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JULY 16TH NUCLEAR EXPLOSION:

ATTEMPT TO OBTAIN GAMMA-RAY KINEPHOTOGRAPHS

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ABSTRACT

In an attempt to obtain motion-picture records of the movements of the fission products during the first few hundredths of a second, apparatus was constructed in which a gamma-ray image of the "ball of fire" was projected on a fluorescent screen through a small aperture in a block of lead; buried motion-picture cameras of standard type and of the Marley type were to make optical pictures of the screen. The records show only heavy radiation-fogging, which was more than 100 times more intense than had been predicted from the expected irradiation of the films, including the effect of secondary gammas due to neutrons. The cause of this very intense irradiation is not yet known.

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General Description of Apparatus

The gamma-ray "pin-hole" image was formed, by a lead structure shown in vertical section in Fig. 1, upon a fluorescent screen that was immediatel inside a steel "window" of half-inch thickness welded onto a heavy steel tube. A silvered glass plane mirror of elliptical outline enabled this screen to be photographed by cameras housed within another steel tube inside the lower end of the main tube, and about 5 feet below ground level. The upper end of the main tube was closed by a heavy and virtually light-tight lid, and a structure of lead, sand and borax was built above and around this lid as indicated in the figure. Stations were established at 150 yards and 275 yards to the south of "0"; the camera at the 150 yards station was of the multi-lens, rotating aperture type, while at the 275 yards station there were two Bell-Howell 16-mm motion-picture cameras, one operating at 16 frames and the other at 64 frames per second, and both having lens apertures of F/1.5. The cameras were turned on electromagnetically by signals from the automatic timing system provided by J. L. McKibben; by devices described later, the inner steel tubes containing the cameras were made light tight shortly after the ground shock reached the installations.

Fluorescent Screen

With the cooperation of Group G-11 and of various commercial firms, a search was made for a fluorescent coating that combined high sensitivity to gamma rays with short persistence of luminosity. The best material discovered was a ZnO - Zn phosphor (No. A-1-1146) made by R.C.A. laboratories. The sensitivity of this substance to radium gamma rays is such that when it is photo-

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graphed on Super XX film with a lens aperture of F/1.5, a faint but easily perceptible blackening of the film is produced when the phosphor receives an irradiation of 1 roentgen. ZnO-Zn phosphors are known to be outstanding in respect of short persistense; as a check that this phosphor was no exception to the rule, a simple experiment with a rotating phosphor-covered disc was performed, and showed no perceptible luminosity remaining 2 mm after the cessation of irradiation. In order to increase the brightness of the screen when it is observed in a direction nearly normal to its general surface, the screen was corrugated by circular grooves indicated in section in Fig. 1. If the ratio of depth to width of each channel had been infinite, and the walls between the channels had been of negligible thickness, the forward luminosity would be $1/(1 - D)$ times that from a plane surface, where D is the diffused reflection coefficient of the coating for the light that it emits. For ZnO, D is of the order of 0.8; thus under ideal conditions the corrugation would give a five-fold gain in brightness; in practice the gain lay between 2 and 3. Thus one roentgen should give a very clear perceptible blackening with the F/1.5 lenses used.

<u>Estimate of intensity of image and of shielding required to prevent serious radiation fogging</u>:

The rate of emission of gammas from the fission products of 49 during the first hundredth of a second is not very certainly known but is believed to be of the order of 10^{-11} curie per fission. The rate of irradiation, due to 10^{24} fissions, of a bare surface at the distance of the farther of our stations (about 250 meters) will therefore be of the order of

$a \cdot 10^{24} \cdot 10^{-11} \cdot 2.3/(2.5 \cdot 10^{4})^{2}$ roentgen per second, where a represents the loss by absorption in the air and 2.3 r/sec is taken as the irradiation due to 1 curie at 1 cm. Since a is of the order of 10^{-1}, the rate of irradiation

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is of the order of 4000 r/sec. At a few hundredths of a second it will be somewhat less. At the nearer station it should be greater by a factor of perhaps six at all times. When the source is so small that no detail can be resolved by the pinhole system, the irradiation of the fluorescent screen will be the same as if it was bare; thus the initial intensity will be something like 4000 r/sec and, with the lenses used, a reasonable image should be obtained with exposures somewhat below a millisecond.

