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A STUDY OF AN ACCIDENTAL RADIATION BURST

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ABSTRACT

An accidental burst of radiation occurred at the Pajarito remote control laboratory on 1 February 1951 during remote control operation of one of the assembly machines. There was no personnel hazard. Normal operations were resumed within twenty-four hours, and the active material involved in the burst was returned to service withing three weeks. It has been determined that the burst resulted in $\sim 10^{17}$ fissions in the active material, equivalent to an average power developed of 15 megawatts for 0.2 second. This report describes the effects of the burst, and analyzes the probable causes in some detail.

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A STUDY OF THE ACCIDENTAL RADIATION BURST WHICH OCCURRED AT THE PAJARITO REMOTE CONTROL LABORATORY ON 1 FEBRUARY 1951.

I. INTRODUCTION

On the afternoon of 1 February 1951, the remote-control operations crew at the Pajarito Site undertook to measure the separation distance at which two particular Oralloy shapes might become critical. This distance was measured for the two active masses in air, and in effectively infinite water tamping. The measurements were made using the Aquarium machine.

These measurements on the active-material shapes were the last in a series of proximity and water-immersion tests carried out over a period of about two months, during which time the critical separation distances of pairs of a variety of shapes and masses of active material were measured, both in air and under water. The operations crew on duty for these measurements was the same crew that had performed all previous Aquarium machine experiments involving the proximity of various quantities of active material under water.

Figure 1 is a schematic drawing of the Aquarium machine as set up for proximity measurements. Figure 2 is a photograph of the machine. It consists essentially of a water tank with remotely controlled flood and drain valves, means for suspending two masses of active material in the tank, and remotely controlled means for running these masses together and apart. The machine is located in the Kiva at the Pajarito Canyon Site, about 1200 feet from the control

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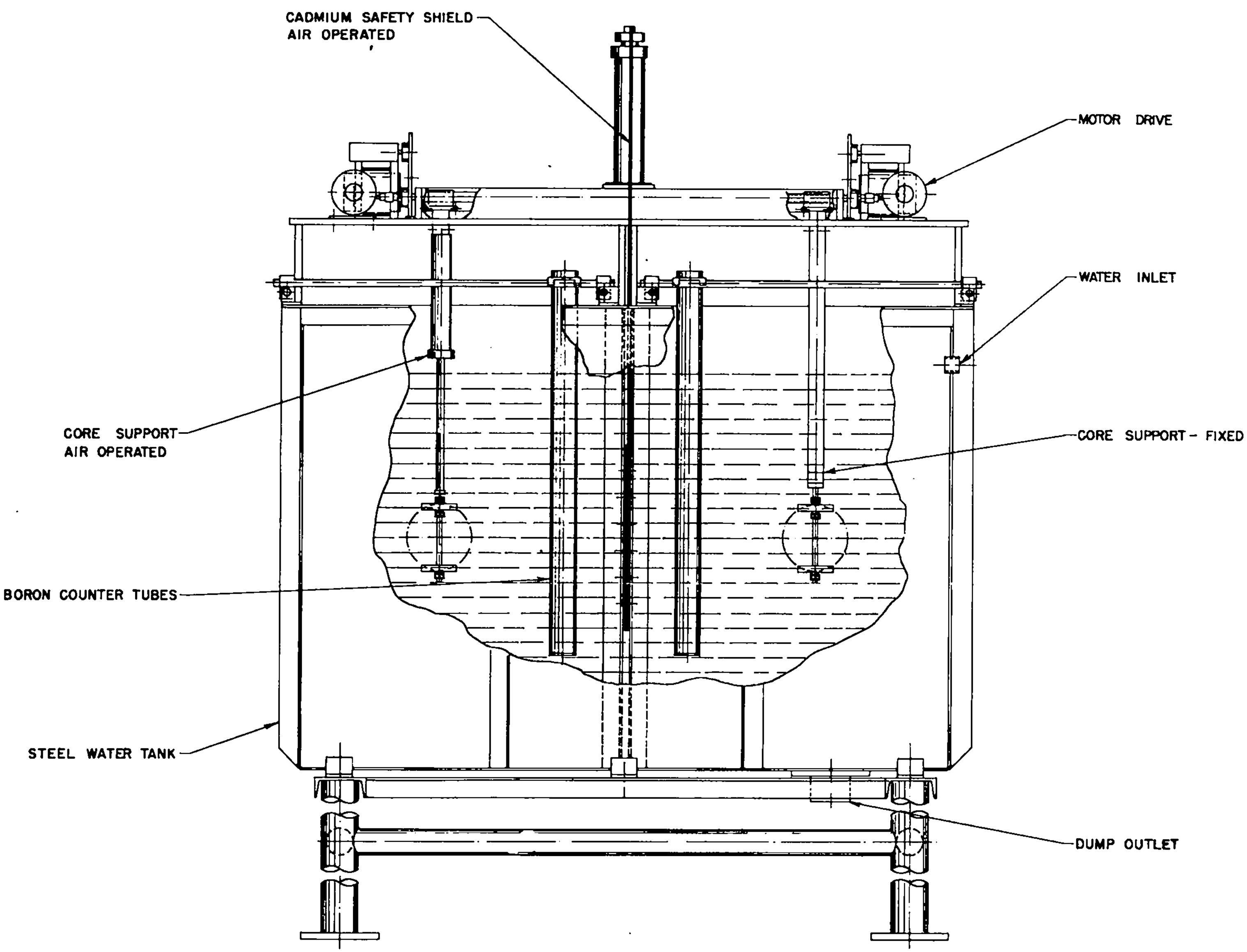

FIG. 1. General assembly Aquarium machine.

