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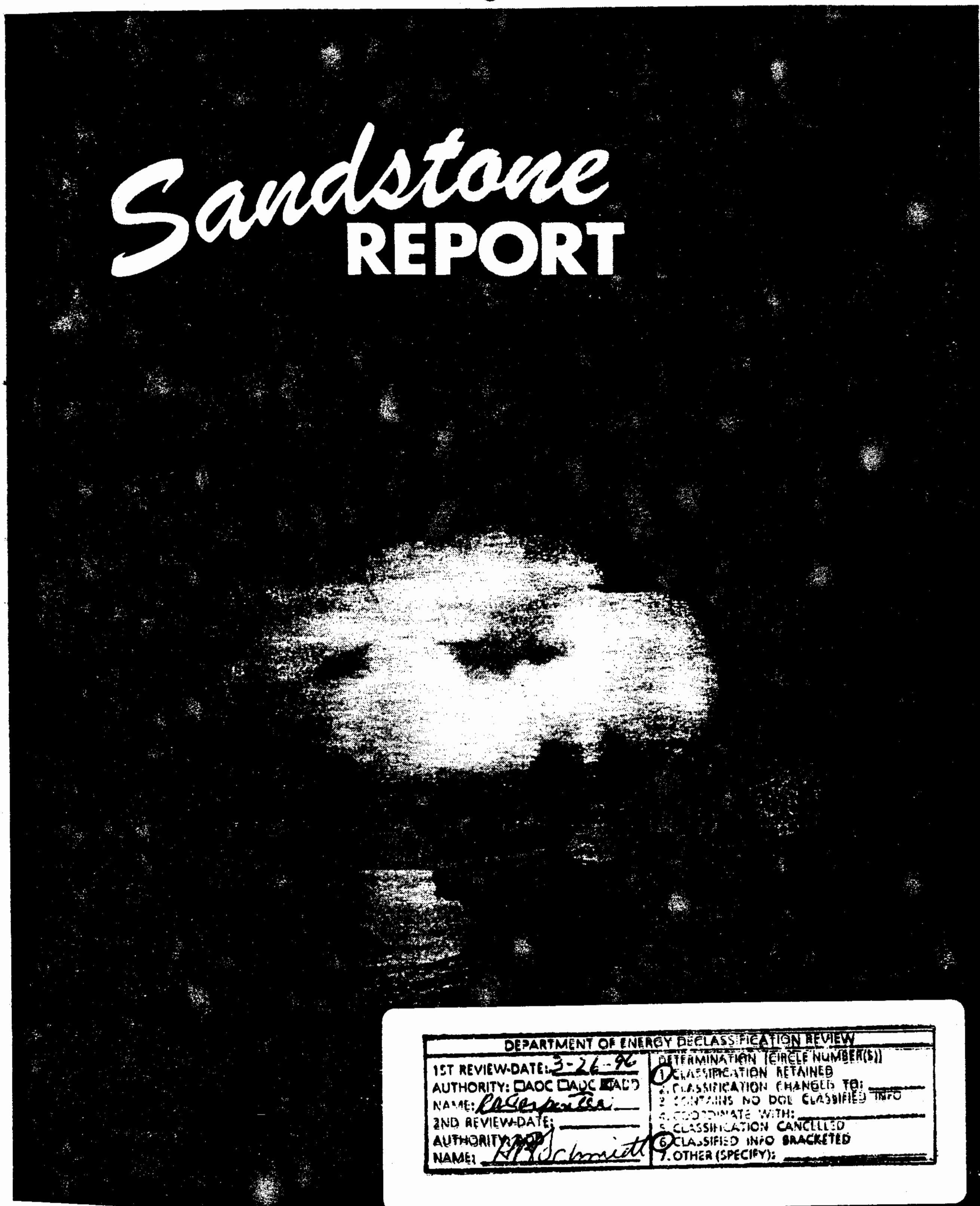

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SCIENTIFIC DIRECTOR'S REPORT OF ATOMIC WEAPON TESTS AT ENIWETOK, 1948

SANDSTONE HANDBOOK OF NUCLEAR EXPLOSIONS (U)

Editor, Frederick Reines

JCL-65-~~485~~ 845

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1.2 SUMMARY OF CONTENTS

Chapter 1

This chapter describes the purpose and contents of the Handbook and gives in Table 1.1 a timetable of events which take place in a nuclear explosion, in Table 1.2 a summary of values for certain important quantities such as predicted energy releases, and a statement of the purpose of Operation Sandstone.

