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LOS ALAMOS SCIENTIFIC LABORATORY

LOS ALAMOS of the NEW MEXICO

University of California

Kiwi-TNT "Explosion"

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Kiwi-TNT "Explosion"

by

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ABSTRACT

The effects of the Kiwi-TNT* "explosion" are compared with the effects of various types of explosions and appear to be most similar to those of black powder.

*Kiwi Transient Nuclear Test

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FOREWORD

The Kiwi-TNT excursion, which was carried out January 12, 1965 at the Nuclear Rocket Development Site, represents the single most important step towards predicting potential nuclear incidents of interest to the Rover Flight Safety Program. The normalization of calculations to the experimental results obtained in this excursion has placed a high confidence level on all nuclear accident predictions.

Uncertainties in the knowledge of the physical properties of the core materials under the extreme time-temperature-pressure conditions existing during a large excursion made a determination of the expected energy release difficult. It was particularly hard to predict the energy which is converted from heat energy to mechanical energy and relate this to the normal chemical energy release obtained from a chemical explosive. The results of the Kiwi-TNT experiment together with the discussion in this report have materially assisted in an interpretation of the mechanical or "explosive" energy release which occurred in the experiment. This report furthermore does well in defining the upper limit of the physical consequences from such a reactor incident.

L. D. P. King
Chairman
Rover Flight Safety Office

CHARACTERISTICS OF EXPLOSIONS

Kiwi-TNT was "exploded" in the sense of a violent disruption and dispersion of an originally intact object. In no way did that explosion resemble the conventional nuclear detonation; rather, the rocket reactor blew up very much as if it had been charged with black powder.

Physical or chemical examples that might be used for comparison are explosions of dust, gas/air at atmospheric and elevated pressures, entrapped cryogenic fluids, boilers, high explosives, and black powder. Explosions occur from the energy released in the volume change of the exploding or deflagrating material or from the heating of air by the deflagrating material. The violence of the explosion is dependent somewhat on the volume change but more on the rate at which this change takes place.

The gases produced by detonating high explosives occupy a volume, at ambient temperature and pressure, about 1000 times[1] that of the unreacted material; the factor for nitroglycerin is about 1250.[2] However, this reaction is extremely rapid, taking perhaps a twentieth, for an energy equivalent amount of high explosives, of the time required to vaporize a part of the Kiwi core. Vaporized water expands 1240 times although in boiler explosions, because of the elevated temperatures usually existing at the time of an explosion, the expansion is as great as 1500 to 1700 times.[3] A cryogenic fluid such as liquefied hydrogen changing to a gas at standard temperature and pressure increases by 850 volumes.

Black powder is one of the few explosive materials which acts by exothermic chemical reaction of physically mixed reactants rather than exothermic chemical decomposition of a chemical compound. From the solid form, the volume of its products of combustion increases by a factor of about 430.[4]

Gas/air mixtures at atmospheric pressures will deflagrate within certain limits but with much less violence than the Kiwi-TNT event. A hydrogen/air mixture of stoichiometric proportions in a contained volume will demonstrate a pressure rise of about 10 psi per millisecond.[5]

Explosions involving an organic dust such as cornstarch with a particle size less than 20 microns and a concentration exceeding one gram per cubic foot of air demonstrate a pressure rise of about 5 psi per millisecond.[5]

The volume change for sublimed graphite, assuming a C_3 molecule for the vaporized material, is 1100 times just for the phase change, but when the appropriate vaporizing temperature of about 3900°K is used this is increased 13-fold for a total volume change at constant pressure of 14,300 times.

MISSILES

The Kiwi-TNT event threw many missiles of various sizes and weights up to 2000 feet. The missile distribution was similar to that from chemical high explosives in that there were many small pieces some of which went substantial distances.[6] However, unlike those from high explosives which give an almost instantaneous pressure rise from the detonation wave, these missiles did not show the typical shredding and stretching (see Fig. 1).