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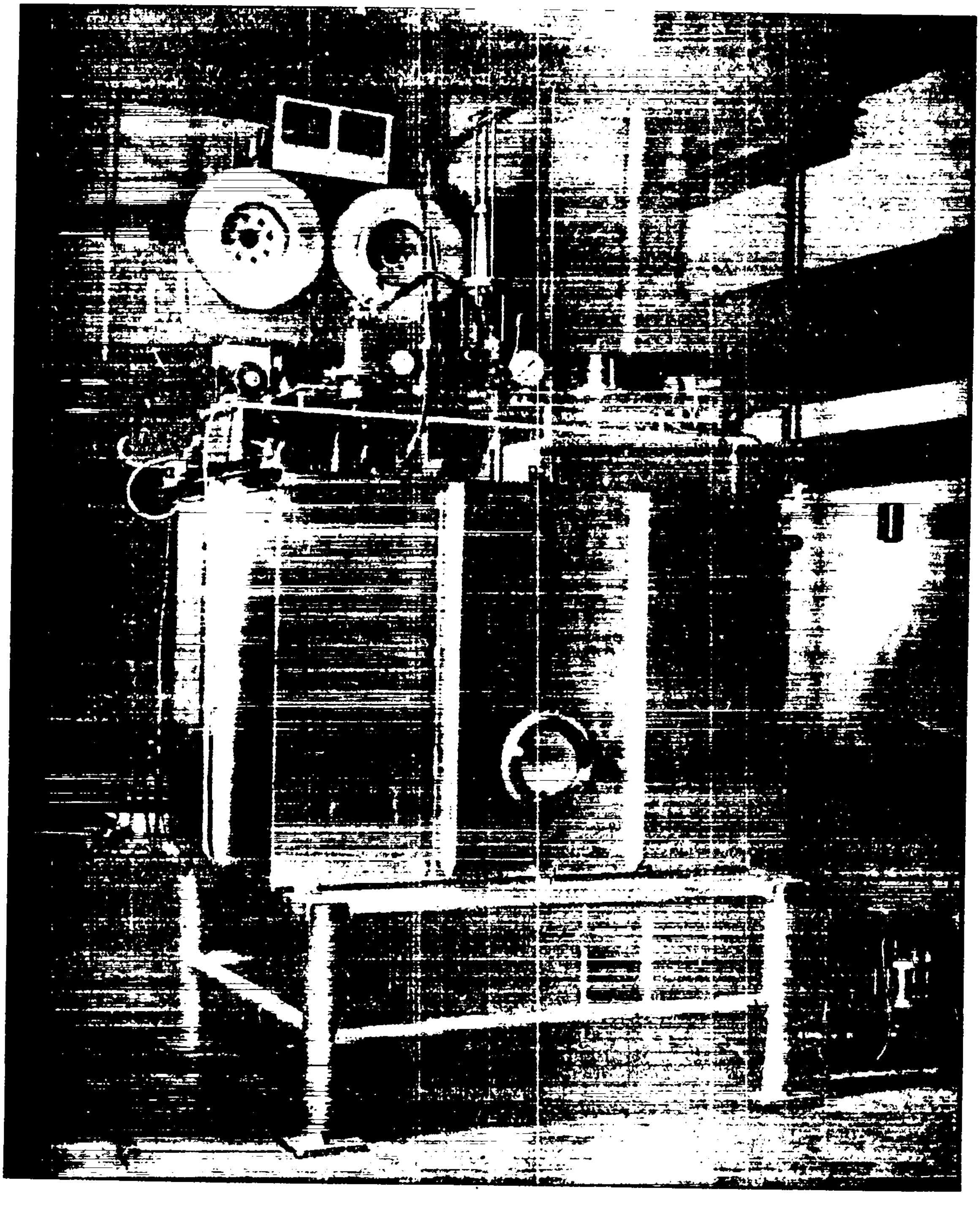

FIG. 2. The Aquarium machine.

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station. A fenced and locked enclosure prevents personnel from approaching the Kiva closer than about 1200 feet when remote-control assembly operations are in progress.

The Aquarium is fitted with three safety devices, all three of which act in case the neutron flux in or near the machine should exceed a predetermined value. These safety devices are:

(1) A 2 1/2" water dump valve.

(2) A Cd shield which drops between the two active-material masses.

(3) An air-operated lift, which raises one of the two masses a distance of six inches, reducing the water tamping around that mass.

In addition, the mechanism controlling the horizontal motion of the masses starts moving them apart, continuing this motion until the two masses are at extreme separation (about 30 inches, center-to-center). These safety devices may be actuated by hand, or by any one or all of three neutron monitors, two of which are located at the tank, and one about 25 feet away across the Kiva.

Four boron-lined chambers for measuring the neutron flux in the tank were inserted in watertight tubes and positioned in the tank near the active assemblies. Pulses from these chambers were amplified and fed to four scalers located in the control room. Also, two neutron chambers, one with linear and one with logarithmic amplification, were located about 30 feet from the tank. The level of neutron intensity seen by these two chambers is recorded on G. E. recorders located in the control room. The linear amplifier has six sensitivity scales, each separated by a factor of ten from its neighbors. A point source of $\sim 10^8$ neutrons per second located in the (dry) Aquarium just begins to register on the most sensitive scale of the linear amplifier.

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In addition to the monitors and detectors described above, a number of dental x-ray film badges are planted in various positions around the Kiva. These badges are changed and read every two weeks. The planted-badges on 1 February 1951 included high-sensitivity Eastman film (changed a few days previously) and some low-sensitivity Adlux film which had not been changed for about two years.

The active material used in the present tests was a set of Oy-93.5%, "universal cylinder rings". Cylinders made up from these rings are about one per cent low in gross density since they must be built up using between 80 and 90 small parts. The two shapes used for this test were a solid cylinder of mass 24.4 kg. (called A) and a hollow cylinder of mass 38.5 kg. (called B). A set of Tuballoy "universal rings" is available to mock up cylindrical assemblies for unmultiplied counts.

Sheet cadmium 10 mils thick was fastened to the outside cylindrical surface of A, except for a narrow portion near one end, and to the inside cylindrical surface of B.

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II. THE RADIATION BURST

The Pajarito crew first measured the self-multiplication of the hollow cylinder (B) in effectively infinite water tamping: a value of 6.86 was found. A paraffin cylinder was used as a central source support and filled the central cavity completely. The self-multiplication of the solid cylinder (A) in water had been found in previous measurements to be 11.3. This determined that for proximity work the neutron source should be located in A since it is the more reactive of the two masses.

Tu mockups of A and B were mounted with axes vertical on the traveling supports of the Aquarium machine, with neutron mock-fission source MF-11 centered in the A mockup, and the shapes were run together to a surface-to-surface separation of 0.50 inch as determined by actual measurement. Readings of the selsyn position indicators in the control room (which indicate the position of each mass to one-hundredth of an inch) were recorded, and other distance settings were determined from these readings. The operation of the safety devices, or "scrams", described in Section I, were checked several times at this closest position of approach. It was found that the Cd safety shield dropped between the components without touching them, and that the air pressure on the air-lift cylinder was sufficient to lift A six inches in a few tenths of a second. The water dump valve opened properly, and the mechanisms controlling horizontal motion of the shapes separated them normally on each test.

A series of unmultiplied counts was then taken over the full range of possible separation distances to 0.50 inch, using the four boron-lined chambers and the control-room scalers described in Section I. This was done with the tank empty, and with enough water in the tank (22.5 inches)

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to cover the top of each of the masses with at least six inches of water. The tank was then drained, and the Oy shapes were substituted for the Tu. All subsequent assembly operations were carried out by remote control, with the closest personnel in the control room about 1200 feet from the machine. A television camera transmitter was focused on the action in the tank, with the center of action about three feet from the TV camera lens, so that motion of the masses could be observed on the receiver, in the control room.

Proximity measurements were first made with the shapes in air. A series of multiplied counts was obtained for decreasing A - B separations, and reciprocal multiplication was plotted as a function of separation distance (see Fig. 3). The total multiplication for 0.50" separation of the masses was found to be 3.41, and the curve (Fig. 3) extrapolates to a total multiplication of 3.65 for the masses in contact.

A and B were then run apart to maximum separation, and water was run into the tank to the same level used in the unmultiplied counts. Once again the distance between the masses was decreased in steps, taking a multiplied count at each step, and plotting reciprocal multiplication as a function of separation distance after each step to monitor the safety of further reducing the separation distance (Fig. 3).