Chapter 2

After a description of the various models, there is a discussion of the pre-nuclear stage during which detonators are fired, active material is assembled into a supercritical configuration, and neutrons are introduced into the system by the initiator. The time from detonation to initiation, called the transit time, is listed for various models. The experiment designed to measure transit time is described and the use of the results of this experiment is discussed.

Chapter 3

Various stages in the development of nuclear energy as the bomb prepares to expand are described. Theoretical curves for the multiplication rate are presented. The value of a measurement of this rate for diagnosing the performance of the bomb is discussed. The probability of predetonation is

6

considered in some detail and curves are given for the probability of an explosion with less than a certain yield. Comments are made on the hydrodynamic phases of nuclear energy generation with the view of explaining estimates of efficiency and energy yield of an explosion. An analysis is made of two proposed experiments for measuring the initial multiplication rate.

Chapter 4

Neutron effects in a nuclear explosion are described. Estimates are given for the expected intensities of neutrons of energy $\geqslant 3$ Mev. Neutron threshold-detector experiments which will be done are described.

Chapter 5

The status of theory and experiment on gamma radiation is described briefly. A detailed description is given of the gamma radiation experiments planned for the 1948 tests.

Chapter 6

The development of the shock in air caused by a nuclear explosion is described. Curves are presented for the variation of pressure with distance, pressure with time at fixed distances, impulse versus distance, arrival time of shock versus distance, for different nuclear energy releases. A detailed timetable is given for the progress of the blast wave as well as for the motion of the cloud. A scheme for determining energy release from ball of fire observations is discussed and calibration curves are included.

Chapter 7

Efficiency is defined as the number of fissions per active atom (i.e., Pu^{239} and/or U^{235}) originally in the bomb core. This chapter elaborates principles of the radiochemical procedure which is used to determine this quantity. [redacted] A summary of the results of previous radiochemical determinations is given.

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Chapter 8

In this chapter, a selection of rough schemes to determine energy yield is presented. Such methods as the observation of the maximum radius of the ball of fire at which the ball is almost uniformly bright and the more conventional use of a microbarograph record are discussed and curves are provided for field use.

Chapter 9

Attention is given to the problem of interpreting the results of experiments. Criteria are presented for the judgment of the success of a test. Various possibilities are

8

analyzed and alternative interpretations are presented for the possible results. Particular attention is paid to the coordinated interpretation of key experiments which measure energy release, initial multiplication rate, and transit time.

Appendices

In the appendices, a collection of useful data is provided. Appendix C on the expected post-shot ground activity is felt to be of particular interest. The question of information which might be obtained from the test site after the test has been discussed in Appendix D.

1.3 PURPOSE OF TESTS

[redacted] Since it is possible to learn something about the mechanism of a nuclear explosion, other experiments than those designed to measure total energy release will be done.

[redacted]

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Table 1.1

Timetable of Events for 20-Kiloton Explosion

(Trinity Type Bomb)

t(sec)	Event
0	Detonators Pulsed
0.4	Ball of fire Max. Radius 400 yds.
0.4	Shock reaches 500 yds.
1.29	Shock reaches 1000 yds.
6.44	Shock reaches 3000 yds.
12	Shock reaches 5100 yds.
12	Ball of fire reaches 2000 ft.
70	Ball of fire reaches 12000 ft.
258	Ball of fire reaches 28000 ft.
598	Ball of fire reaches 40000 ft.

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15

Table 1.2

SUMMARY OF ESSENTIAL INFORMATION

[redacted]

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Chapter 2

THE IMPLOSION

E. Zadina and F. Reines

2.1 INTRODUCTION

During the course of these tests three types of atomic bombs will be detonated. In expected order of detonation they are:

1.
2.
3.

b3

<u>Order of Firing</u>

b3

Criteria for performance and order of detonation appear in Chapter 9.

[redacted]

The term "composite" is applied to those bombs in which the active material consists of both Pu^{239} and U^{235}. [redacted]

Bomb Types

[redacted] Features of the bombs to be tested are given in Figures 2.1, 2.2, and 2.3 and Table 2.1.

2.2 DETONATORS

[redacted]

Transit Time and Simultaneity

[redacted]

(1) Communicated by L. Seely.

