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GASP

CONTAMINATION STUDY

PREPARED BY

MALAKER LABORATORIES, INC.
191 MILL LANE
MOUNTAINSIDE, N. J.

STATUS REPORT

CONTRACT NO. NONR-3095-(00)

JANUARY 1961

PREPARED FOR

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
WASHINGTON, 25, D. C.

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SECRET

CM 102-1

CONTAMINATION STUDY

Prepared by

Dr. S. F. Malaker, C. J. Anderson, R. A. Rossi

MALAKER LABORATORIES, INC.
Mountainside, N.J.

STATUS REPORT

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January 1961

APPROVED BY: Dr. S F Malaker
Dr. S. F. Malaker

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DEPARTMENT OF THE NAVY

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SECRET

FOREWORD

This study was undertaken by the Cross-Malaker Laboratories in January, 1960. During the term of the contract, the name of the Laboratories was changed to Malaker Laboratories, Inc. Therefore, the names of Malaker Laboratories and Cross-Malaker Laboratories are interchangeable in the text of this report.

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ABSTRACT

Calculations and analyses were performed to evaluate the radiological hazards associated with the use of a contained underground fission detonation for the propulsion of large space platforms. This investigation included a study of fission product release, neutron induced activity, ground water contamination, chemical reactions, decontamination and closure mechanisms. Analytical results, representing extreme conditions, were obtained for a defined reference system.

The key to control of the environmental hazard in the GASP system is the closure mechanism - if operating properly, the radiological hazard is acceptable but upon failure, the hazard may be substantial.

FINAL REPORT

RESEARCH CONTRACT NONR-3095-(00)

CONTAMINATION STUDY

CROSS-MALAKER PROJECT CM-102

Research Supervisor: *Dr. Stephen F. Malaker*

Staff: *Charles J. Anderson, Richard A. Rossi*

INTRODUCTION

A study of radioactive contamination effects resulting from an underground nuclear detonation was initiated on February 13, 1960, under contract NONR-3095-(00) between the Office of Naval Research and the Cross-Malaker Laboratories, Inc., a subsidiary of the Cross Company. The prime objective of the study was to investigate and evaluate the radiological hazard associated with the launching of a space vehicle employing an underground shaft and a contained nuclear detonation as proposed in Project GASP.

SUMMARY & CONCLUSIONS

Under active investigation is the feasibility of utilizing an underground nuclear detonation as a means of accelerating large masses to achieve orbital velocities. The feasibility studies, to date, of the Ground Accelerated Space Platform (GASP) Project are encouraging. Independent of engineering feasibility are the health and safety aspects of such a proposal. The present investigation was undertaken to evaluate the radiological hazards associated with Project GASP.

Since design studies have not established definite characteristics of the GASP System, an arbitrary reference system was selected in this study as a basis for evaluating the hazards. A one (1) kiloton nuclear charge was assumed in the reference system. This affords relatively easy extrapolation of environmental radiation levels for larger yield detonations. A U-235 fission process in contrast to a fusion reaction was selected in this study. The use of a thermonuclear explosion would greatly reduce the fission product activity and the associated radiological hazards.

Invariably, some or all of the propellant gas will be released from the shaft of the system following the launching of the projectile. In harmony with the widely supported policy of

reducing airborne contamination for the protection of the health and safety of the public, it is extremely desirable to reduce the quantity of fission products escaping into the atmosphere. For this and other reasons, some means of preventing total escape of the gases should be incorporated in the GASP design. There are a number of approaches possible, some of which are contained herein. For purposes of discussion, a closure device has been included in the reference system. The device will seal the top of the shaft after passage of the vehicle, thereby preventing the escape of the bulk of the propellant gas. Since the design of the facility has not been finalized and because of the uncertainties as to the behavior of the propelling gas, calculations were performed assuming various fractions of gas escape. In some of the analyses a release percentage of .02% was selected. A discussion of the basis for this selection has been included in the text.

The mode of release of the gases may be simulated for purposes of analysis by three general release mechanisms. These are (1) a relatively slow release, (2) a release from an underground detonation, and (3) an instantaneous release similar to a jet. The particular mode of release which occurs depends on a number of indefinite circumstances. Therefore, an evaluation of the above three mechanisms of release should cover the range of possibilities.

A slow release might occur upon a controlled release of the gas subsequent to treatment for fission product removal. A minor failure such as a small breach in the shaft lining would be another example. In any case, the fractional release of fission products will be less than 100%. A release of 0.02% of the fission products was assumed for controllable cases and 1% for minor failures. The wind velocity and local meterological conditions play significant roles in determining the radiological hazard. Under the worst meteorological conditions, neglecting washout, and a release of 1% of the fission products, an exclusion radius of about 4 miles appears satisfactory to protect the health and safety of the public. The radiation dosage should be less than 25R outside of this area. Direct radiation is the prime contributor to the total dosage. Therefore, the contribution of the fallout in estimating the exclusion zone was neglected. Calculated results clearly show the importance of scheduling the launchings under favorable meteorological conditions. However, it may be imperative to perform a launching in inclement weather. The results presented for unfavorable meteorological conditions should be consulted to aid in the evaluating the additional hazard.

Attempts to correlate data from past underground detonations were not very successful. The conditions were too different from the GASP conditions to afford any reasonable extrapolation.

Nevertheless, a qualitative analysis indicates that total release of the gases would not present an unduly severe radiological hazard.

The release of the gas as a jet results in greater dilution of the fission products than during the previous mechanisms. The anticipated cloud heights are of the order of 20,000 feet. Under these conditions, the dosage as a result of direct shine is an isignificant contribution to the total dosage. The main radiological hazard is the inhalation of select fission products such as the iodines and strontium. The point of maximum dosage may lie a great distance from the launching site. It is difficult to accurately estimate the distance because of the undertainties associated with defining meteorological conditions. The whole body external dose is 1.4 R at the point of maximum dosage. The bone dose due to strontium 90 is less than 6% of the acceptable emergency dose (AED) while the iodine dose to the thyroids is less than 4% of the AED. The potential radiation dose distant from the GASP site is acceptable within the limits of the defined reference system and assumptions.

Analytical tools are not available to analyze what purports to be the most serious radiological hazard problem associated with Project GASP, the close-in hazard. The expected close-in radiation levels will be high. It is not possible to estimate with any accuracy what the levels would be for a system with which there has been no experience. Therefore, it remains to use other means of estimating the close-in hazard.

Neutron activation of the shaft and covolume was considered as a potential source of direct radiation. Since the high neutron density will be of short duration and will exist predominantly in the covolume of the system, the greatest induced activity will occur therein. Mn^{56}, Si^{31} *and* Cr^{51} *are the prime contributors to the bulk of the activity if steel is used as the material of construction for the covolume and shaft. The first two isotopes have short half-lives and will be insignificant after a day or two.* Cr^{51} *may be troublesome should internal access to the system be necessary. A steel containing very little chrome would be advisable. For the surrounding earth, the contribution of the induced activity is extremely small and is not considered a problem.*

Contamination of the ground waters appear to be highly impossible for the GASP system if the nuclear detonation occurs at the extreme depths. Even if the fission products were to escape from the containment shell, they would probably be fixed on the surrounding soil by an ion exchange or adsorption mechanism. If the detonation is closer to ground level, then there may be a problem if the hydrology and geology of the surrounding earth are unfavorable.

The use of a GASP facility for more than one launching requires the decontamination of the facility to reduce the radiation to an acceptable level. Decontamination problems in the GASP system depend to a large extent on the particular section of the system under consideration. The area surrounding the launching

shaft should be designed to facilitate the clean up of close-in fallout and washout. Many of the techniques and procedures devised for the clean up of bomb test areas and more recently nuclear airplane runways may be applicable to this part of the system. This includes such items as coating the site surface with a protective coating or paving the surrounding area with a hard-sloped surface with associated drains leading to drainage basins, storage tanks, etc. Design features of the shaft might include the coating of the steel shaft with a liner or insert of a material on which the fission products will deposit and later be removed with the liner. Four processes for treating the propellant gas were discussed. The method used in decontamination and collection of the fission products must take into consideration the process for their ultimate storage or disposal. After the type and nature of the wastes are defined, then they can be more closely examined in view of the applicability of known waste treatment methods.

The importance of a form of closure for the GASP system has been shown. There are several approaches to secure closure which may be suitable. In essence, the mechanics of closure can be broken down into three principle parts, namely (1) actuation of the closure device, (2) retardation of the gas and/or sabot and (3) closure. There are a number of principles upon which the

actuation of the closure device may be based. Needless to say, a positive failure-proof device is required. Some of the possible schemes are based upon pressure, temperature, radiation, optical and electromagnetic sensitive elements. No attempt at this time was made to evaluate the relative merits of the various proposals for this in itself requires a long thorough investigation.

In order to achieve closure, it will probably be necessary to reduce the momentum of the mass of gas by some means. A sabot has been suggested to protect the missile and attenuate the shock, however, in addition it would be an effective device for retarding the gas. An obvious means of slowing down the sabot, and the gases behind it, would be a constriction at the top of the shaft. This constriction may be tapered or step-wise. The incorporation of a small explosive device between the sabot and the vehicle was considered and appears less attractive than other methods. Other schemes considered would utilize a hydraulic plunger arrangement or a drag force system located near the top of the shaft.

Finally, actual closure may be necessary to seal the shaft. Sliding wedges or flaps could be used for this purpose.

Based on the results of the present study a proposal incorporating a series of exploding wire experiments was submitted to the Project Officer. The objective of the proposed laboratory program is to study experimentally factors such as close-in fallout which cannot be adequately treated by analytical techniques.

STATEMENT OF PROBLEM

The Ground Accelerated Space Platform (GASP) concept has been advanced as a means of accelerating large masses to the required velocity for going into orbit. Preliminary studies (1, 2) have shown the hydrodynamic and the construction feasibility of the system. The present investigation was to determine the radiological hazards on the surrounding environment resulting from the detonation.

In order to evaluate the magnitude of this potential problem, the Cross-Mallker study was initiated with the following objectives:

1. *To determine the degree of radiological hazard to the immediate and distant areas resulting from the firing of a GASP under normal firing conditions with emphasis on the hazards from the contaminated propulsion gases escaping from the mouth of the shaft while closure is being effected.*

2. *To evaluate the effect of meterological conditions on the degree of airborne hazard.*

3. To evaluate the radiological hazard in terms of the design of the launching system.

4. To consider various types of credible accidents and their effect on the radiological hazard e.g. failure of the closure mechanism or escape of radioactive material due to failure of the containment shell because of inadequate design or increased yield of the nuclear device.