At a horizontal separation distance of 1.00 inch, the observed multiplication was 65.45, and extrapolation of the approach curve (Fig. 3) indicated that the assembly would reach delayed critical at a separation of about 0.60 inch. It was decided that no appreciable gain in accuracy could be realized by further reducing the separation(1),

(1) A limit of multiplication of 150 for remote control assembly had been imposed on this experiment.

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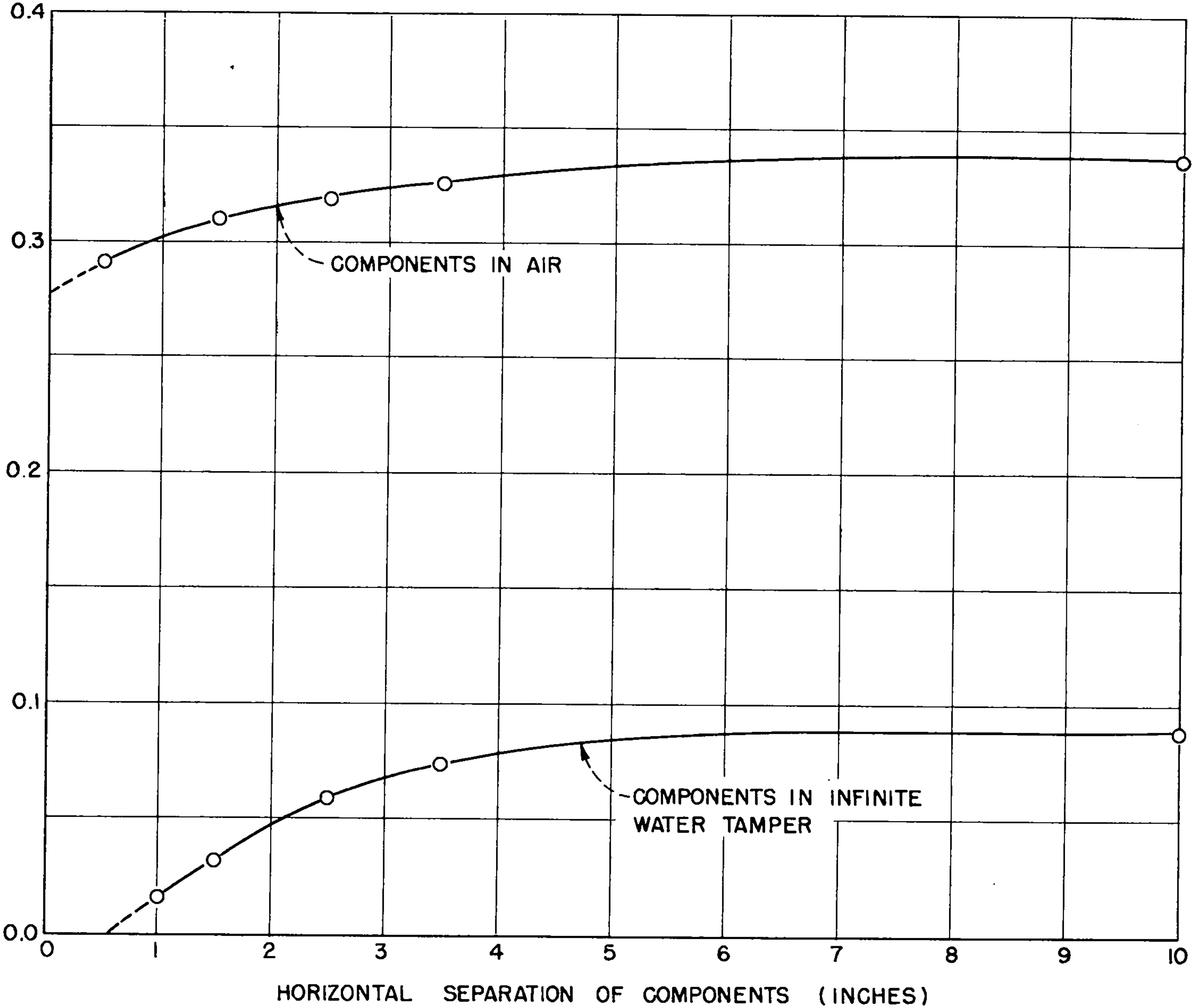

FIG. 3. Proximity measurements on A and B, in air and in effectively infinite water tamping.

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and at 10:20 p.m. the assembly was scrammed using the hand-scram button on the control panel.

Almost instantly, the three monitor-controlled scram relays tripped simultaneously, and their recording monitor needles went off-scale. All scalers counting pulses from the boron-lined neutron chambers in the Aquarium tank were jammed. The linear and logarithmic amplifier recorders were off scale, but the linear amplifier trace was picked up on a less-sensitive scale and the neutron flux was observed to be decaying rapidly. As indicated by selsyns on the control panel and by observation of the television picture, the scram action had progressed and was progressing normally: the lift was up, the Cd safety shield was down between the two masses, the masses were moving apart and appeared to be intact, and water was draining out of the tank. The only abnormal indication on TV was some evidence of steam or smoke at and near the surface of the water.

It was immediately evident that there had been a momentary burst of radiation of considerable magnitude from the Oy assembly in the Aquarium; it was further evident that the assembly was no longer critical, that contamination (if any) was confined to the Kiva area, and that no useful purpose would be served by evacuating the site unless the radiation level in the control area should be found to be abnormally high. A portable scintillometer was used to check the gamma radiation level in the control area, which was found to be negligible[1].

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(1) Subsequent development of a film badge planted in the control room indicated an exposure too low to be read.

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About one hour after the burst, a survey was made part way down the road to the Kiva. At 11:40 p.m. the portable scintillometer indicated a gamma-radiation level of 0.1-0.2 mr/hr at a distance of about 750 feet from the Kiva. It was apparent that the Kiva could not be entered safely or profitably before morning; consequently, the gate to the Kiva area was again locked and remained so overnight.

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III. THE EFFECTS OF THE BURST

At 6:00 a.m. the following morning the Kiva was entered for a few minutes, and the Oy assemblies in the Aquarium were observed from a catwalk above the machine. The assemblies appeared to be in good condition[1], although a rubber glove used to prevent water from touching A had broken and was scorched, and paper tape used to secure the cadmium to the shapes and to protect the Oy edges from marring by the supports was blackened. The paraffin slug used to fill the cavity in B appeared to have been partially melted and even vaporized as evidenced by paraffin particles adhering to the Cd shield, and a paraffin stalactite about three inches long hanging under the B support.

Representatives of the monitoring section surveyed the Kiva at 9:00 a.m. A "Cutie Pie" beta-gamma detector gave a reading of approximately 2 r/hr at the surface of the Aquarium tank. A survey of the area immediately around the tank gave no indication of contamination. The planted film badges in the Kiva were collected at this time for developing.