As the ball of fire grows, the gamma-ray flux through the hole will be spread over a larger area of the screen, and when the image fills the screen the average intensity will be less in the ratio of the area of the hole to that of the screen, which in our arrangement was about .01, reducing the irradiation to about 40 r/sec or, allowing for some decrease with time of the total emission of gamma-rays, perhaps to 10 or 20 r/sec.

Thus it seemed appropriate to arrange the various cameras to have exposures varying from less than a millisecond to a tenth or a twentieth of a second; the rotating-shutter camera and the standard motion picture cameras covered approximately this range.

Fogging of the final image can be due to two causes: irradiation of the fluorescent screen by rays not passing through the pinhole, and direct irradiation of the photographic film. The former will be avoided if the lead structure surrounding the pinhole attenuates gammas by a factor large compared with the ratio of about 100 between the areas of screen and pinhole, which requires only six or eight centimeters of lead. The latter is much more difficult to discuss but may be divided roughly into three parts: (i) fogging due to fission product gammas when the source is small compared with its distance

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from the camera; (ii) fogging occurring when the active material has spread so far that some of it is above the camera and gammas can pass nearly vertically through the ground instead of having the long oblique path in the ground characteristic of (i); and (iii) fogging due to secondary gammas produced by the capture of fission neutrons in the surface of the ground. Discussions of these processes by Weisskopf, Frisch and Moon led to the conclusion that fogging from all these causes should not correspond to more than 1 r even if the films were left in the ground indefinitely after the explosion, provided that shielding by lead and sand were provided according to the dimensions indicated in Fig. 1. As an additional precaution against neutrons, a six-inch-thick layer of borax was placed in front of the sand pile as shown in the figure.

Cameras

The commercial cameras call for no special comment, though it should be stated that they were switched on electromagnetically at about -1 sec by a signal from McKibben's automatic timing system.

The rotating-aperture camera at S-150 was constructed by us on the principle of the Marley camera and is shown diagrammatically in Fig. 2. The main components are

1) A battery-driven DC electric motor which was switched on by remote control at -12 seconds and switched off by a local time-delay device at about +5 seconds. The motor ran at 50 rps, driving

2) a duraluminum disc, pierced with four circular apertures on perpendicular radii. Each aperture was normally covered by a thin metal shutter pivoted about an axis perpendicular to the disc and nearer to its center than the aperture. When the disc rotated, these shutters moved centrifugally and uncovered the apertures; when the motor was switched off and the speed of rotation

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fell, they were drawn back to their original positions by elastic cords. Each pair of diametrically opposite apertures corresponded in size and radial distance to one of

3) two rings of lenses mounted in a brass plate. The outer ring cc sisted of 25 lenses of 1 cm diameter and 1.6 cm focal length, the inner consisted of 15 lenses of 2 cm diameter and 3.2 cm focal length. The number in each ring being odd, the two opposite apertures exposed nearly opposite lenses in succession this arrangement provided exposures, overlapping in time, at twice the frequency that would have been obtained with the same number of lenses and a single rotating aperture, and was employed to eliminate the chance of accidentally missing the most interesting phase of the explosion. It will be noted that the exposures are not confined to a single revolution of the aperture disc; the camera was designed on the assumption that the brightness of the image would be decreasing so rapidly after the instant of explosion that negligible interference would be caused by light received after the first revolution and before the housing of the camera was closed by the device described later.

4) The images cast by the lenses were received on two Super XX aero films clamped between three brass discs, the upper two discs and the upper film being suitably perforated so that the images due to the outer, short-focus lenses fell on the upper film, while the light from the inner, longer focus lenses passed through holes in the upper film and was focussed on the lower film. Various mechanical details, not shown, ensured the correct positioning of all the components.

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Housing of Cameras

The rotating-disc camera was not designed to be completely light-tight; it had therefore to be installed in and removed from the main steel tube with the minimum exposure to light. There was, moreover, no certainty that the main housing would remain light tight after the shot. The camera was therefore enclosed in another steel tube that could be lowered into the main tube and that carried at its open upper end an arrangement which, when actuated by mechanical shock from the explosion, would release a shower of lead shot that fell around the camera, shielding it perfectly from light and to some extent from gamma rays. Details of this device are shown in Fig. 2; the shot was originally contained in the annular space S, being supported by the ring R that was itself held by wires from 3 glass hooks, the breaking of which released the shot.

The films were loaded into the camera, and the camera loaded into the inner steel tube, in the dark room at the base camp. The upper end of the tube was temporarily covered by a changing-bag until the whole had been lowered into the main housing in the field; a dark tent was then built over the housing, the changing-bag removed, the lead shot poured into the annulus, the mirror inserted, the main lid closed, and the lead and sand shielding completed.