5. To suggest means of reducing radioactive contamination of the surrounding areas, and thereby reduce the associated hazards.

6. To develop an experimental program for studying parameters of the G.A.S.P. system under laboratory conditions.

REFERENCE SYSTEM

The general approach used in this study was to assume certain maximum values for the various parameters and make calculations based upon the assumed system to evaluate the radiological hazards. To obtain this end, the following reference system was defined as a basis for analysis.

The system consists of a facility capable of placing into

orbit a vehicle weighing 10 tons. The vehicle is 4 feet in diameter and 40 feet long. A sabot is below the vehicle to protect it from the propellant gas and shock. Its mass is approximately the same as that of the vehicle. The vehicle and sabot are fired from a 15,000 feet long steel lined shaft which has a 70 feet spherical cavity (covolume) at the bottom to absorb the shock. The spherical cavity has two linings separated by a water barrier, the inner one expendable and the outer reusable. The volume of the shaft and sphere are 190,000 $ft.^3$ and 180,000 $ft.^3$ respectively. Prior to firing, the upper part of the shaft is evacuated and the cavity is filled with a propellant gas such as hydrogen. The specific propellant weight of hydrogen is 72 pounds of hydrogen per ton. Thus, the reference system requires approximately 1440 pounds of hydrogen to accelerate the projectile and sabot to the desired velocity. A kiloton nuclear charge is exploded and the gas expands yielding a launching pressure of 3,000 atmospheres and an initial temperature of 500,000°C. As the gas expands, the vehicle and its sabot accelerate with the vehicle leaving the shaft at a terminal velocity of 40,000 ft/sec. It takes slightly more than 0.5 seconds to reach this velocity. The average temperature of the gas is approximately 11,000°C when the missile leaves the tube. The vehicle or the sabot activates a closing device as it travels up the shaft so that the bulk of the propelling gases and radioactive debris are contained. Some of the propelling gas as well as the vaporized bomb components will escape. The released gases

carrying fission products, form a cloud which rises and expands. The larger radioactive particulate will fall back to earth in the immediate area of the shaft.

RESULTS OF UNDERGROUND DETONATION TESTS

During the past few years, the AEC has conducted a series of underground detonations to investigate their characteristics. Although the data gathered from these tests cannot be directly applied to the GASP system because of widely dissimilar conditions, valuable qualitative information may be applicable. The following summarizes the pertinent observations:

(1) Gas escaped from the zero room into the tunnel in only 1 of the 5 tests in which there was no breakthrough to the surface.

(2) The major portion (65-80%) of the gross fission products (3) activity is in dilute solid solution in the earth surrounding the zero room. The remainder is distributed throughout the collapsed zone of the chimney and is deposited on the surface of the broken material.

(3) In the Neptune Event (4) the surface was disrupted by material and gas venting with sufficient force

to throw large rocks in the air. The resultant dust plume rose to a height of about 10̊00 feet above the terrain. Integration of the total fallout patterns on the surface gave 1-2% of the total fission activity produced by the explosion even though maximum crater dimensions were realized. Almost all of the radioactivity that did escape from the crater was deposited on large particles which fell near the crater. After one hour, the radiation level in the crater was less than 1000 r/hr. The direction and shape of the fallout pattern were determined by low altitude wind direction and velocity, and the direct cloud height.

(4) A base surge forms (5) following a sub-surface detonation when the material in the column falls back to the surface. The finer particles roll out radially along the surface to form a low cloud which appears following the subsidence of the initial throwout. If the column is contaminated by the fire-ball, the contamination must be produced by mixing with the early remnants of the fire-ball.

(5) Early fallout is deficient in those fission products such as Sr^{89} and Ba^{140} having gaseous precursors.

DEPTH FOR COMPLETE CONTAINMENT

If a nuclear detonation occurs at a shallow depth, a fireball is evident as it breaks through the earth surface before it is obscured by clouds of dirt and dust. The released gases carry up into the air large quantities of earth, rock and debris in the form of a cylindrical column fanning out as it rises into the shape of an inverted cone. If the site of the detonation is sufficiently below the surface, the entire gas and fission product release is contained in the earth. As derived from the Rainier (6) detonation, the value for the depth of complete containment is given by:

$$D = 450\ W^{1/3} \qquad (1)$$

where D is the depth of burial in feet and W is the yield in kilotons.

The radioactivity from Rainier was completely contained within a radius of 60 feet. For turf, this radius R, is given by:

$$R = 50\ W^{1/3} \qquad (2)$$

Figure 1 shows a plot of D and R, calculated using the above equations for various size detonations. These equations were developed for unsupported turf. The use of a reinforced structure

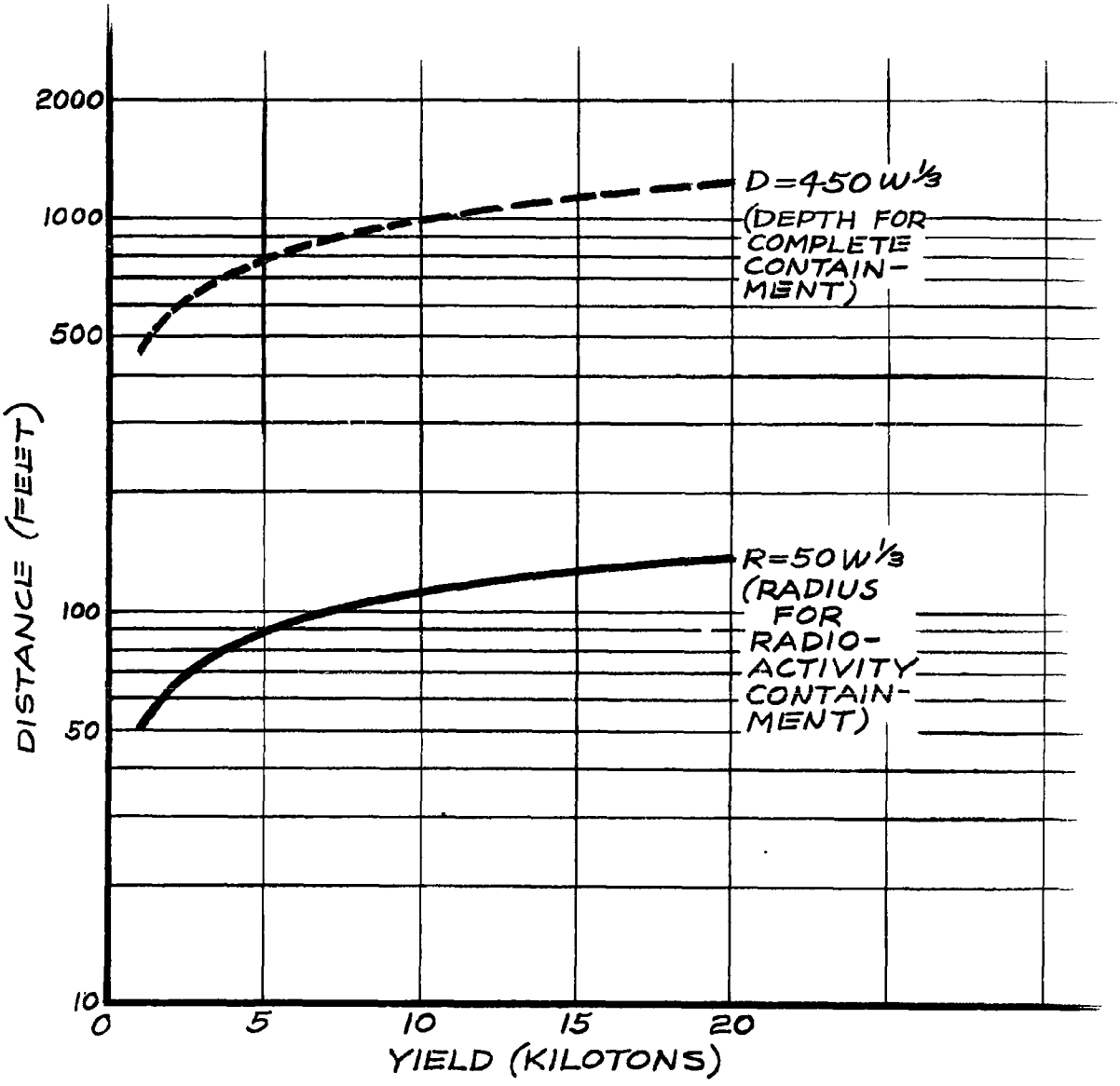


FIG. 1

CONTAINMENT OF UNDERGROUND DETONATION

Cross Canalaker
LABORATORIES, INC,
MOUNTAINSIDE, N.J.

would reduce the depth requirement.

There is little danger of not containing the explosion in the reference design since the detonation occurs at a depth of about 15,000 feet for a vertical shaft. If a horizontal tube or series of explosions is used, the detonation section must be located at least 1,000 feet below the surface unless special containment shields are included in the design.

ESTIMATE OF FISSION PRODUCT ESCAPE

Ideally, there should be no escape of fission products, but in practice it will require about 0.01 seconds for the closure device to close. The shaft in the reference system has a cross section of 12.6 $ft.^2$, therefore, assuming a constant gas velocity of 40,000 ft/sec, 5,000 $ft.^3$ of gas will escape. This is only an order of magnitude since the gas escape velocity will not remain constant at 40,000 ft/sec. The escaped gas represents less than 1.5% of the total gas since the combined volume of the shaft and covolume is about 370,000 $ft.^3$ The quantity of fission products escaping with the gas depends upon their distribution. Approximately 2% of the fission products will escape if it is conservatively assumed that they are uniformly dispersed in the gas. This represents a large quantity of fission products. However, a uniform dispersion is unlikely. The fission products

are initially completely vaporized, but as the gas expands and cools down, there is a high probability of deposition on or interaction with the walls of the shaft. There will be an erosion or vaporization of some of the material with a resulting dilution of fission products. Thus, the exiting gas will be slightly deficient in some of the fission products.