Special tools (pliers, wire cutters, hack saw, etc.) with handles about five feet long were made ready, and procedures were worked out for removing a sample of Oy from the A assembly for counting. At 2:00 p.m. the overhead crane in the Kiva was hooked to the A assembly, electrical and air leads to the lift plunger were cut,

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(1) Blistering of one of the outside rings in B was discovered on disassembly a week later.

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the hanger pins were driven out, and the mass and its support were lifted out of the tank and lowered onto a piece of foam rubber behind a lead screen 2" thick built up on the Kiva floor. Nuts clamping the assembly together were removed with long-handled pliers, and these pliers were used to remove neutron source MF-11 and a small cylinder of Oy (weight 17.0 gms) from the center of the assembly. The source was undamaged. The universal rings came apart readily, with no evidence of swelling or binding. However, considerable discoloration of the Oy was evident, with blue, gold, and silver colors replacing the dark oxide color in many places. Disassembly was deferred for one week to allow the radiation level from short-lived fission products in the active material to die down.

Scheduled remote-control operations in the Kiva were resumed the morning of February 3rd. By the afternoon of the 3rd, the radiation level outside the Kiva building was negligible, and the gate to the Kiva area was opened(1).

Development of the planted film badges indicated that the Eastman (sensitive) film was too dense to be read. However, the Adlux film (two years in the Kiva) gave a reading of $\sim$180 r at a position about 9 feet from the center of the tank, and an average of 80 r on the other walls of the Kiva.

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(1) The Kiva building is kept locked except during remote-control operations, at which time the Kiva area is cleared and the access gate is locked.

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This would give an estimated maximum of 100 r due to the burst at a distance of 9 feet from the assembly. From inverse square considerations, a person standing beside the tank at the time of the burst would have received a (lethal) whole-body radiation dose of 1500-2000 r[1].

An estimate of the total number of fissions occurring in the burst was made by comparing the fission fragment gamma activity from the small cylinder of Oy taken from the center of A with a similar cylinder that was irradiated in the Topsy critical assembly machine. The decay curves of the two slugs are shown in Fig. 4. The gamma activities were counted with a Geiger counter and with a scintillation counter. The difference in curvature of the Geiger counter and scintillation counter curves is probably due to the fact that sensitivity dependence on energy of the two detectors is not the same.

The data on the irradiation of the Oy slugs are tabulated below.

	Topsy (Oy-Ni)	Aquarium
Mass of assembly (kg)	21.2	64
Mass of slug (gm)	28.9	17.0
Fissions in Topsy for observed slug activation	2.33×10^{15}	----
Relative slug activity per gm 25 hours after irradiation	1	8.8

(1) Maximum exposure of personnel involved both in the burst and in clean-up operations, as determined from personal film badges (2-week period), was 110 mr.

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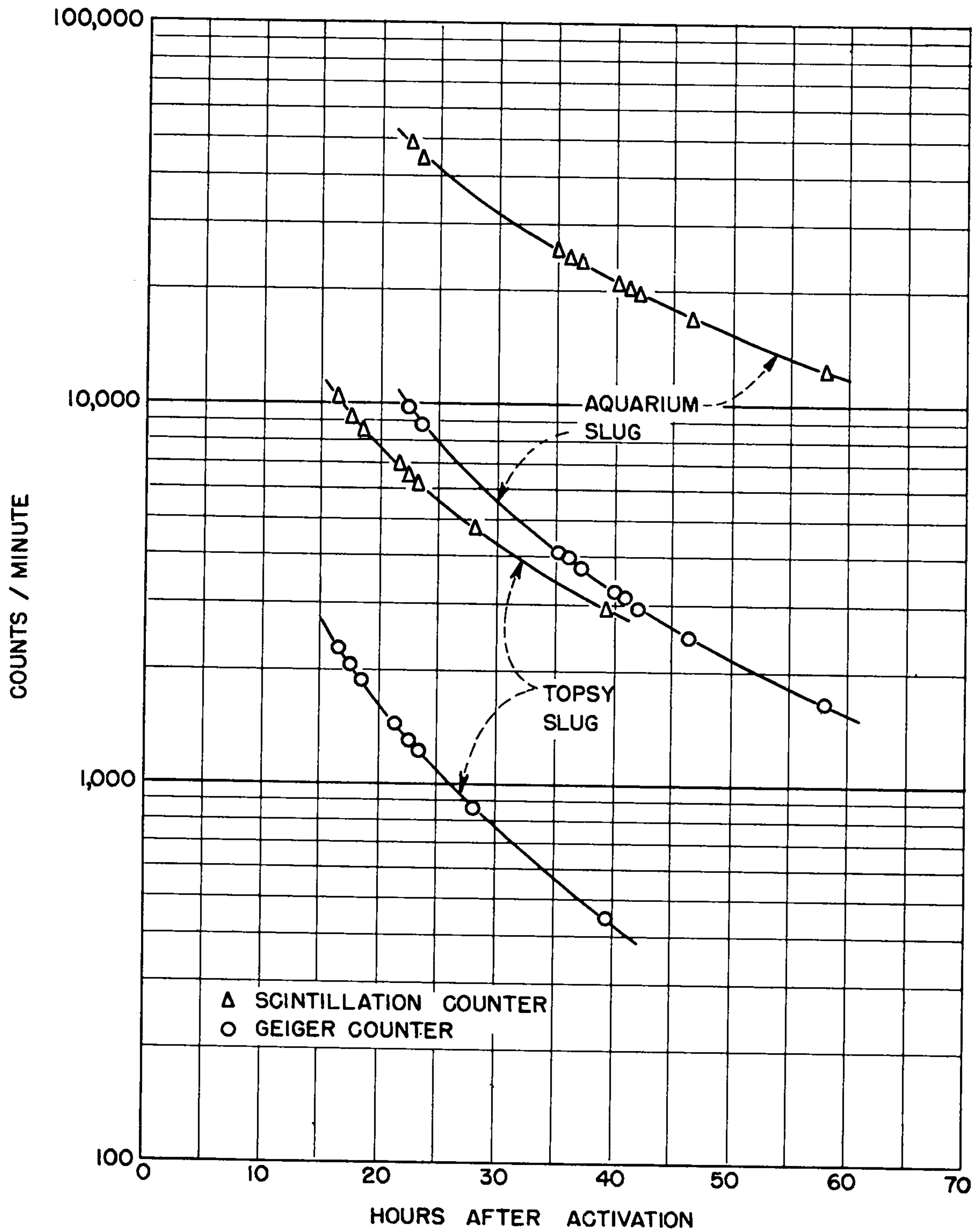

FIG. 4. Comparative decay curves of Oy slugs from Topsy reactor irradiation and from the Aquarium radiation burst.

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The average number of fissions per gram for the Topsy irradiation from the above data is 1.10×10^{11}. Since the fission rate in the center of Topsy is 1.68 times the average rate, the number of fissions per gram in the Topsy slug was 1.83×10^{11}. The number of fissions per gram in the Aquarium slug was therefore 1.6×10^{12}. Since the Aquarium assembly was quite non-symmetrical, one can only assume that the number of fissions occurring in the slug was representative of the assembly average. On the basis of this assumption, the total number of fissions occurring during the burst from the Aquarium assembly was 1.0×10^{17} fissions. Assuming 188 Mev of heat energy per fission, this represents an energy release of 835 watt-hours, which, for a burst duration of 0.2 second[(1)] would make the power developed during the burst $\sim$15 megawatts.