The commercial cameras at 275 yards were similarly housed, except that since a small central aperture at the top of the inner steel tube was sufficient to allow entry of all rays from the fluorescent screen, the lead-shot device was replaced by a small spring-loaded self-latching trap-door, initially held open by a wire attached to the mirror (see Fig. 1). When the mirror was shattered by the explosion, this door closed and made the camera housing light-tight.

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Recovery of Cameras

Since the recovery of the cameras was expected to occupy an hour or two, it was deferred until approximately two weeks after the shot, by which time the delayed ionization in the neighborhood of the station had decayed to the order of 1 r/hr.

Before describing the process of removal, it is appropriate to recall the mechanical effects of the blast upon the sand piles and neighboring objects. The sand pile at S-150 appeared virtually unaffected, though the paper sacks of borax had been broken and much of the borax removed by blast or weathering. Exposed woodwork had been considerably scorched. A green lattice of fused sand covered most of the northern surface, and some of the other surfaces, of the sand pile. In contrast to the small disturbance suffered by this pile, a small stack of unused lead shielding blocks, weighing on the average 15 lbs each, and lying about 10 yards to the east of the center of the sand pile, was almost completely dispersed. Some of the blocks were thrown 100 yards to the south and during their flight lost about 5% of their material by melting and/or sand blasting; that this loss was suffered in flight was shown by the roughly uniform removal of material from all sides of the blocks, and the equal rounding of their corners. Similar blocks that had remained on the ground near the sand pile had lost material from their exposed surfaces only, and a large fraction of the molten lead had run into the sand and congealed around the base of each block.

The more distant sand pile, at 275 yards suffered much more disturbance than the nearer one; the sand was nearly all removed though the lead shielding structure was almost untouched;

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These observations indicate extreme irregularity in the air blast; the only fact that suggests any correlation is that a narrow and well defined green "streamer" can be seen from the aerial photographs to lie directly over the lead pile and the 275 yards sand pile, which were violently disturbed, but to miss the 150 yard pile which was little affected. Discussion of this fact with R.R. Wilson led to the suggestions that the green streamers might indicate and be caused by extremely narrow and powerful Munroe jets, and that there might be some hope of identifying these jets on the fastax pictures taken by group G-11. Mack has been consulted but reports that such jets are not visible on the pictures taken by his group, though that does not mean that they did not exist.

The removal of the 275-yard motion-picture cameras was comparatively easy; it was necessary only to remove some lead blocks, open the steel lid and haul out the inner tube, which was taken back to the base camp. The 150-yard sand pile had, however, to be dug away, and it was considered advisable to use a crane truck to remove the main steel tube, carry it back to camp, lower it into a previously prepared hole such that the upper end of the tube was at convenient working height, drop a portable dark room over it and remove the inner parts in comparative leisure and complete darkness. During this operation, H.S. Allen and his assistants operated the crane truck, while Bainbridge acted as radiation monitor. Their help was very greatly appreciated.

Results

All cameras were removed in good order, and there was no evidence of any leakage of light to any film; nevertheless all films were completely and uniformly fogged to an intensity corresponding, as was shown by subsequent experiments with similar specimens and a radium gamma-ray source, to about 500 roentgens, there being

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no great difference between the amount of fogging of the 275-yard and 150-yard films. This last fact may perhaps indicate that the fogging occurred subsequent to the arrival of the blast wave, the survival of the sand pile at 150 yards compensating for the shorter distance. However, in view of the apparently very irregular motion of air and presumably of active material in the blast wave, deductions of this kind are highly speculative. It seems clear that very hard gamma rays or fast neutrons were present in much greater numbers than had been estimated by Weisskopf, Frisch and Moon when the shielding of the cameras was planned. In the hope that some evidence of (γ,n) or (n,γ) reactions might be found at depths comparable with that at which the cameras were, specimens of the sand were obtained from the sides of the hole at 150 yards from which the large steel tube had been removed; to avoid contamination from surface material that might have blown into the hole, the specimens were taken from points about 2 inches within the exposed cylindrical surface of the hole. These specimens are under examination by H.L. Anderson's group for beta activity and for the decay thereof; the only fact that has yet been established with certainty is that the samples taken well below ground level show activities that decay much more slowly than does the activity of sand (excluding molten sand, which may have been blown from the neighborhood of the crater) obtained 2 inches below ground level. It is just possible that prolonged examination of these samples may enable identification of the isotopes responsible for their activities and may enable something more to be said about the radiation responsible for the fogging of the film. The best hope seems, however, to lie in experiments at future tests of nuclear explosions; if such tests are made over land it would be interesting to bury at various depth a number of specimens of various elements and to investigate the delayed activities induced in them.