The amount of fission product release can be minimized by incorporating novel design features in the facility. For example, the injection of a spray of water near the top of the shaft to rapidly reduce the pressure and to dilute the concentration of the fission products in the gas. The water shield in the covolume will have a similar effect. It may be possible to minimize fission product escape from the covolume by utilizing a favorable bomb geometry and covolume design. An expansion chamber near the top of the shaft plus a faster acting closure device will considerably decrease the escape of fission products. More importantly, the incorporation of the recently developed "clean" nuclear detonations devices instead of those that were used in most of the underground tests to date will greatly help.

An estimate of the value of each of the above suggestions was made and a fission product release reduction factor assigned

as shown below.

FEATURE	FACTOR
Use of Sabot	20
Dilution of gas by water & interaction with materials	10
Faster acting closure device	2
Institution of "clean" nuclear detonations	50
Favorable covolume and bomb design	5
Incorporation of an expansion chamber	5

It is assumed for the purpose of analysis, that fission product release can be reduced by a factor of at least 100 by incorporation of some or all of the design features, therefore, the release under normal operating conditions would be about 0.02%.

RELEASE OF FISSION PRODUCTS TO ENVIRONMENT

When the vehicle exits from the shaft some of the gas will escape. The behavior of the gas as it leaves the shaft can be visualized in several ways. This section considers three types of gas release, namely, (1) a relatively slow release similar to that usually considered in reactor hazards analyses, (2) a release as in an underground detonation, (3) an instantaneous release as in the case of a near ground level nuclear

detonation. Each of these is discussed separately in the following with regards to radioactive cloud rise, cloud height, fallout, etc. These examples present the extremes and as such, give the range of the anticipated hazards. After establishing these, an effort will be made to determine the most probable condition.

I. SLOW RELEASE OF FISSION PRODUCTS

Calculations were performed to obtain the order of magnitude of the hazard associated with the complete release of all fission products from a kiloton detonation. This size detonation was selected for ease of scaling the hazards for larger or smaller sized detonations. These calculations can be extrapolated to other conditions using the appropriate factors for fission yield and fraction of gas escaped. Reactor hazards analysis techniques and equations were used as a first approximation for cloud height, accumulated exposure to a ground receptor, fallout and washout. Although this approach appears arbitrary, it is supported by the behavior by the release of fission products from the Neptune Event.(4) There will most likely be a slow continuous release of gas in spite of the use of devices such as a sabot or fast acting closure mechanism to prevent the escape of the gas.

A. CLOUD HEIGHT

The gas will escape as a cloud containing fission products. The cloud will disperse as it rises and will be carried along with

the wind. The range of cloud heights may be between zero (essentially no rise) and a height somewhat less than that of an atomic bomb. Two approaches have been used to calculate cloud rise from a reactor. Sutton (7) using the theory of diffusion determines the height at which the cloud and the environment are at the same temperature, while Machta assumes a constant rate of environmental air entrainment. In the latter, the cloud rise is important and is more applicable to large clouds. Because of the uncertainties in determining many of the terms in these equations, the height of cloud rise is usually calculated using a less rigorous form. In reactor hazard analysis, a cloud rise has been estimated using an equation based on the work of Sutton.

$$H = (\ln 10)^{\frac{1}{2}} (C_z) X^{(2-n)/2} \qquad (3)$$

Where X = downstream distance (meters)

C_z = diffusion parameter

n = stability parameter

H = height in meters

This equation defines the plume "boundary" so that its concentration falls to 10% of its axial value.

Two conditions are considered in the present calculations, namely stable and unstable conditions. Typical values for the diffusion and stability parameters were assumed as:

Condition	C_z	n
Stable	0.06	0.50
Unstable	0.21	0.20

Thus, equation (3) becomes for stable conditions:

$$H = 0.0915\ (X)^{0.75} \qquad (4)$$

and for unstable conditions:

$$H = 0.32\ (X)^{0.90} \qquad (5)$$

Cloud heights calculated for stable and unstable conditions as a function of downwind distance are given in Table I.

B. ACCUMULATED EXPOSURE TO A GROUND RECEPTOR

The fission of 0.11 pounds of uranium or plutonium will release the same amount of energy as 1000 tons of TNT (8), therefore, the number of fissions per kiloton equals:

$$0.11\ \frac{lb.}{Kiloton} \times \frac{454G}{lb.} \times \frac{mol}{235G} \times \frac{6X10^{23}fissions}{mol} = 1.278 \times 10^{23}\ \frac{Fissions}{Kiloton}$$

If 100% of the total fission products are released and contained in a cloud with 60% of the activity effective (9) to ground receptor, then the accumulated dosage in roentgens is given by:

$$D = \frac{(F)\ (1.86 \times 10^{-6})\ v^{0.2}}{H\ (d)^{2.2}}\ Roentgens \qquad (6)$$

TABLE I

CLOUD HEIGHT

DISTANCE DOWNWIND		HEIGHT OF CLOUD (METERS)	
Feet	Meters	Stable Conditions	Unstable Conditions
100	30.5	1.19	6.9
250	76.0	2.36	15.8
500	152	3.96	29.5
1000	304	6.66	53.5
1 Mile	1610	23.3	246
2.5 "	4030	46.3	563
5 "	8050	77.7	1047
10 "	16100	130.8	1955
25 "	40300	260.2	4467

where:

F = total number of fissions produced

v = wind velocity (cm/sec)

d = distance from origin (cm)

D = accumulated dose (roentgens)

H = cloud height (meters)

Substituting $F = 1.278 \times 10^{23}$ (1 Kiloton detonation) in equation (6) gives:

$$D = \frac{2.377 \times 10^{17} \; v^{0.2}}{H \; d^{2.2}} \qquad (7)$$

Accumulated doses calculated using this equation are given in Tables II and III for stable and unstable conditions, respectively. These data are based on the complete escape of all the fission products from a kiloton detonation. For incomplete escape of the fission products, multiply the values given in the tables by a factor representing the fraction escaped. Multiply by the yield in kilotons for smaller or larger detonations.

The Reactor Safeguards Committee defines the exclusion radius as the distance within which the accumulated dosage is greater than 25 roentgen. Substituting $D = 25$, $r = d$, $X = d/100$ and equations (4) or (5) in equation (7) are solving for r gives the following for the exclusion radius for a kiloton detonation under stable conditions:

$$r = 1.9 \times 10^{6} \; v^{0.0678} \text{ cm} \qquad (8)$$

Distance	1 MPH	5 MPH	10 MPH	20 MPH	50 MPH	100 MPH	150 MPH
100 FT.	9.22×10^{9}	1.27×10^{10}	1.46×10^{10}	1.68×10^{10}	2.02×10^{10}	2.32×10^{10}	2.51×10^{10}
250 "	6.24×10^{8}	8.61×10^{8}	9.89×10^{8}	1.14×10^{9}	1.37×10^{9}	1.57×10^{9}	1.70×10^{9}
500 "	8.10×10^{7}	1.12×10^{8}	1.28×10^{8}	1.47×10^{8}	1.77×10^{8}	2.03×10^{8}	2.20×10^{8}
1000 "	1.05×10^{7}	1.45×10^{7}	1.66×10^{7}	1.91×10^{7}	2.29×10^{7}	2.63×10^{7}	2.85×10^{7}
1 Mile	7.65×10^{4}	1.06×10^{5}	1.21×10^{5}	1.39×10^{5}	1.67×10^{5}	1.92×10^{5}	2.08×10^{5}
2.5 "	5.05×10^{3}	7.13×10^{3}	8.00×10^{3}	9.19×10^{3}	1.11×10^{4}	1.27×10^{4}	1.38×10^{4}
5 "	6.65×10^{2}	9.18×10^{2}	1.05×10^{3}	1.21×10^{3}	1.45×10^{3}	1.67×10^{3}	1.81×10^{3}
10 "	8.82×10	1.22×10^{2}	1.40×10^{2}	1.60×10^{2}	1.93×10^{2}	2.22×10^{2}	2.40×10^{2}
25 "	5.74	7.92	9.09	1.04×10	1.26×10	1.44×10	1.56×10

T A B L E II

ACCUMULATED DOSAGE TO GROUND RECEPTOR

STABLE CONDITIONS

(1 Kiloton Detonation)

DOSE IN ROENTGENS

Distance	1 MPH	5 MPH	10 MPH	20 MPH	50 MPH	100 MPH	150 MPH
100 Feet	1.59×10^{9}	2.19×10^{9}	2.52×10^{9}	2.89×10^{9}	3.48×10^{9}	3.99×10^{9}	4.33×10
250 "	9.32×10^{7}	1.29×10^{8}	1.48×10^{8}	1.70×10^{8}	2.04×10^{8}	2.34×10^{8}	2.54×10^{8}
500 "	1.09×10^{7}	1.50×10^{7}	1.72×10^{7}	1.98×10^{7}	2.38×10^{7}	2.73×10^{7}	2.96×10^{7}
1000 "	1.31×10^{6}	1.80×10^{6}	2.07×10^{6}	2.37×10^{6}	2.85×10^{6}	3.28×10^{6}	3.55×10^{6}
1 Mile	7.25×10^{3}	1.00×10^{4}	1.15×10^{4}	1.32×10^{4}	1.59×10^{4}	1.82×10^{4}	1.97×10^{4}
2.5 "	4.15×10^{2}	5.74×10^{2}	6.58×10^{2}	7.56×10^{2}	9.09×10^{2}	1.04×10^{3}	1.13×10^{3}
5 "	4.94×10	6.81×10	7.82×10	8.98×10	1.08×10^{2}	1.24×10^{2}	1.34×10^{2}
10 "	5.75×10^{-1}	7.94×10^{-1}	9.12×10^{-1}	1.05×10	1.26×10	1.45×10	1.57×10
25 "	3.34×10^{-1}	4.61×10^{-1}	5.30×10^{-1}	6.08×10^{-1}	7.31×10^{-1}	8.39×10^{-1}	9.10×10^{-1}

TABLE III

ACCUMULATED DOSAGE TO GROUND RECEPTOR

UNSTABLE CONDITIONS

(1 Kiloton Detonation)