Disassembly was scheduled for the afternoon of 8 February. At 2:00 p.m. on the 7th of February, nine high-range Keleket gamma-ray ionization dosimeters (pencil type) were placed in various positions around the A assembly (on the Kiva floor), and around the B assembly (still hanging in the tank). These were picked up and read at 2:30 p.m. 8 February, just prior to starting disassembly. Positions and readings are given in Table I. The components were obviously still too active to permit hand disassembly, so the operations were carried out as before with long-handled pliers. Pocket type (low range) dosimeters were worn by operating personnel and were checked periodically during disassembly. Whole-body exposures of the four persons involved ranged from 17 mr to 28 mr (about half daily tolerance) integrated over the time required for disassembly.

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(1) See Section IV of this report.

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Small amounts of Oy oxide and blistered metal flakes and fragments were recovered from the assemblies and from the bottom of the tank. No material was lost.

After disassembly, the universal rings were stored in their carrying cases until 20 February, at which time they were cleaned using a dry-box and standard cleaning procedures. Five blistered rings were remachined, and the entire set of universal rings was returned to service.

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TABLE I. Radiation intensities near the active assemblies on the seventh day after the burst

Location	Distance from active material (inches)	Integrated radiation for 24.5 hours (roentgens)	Average Intensity per hr (r/hr)
Inside center hole (A)	(surrounded)	80.3	3.28
Alongside A	0.0	44.0	1.80
Alongside A	1.0	38.1	1.55
On top of B support plate.	0.2	47.8	1.95
Above B	3.0	10.0	0.41
Above B	3.0	10.8	0.44
On bridge over B	30.0	0.8	0.033
On Cd safety shield opposite B	10.0	6.6	0.27
On tank wall opposite B	15.0	2.2	0.09

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IV. CAUSES OF THE BURST

The facts that the action of scramming the assembly precipitated the radiation burst, and that motion of the vertical lift on the A is the only one of the scram actions that could conceivably have increased assembly reactivity, led at once to an investigation of the following potential causes of the burst:

(1) Location of the center of reactivity of the vertically movable assembly (A) below the center of reactivity of the vertically fixed assembly (B), so that vertical upward movement of A would result in a transient reduction in the distance between centers of reactivity.

(2) Displacement of the center of reactivity of A away from the center of mass.

(a) up, if the tamping effect of a dense metal plate at the upper end predominates, or

(b) down, if the effect of the bare (not Cd coated) lower end portion predominates.

(3) Actual drawing-together of the two Oy assemblies, caused by either or both of the following:

(a) A Bernoulli effect pressure reduction between the assemblies, caused by the vertical movement of one of them.

(b) Unbalanced water drag forces acting on the top of the A assembly as it moves upward, displacing it toward the target.

Results of this investigation indicate that all three of the potential causes were indeed actual causes, and each contributed to the magnitude of the burst. These causes will be discussed individually, and then their collective effects will be summarized.

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Cause (1)

Tu mockups of the active assemblies were remounted on the supports in the tank, and the vertical positions of the centers of Tu mass were measured accurately. The center of mass of the Tu A mockup was found to be 2.70" lower than that of the Tu B mockup. At 1.00" surface-to-surface separation, the centers of mass were thus 6.19" apart horizontally, and 2.70" apart vertically. The diagonal distance is therefore 6.75", so that the centers of mass of the components come momentarily 0.56" closer together on vertical scramming of the A assembly.

From Fig. 3, a reduction of the center-to-center distance of about 0.40" would be sufficient to bring the assembly as a whole to a delayed critical condition. From measurements made on other Oy assemblies, it has been found that the mass interval between a multiplication of $\sim$50 and delayed critical is the same as the mass interval between delayed critical and prompt critical. If we assume that this applies also to distances in proximity work, then from Fig. 3 the distance between a multiplication of 50 and delayed critical is 0.55". Thus the centers of reactivity of the two masses would have to be brought 0.40" + 0.55" = 0.95" closer together to reach a prompt critical condition.

Cause (1) is therefore sufficient in itself to bring about a delayed critical condition, but is insufficient to make the assembly prompt critical.

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Cause (2)

The magnitude of the displacement of the center of reactivity of A away from its center of mass can be expected to be the resultant of two effects working in opposite directions:

(1) A shift toward the solidly tamped (upward) end if the tamping effect caused by the dense metal plate is greater than that of water.

(2) A shift toward the bare (not Cd-coated) end caused by the increase reactivity of non-Cd-coated Oy in a moderating medium over Cd-coated Oy.

On February 23rd an experiment was performed to measure the resultant of these two effects for various conditions of reactivity well below delayed critical, so that the displacement at critical could be estimated by extrapolation. The experiment was conducted as follows.

Tu mockups of the Oy masses as they were at the time of the burst were mounted on their supports in the tank with source MF-11 centered in A as before. Electrical stops were set to prevent moving the parts closer together than 2.00 inches horizontally. The air-lift plunger was inactivated, and a series of unmultiplied counts was taken with the tank filled with 22.5" of water and with the lift plunger clamped successively at positions down, up 1", up 2", up 3", up 4", and up 5", each for A - B horizontal separations of 2.0", 2.5", 3.0", 3.5", and 4.0". Oy masses were then substituted for Tu, and the above sequence was repeated by remote control, taking a multiplied count at each step. For each horizontal distance between masses, a curve was plotted of reciprocal multiplication as a function of vertical distance of A.

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If there were no shift of the center of reactivity of A away from the center of Oy mass, one would expect the minimum for each of these curves to occur at an A vertical position of up 2.70", since at this position the Oy centers of mass are at the position of closest approach. Any displacement of minima away from 2.70" must be due to the competing Cause (2) effects described above.

The results of this experiment are illustrated in Fig. 5. For an A - B horizontal separation of 4.0", the center of reactivity of A is apparently 2.70" - 2.05" = 0.65" above the center of mass. As the horizontal distance between the components is decreased, the center of reactivity moves downward, until at a horizontal separation of about 2.3", the center of mass and the center of reactivity coincide. At a separation of 2.00", the center of reactivity of A is 0.30" below the center of Oy mass. By linear extrapolation for a critical condition, the center of reactivity would be 0.85" below the Oy center of mass. This would place the center of reactivity of A 2.70" + 0.85" = 3.55" below the center of reactivity of B, resulting in a distance of 7.12" between these centers. The distance between centers would thus be reduced by 7.12" - 6.19" = 0.93" by vertical upward motion of A, bringing the Assembly as a whole to the verge of prompt criticality.

It appears, therefore, that although a combination of Causes (1) and (2) may possibly bring about a prompt critical condition, a burst of the magnitude actually observed is unlikely from these two causes alone.

