Special Applications and Measurements, of the International Congress of Photogrammetry Meeting which is to be held in London during September 1960. We hope that this panel will be of some support to Professor Doyle in preparing his report on United States activities since the last Congress held at Stockholm in 1956.

Our participants hail from the Great Lakes, Cape Cod, Atlantic Missile Range, Pacific Missile Range, and other areas throughout our fine land. They represent large, medium, and small commercial organizations and one of our largest and renowned engineering institutions. Their subject matter is varied and they are a dedicated group.

Photography of Nuclear Detonation[*]

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ABSTRACT: *The use of photography as a measurement technique in the testing of nuclear weapons is discussed in connection with selectively edited weapons test films. The problems of photography in a nuclear detonation environment are pointed out. The utility of photography, and subsequent photogrammetric data reduction, is shown in the areas of shock wave propagation and fireball growth.*

INTRODUCTION BEFORE START OF FILM:

ALL have seen pictures of movies of atomic explosions. Some of the pictures to be shown here have been released, and many are similar to released pictures. We bring these together to illustrate some things we are trying to measure, and as examples of the sort of work we are trying to do.

Much work we do photographically is in an effort to learn how *shock waves* are formed, how propagated, and what happens to them. The shock wave itself is invisible very quickly after it is separated from the fireball. There is a great interest in just what happens when it does separate; this is in the region of extremely strong shock.

We take pictures of shock by essentially a Schlieren technique. The wave is a very hot surface. While not hot enough to be seen, it is hot enough to refract light as it comes through. So if there is a source of light behind the shock front, one can exactly determine the position of the shock wave.

To get a look at the shock wave, in many operations, people have been shooting off rocket trails. Pictures of these have been in the papers. With high-speed photography, as the shock wave progresses in front of the rocket trail, there can be seen a little ripple in the trail showing where it was and how it progressed.

Sometimes we have put up little puffs of smoke and these are physically moved by the shock after the wave passes. Also at times direct photography is possible just from the general light existing—reflected from the desert behind, reflected by the mountains, light from clouds overhead—which allows seeing almost the whole of the shock wave. All shock pictures are, of course, taken at high speed, to make possible seeing things that otherwise would go by too fast to be

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[*] The paper consists of introductory remarks and narrative discussion for the scientific film, "Photography of Nuclear Detonations." These were prepared by Dr. Lewis Fussell, Jr., Director of Research for Edgerton, Germeshausen & Grier, Inc. and were read by Mr. Seacord at the 25th Annual Meeting of the Society, Hotel Shoreham, Washington, D. C., March 10, 1959. This paper is a part of the panel on Special Applications of Photogrammetry.

seen by the naked eye.

In some of the pictures will be seen the so-called cloud chamber effect; this is a result of the shock wave. Behind the shock front of very high pressure, there is always a rarefied region; when this region reaches air containing water vapor, this vapor condenses out as a very large cloud that obscures almost everything. As the pressure returns to normal, the water vapor returns to its gaseous state and the air is clear again.

Also to be seen in the pictures are a number of cases in which things have caught fire. This is due to the instantaneous thermal or heat radiation that comes out of the bomb. If one is close enough to the bomb when the explosion goes off, there is enough heat formed immediately to set fire to things or to make them smoke. In many pictures will be seen smoke coming across the field of view and obscuring the camera. This is another of the hazards under which we operate.

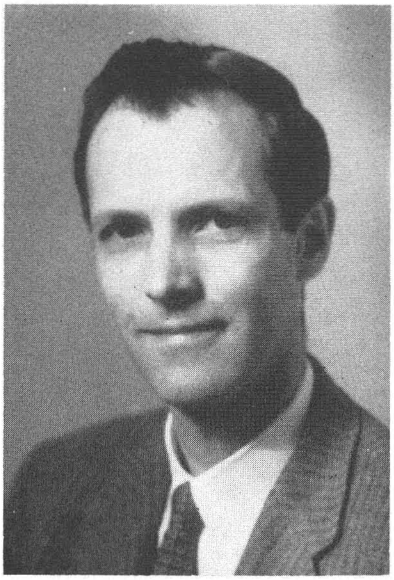
For all of these cameras we have to provide a time scale, and since we use slow film as a rule, we must have a lot of light for timing. We can't use the ordinary argon bulbs that are used to mark film in standard cameras. We actually use a small spark gap which is imaged on the film through a simple lens and we hit the spark gap with something like 10,000 volts on every pulse. The electronic circuitry comes from a tuning form and is fairly well worked out by now. The timing marks will show on the edge of the picture in some scenes.