DOSE IN ROENTGENS

and similarly, for unstable conditions:

$$r = 7.87 \times 10^{5} v^{0.0645} \text{ cm} \qquad (9)$$

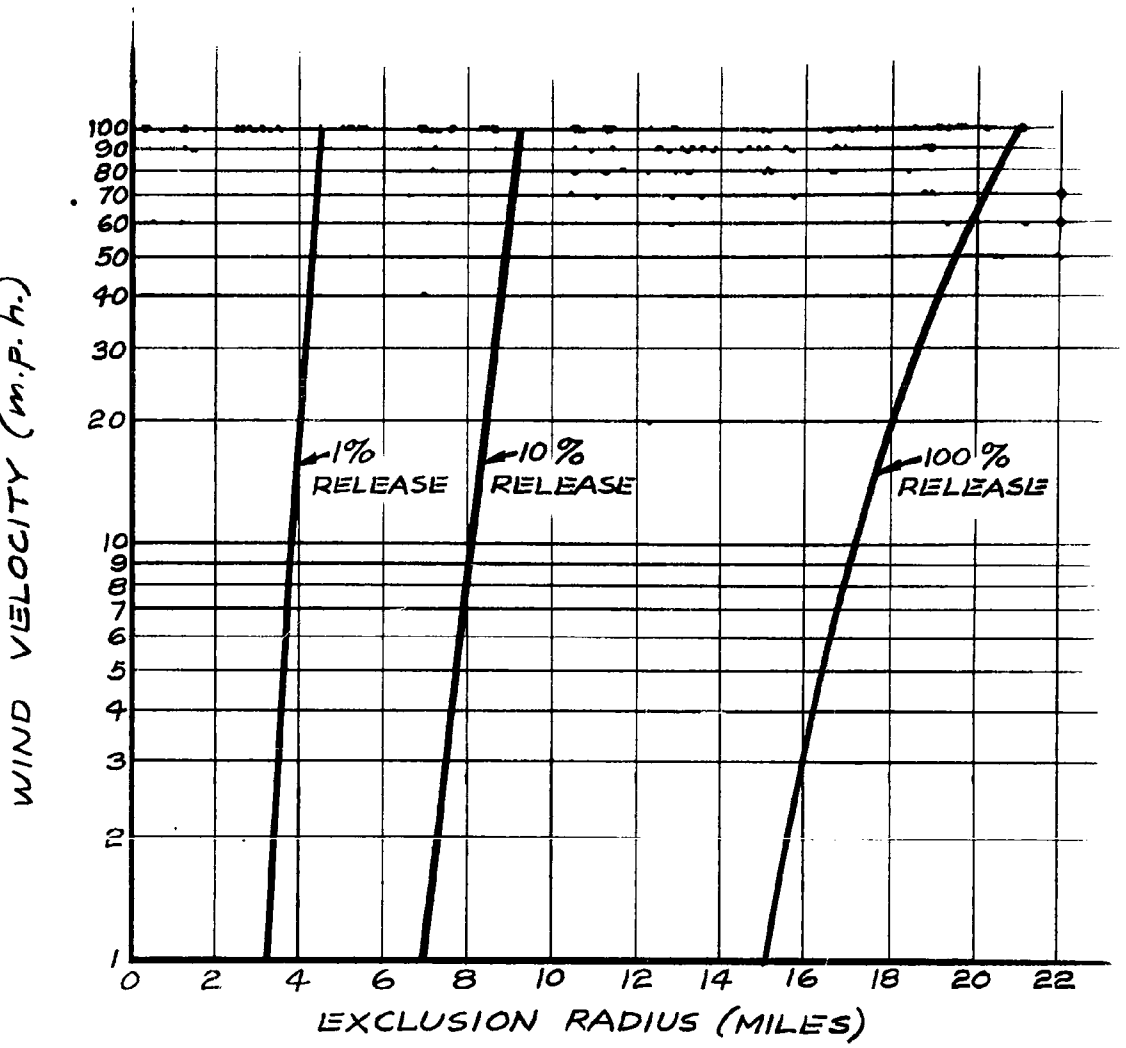
Values for the exclusion radii as a function of wind velocity are plotted in Figures (2) and (3).

The above equations for exclusion radii were derived for the case of 100% release of the fission products and a yield of 1 kiloton. To obtain similar equations for fractional gas releases and other fission yields, the appropriate number must be substituted in equation (6) and the new exclusion radii equations derived.

The curves of Figures (2) and (3) indicate a fairly large exclusion radius is necessary. However, it should be borne in mind that the calculations were performed for 100% release while under normal operating conditions the release would be of the order of only a few percent. For purposes of illustration, curves for 1 and 10 percent release are included in Figures (2) and (3).

C. FALLOUT

Fallout refers to the deposition of radioactive matter from an airborne cloud during non-precipitating weather and includes the effects of both gravitational settling and impaction. The maximum deposition at a distance downwind for a continuous



EXCLUSION RADII (STABLE CONDITIONS)

FIG. 2

WIND VELOCITY VS EXCLUSION RADIUS

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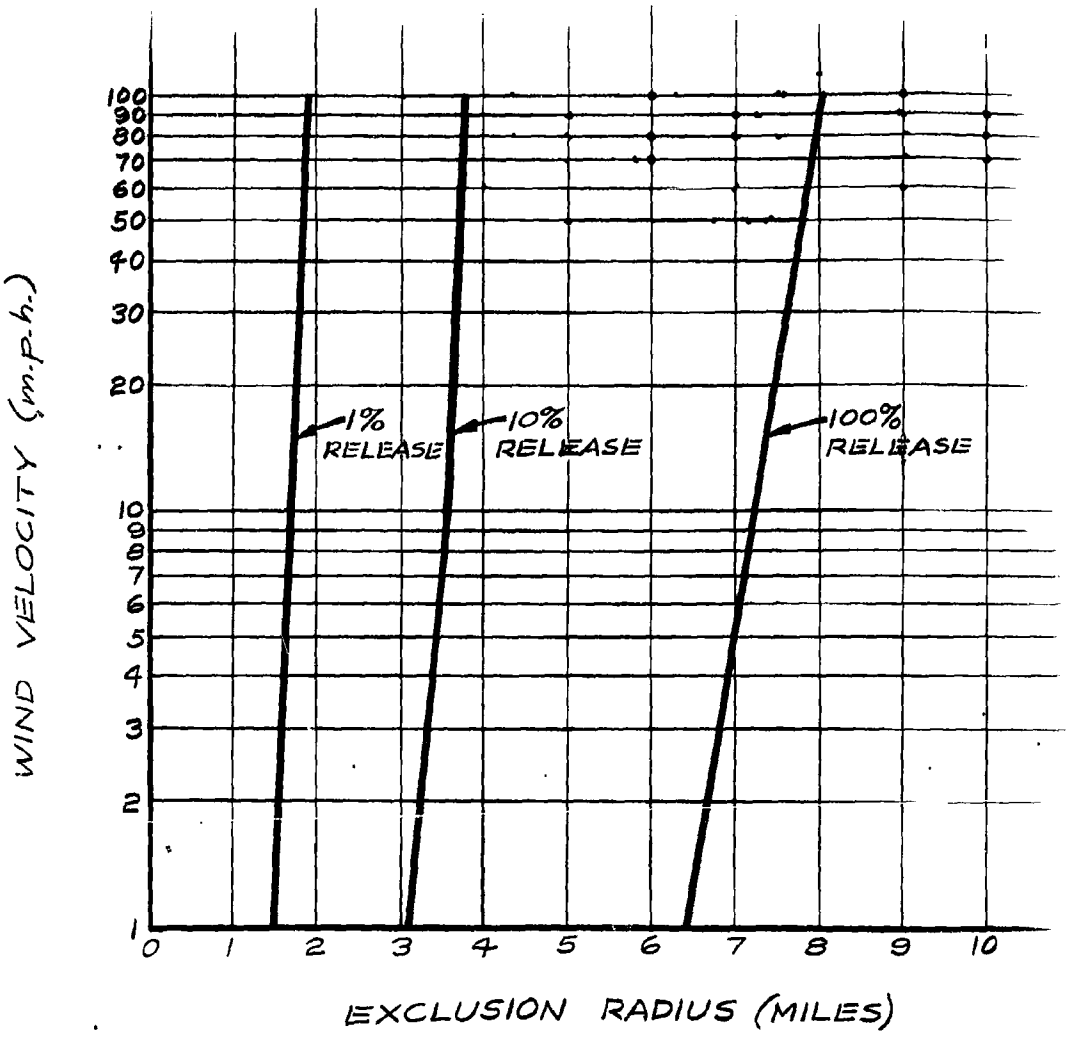

FIG. 3

EXCLUSION RADIUS (UNSTABLE CONDITIONS)

"WIND VELOCITY VS. EXCLUSION RADIUS"

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release is given by:

$$w = \frac{n\, Q_R}{2\, e\Pi^{\frac{1}{2}}\, C_y\, d^{2-(n/2)}} \qquad (10)$$

where

w = deposition rate (mev/sec^2-m^2)

Q_R = source release rate (mev/sec^2)

n = stability parameter

C_y = diffusion coefficient ($m^{n/2}$)

d = downwind distance (m)

It has been assumed for purposes of calculation that complete release of the fission products will occur. For the actual situation there are a number of possibilities as to the mode of gas release for this assumed condition of a slow release. One might involve an initial puff with a subsequent steady release. Another could be a continuous steady stream of gas. In another case, a controlled release following some type of treatment to reduce the fission product concentration might ensue.

To analyze rigorously each of the potential modes of release would be quite burdensome and would not contribute greatly to the overall contamination evaluation. Therefore, the approach taken assuming a constant gas release rate for a finite period of time appears justified.