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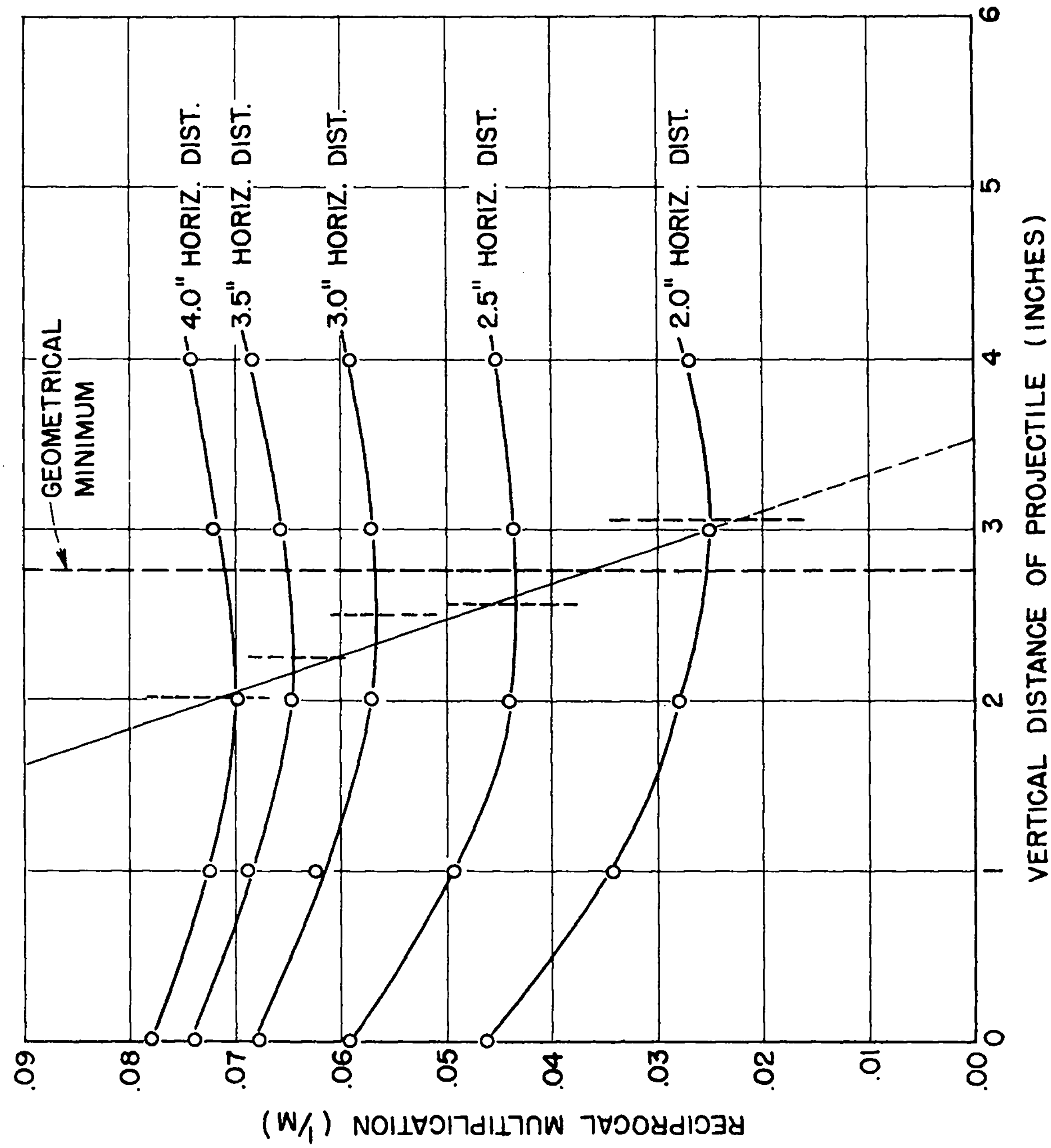

FIG. 5. Plot of reciprocal multiplication vs vertical position of A for various horizontal separation distances between A and B, in effectively infinite water tamping.

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Cause (3)

The motion of A under the action of the air-lift plunger was studied employing Tu mockups of the active assemblies, both in air and in water, by means of a Fastax camera. A glass "porthole" six inches in diameter was installed in the Aquarium tank directly opposite the position of the assemblies (see Fig. 2). The Fastax camera was mounted outside the tank adjacent to the porthole in such a position as to view the motion of A relative to B when the A air-lift was actuated by scramming the assembly. A and B were set at a horizontal separation distance of 1.00", the camera was started at a rate of 840 frames per second, and the scram button on the control panel in the control room was pushed. This was done for the parts in air as well as in 22.5" water. The films were then developed and read using a comparator.

Sequences of sample films are shown in Fig. 6 for air and for water in the tank. In both cases, the first action of A is to move toward B. Figure 7 is a plot of the A - B separation distance as A moves upward on scramming. Times from the start of the motion are also indicated. At an A position up 3.55" (in water), at which point the centers of reactivity of A and B should be directly opposite in a horizontal plane, A is seen to be 0.39" closer to B horizontally than at the start of the motion[1]. This is more than enough, when combined with Causes (1) and (2) to drive the assembly well into the prompt critical region.

(1) The Fastax camera sequences also indicate that the cadmium shield does not drop between the masses until after the vertical motion of the air-lift plunger is completed. Free-fall time for the shield (0.25 sec) does not apply because the shield is supported by an air cylinder, which, although opened to the atmosphere by scramming, slows up the rate of fall noticeably. Actual fall-time is about 0.7 sec.