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[redacted]

15

Transit Time and Simultaneity (continued)

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2.3 HIGH EXPLOSIVE

b3

[redacted]

17

b3

Lens

Design

b3

~~20~~ 18

[redacted]

[redacted]

b3

FIG. 2.4

[redacted]

19

Lens

Design

20

2.4

2.5 PHENOMENA OCCURRING IN IMPLODED ASSEMBLIES

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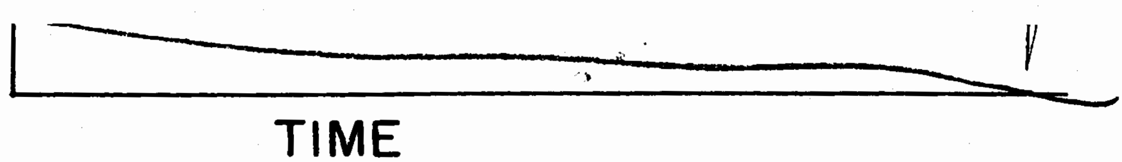

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25

[redacted]

Table 2.2

Time Sequence Of Events During Implosion In μSec

[redacted]

[redacted]

[redacted] b3

Implosion Time-Table

Adjacent to these are listed, where measurements exist, the corresponding times obtained experimentally by the pin method. Zero time in all cases is the moment at which the voltage pulse arrives at the detonator.

The chief criterion by which the success of an implosion is judged is the degree of compression achieved in the core of active material. The reason for this is that the critical mass is roughly inversely proportional to the square of the density. Thus if the density is doubled, the critical mass will be smaller by about a factor of 4 [redacted]

Compressions

[redacted] b3

[redacted]

27

31

Compressions

b2

28
32

[redacted]

[redacted]

29

30

Table 2.3

[redacted]

[redacted]

32

2.6 COMPARISON OF IBM AND PIN METHOD TRANSIT TIME

We shall mention here some of the assumptions which go into IBM calculations of the transit times listed in Table 2.2. The values listed in the table were obtained by a reason-able interpolation between IBM runs in cases where runs which approximated the test weapons did not exist, and by extrapolation of pin measurements using IBM results.

