immediately obvious: the use of dense gases with low shock velocities; and, the use of very thin witness plates through which the larger fragments can easily punch without any appreciable loss in velocity or change in direction but which are strong enough to retard the very fine particles which make up the dense cloud. Filling a sealed target tank with a non-toxic, inert gas such as sulfur hexafluoride and then pumping it out to recover this gas may not be too high a price to pay for clean fragmentation data. Excellent separation between the heavy fragments and the very light cloud may be achievable in very short distances. However, these techniques will be unnecessary if the debris cloud can be directly penetrated by other means.

f. Provide for more than one image sensor per laser. By means of a simple beam splitter, more than one image sensor can be illuminated by the light from the same laser. By adjusting the filters in front of the image sensors, one can be made to have a high sensitivity so that it can detect the small amount of light which is capable of penetrating a moderately dense cloud. The other can be made insensitive and be used to record that portion of the image not obscured by the fine particulate cloud. By having detectors of differing sensitivities, the dynamic range of the fragment detection can be dramatically increased. In combination with one or more of the above methods of decreasing the cloud density, it is very probable that the fine particulate cloud can be penetrated to reveal the sizes and velocities of the fragments which lie within it.

g. Change the form of the main condensing lenses. The use of a single condensing lens introduced severe spherical aberration into the present C-S camera system. After recognizing this fact, a new arrangement of lenses was constructed for a C-S camera which the contractor was building for the U.S. Army Material testing laboratory in Watertown, Massachusetts. Instead of one single lens having a focal len of 50 cm. two lenses, each of 100 cm focal length were used. These lenses were mounted close together with a spanning of approximately 19 mm to produce an assembly having a focal length close to 50 cm, the same as that of the one single lens used during this program. It was found that, by arranging the new lenses so that their curved surfaces were facing in the same direction (towards the lasers) that a great improvement in the size of the field of view was achieved. Such an assembly was twice as expensive as the single lens used in this study, but a 9-inch diameter field of view was obtained at a distance of 7-inches from the condensing lens assembly. This was nearly twice as large as the effective size of the sample volume in the present program. Increasing the length of the C-S camera would also increase the size of the active volume because the laser light passing through the sample volume would not have to converge as rapidly as it did in the present small camera system. An ideal solution would be to use achromatic aerial camera lenses, but these may not be available in large enough sizes and may be prohibitively expensive. Probably the most cost-effective method is to employ the present type of lenses, but to use multiple lenses to reduce the effects of spherical aberration.

h. Employ anti-reflective coatings on the image sensors. If CCD or CID sensors are used, this may not be important since it is not certain at this time that they will exhibit the intense interference patterns as the vidicon tubes did. If vidicon tubes are employed as sensors, their faceplates should be covered with an anti-reflective coating. A single-layer coating, which is quite inexpensive to apply, will reduce the intense modulation by about a factor of 16. Multiple-layer anti-reflection coatings, tuned to the wavelength of the lasers, can reduce interference effects to completely unimportant levels. Even if the interference patterns cannot be completely eliminated, a digital image processing system can eliminate them by image subtraction. If an automatic computerized system is available, then just before an impact experiment is conducted, a set of reference images can be recorded by triggering the C-S camera when all the components of the optical system are in their normal states. The images recorded in this instance will be influenced by all the various types of imperfections such as windows which may have striae or other types of inhomogeneities, dust or scratches on the optical components, variations in the sensitivity of the image sensors, etc.

Then, when the real images are recorded during an impact experiment, the "before" images may be digitally subtracted from them thereby eliminating the effects of any imperfections which may be present. This technique is very useful, requires very little time to accomplish, and enhances the visibilit the images of any changes induced by the impact event.