Under the condition the activity deposited at a point downwind is given by:

$$\psi = \int_{t_1}^{t_2} w\, dt \qquad (11)$$

where

$$w = \text{deposition (mev/sec-m}^2\text{)}$$

$$t_1 = 0$$

$$t_2 = t$$

$$\therefore \quad \chi = wt \tag{12}$$

Substituting equation (10) for w gives:

$$\chi = \frac{n\, Q_R\, t}{2\, e\Pi^{\frac{1}{2}}\, C_y \rho^{2-(n/2)}} \tag{13}$$

but $Q = Q_R t$ since gas release rate is constant, thus yielding:

$$\chi = \frac{n\, Q}{2\, e\Pi^{\frac{1}{2}}\, C_y \rho^{2-(n/2)}} \tag{14}$$

From the Summary Report of the Reactor Safeguards Committee, the effectiveness of radiation due to precipitated activity is 1.3×10^{-8} R/day for gamma radiation of 1 mev/sec-m^2 and 1.3×10^{-7} R/day for beta activity. Since roughly equal fractions of the energy go off as gamma and as beta radiation and converting to hours, the effectiveness is 3.0×10^{-9} R/hour for 1 Mev/sec-m^2 of ground deposited activity. Thus, the following equation is obtained for the dose rate:

$$D_R = \chi\ (\text{Mev/sec-m}^2) \times \left(\frac{3.0 \times 10^{-9}\ \text{R/hr}}{\text{Mev/sec-m}^2}\right) \tag{15}$$

Substituting equation (14) and (11) gives:

$$D_R = \frac{3.0 \times 10^{-9}\, n\, Q}{2e\Pi^{\frac{1}{2}}\, C_y \rho^{\,2-(n/2)}} \quad \text{R/hr} \tag{16}$$

The activity resulting from the instantaneous formation of fission

products is approximated by the Way-Wigner equation:

$$Q = F \times 2.66\ t^{-1.2} = 3.4 \times 10^{23}\ t^{-1.2}\ \text{mev/sec} \qquad (17)$$

where

F = number of fissions (1.278×10^{23} fissions/kiloton)

t = time (seconds)

Substituting equation (17) in (16) gives:

$$D_R = \frac{1.061 \times 10^{14}\ n\ t^{-1.2}}{C_y\ d^{2-(n/2)}} \qquad (18)$$

since $d = \bar{u}\ t$ ($\bar{u}$ = mean wind velocity - meters/sec)

$$D_R = \frac{1.061 \times 10^{14}\ n\ (\bar{u})^{1.2}}{C_y\ d^{3.2-(n/2)}} \qquad (19)$$

The total integrated dose (TID) is given by:

$$TID = \int_{t_1}^{t^2} D_R^{\,1}\ dt \qquad (20)$$

where $D_R^{\,1}$ = dose rate due to initial level of activity

Substituting $D_R^{\,1} = D_R\ t^{-1.2}$ and defining limits from 10 seconds to infinity ($D_R^{\,1}$ and D_R must be in units of R/sec.) gives:

$$TID = \int_{10}^{\infty} D_R\ t^{-1.2}\ dt = 5\ D_R\ t^{-0.2}\Big]_{10}^{\infty} = 3.15\ D_R \qquad (21)$$

Converting equation (19) to seconds and substituting in (21) gives:

$$TID = \frac{9.28 \times 10^{10} \; n \; (\bar{u})^{1.2}}{C_y \; d^{3.2 - (n/2)}} \qquad (22)$$

For stable conditions $n = 0.5$ and $C_y = 0.1$, thus equation (22) becomes:

$$TID = \frac{4.64 \times 10^{11} \; (\bar{u})^{1.2}}{d^{2.95}} \qquad (23)$$

while for unstable conditions $n = 0.2$ and $C_y = 0.37$ so

$$TID = \frac{5.02 \times 10^{10} \; (\bar{u})^{1.2}}{d^{3.1}} \qquad (24)$$

The total integrated dose is given as a function of distance for stable and unstable conditions in Tables IV and V, respectively. These values are based on a system releasing the fission products from a one kiloton detonation. They are readily applied to other conditions by multiplying by the fraction of fission products escaped and the yield in kilotons.

D. <u>WASHOUT</u>

Washout deposition refers to radioactivity deposited on the earth by the scrubbing action of raindrops or snowflakes passing through a radioactive cloud. The total washout is often considered the "worst possible airborne contamination condition" in reactor hazard analyses. An upper limit to the possible hazard

Distance	WIND VELOCITY						
	1 MPH	5 MPH	10 MPH	20 MPH	50 MPH	100 MPH	150 MPH
100 Feet	7.39×10^{6}	5.10×10^{7}	1.11×10^{8}	2.69×10^{8}	8.09×10^{8}	1.66×10^{9}	3.02×10^{9}
250 "	4.95×10^{5}	3.42×10^{6}	7.85×10^{6}	1.80×10^{7}	5.42×10^{7}	1.11×10^{8}	2.03×10^{8}
500 "	6.41×10^{4}	4.42×10^{5}	1.02×10^{6}	2.33×10^{6}	7.01×10^{6}	1.44×10^{7}	2.62×10^{7}
1000 "	8.30×10^{3}	5.73×10^{4}	1.32×10^{5}	3.02×10^{5}	9.08×10^{5}	1.87×10^{6}	3.39×10^{6}
1.0 Mile	6.13×10^{1}	4.23×10^{2}	9.72×10^{2}	2.23×10^{3}	6.70×10^{3}	1.38×10^{4}	2.51×10^{4}
2.5 "	4.11	2.83×10^{1}	6.51×10^{1}	1.49×10^{2}	4.49×10^{2}	9.24×10^{2}	1.68×10^{3}
5.0 "	5.32×10^{-1}	3.67	8.43	1.93×10^{1}	5.81×10^{1}	1.20×10^{2}	2.17×10^{2}
10.0 "	6.88×10^{-2}	4.74×10^{-1}	1.09	2.50	7.52	1.57×10^{1}	2.81×10^{1}
25.0 "	4.61×10^{-3}	3.18×10^{-2}	7.30×10^{-2}	1.68×10^{-1}	5.04×10^{-1}	1.04	1.88
50.0 "	5.96×10^{-4}	4.11×10^{-3}	9.45×10^{-3}	2.17×10^{-2}	6.52×10^{-2}	1.34×10^{-1}	2.44×10^{-1}
100.0"	7.72×10^{-5}	5.33×10^{-4}	1.22×10^{-3}	2.81×10^{-3}	8.44×10^{-3}	1.74×10^{-3}	3.15×10^{-2}

TABLE IV

RADIOACTIVE FALLOUT

TOTAL INTEGRAL DOSE STABLE CONDITIONS

(ROENTGENS)

Distance	WIND VELOCITY						
	1 MPH	5 MPH	10 MPH	20 MPH	50 MPH	100 MPH	150 MPH
100 Feet	4.79×10^{5}	3.30×10^{6}	7.59×10^{6}	1.74×10^{7}	5.24×10^{7}	1.20×10^{8}	1.95×10^{8}
250 "	2.79×10^{4}	1.93×10^{5}	4.43×10^{5}	1.01×10^{6}	3.06×10^{6}	7.03×10^{6}	1.14×10^{7}
500 "	3.26×10^{3}	2.25×10^{4}	5.17×10^{4}	1.18×10^{5}	3.56×10^{5}	8.20×10^{5}	1.33×10^{6}
1000 "	3.80×10^{2}	2.62×10^{3}	6.03×10^{3}	1.38×10^{4}	4.16×10^{4}	9.56×10^{4}	1.55×10^{5}
1.0 Mile	2.19	1.51×10^{1}	3.47×10^{1}	7.97×10^{1}	2.39×10^{2}	5.50×10^{2}	8.95×10^{2}
2.5 "	1.27×10^{-1}	8.82×10^{-1}	2.02	4.65	1.39×10^{1}	3.21×10^{1}	5.22×10^{1}
5.0 "	1.49×10^{-2}	1.02×10^{-1}	2.36×10^{-1}	5.43×10^{-1}	1.63	3.74	6.09
10.0 "	1.74×10^{-3}	1.20×10^{-2}	2.75×10^{-2}	6.34×10^{-2}	1.90×10^{-1}	4.37×10^{-1}	7.11×10^{-1}
25.0 "	1.01×10^{-5}	7.01×10^{-4}	1.61×10^{-3}	3.70×10^{-3}	1.10×10^{-2}	2.55×10^{-2}	4.15×10^{-2}
50.0 "	1.18×10^{-5}	8.17×10^{-5}	1.87×10^{-4}	4.31×10^{-4}	1.29×10^{-3}	2.97×10^{-3}	4.84×10^{-3}
100.0"	1.38×10^{-6}	9.53×10^{-6}	2.19×10^{-5}	5.03×10^{-5}	1.51×10^{-4}	3.47×10^{-4}	5.64×10^{-4}

TABLE V

RADIOACTIVE FALLOUT

TOTAL INTEGRAL DOSE - UNSTABLE CONDITIONS

due to the total instantaneous washout of a cloud (7) containing airborne material is approximated by:

$$\chi = \frac{Q_g}{\pi^{\frac{1}{2}} C_y \bar{u} d^{(2-n)/2}} \qquad (25)$$

This is applicable for a continuous release of fission products from the source.

The symbols are the same as those used in the fallout section. Substituting $C_y = 0.1$ and $n = 0.5$ and using the technique developed in the fallout section, the following equation is derived for the total integral dose for the washout conditions:

$$TID = 5 \times 10^{12} \frac{\bar{u}^{0.2}}{d^{1.95}} \qquad (26)$$

The total integrated dose for different wind speeds and distances are given in Table VI. These can be scaled to other conditions as in the above.

E. ANALYSIS

The treatment in this section dealing with the slow release of fission products is of value in the evaluation of hazards from a number of possible circumstances. The circumstances might be controllable or perhaps a result of some sort of failure. The controllable circumstances would be a controlled release of the gases. One example of a failure would be a small breach in the

Distance	WIND VELOCITY						
	1 MPH	5 MPH	10 MPH	20 MPH	50 MPH	100 MPH	150 MPH
100 Feet	4.80×10^{9}	7.50×10^{9}	8.61×10^{9}	9.90×10^{9}	1.1884×10^{10}	1.3653×10^{10}	1.4808×10^{10}
250 "	8.03×10^{8}	1.26×10^{9}	1.44×10^{9}	1.66×10^{9}	1.9904×10^{9}	2.2866×10^{9}	2.4802×10^{9}
500 "	2.08×10^{8}	3.25×10^{8}	3.73×10^{8}	4.29×10^{8}	5.1523×10^{8}	5.9192×10^{8}	6.4203×10^{8}
1000 "	5.38×10^{7}	8.42×10^{7}	9.66×10^{7}	1.11×10^{8}	1.331×10^{8}	1.5315×10^{8}	1.6612×10^{8}
1.0 Mile	2.10×10^{6}	3.28×10^{6}	3.77×10^{6}	4.33×10^{6}	5.1983×10^{6}	5.9721×10^{6}	6.4777×10^{6}
2.5 "	3.51×10^{5}	5.49×10^{5}	6.31×10^{5}	7.25×10^{5}	8.7044×10^{5}	1.0000×10^{6}	1.0847×10^{6}
5.0 "	9.14×10^{4}	1.43×10^{5}	1.64×10^{5}	1.89×10^{5}	2.2640×10^{5}	2.6010×10^{5}	2.8212×10^{5}
10.0"	2.35×10^{4}	3.68×10^{4}	4.23×10^{4}	4.86×10^{4}	5.8339×10^{4}	6.7022×10^{4}	7.2696×10^{4}
25.0 "	3.94×10^{3}	6.17×10^{3}	7.08×10^{3}	8.14×10^{3}	9.7711×10^{3}	1.1225×10^{4}	1.2176×10^{4}
50.0 "	1.02×10^{3}	1.60×10^{3}	1.83×10^{3}	2.11×10^{3}	2.5292×10^{3}	2.9057×10^{3}	3.1517×10^{3}
100.0"	2.64×10^{2}	4.13×10^{2}	4.74×10^{2}	5.45×10^{2}	6.5436×10^{2}	7.5176×10^{2}	8.1540×10^{2}

TABLE VI

RADIATION DOSE - WASHOUT CONDITION

DOSE (ROENTGEN)

shaft lining. In any case, it is highly possible that the fractional release of fission products will be somewhat less than 100%. For controllable cases, the release has been taken as .02% and for minor failure circumstances a release of 1% is estimated. For these releases, Table VII shows the doses obtainable for the condition of cloud shine, fallout, and washout as a function of distance downwind.