Theoretical Calculation

Equation of State of Explosive

Equation of State of Explosive

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35

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Equation of State of Metals

63

36

SECRET

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37
#

2.7 IMPLOSION TRANSIT TIME MEASUREMENTS

Firing

Circuit

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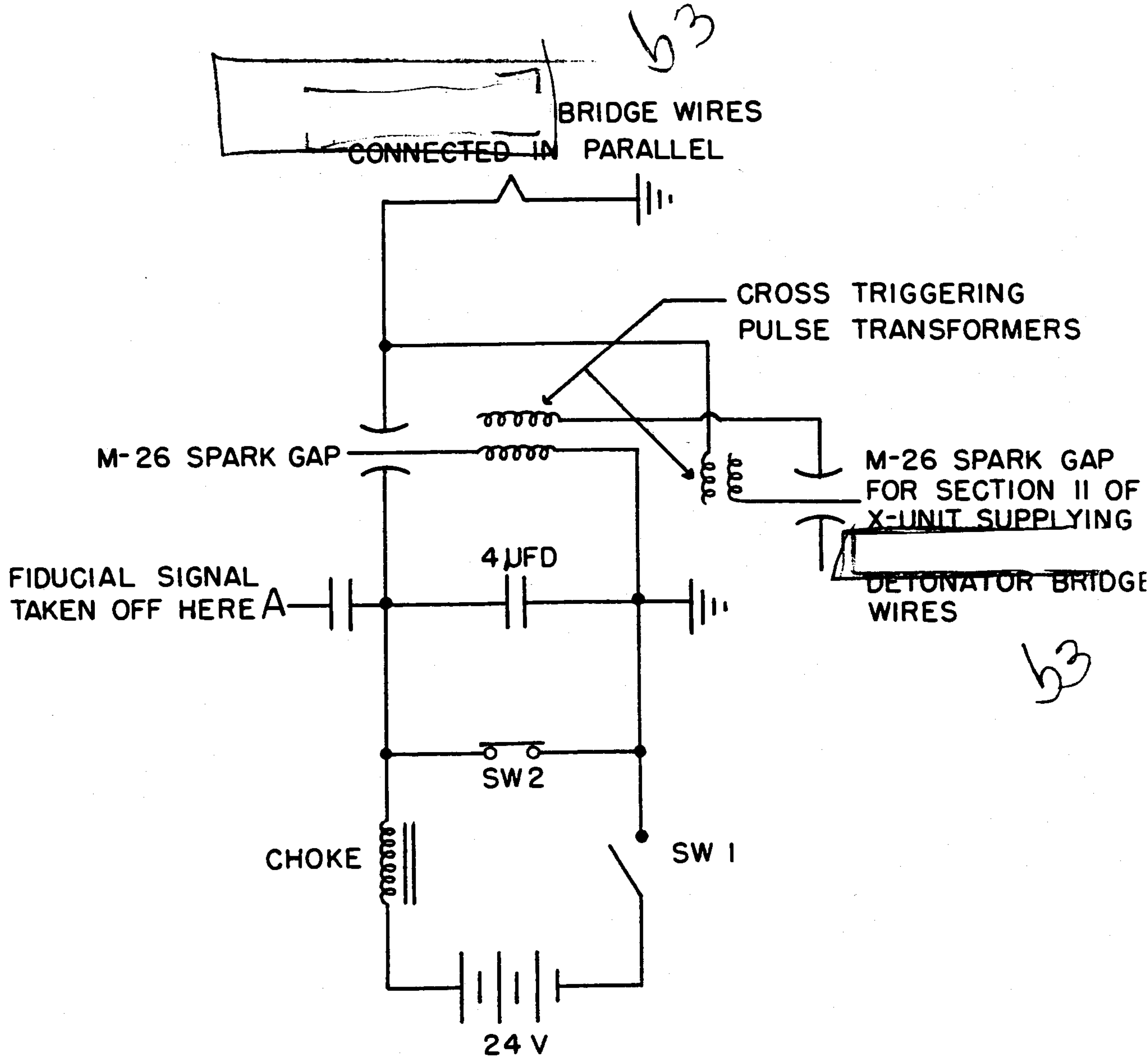
SIMPLIFIED WIRING DIAGRAM OF
DETONATOR FIRING CIRCUIT

FIGURE 2.6



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[redacted]

Firing Circuit

63

Field Set-up

μ sec. A part of the same pulse is passed through a delay circuit of known delay time from which it is fed to the plates of the oscilloscope where it appears as a pip on the screen trace. The delay circuit is introduced so that the beginning of the fiducial pip may be more accurately and conveniently located. The ionization chamber which detects the gamma rays

40

emerging from the bomb[1] is located 333.3 yards from the tower. The pulse from this chamber is fed into an amplifier from which it passes through coaxial cable to the same delay circuit used for the fiducial pulse. It is then impressed on the plates of the oscilloscope and appears as a pip on the tracing nearer the center of the spiral than the fiducial pip.

Field Set-up

An attempt will also be made in the first test to detect the emergent gamma rays with a photomultiplier tube. The tube will be placed at the 1300-yard station and the pulse produced by the gamma rays fed to an amplifier connected to the plates of another spiral oscilloscope. Neither the spectral sensitivity of the photo tube for gamma rays nor the spectrum of the emergent gamma ---

(1) [redacted]

63

47
46

is well known. If it turns out that the photo-multiplier tube method of measuring transit times is unsatisfactory, it will be replaced in the succeeding tests by the ionization chamber method.

The transit time of the gamma rays between the bomb and the detecting device can, of course, be computed very accurately. The time of passage of the fiducial pulse down the coaxial cable will be determined

2.8 INTERPRETATION OF EXPERIMENTAL RESULTS

Table 2.4 summarizes the predicted transit times for the various models.

Table 2.4

(2) Also referred to as the reciprocal e-folding time of the reaction.

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CHAPTER 7

MEASUREMENT OF BOMB EFFICIENCIES BY RADIOCHEMICAL METHODS

R. W. Spence

7.1 DEFINITION OF EFFICIENCY

At Trinity and at Bikini the bomb efficiency, E, was defined as follows:

$$E = \frac{\text{Total number of fissions}}{\text{Total number of } Pu^{239} \text{ atoms originally in bomb core}} \qquad (7.1)$$

The corresponding definition for a composite bomb, one containing both Pu^{239} and separated U^{235}, would be:

$$E = \frac{\text{Total number of fissions}}{\text{Number of } Pu^{239} \text{ atoms originally in bomb core} + \text{number of } U^{235} \text{ atoms originally in bomb core}} \qquad (7.2)$$

This is again a figure which one would

consider[1] in the economics of bomb production. Another significant set of numbers which are more difficult to obtain is the fraction of fissions which occur in each of the various bomb components.