It's been surprising to find out how rugged a camera is. Cameras have been blown several hundred yards from a station. We have gone to a station where a camera was supposed to be, turned around with out backs to the center of the blast, walked and found the camera, intact, and the undamaged film inside it.

THE FILM*

One task of our company is taking scientific pictures of weapons tests—here photography is used as a precision tool, to help the scientists and engineers who are trying to learn something about weapons design and weapons effects. Los Alamos, of course, is interested in scientific work. Special Weapons are primarily concerned with military effects.

No. 1 was taken from an airplane that has dropped a bomb. Below, on the desert, electrical controls have begun to phase in the equipment that governs many cameras—high-speed, slow-motion, time-lapse cameras. There is only one chance to get your pictures—you can't take a test film and come back later on and do the real shot.


DANIEL F. SEACORD, JR.

The burst is seen from the ground. (No. 2).

In the company we have a group of expert photographers, men who set up the cameras, electricians who run the control equipment, men who run the processing units, and a group who analyze the records to find out what we learned. The whole program has to be planned in complete detail ahead of time. You have to allow for all sorts of uncertainties—things that may happen or may go wrong during the experiment. You have to provide back-up equipment so that if one set of cameras fails, you will get the information from another set of cameras. You install the equipment, and you test it, over and over again, to be quite sure that all the control equipment and everything that is needed is working properly.

The thermal pulse has started the poles burning. (No. 4).

Most installations are so close to the explosion that they cannot be manned during the shot itself. They must be controlled remotely.

You must protect the equipment because effects from the explosions can damage either the cameras or the film. Shock can shake up the cameras and sometimes cause power failure. Heat comes up very quickly at the time of the explosion, and you have nuclear radia-

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* Nuclear Detonations; Atomic Energy Commission by E. G. & G., Inc.; Supervision LASL and AFSWP.

tion which can fog film very quickly and completely.

Many of these pictures have to be taken at speeds as high as 3,000 frames a second. The growth of the fireball shows if there are any changes in shape. After this early phase, other cameras study the later effects of shock and of thermal radiation.

In No. 7 a prism has been used to produce a double picture of the fireball—one image filtered blue, one red—a single film shows the bomb as seen by blue light and as seen by red light. This shows the relative differences in the light output of the bomb in the different portions of the spectrum.

A set of rockets going up is shown (Nos. 8 and 9), and the ripples on the trails as the shock progresses, and then the formation of the cloud chamber.

A unique feature comes from the very wide ranges of time, space, and brightness that must be accounted for. For example, we take pictures during the first millionth of a second and we extend onward from this first millionth of a second (first microsecond) for upwards of an hour. And this is a range of times of the order of a billion to one.

In space we frequently have to resolve fractions of an inch in some equipment that is placed nearby. Later on we have to photograph a cloud that may be hundreds of miles in diameter. This is a factor of 10 million or more.

The range of illumination that is available for taking these pictures varies by an even greater factor. Obviously, you don't do all the work with one camera. You do it with many cameras set to operate at different speeds, different fields of view, and which are set to take the pictures at certain discrete times.

The next scene (No. 11) is more of a close up . . . a spectacular view right in close to ground zero.

Now we have set off some smoke, and have a background of mountains for viewing the shock wave (No. 12). We actually regard as a successful color film one that has good contrast in the colors, even if they are not correctly rendered colors. It is more important that we see there is a difference between one part of the picture and another.

The fireball is recorded together with the ripples refracted by the shock wave in some rocket trails at the side of the frame. (No. 13).

The shock wave starts on its way out across the desert. (No. 14).

The shock wave continues and can be seen in the upper right corner of No. 15 proceeding down the rocket trail, and continuing on as the reflected shock wave appears to climb back up the trail.

Further out now, the wave is somewhat slowed down. (No. 16).

Finally, more than a mile from the detonation, we can still see the wave. (No. 17).

No. 18 shows what the shock wave really looks like going by. This camera is close to the ground, and its field of view is quickly obscured.

Again the shock wave goes by. The row of lights in No. 19 shows how the visibility near the ground is lost.

By raising the camera a dozen feet or so out of the dust, we can look out and over the confusion. (No. 20).