The exclusion zone for the GASP site should be based upon the hazards resulting from the maximum plausible accident situation. For this reason, the exclusion radii as depicted in Figures 2 and 3 have been plotted for releases of 1, 10 and 100%. Under the worst meterological conditions (excluding washout) and a slow fission product release of 1%, an exclusion radius of about 4 miles appears satisfactory to protect the health and safety of the public. It should be noted that the exclusion radii equations were based upon the dose received solely from the direct radiation of the cloud. No provision was made to incorporate the accumulated dose from fallout or washout. The ratio of the fallout dose to the direct cloud dose is small. Therefore, it appears justified to neglect its contribution for purposes of estimation of the exclusion zone. The resulting doses from washout conditions are high. Hazard analyses of the washout situation are usually performed for academic purposes only, for it is totally impractical to attempt to establish an exclusion zone based

DISTANCE	ACCUMULATED DOSAGE TO GROUND RECEPTOR				RADIATION FALLOUT TOTAL INTEGRAL DOSE				WASHOUT	
	STABLE CONDITIONS		UNSTABLE CONDITIONS		STABLE CONDITIONS		UNSTABLE CONDITIONS			
	0.02% *	1.0%	0.02%	1.0%	0.02%	1.0%	0.02%	1.0%	0.02%	1.0%
100 Ft.	3.4×10^{6}	1.7×10^{8}	5.8×10^{5}	2.9×10^{7}	5.4×10^{4}	2.7×10^{6}	3.4×10^{3}	1.7×10^{5}	2.0×10^{6}	9.9×10^{7}
250 "	2.2×10^{5}	1.1×10^{7}	3.4×10^{4}	1.7×10^{6}	3.6×10^{3}	1.8×10^{5}	2.0×10^{2}	1.0×10^{4}	3.4×10^{5}	1.7×10^{7}
500 "	3.0×10^{4}	1.5×10^{6}	4.0×10^{3}	2.0×10^{5}	4.6×10^{2}	2.3×10^{4}	2.4×10	1.2×10^{3}	8.6×10^{4}	4.3×10^{6}
1000 "	3.8×10^{3}	1.9×10^{5}	4.8×10^{2}	2.4×10^{4}	6.0×10	3.0×10^{3}	2.8	1.4×10^{2}	2.2×10^{4}	1.1×10^{6}
1 Mile	2.8×10	1.4×10^{3}	2.6	1.3×10^{2}	4.4×10^{-1}	2.2×10	1.6×10^{-2}	8.0×10^{-1}	8.6×10^{2}	4.3×10^{4}
2.5 "	1.8	9.2×10^{1}	1.5×10^{-1}	7.6	3.0×10^{-2}	1.5	9.4×10^{-4}	4.7×10^{-2}	1.5×10	7.3×10^{3}
5.0 "	2.4×10^{-1}	1.2×10^{1}	1.8×10^{-2}	9.0×10^{-1}	3.8×10^{-3}	1.9×10^{-1}	1.1×10^{-4}	5.4×10^{-3}	3.8×10	1.9×10^{3}
10.0 "	3.2×10^{-2}	1.6	2.2×10^{-3}	1.1×10^{-1}	5.0×10^{-4}	2.5×10^{-2}	1.3×10^{-5}	6.3×10^{-3}	9.8	4.9×10^{2}
25.0 "	2.0×10^{-3}	1.0×10^{-1}	1.2×10^{-4}	6.1×10^{-3}	3.2×10^{-5}	1.6×10^{-3}	7.4×10^{-7}	3.7×10^{-5}	1.6	8.1 X 10

TABLE VII

RADIATION HAZARD - WIND VELOCITY 20 MPH

(ROENTGENS)

* % of Total Fission Products Released To The Environment.

upon the dose which would be received as a result of a washout. It can be stated conclusively that the vast majority of reactor installations in this country would have inadequate exclusion zones if they were based upon the washout condition. The above indicates the need for placing meteorological controls upon the scheduling of shots. Results previously presented clearly show the importance of initiating shots under favorable meteorological conditions. It is recognized that under extreme circumstances it may be imperative to perform a launching in inclement weather. For this circumstance, the results presented for unfavorable meteorological conditions should be consulted to aid in the evaluation of the additional risk involved.

II. SUBSURFACE EXPLOSIONS

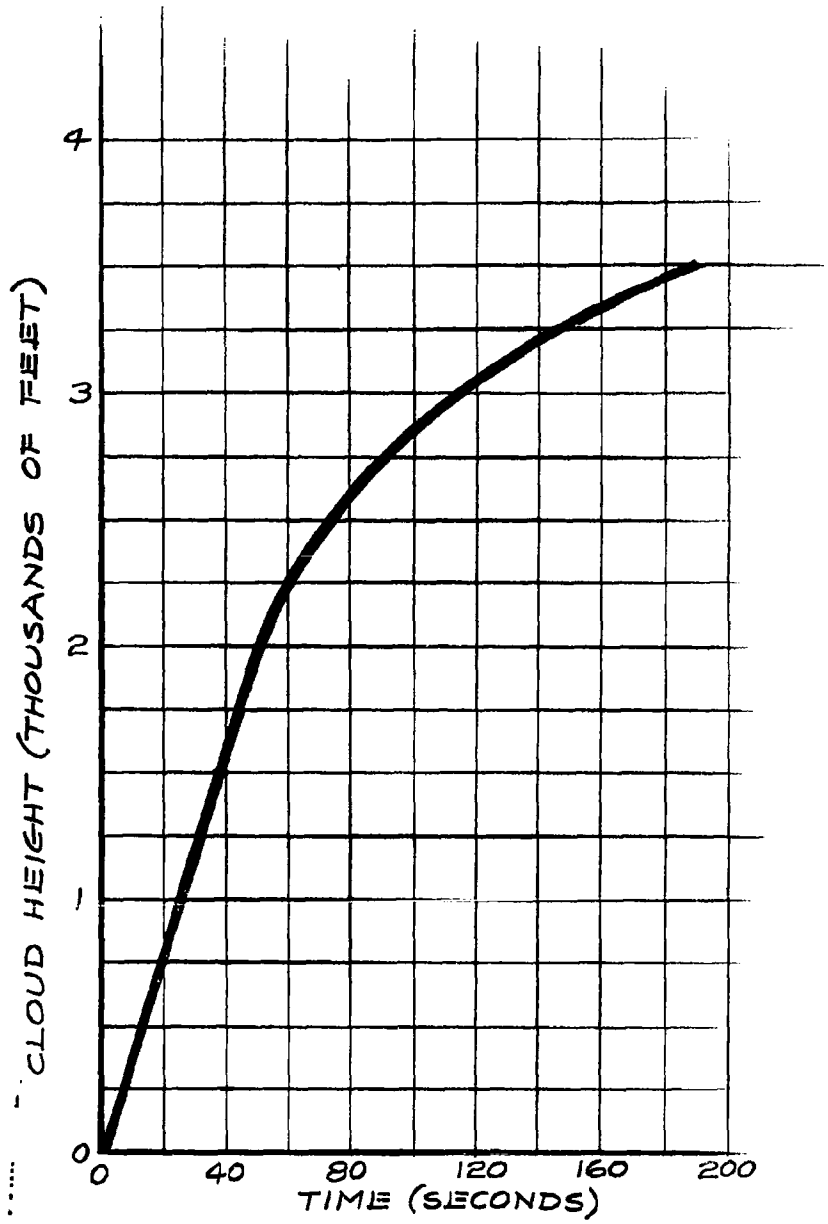
The cloud resulting from an underground detonation will not rise as rapidly or as high as that from an above surface detonation. In fact, if the detonation occurs sufficiently deep, there will be no venting or escape of gas,(this of course, assumes that the earth is unsupported).

The results of Operation Teapot (5) may give an insight into the radiation hazard problems. In Operation Teapot, 1.2 kilotons charge was detonated at 65 feet below the surface. Tentative results indicate that throw-out reached a height of 700 feet and a maximum diameter of 1300 yd. The throw-out was complete in

about 17 sec. The base surge first became visible at about 33 seconds and continued to expand until about 116 sec. The surge height was about 340 feet on the upwind and 100 feet on the downwind sides, respectively. After the subsiding of the surge, a cloud became visible. A plot of the cloud height as a function of time is given in Figure 4. A comparison of this data with that given previously for cloud height calculated for a reactor incident indicates that a faster rise time and a higher altitude (Table I) was obtained in Operation Teapot. The radiation level at ground zero was greater than 6000 r/hr after a lapse of 1 hour. The decrease in the activity followed the $t^{-1.2}$ decay law.

Aerial photographs of the area one mile from ground zero indicated that the region of heavy material fallout extended about 1 mile in a southwest direction. Figure 5 illustrates the radiation levels resulting from fallout at 1 hour after detonation.

It is recognized that the conditions for the described subsurface detonation vary greatly from those to be encountered in the GASP system. Nevertheless, the results of the test point up the conservativeness of the hazards calculations presented in the previous section. In the GASP system the detonation will occur in a "clean" environment contained by a steel enclosure while Operation Teapot utilized no means of earthen support. Therefore, a considerably higher quantity of fallout is to be expected.



CLOUD HEIGHT VS TIME
OPERATION TEAPOT *

FIG. 4

* BOUTON, E. H., HARDIN, L. M., SCHUNCHYK, M. S., OPERATION TEAPOT PRELIMINARY REPORT FALLOUT STUDIES, CHEMICAL AND RADIOLOGICAL LABORATORIES, ARMY CHEMICAL CENTER, MARYLAND.