7.2 METHOD OF DETERMINING EFFICIENCY USED AT BIKINI

63

48

[redacted]

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We consider in the above equation only the fractions corresponding to the sample.

[redacted]

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50

Efficiency of Composite Bomb

7.3 METHOD OF DETERMINING EFFICIENCY BY OBTAINING FRACTION OF BOMB IN SAMPLE

[redacted]

b3

No conclusive results were obtained in the Bikini shots because of lack of time and personnel; however, the idea is certainly attractive.

b3 [redacted]

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7.4 DETERMINATION OF TERMS IN EFFICIENCY EQUATION

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<u>Sample</u>

<u>Activity</u>

<u>and Fissions</u>

<u>in Sample</u>

b3

[redacted]

63

[redacted]

α Activity

Used to

Determine

α-Factor

63

60

b5

62

b3

The methods of determining the various quantities involved in (7.17) have already been described. We present here (Table 7.1) a resume of these quantities for each of the shots together with an estimate of the precision of each of these measurements.

[redacted]

Table 7.1

Summary of Radiochemical Analysis
of Trinity and Bikini Able and Baker

[redacted]

~~90~~ 66

Hugoniot equations. A knowledge of T_B gives in principle, knowledge of the other two quantities ρ_B and P_B. In view of the validity of the point-source approximation, the energy contained in the sphere of diameter D_B and hence, the energy release is proportional for different nuclear explosions only to the volume or to D_B^3 providing ρ_o, P_o, and T_o are identical for the explosions being compared, i.e.,

$$\frac{W_2}{W_1} = \left(\frac{D_{2B}}{D_{1B}}\right)^3 \qquad (8.1)$$

$$W = KD_B^3$$

Correction for Air Density

The value of T_o at Eniwetok at test time is expected not to be significantly different from that in evidence at the Trinity test. The difference in moisture content of the air is also expected to have a higher order effect on the observed D_B. However, the pre-shot air density, ρ_o, and pressure, P_o, at Trinity was markedly different than that at sea level and a correction in K is therefore indicated. A simple consideration shows that for strong shocks, the volume containing a given energy is inversely proportional tc the initial density. Inserting the ratio of densities at Trinity and Eniwetok, 1/1.19, together with the Trinity breakaway diameter $D_B = 210$ meters, and the Trinity energy release, twenty-two kilotons TNT, we get (See Figure 8.2)

$$W = 2.8 \times 10^{-6} D_B^3 \qquad (8.2)$$

W = energy release in kilotons TNT, and

D_B = breakaway diameter in meters.

8.1.1 Experimental Considerations

The breakaway diameter may be obtained on the scene by visual observation or, more accurately, through the use of motion-picture cameras of moderate speed (~ 100 frames/sec).

Motion Picture Record

In analyzing a motion-picture camera record taken at ~ 100 frames/sec, it is suggested that for improved accuracy an interpolation be made between the relevant frames. It is to be noted that the ball of fire changes very little in a time interval of ~ 3×10^{-2} seconds around breakaway time. For example, at Trinity the ball of fire

71

radius took $\sim 2.7 \times 10^{-2}$ seconds to grow from 20 per cent below to 20 per cent above the breakaway value.

Visual Observation

A more rapid, if less accurate, statement of the breakaway size can be obtained by the use of binoculars or telescopes with reticulated eyepieces. A suggested observational technique is as follows. Mount and aim binoculars or telescopes in advance of shot at known distance from the zero point. For a few minutes before the shot, look into a flashlight to better prepare the eyes for the bright flash to come. Then, look at zero point and as soon as a flash is seen, shut eyes and observe the after-image at leisure and read the size of the ball off the eyepieces scale.

Simple eyepiece markings such as X, O, and the like are suggested as easier to reach than a number scale. At least two, and preferably more, observers should be employed.

8.2 TELEMETERED PRESSURE-DISTANCE DATA

Assuming that the telemetering system will yield pressure-distance data rapidly, a figure for the energy release can be obtained by comparing the experimental results with the curves given in Figure 6.3, Chapter 6.