Other kinds of explosions like those of dust or atmospheric gas/air do not produce the rate of pressure rise that yields missiles like those from Kiwi-TNT, nor do such missiles travel so far. Boiler explosions usually produce large missiles but only a few.[3] Explosions of combustible

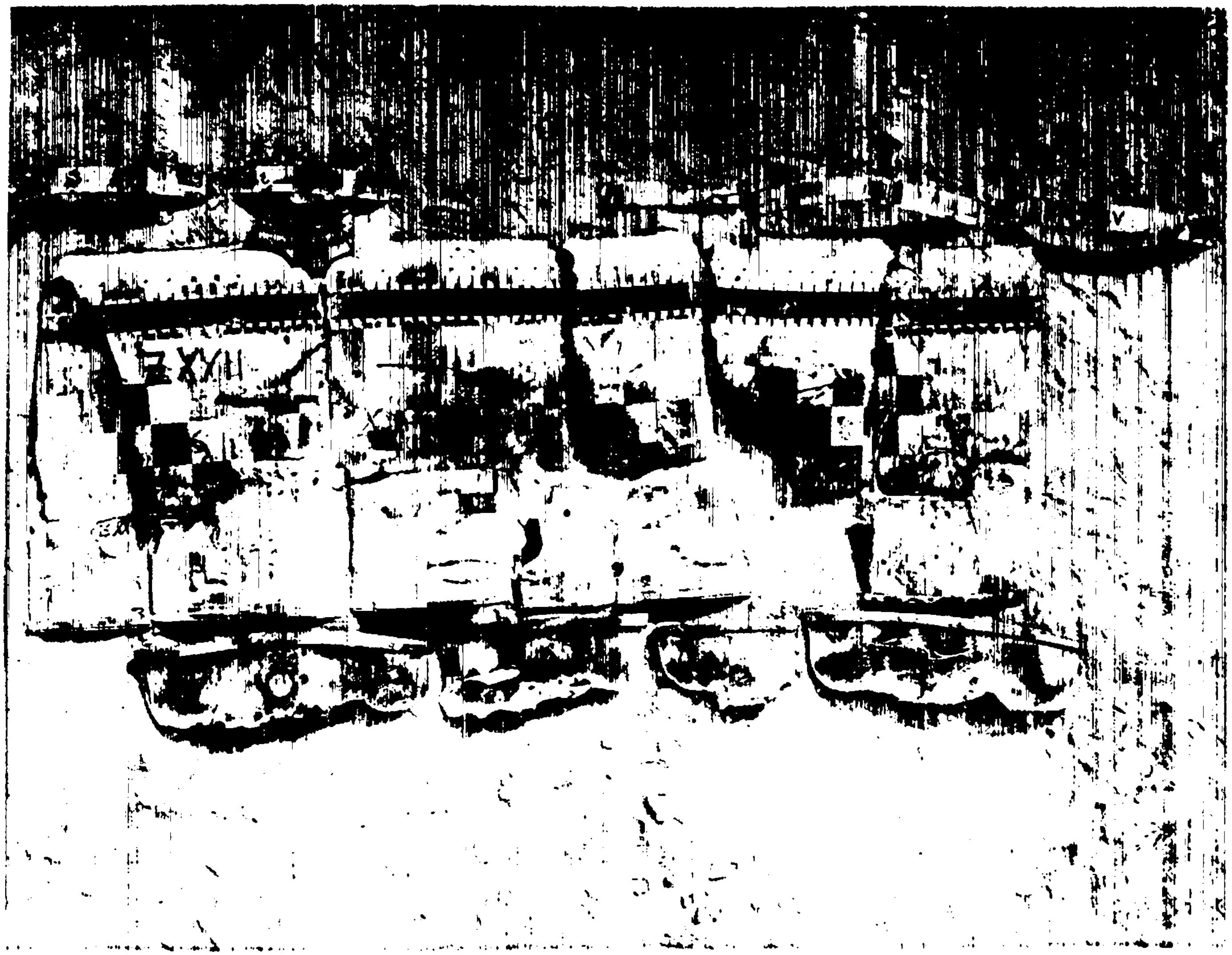

Figure 1. Fragments of the pressure shell. Each painted square is six inches on a side.

gas mixed with air or oxygen at high pressures have missile patterns more nearly like that of Kiwi-TNT. High pressure oxygen cylinders contaminated with hydrocarbons have exploded with effects similar to this incident. Thus, from the behavior of the missiles it is concluded that the Kiwi-TNT event resembled a deflagrating explosive such as black powder more than it did a detonating or brisant one, such as tnt.