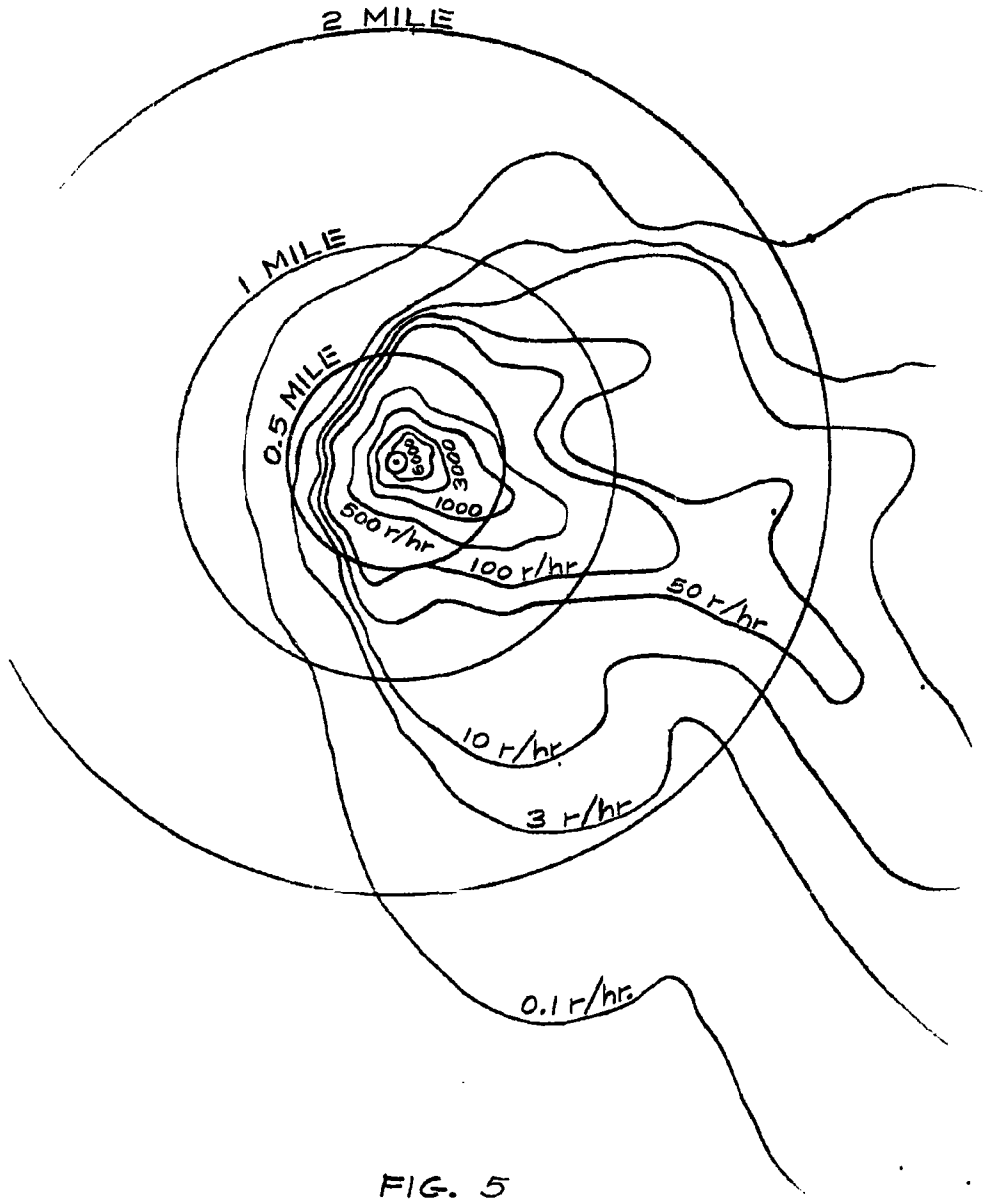


FIG. 5

DOSE RATE H+1 HR—OPERATION TEAPOT *

* BOUTON, E. H., HARDIN, L.M., SCHUMCHYK, M. J., OPERATION TEAPOT, PRELIMINARY REPORT, FALLOUT STUDIES, CHEMICAL AND RADIOLOGICAL LABORATORIES, ARMY CHEMICAL CENTER, MD.

Keeping in mind that the fallout dose would be, most likely, orders of magnitudes greater for Teapot than GASP, we find that the isodose curves of Figure 5 indicate that the majority of the fallout remained in close to ground zero.

III. RELEASE AS HIGH ENERGY JET - The propellant gas initially leaves the shaft at a velocity of 40,000 ft/sec and at an initial pressure of 3000 atmospheres. Under these conditions the gas will shoot up into the atmosphere as a relatively thin column and then expand as dictated by ambient conditions. Turbulence at the edge of the column will cause some mixing with the atmosphere. If the proper proportion of hydrogen and air are attained, a violent explosive reaction will occur resulting in a secondary detonation. This will produce water and may cause an instantaneous washout, thereby increasing the contamination per unit area.

The resultant fallout pattern and the radiological hazard resulting from releases of radioactive material depends to a large extent on the height to which the cloud ascends. The cloud height is dependent upon the local meteorological parameters. Also playing an important part in the ultimate contamination problem are the direction and speeds of the prevailing winds at all altitudes and meteorological conditions distant from the point of detonation.

A. CLOUD HEIGHT

There are a number of methods available for computing the expected height of radioactive effluents emitted into the

atmosphere as a stream. Among these are (1) a semi-empirical approach utilizing the results from bomb bursts and (2) semi-empirical equations developed from diffusion experiments for effective stack height determination.

BOMB BURST - In the case of a bomb burst, the rate of cloud rise depends upon meteorological conditions and the energy yield of the bomb. The eventual height depends upon the heat energy, temperature gradient and the gas density.

For surface and air blasts, the cloud rise (10) as a function of time and yield is given by:

$$\Delta h = 200\, W^{0.19}\, t^{\left(\frac{0.82}{W^{0.01}}\right)} \qquad (27)$$

where Δh = cloud rise, feet

W = yield, kilotons

t = time, seconds

Figure 6 shows a plot of the cloud rise for the first 10 seconds after a one kiloton detonation. In general, any nuclear cloud (10) regardless of yield reaches its maximum height in 7 minutes after detonation. The maximum height for a kiloton detonation, calculated using the above equation is 28,400 feet. The cloud has sufficient energy to reach this altitude under favorable meteorological conditions. In the event of unfavorable conditions such as an inversion, the cloud will not rise to this height but level off at a lower altitude.

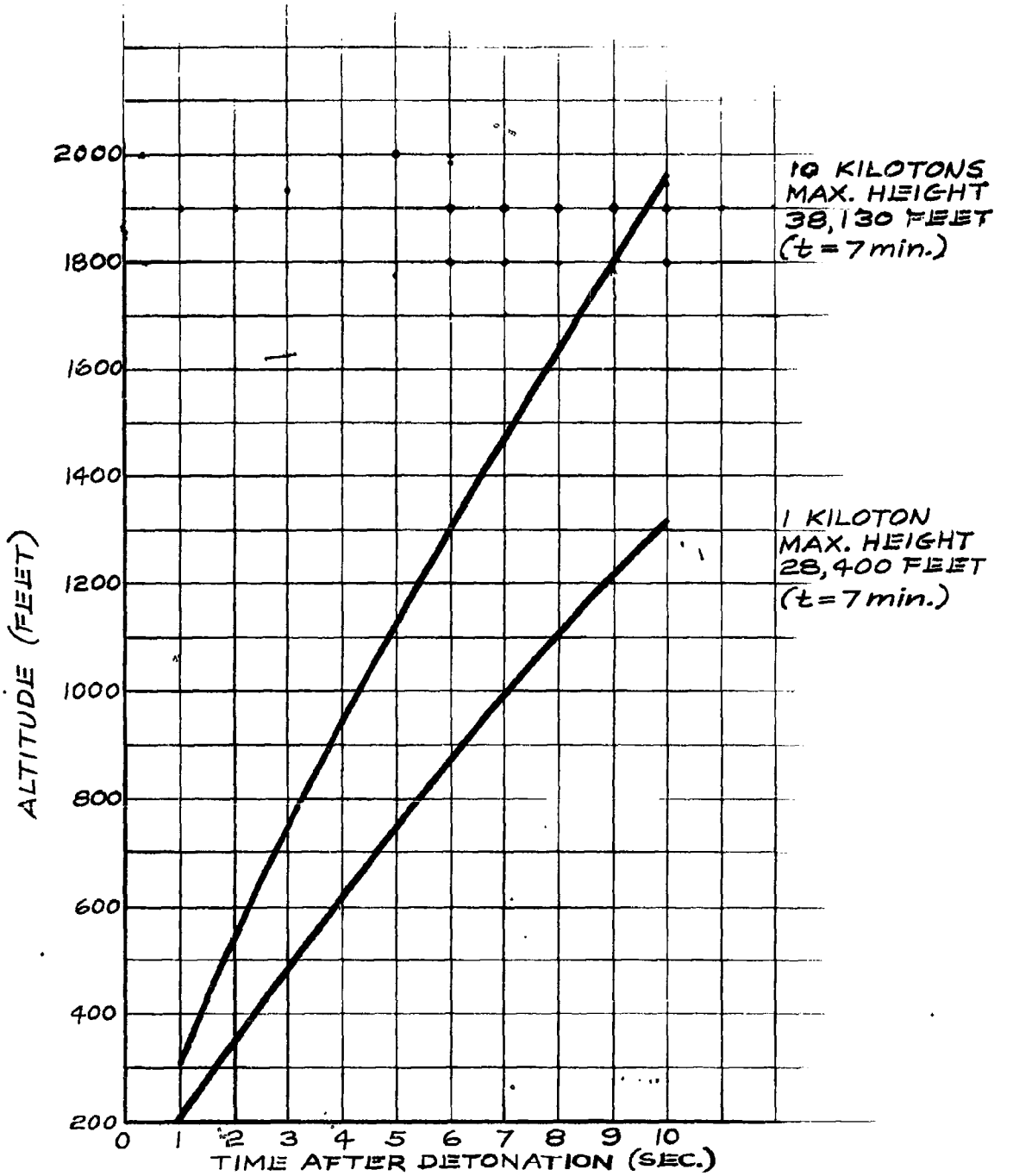


FIG. 6

CLOUD HEIGHT VS TIME

Cross Malaker
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MOUNTAINSIDE, N.J.