Now we will go out to the Pacific for a bit, (No. 21) and get away from some of this choking dust. Most noticeable about tests over water is the generous and full-size cloud chamber. The water is also handy for recording the progress of the shock wave.

Looking at some high-speed films, there will be noticed the apparently extreme dip in the initial brightness of the fireball. (No. 22). It can be said that at the time the bomb goes off it has a temperature greater than a million degrees Centigrade. The sun has a temperature of only 6,000 degrees.

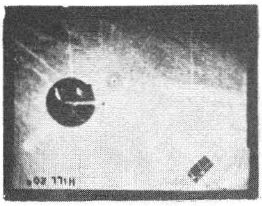
After the first flash, the apparent brightness falls rapidly and passes through a minimum time, with a temperature in the order of 2,000 degrees. (No. 23). After this it gets brighter again and then falls continuously until the light goes clear out.

The next few films are typical of Pacific detonations. . . . The burst (No. 25). The cloud chamber (No. 26). The shock coming across the water No. 27). The camera rocking as the shock wave hits it (No. 28). Notice the shock against the clouds.

You can imagine that the radiation sensitivity of the film in these cameras must have to be extremely low—a thousand Roentgen units must give only a slight fog. A Roentgen unit is the measure of the amount of dosage that is absorbed, and I think 600 Roentgen units is supposed to be fatal. One Roentgen unit is quite a dose. We have had usable pictures that had been exposed to 20,000 R.

We try to put as much information as we can on every film. For reading the films, we use standard machine tool comparators, which give us readings to 2-10,000ths of an inch, or 2-100ths of a millimeter. We try wherever possible to choose our lenses, our films, our cameras, to give us the best resolution we can get.

Here is the shock wave, almost lost in the



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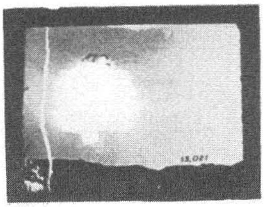

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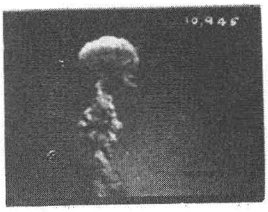

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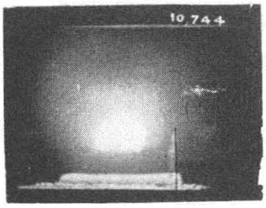

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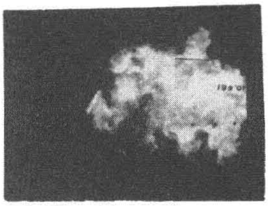

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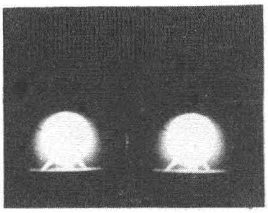

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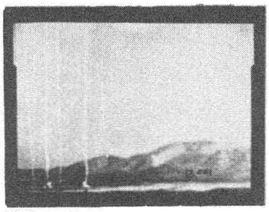

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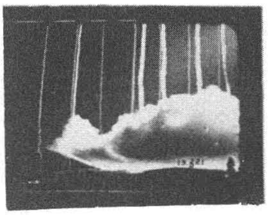

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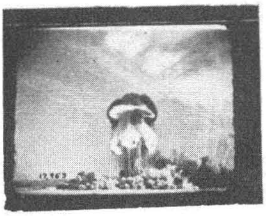

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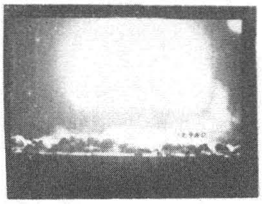

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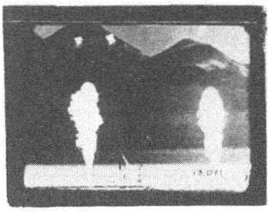

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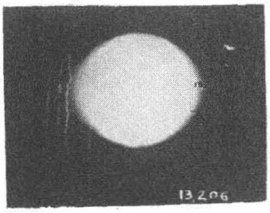

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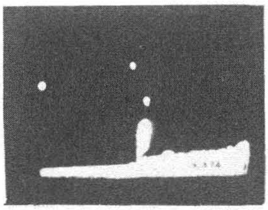

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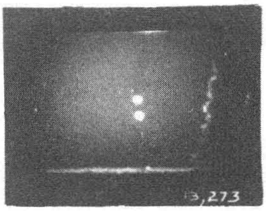