HEAT

The charring of wooden poles as far out as 70 feet and the bright ball of hot and burning graphite during Kiwi-TNT are phenomena not usually seen in explosions. Brightness is a function of temperature and emissivity, and carbon is an efficient emitter at 3900°K, in contrast to other explosives. High explosives detonate so rapidly that they are poor heat sources and essentially undergo only an exothermic decomposition; that is, they go from the solid or liquid to the gaseous phase without burning and usually without scorching the environment. Dust explosions do not have a very high energy density and are not very bright. Gas explosions do not scorch things very much even if the mixture is fuel rich.

OVERPRESSURES AT A DISTANCE

Two blast gauges located 100 feet from the Kiwi-TNT experiment gave readings of 3 and 5 psi. The lower reading could have come from a surface burst of a 125-pound, hemispherical charge of tnt.[7,8] The higher reading is consistent with a similar charge weighing about 300 pounds.

Within the Test Cell "C" complex there were corrugated metal building walls which faced the Kiwi-TNT experiment, 600 to 700 feet away. These buildings are designed for 100-mile-per-hour winds, and there was no sign of damage to any of them. None would be expected following an explosion of about 100 pounds of tnt, but a 300-pound explosion might have affected them.

There were several office trailers located 800 to 1000 feet from the Kiwi-TNT experiment. These lightly built structures showed that the walls had deflected, as there were many wall fixtures (telephones and thermostats) thrown to the floor. However, no damage was done to the walls. There were a few broken windows, but not all the windows were broken even in the closest trailers and the facing walls. This appears consistent with an explosion approximately like that of 100 pounds of tnt.[9]

ANALYSIS OF THE KIWI-TNT EXPLOSIVE PHENOMENA

Assume:
1) Graphite mass, 10^6 grams
2) Vaporization of about 10%, 10^5 grams
3) Density, 1.8
4) Molecular species of vaporized graphite, C_3
5) Time of vaporization, 1 msec
6) Temperature of vaporization, 3900°K

Then

original graphite volume $\frac{10^6}{1.8} = 5.56 \times 10^5$ cc

volume of graphite vaporized $\frac{10^5}{1.8} = 5.56 \times 10^4$ cc

volume of graphite vapor 36 g. C_3 = 22,400 cc at standard temperature (about 300°K)

36 g. C_3 = 22,400 cc

$$\frac{10^5}{36} = \frac{X}{2.24 \times 10^4} = 6.2 \times 10^7 \text{ cc}$$

$$6.2 \times 10^7 \times \frac{3900}{300} = 8 \times 10^8 \text{ cc}$$

estimated volume of voids within Kiwi pressure shell $< 9 \times 10^5$ cc

The Kiwi pressure shell is operated at about 1000 psi. Normal over-pressure test is at about 1200 psi. It is felt that the shell would leak under static pressure at about 1500 psi and come apart under a dynamic load above 3000 psi.

The excess of the volume of graphite vapor generated over the voids in the shell is 1000-fold. As the top of the reactor was open, even the fast rate-of-rise pressure generated may have been significantly reduced. Even if this reduction is assumed to have been one-half, the pressure in the shell would have been about 7000 psi, quite enough to destroy the pressure shell. It is estimated that the resultant pressure rise if 100 pounds of high explosives had been detonated inside the Kiwi-TNT shell would have been about 10,000 psi at the shell.

An examination of the Kiwi-TNT zero point after the experiment shows evidence not exactly typical of a high explosives accident. While it is not completely inconsistent with an explosion involving about 100 pounds of tnt, it is certainly inconsistent with one involving significantly more, say 300 to 500 pounds. In the latter case, one would probably expect more sweeping away of the debris beneath the explosion, and possibly even cratering, which did not occur (see Fig. 2).