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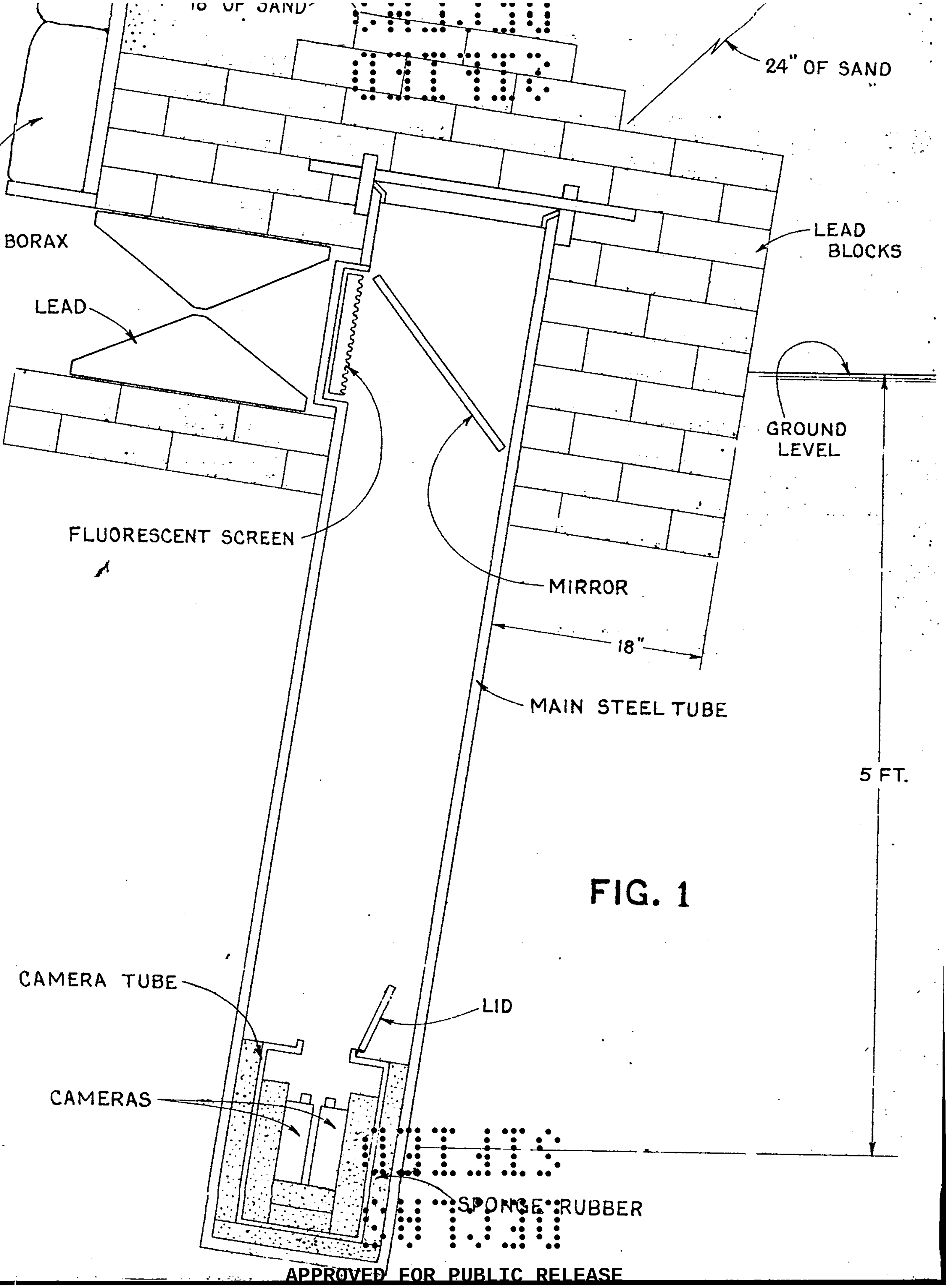
24" OF SAND
BORAX
LEAD BLOCKS
LEAD
GROUND LEVEL
FLUORESCENT SCREEN
MIRROR
18"
MAIN STEEL TUBE
5 FT.
CAMERA TUBE
LID
CAMERAS
SPONGE RUBBER