Methods (8.1) and (8.2) are superior to any of the following.(1)

8.3 TIME OF ARRIVAL OF SHOCK WAVE

The time of arrival of the shock wave depends on the strength of the explosion. Figure 8.3 is a plot of the time of arrival versus distance from the explosion for 10 kilotons. A second curve on Figure 8.3 gives the correction to be applied to the 10-kiloton curve in the case of larger explosions. From the curve, it can be seen that an error of $\pm$ 0.1 second carries with

(1) In view of the approximate nature of these estimates we will not differentiate between energy in blast and total energy release.

it an error of ~ 10 kilotons at 20 kilotons. An observation of this type would therefore require instrumentation as well as some preliminary experiments on the velocity of sound[2] under conditions similar to those of the actual tests.

This method suffers from the uncertainty induced in the arrival time, especially at great distances by atmospheric conditions. For example, the loss of energy from the blast by evaporation of sea water in the blast wave could lower the apparent energy release by as much as ~1/2. A similar criticism applies to the microbarograph record (cf. below).

8.4 THE CLOUD-CHAMBER EFFECT

Under certain conditions, a cloud of water droplets will form when an atomic bomb is detonated. In order to see how this cloud-chamber effect operates, let us

(2) When such experimental values become available, Figure 8.3 should be re-examined for consistency with them.

value after the pulse has passed.

Now, consider the case in which the unshocked air is completely saturated. In view of the above, we can expect condensation to occur first at that value of peak overpressure which is followed in the suction phase by a drop in temperature sufficiently far below that of the unshocked air to cause the degree of supersaturation required for condensation to occur. We should, therefore, expect that an observer at some distance from the event should see no condensation out to a given radius. From this critical radius and outward to a distance which is again determined by the degree of supersaturation necessary to cause condensation, a cloud is expected to form.

If the air is initially slightly less than saturated, the point at which the cloud starts forming will be somewhat more distant from the point of detonation, the critical radius occurring where the minimum temperature in the blast wave is somewhat below the unshocked temperature. The radius at which the cloud forms is thus seen to be related to the shock pressure and the relative humidity in the region of interest.

Figure 8.4 gives the minimum relative humidity for cloud formation at distances of interest(3) for a 20-kiloton explosion. To obtain the energy release, it is only necessary to observe the relative humidity before the shot and then scale the distance at which the cloud is observed to form by the $W^{1/3}$ factor required to make the distance agree with that obtained from Figure 8.4. In the present state of knowledge this method is probably not better than a factor of two.

8.5 CRATERING

In the absence of reliable experimental results using HE, we scale the Trinity results, assuming that coral and Trinity soil behave similarly under the action of blast. This procedure yields the

(3) This curve is from LA-550.

formula plotted in Figure 8.5.

$$W = C \left[1+\left(\frac{R}{200}\right)^2\right]^{3/2} \qquad (8.3)$$

where C = 30 when R is the radius in feet for pulverizing macadam, and

C = 1 when R is the radius out to which dishing occurred.

This method is perhaps good to a factor of two.

8.6 RADIUS OF FIRED CORAL

In the region of strong shocks, $T \sim W/T^3$ where T is the temperature. Coral is essentially $CaCO_3$ with a temperature of decomposition of $\sim 700°C$; Trinity soil is essentially SiO_2 and fuses at $\sim 1500°C$. Inserting these numbers into the above relationship we find that, sealing from the Trinity fused area (Figure 8.6).

$$W = 1.4 \times 10^{-5} R^3; \text{ W in kilotons, R in feet.} \qquad (8.4)$$

This method is probably only good to a factor of two because of the irregularity of the fused area, the differences in the

chemical reactions and thermal conductivities of SiO_2 and $CaCO_3$.

8.7 MICROBAROGRAPH

Figure 8.7 gives the shock overpressure versus distance in a pressure range from 0.4 to 0.03 psi. The numbers on which this figure is based are taken from a semi-acoustic theory of Fuchs and Bethe.[4] In view of the sensitivity of the overpressure to the atmospheric conditions (cf. Section 8.3), this method is probably no better than a factor of two or three in predicting the energy release.