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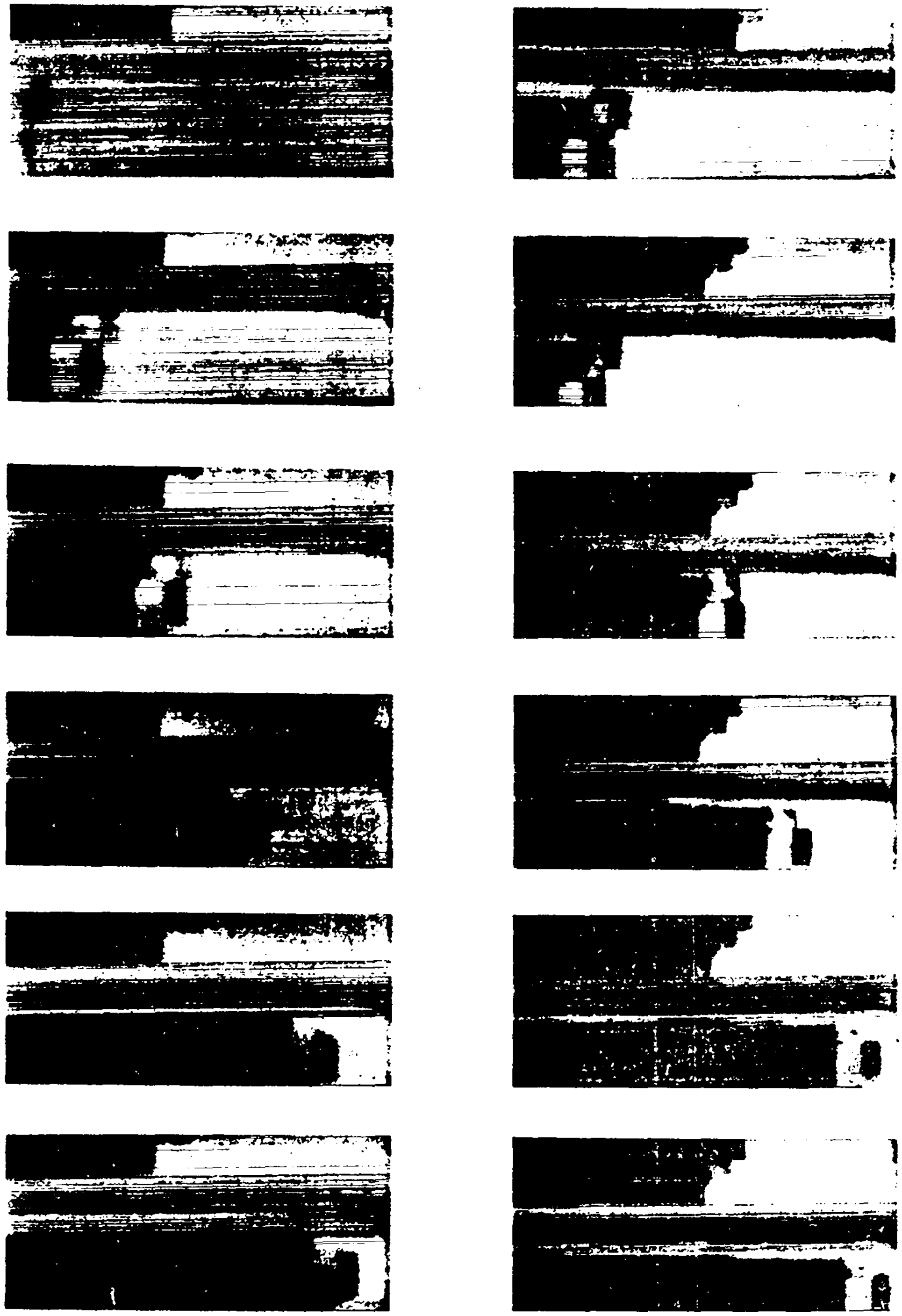

FIG. 6. Sequences of Fastax camera films indicating relative positions of A and B during the scramming action. The sequence in the vertical column on the left was taken with the masses in air; that in the vertical column on the right was taken with the masses under water.

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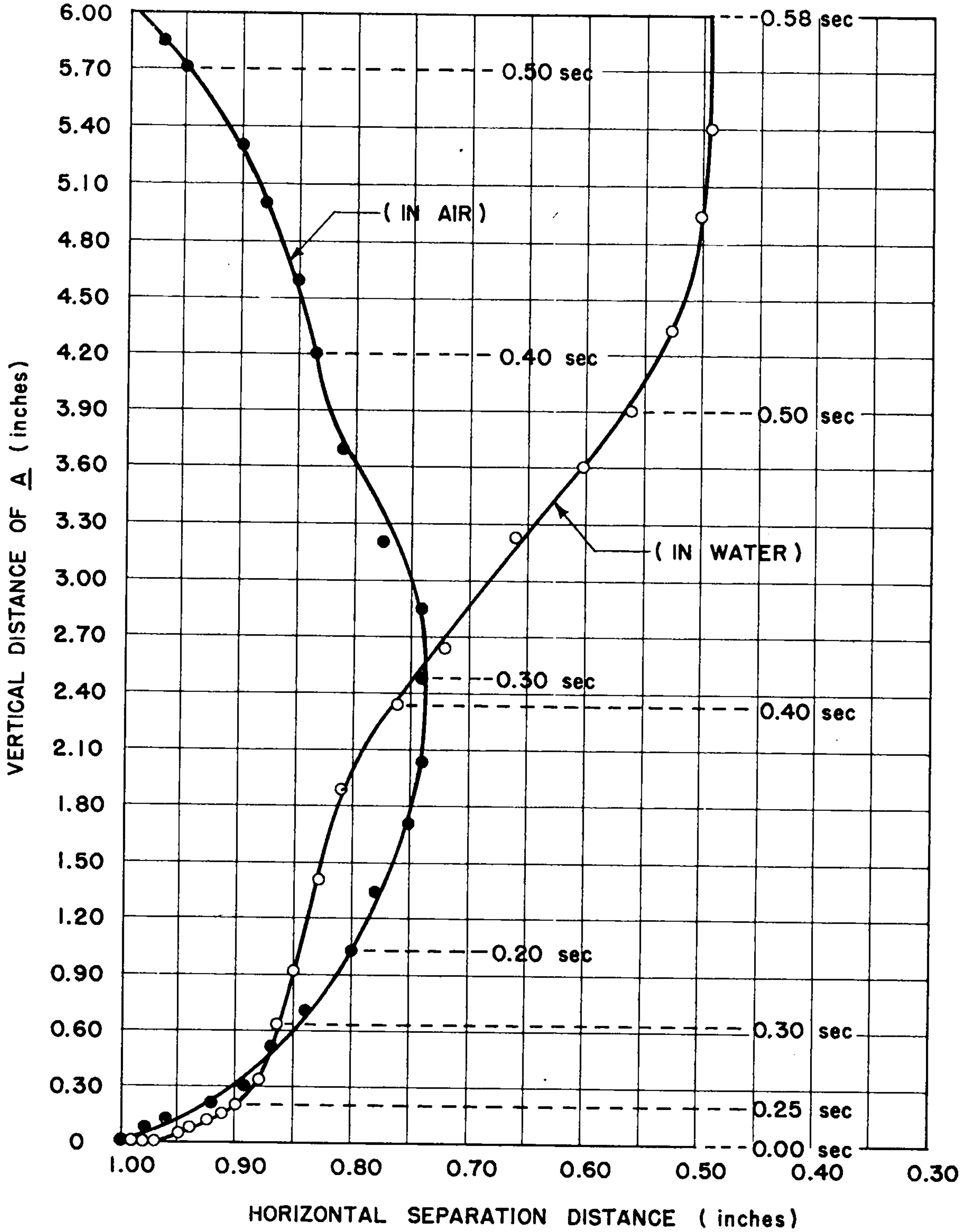

FIG. 7. Plot of the relative motion of A and B during scramming action, in air and in water, as read by comparator from Fastax camera traces.

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Following up the underwater curve of Fig. 7, and combining effects with those due to Causes (1) and (2), the points in the vertical travel of A at which the assembly as a whole became delayed critical, then (potentially) prompt critical[2], and back through prompt critical to delayed critical and subcritical, have been estimated. From this, the periods of time during which the assembly was delayed critical and prompt critical have also been estimated. These data are summarized below.

Assembly delayed critical for A "up 0.65" to "up 2.0", a period of 0.08 second.

Assembly potentially prompt critical for A "up 2.0" to "up 5.9", a period of 0.20 second.