FIG. 1

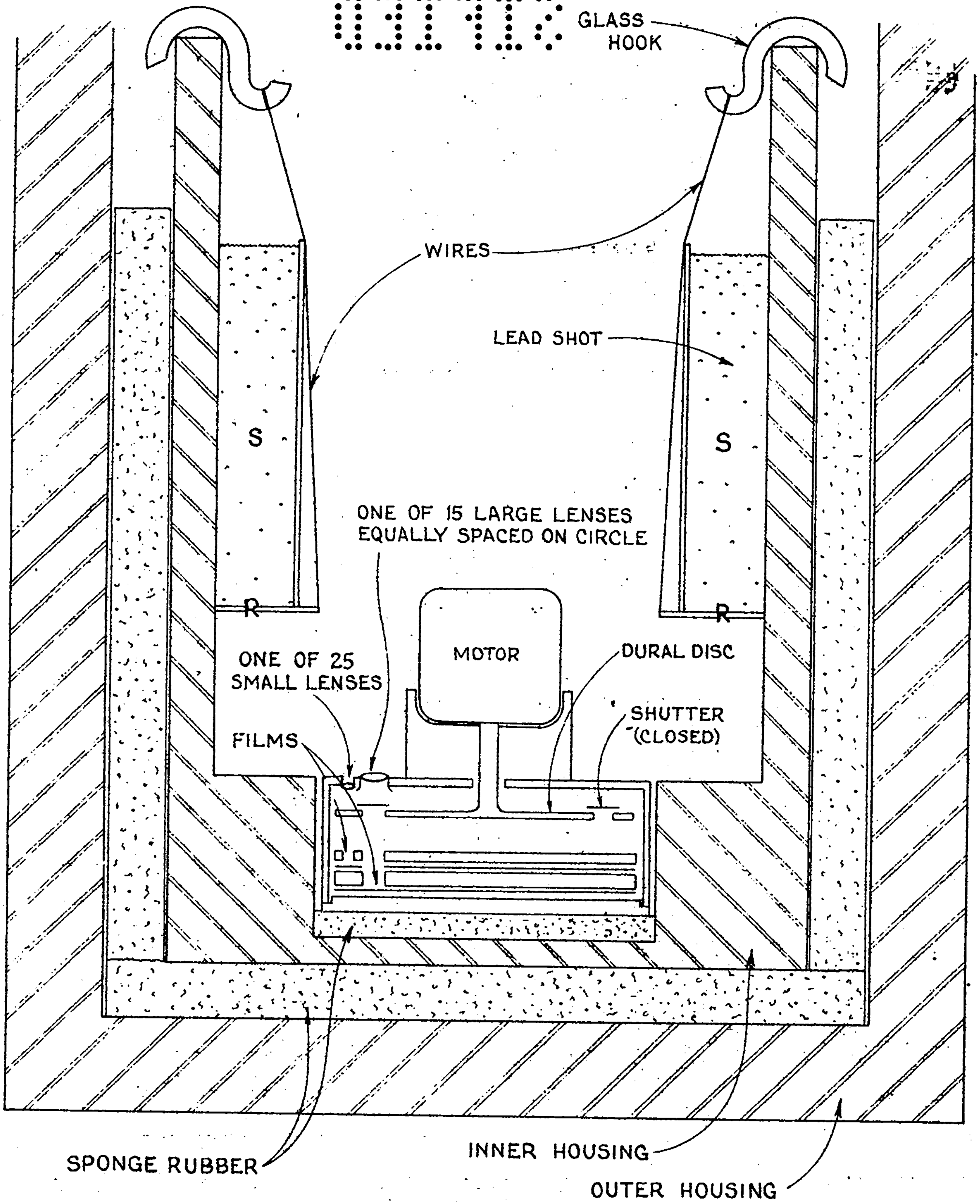
GLASS HOOK
WIRES
LEAD SHOT
S
S
R
R
ONE OF 15 LARGE LENSES EQUALLY SPACED ON CIRCLE
MOTOR
ONE OF 25 SMALL LENSES
DURAL DISC
SHUTTER (CLOSED)
FILMS
SPONGE RUBBER
INNER HOUSING
OUTER HOUSING

FIG. 2

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