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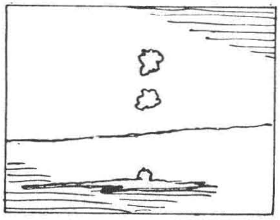

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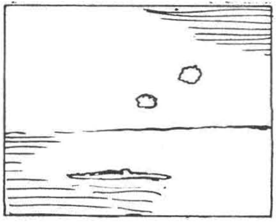

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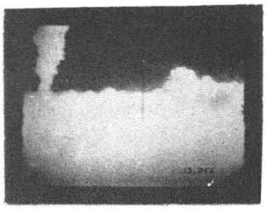

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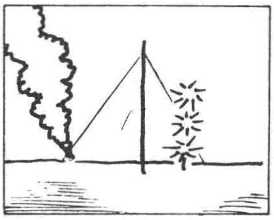

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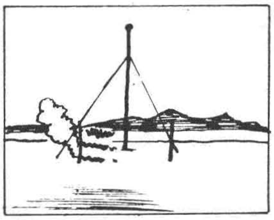

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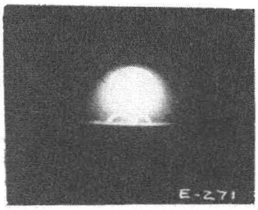

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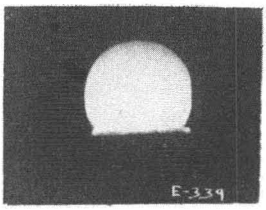

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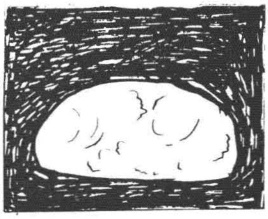

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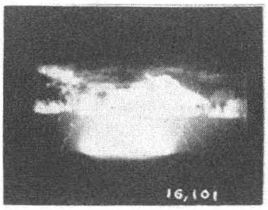

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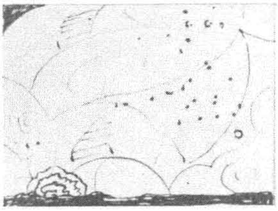

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confusion of smoke and debris. (No. 30). This illustrates the really primitive conditions under which we operate during a Pacific test.

You have been shown photographic examples taken from years of tests and experimental work. The scientists and engineers who accept the challenge of these problems in the laboratory and in the field know one reward—the importance of their effort to the national defense. Those who are doing the work know the horror and the chaos with which they are dealing, and we all hope and believe that the knowledge gained—carefully disseminated—may help prevent the use of such weapons in anger.

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*Precision Photogrammetry in Missile Testing**

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ABSTRACT: *Ballistic cameras employed at the Atlantic Missile Range are described and the operational procedures and the philosophy underlying their use are outlined. Certain aspects of the data reduction are considered. The accuracies attainable from the ballistic camera system are discussed in relation to those attainable from other missile tracking systems. Some important applications of ballistic cameras are indicated.*

INTRODUCTION

THE ballistic camera has been facetiously described as a glorified box camera. In some respects this description is rather appropriate, for one of the paramount virtues of the ballistic camera is its essential simplicity. On the other hand, the extraordinarily precise construction of the ballistic camera makes it a masterpiece of the opticomechanical industry. Because of its extreme precision, the ballistic camera provides a missile tracking system capable of producing position data having an absolute accuracy unattainable by any other system. Consequently, a major function of the ballistic camera system at the Atlantic Missile Range is to provide a standard for the evaluation and calibration of other tracking systems.

DUANE C. BROWN

DESCRIPTION OF THE CAMERAS

The ballistic cameras currently employed at the Atlantic Missile Range, the Wild BC-4's, consist essentially of modified RC-5 aerial cameras mounted on the base of the celebrated Wild T-4 astronomical theodolite. Three different camera cones are used: the 115 mm. Aviogon (f/5.6; field 76° square), the 210 mm. Aviotar (f/4.2; field 47° square), and the 300 mm. Astrotar (f/2.6; field 33° square). The distortion of each lens is calibrated by means of star recordings to an accuracy of one micron or better. Photographic

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* Presented at the Society's 25th Annual Meeting, Hotel Shoreham, Washington, D. C. March 10, 1959. This paper is a part of the panel on Special Applications of Photogrammetry.