8.8 BOLOMETER

Since (cf. Section 6.4) the fraction of the energy released in the form of radiant energy in a nuclear explosion is to good precision independent of the type of bomb, it is possible to obtain an estimate for the total energy released in

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(4) LA-1021, Chapter 8.

SECRET

88

CHAPTER 9

REASONING FROM EXPERIMENTAL RESULTS

F. Reines and H. Mayer

9.1 INTRODUCTION

To implement the purpose of the Eniwetok tests, the most important set of experiments are those that measure the efficiency of the nuclear explosion. These include, in order of demonstrated reliability, the radiochemical measurement of the number of fissions, the ball of fire observations, and the blast measurements. Of secondary importance are the transit time and multiplication rate, alpha, measurements which are, however, particularly useful in checking our ideas of the processes which occur in a nuclear explosion. A host of additional experiments will be performed, providing information of more general scientific interest, but at present they can only be crudely related to the internal workings of an atomic bomb. This chapter, therefore, will concentrate on the coordinated interpretation of

Efficiency

α

Transit Time

the efficiency, transit time, and alpha measurements.

9.2 ABSOLUTE EFFICIENCIES

A good measure of the performance of a particular design of atomic bomb is its efficiency, i.e., the number of fissions per valuable (separated U^{235} or Pu^{239}) fissile atom present.

However, there exist other goals than high efficiency alone:

[redacted]

$$F.M. = \frac{W^{2/3}}{8M_{Pu}239 + 6M_{U}235} \qquad (9.1)$$

Here $M_{Pu}239$ is the mass of Pu^{239}, M_{U}^{235} is mass of separated U^{235} in the bomb and we assume a relative economic v value of the two materials given by the weighting numbers in (9.1).[1] The estimated figures of merit for the various models relative to Trinity are as follows:

Table 9.1

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The observed figure of merit, corrected perhaps for current or estimated future costs of Pu^{239} and U^{235}, is the suggested criterion

(1)

DOE b3

92

[redacted]

for the relative merit of the particular bomb design.

9.4 DIAGNOSTIC USE OF ALPHA AND TRANSIT TIME

Criteria for Performance

It may happen that some accident interferes with the proper operation of one or more of the bombs, resulting in poor efficiency. On the basis of a single shot, it would not be prudent to discard such models. We are therefore vitally concerned with criteria we can use to diagnose the operation of the weapon, with the view of identifying such accidents. The positive result of the use of these diagnostic criteria will be to exclude from consideration non-representative efficiency values.

The two most effective criteria are found in the alpha and the transit time measurements. The transit time referred to in these tables is defined as the time from the firing of the high explosive detonators to the beginning of the explosive nuclear chain.

Various possibilities for the transit time, τ, and multiplication rate, α, are listed in Table 9.2 below with a brief key phrase in explanation. More extensive comments follow the table.

<u>Consider Plausible Explanations</u>

We give only the more plausible explanations for the results and are quite aware that we have not thought of all possibilities. The universal explanation that the theories on which α and τ are based are not valid has in general been given only when another more plausible interpretation was lacking.

Table 9.2

Summary of Possible Results for Alpha and Transit Time and Their Interpretation

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9.5 COMMENTS

Confirmation of Efficiency Formula

The primary objective of the Eniwetok tests (cf. Chap. 1) can be realized through a study of the previously mentioned experiments. In the fortunate circumstance that the efficiency of the bomb is that predicted, we will have valuable experimental verification of the semi-empirical Bethe-Feynman efficiency formula over a wide range of bomb models. We may then use this formula with greater confidence in future predictions for bombs of similar design. The extent to which the formula applies to different models may also be learned from these tests.

Probabilities

From the test of a limited number of bombs, and particularly only one bomb of a given type, we can never hope to learn about questions involving probabilities, for example, predetonation. The use of large numbers of bombs in warfare may well change our attitude towards the conclusions of these

98

tests because such probability considerations will then apply.

Weapons as Research Tool

In addition to the primary objective, information of more general scientific interest may be furnished by the variety of experiments to be performed, e.g., gamma-x-ray attenuation in air. It should be recognized that nuclear explosion provides conditions found nowhere else in the universe — for example, temperatures [redacted] enormous neutron and gamma fluxes, quantities of radioactive material in fantastic amounts, radiation pressures exceeding those found in the sun — and should be exploited, wherever possible as a research tool.

DOE b3

[redacted]

[redacted]