What is unique about this incident is that it appears that a violent pushing took place as though one had a large, old-fashioned 4th of July rocket turned upside down and it exploded shortly after ignition. Such a rocket loaded with about 200 to 300 pounds of black powder might have produced an effect similar to the Kiwi-TNT experiment. The time for that bulk of black powder to have explosively deflagrated is about the same as that for the Kiwi-TNT event.[10,11]

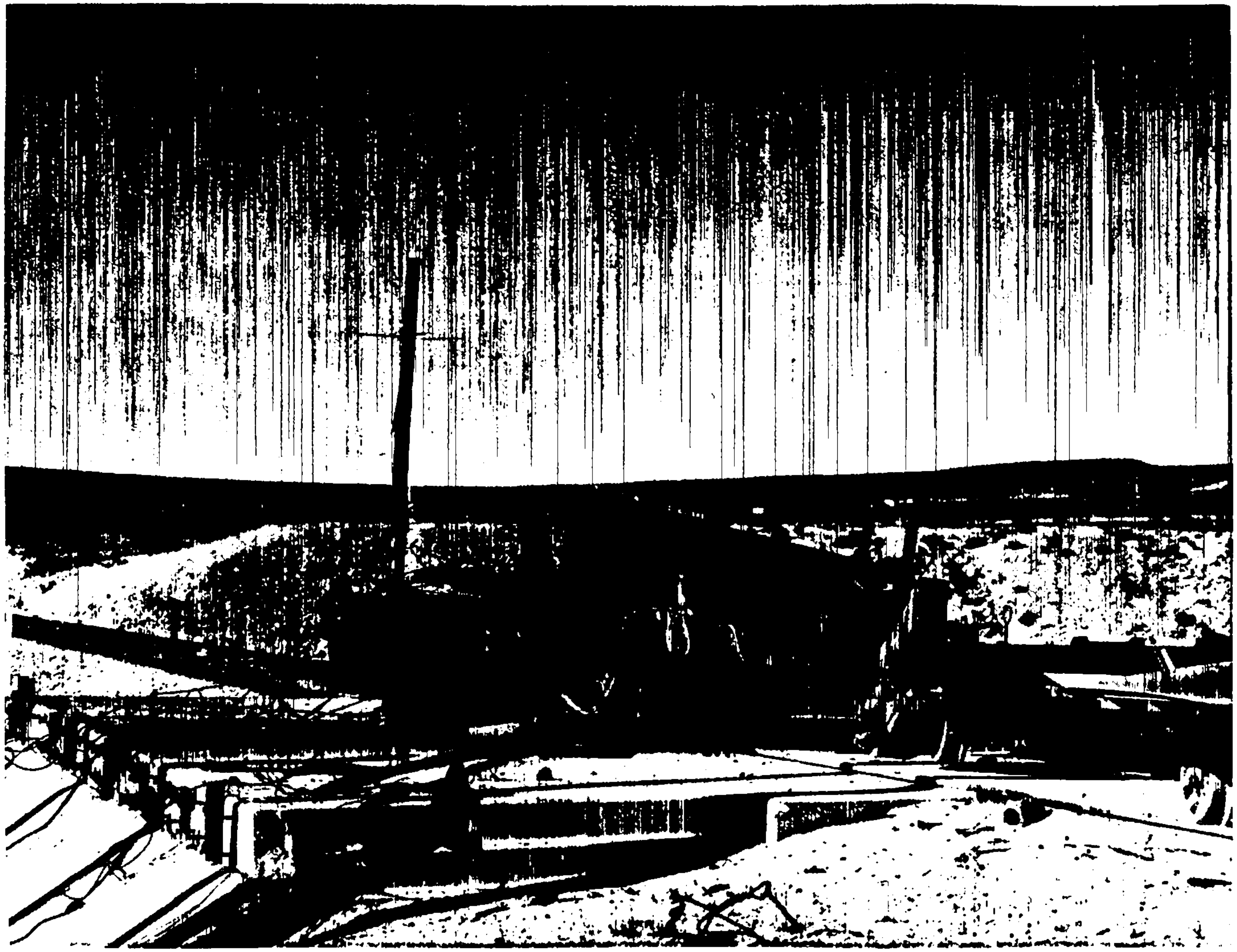

Figure 2. Zero point after the Kiwi-TNT experiment.

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