Assembly delayed critical for A "up 5.9" to limit of travel (6.0), and for a period of ~0.2 second thereafter.

These results are shown graphically in Fig. 8, which is a plot of the effective separation distance between A and B centers of reactivity as a function of the vertical position of A during scramming action, representing the combined effect of Causes (1), (2), and (3).

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(2) It cannot be stated definitely that the assembly was actually prompt critical for any length of time, or even that it became prompt critical at all. Such effects as thermal expansion of the active material and production of steam at the surface of the material (pushing back the water tamper) tend to reduce assembly reactivity sharply. It is possible that the generation of steam may prevent a potentially prompt critical assembly in water from ever actually reaching that condition, causing the reactivity level to oscillate at the threshold of prompt criticality as steam is alternately generated and dissipated at the surface of the assembly. Then, too, it is probable that the supercritical behavior of a metal system in water is strongly influenced by the presence of large numbers of slow (thermalized) neutrons, whose relatively long time of flight tends to hold the system alpha to a low value compared to the alpha of all-metal systems.

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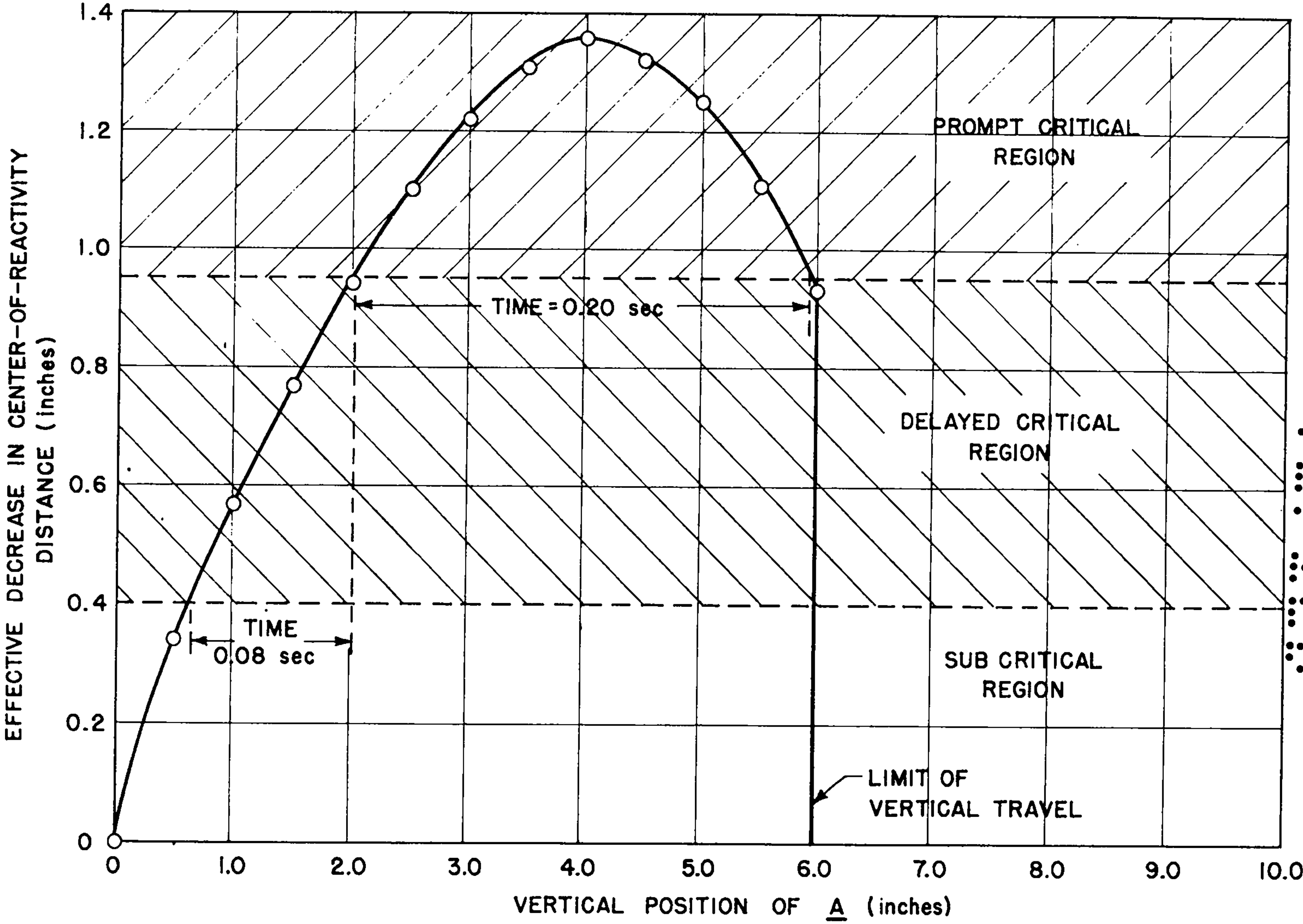

FIG. 8. Plot showing the combined effect of Causes (1), (2), and (3).

V. CONCLUSIONS

The most striking impression one gets after a careful analysis of the causes and effects of this accident is that the burst could easily have been far more serious. High temperatures were developed in and near the active assemblies, as evidenced by the melted paraffin. Slightly higher temperatures than those developed would have been sufficient to melt down the Cd jackets; in such a case the A assembly would by itself be supercritical under water, prolonging the burst for a period of several seconds--perhaps long enough to have melted down the A assembly and to have seriously contaminated the Kiva building.

It is evident that it took all three of the causes discussed in Section IV to make a serious burst; in the absence of any one of the three, the relatively slight momentary rise in radiation level caused by the other two might have escaped notice altogether.

The following are offered by way of conclusion:

(1) Proximity experiments potentially involving the presence in an assembly of considerably more than one prompt critical mass of active material, are in a class of experiment quite apart from the ordinary experiment involving only one critical mass, and should be given more than ordinary care in planning, preparation, and execution.

(2) Assembly mechanisms should be exhaustively checked with Tu or other inactive mockups for operation as intended. Where the action is very fast, as in the Aquarium air-lift, the check should include scribes, reference points, and even fast camera analysis if necessary.

(3) Placement of masses must insure that the centers of reactivity are prevented by positive stops and/or guides from approaching one another more closely than a predetermined safe minimum. If the location of the center of reactivity of one or both of the masses is not known by symmetry or otherwise, its location should be measured.

(4) Use of tangential scramming motion should be avoided in the design of remote control machines for proximity work.

In view of the difficulty experienced in arriving quickly at a quantitative assessment of the magnitude of the burst, the following new instrumentation is planned for Pajarito Site:

(1) A recording monitor (located in the control room) which will provide a record of the radiation level in the control room itself.

(2) A multi-range radiation monitor for the Kiva (recording at the control room), normally kept on the least sensitive scale, with sensitivity control in the control room.

(3) Neutron detector packets distributed about the Kiva.

The precautions indicated in conclusions (1) through (4) above have been incorporated in the group philosophy of W-2, and all new experiments and new assembly equipment will be examined carefully as to their conformity with the principles of safety stated therein.