STACK HEIGHT APPROACH - *The Holland Equation (11) is a semi-empirical relationship based on the results of a study conducted at Oak Ridge National Laboratory for calculating effective heights for gas effluent coming from a stack under stable conditions. Values obtained using this equation adequately describes most types of effluents but the present application requires an extremely large extrapolation of the experimental results. As such, these calculations are only qualitative. This equation describes the height in terms of two properties of the gas, namely, the exit momentum and bouyancy. It is given by:*

$$\bar{u}\,\Delta h = 1.02\, vd + 7.58 \times 10^{-2} Q \qquad (28)$$

where

Δh = *effective stack height increment (ft)*

$\bar{u}$ = *average wind speed (mph)*

v = *stack gas velocity (ft/sec)*

Q = *heat released from stack (Btu/sec)*

d = *stack diameter (ft)*

$1.02\, vd$ = *momentum term*

$7.56 \times 10^{-2} Q$ = *bouyancy term*

For $Q = 1.28 \times 10^{8}$ *Btu/sec,* $v = 40{,}000$ *ft/sec,* $d = 4$ *ft and* $\bar{u} =$ *40 mph,* Δh *is in the order of 250,000 feet.*

In another approach the effective stack height (12) is based on the total thermal rise and is given by:

$$\Delta h = d \left(\frac{v}{\mu}\right)^{1.4} \left(1 + \frac{T}{T_s}\right) \qquad (29)$$

where

Δh = effective stack height increment (ft)

v = stack velocity (ft/sec)

T = excess temperature of stack (^{o}R)

T_s = absolute temperature of stack (^{o}R)

For $T/T_s = 1$, $d = 4$ ft, $v = 40{,}000$ ft/sec. $\bar{\mu} = 40$ mph, Δh is about 127,000 feet.

EXPECTED CLOUD HEIGHT - In summary, the cloud heights resulting from the bomb bursts are governed by the troposphere. The effective stack height equations indicate that the existing gas has sufficient energy to attain very high altitudes, but it is perhaps overly optimistic to expect the stream to penetrate the tropopause. Climatological information on the change of wind speed with altitude for various parts of the country indicate that the tropopause occurs at an altitude of 25,000 to 35,000 feet in the summer, while in the winter at 30,000 to 40,000 feet. Therefore, a conservative estimate of the cloud height is to assume that the effluent ascends to a height of 20,000 feet and then diffuses horizontally maintaining this approximate height. This height will be used for calculations in the following sections.

B. *DISTANCE TO MAXIMUM DOSAGE*

The distance to the point of maximum exposure is given by:

$$d\ (max) = \left(\frac{h^2}{\sigma^2}\right)^{\frac{1}{2-n}} \qquad (30)$$

where

$d\ (max)$ = *distance (m)*

h = *cloud height (m)*

σ^2 = *diffusion parameter* $(m^{\frac{1}{n}})^2$

n = *stability parameter*

The distance is greatly affected by the atmospheric parameter, for example, the distances calculated for a cloud height of 20,000 feet and the following values for C and n :

CONDITION	*C*	*n*
Stable	*0.06*	*0.50*
Unstable	*0.21*	*0.20*

are 55 and 3000 miles for unstable and stable conditions, respectively. The calculated distance of 3000 miles may be misleading. A height of 20,000 feet was assumed and under the defined stable conditions, the cloud would probably not reach this altitude. It appears reasonable to assume that the point of maximum dosage would be within a few hundred miles of the launching shaft.

C. *MAXIMUM DOSAGE - WHOLE BODY*

The radiation dosage at the point of maximum dosage is calculated in the following:

Curies of fission products/fission = $1.03 \times 10^{-16} t^{-1.2}$ (31)

where t is in days and

fissions/kiloton = 1.28×10^{23}

curies / kiloton = $1.3 \times 10^{7} t^{-1.2}$

total volume of system = $370{,}000\ ft^3$

$$\text{Fission product concentration} = \frac{1.3 \times 10^{7} t^{-1.2}}{.37 \times 10^{6}} = 35 t^{-1.2}\ \text{curies}/ft^3 \quad (32)$$

Figure 6 shows the time (7 minutes) required for a 1 KT surface burst to achieve its maximum height of 28,000 feet. In the case under discussion since the system is acting as a jet, it is reasonable to assume a shorter time to achieve the maximum height. An ascension time of 1 minute is taken for the jet case.

The fission product concentration at 60 seconds is taken as the source concentration of the instantaneous elevated radiation source. It appears reasonable to expect that the release will behave as an instantaneous release. For purposes of calculation, it is conservatively assumed that 10% of the volume is released. The fission product concentration in the exhaust gas is:

$$\frac{35}{\left(\frac{60}{24 \times 3600}\right)^{1.2}} = 2.13 \times 10^{5}\ \text{curies}/ft^3 \quad (33)$$

The total activity escaping to the atmosphere is

Activity = $2.13 \times 10^{5} \times 3.7 \times 10^{4} = 7.9 \times 10^{9}$ curies (34)

The total integrated dose (TID) at the point of maximum concentration is given by:

$$TID_{max} = \frac{2\,Q}{e\,\bar{u}\,h^2} \qquad (35)$$

wher Q = curies of fission products

$\bar{u}$ = mean wind velocity (m/sec)(assumed to be 40 mi/hr)

h = effective height (m)

$$TID_{max} = \frac{2 \times 7.9 \times 10^9}{(0.447 \times 40)(6100)^2} = 3.61 \quad \frac{curies\text{-}sec}{m^3} \qquad (36)$$

Since 1 $\frac{curie\text{-}sec}{m^3}$ = 0.547 E roentgen and taking

E = 0.7 Mev, the total whole body dose is 1.4 R.

D. MAXIMUM DOSAGE - INHALATION

For high cloud heights as occurring for the conditions assumed, a major contributor to total body dose will most likely result from inhalation of the fission products. Inasmuch as the worst offenders are strontium and the iodines, only these are considered.

Equation (36) gives the TID max for all the radioactive sources. Since only specific isotopes are of immediate interest, the value must be multiplied by the appropriate factors. For I^{131}, an exposure to 1 curie-sec/m^3 of total fission product activity results in the body retaining 27 μc of iodine. The

allowable emergency dose, AED (22) for I^{131} is 2000 rad which corresponds to inhaling and retaining 2660μc of iodine 131. The dose to the thyroid is:

$$\frac{27 \times 3.6 \times 2000}{2660} = 73 \text{ Rads} \qquad (37)$$

This corresponds to only 3.7% of the AED.

In the case of Sr^{90}, exposure to 1 curie-sec/m^3 results in inhaling 0.16μc of Sr^{90} by the body. One AED corresponds to inhaling 10μc of Sr^{90}. For the GASP assumptions, the Sr^{90} contribution is 5.8% of the AED.

E. ANALYSIS

Treating the gas release as a jet results in greater dilution of the fission products than in the previous treatments. The anticipated cloud heights are of the order of 20,000 feet. At these extremely high altitudes the contribution of direct shine to the total whole body dose in all probability will be small. Of greater significance would be the hazard presented by potentional inhalation of the fission products.

In view of the ultimate high altitude of the cloud, the point of maximum dosage would be a great distance from the launching site. This does not consider the close-in radiation environment. It may be difficult to estimate the point of maximum dosage under the prevailing meteorological conditions

since the ground level meteorological data does not accurately predict the conditions existing at these extremely high altitudes. In any case, these calculations were performed to indicate an order of magnitude of the distance.

The whole body external dose at the point of maximum dosage was calculated to be 1.4R. The bone dose due to strontium 90 was calculated to be less than 6% of the acceptable emergency dose. The dose to the thyroids was calculated to be 73 rads, however, the allowable dose to the thyroid glands is of the order of 2000 rads. In summary, for the assumptions made and the 1 kiloton detonation the potential doses distant from the GASP site are acceptable. The potential doses resulting from conditions other than assumed can be extrapolated from the results herein.

CLOSE-IN FALLOUT

The previous sections utilize standard diffusion equations and are generally reliable for estimating conditions at points distant from ground zero. They estimate the initial distribution of the fallout particles in space on the basis of height and size of the visible cloud. Current methods for predicting radioactive fallout do not provide accurate information on close-in fallout. Primarily, this is because they are based upon diffusion theory rather than on a fundamental theory of the fallout process, that

is, the dynamics of the fallout process before the nuclear cloud stabilizes.

A theory for close-in fallout (13) has been prepared which takes into account the motion of the fallout particles from inception in the fireball until they return to the ground. Even this theory does not provide accurate results in close to ground zero. In fact, the developers of the theory do not consider the results reliable at distances less than 1 mile. Furthermore, this theory was developed utilizing the parameters and conditions associated with a land surface bomb blast. The conditions during launching are considerably different and, therefore, the applicability of this theory to the GASP system is questionable. In view of this, no calculations were made. However, the close-in fallout is very important and will have to be seriously considered in the design of the GASP system. More precise close-in fallout data may be possible as a result of laboratory studies.

NEUTRON INDUCED ACTIVITY

All elements except helium capture neutrons. If the target material contains more than one isotope, each type interacts separately with its own characteristics. Thus, several new isotopes may be produced, some of which are radioactive and others stable. The calculation of neutron induced activity

requires a knowledge of the following factors:

Neutron Exposure - the number of neutrons per sq. cm impinging on the material. More than 99% of the neutrons (14) released during fast fission appear within 10^{-8} seconds of the explosion. Delayed neutron and neutrons produced by secondary (γ, n) reactions need not be considered. It is sufficient to consider only the prompt neutrons in the activation process. Fission explosions produce on the order of 10^{23} neutrons per kiloton.

Neutron Energy - the energy distribution of the neutrons depends on the type of explosion, nuclear material and the geometry of the bomb components. Experiments, conducted at the Nevada Test Site to measure the energy distribution, indicate neutron energies ranging from a fraction of an electron volt up to several million. The energy value of the slow neutrons was fixed at about 0.2 electron volt. The energy groups and neutron distribution assumed in these calculations are shown in Table VIII. Since the activation cross section varies inversely as the energy of the neutron, the contribution of the neutrons in the high energy group may be safely neglected.

Materials - The composition of the material will significantly affect the degree of induced activity since all

TABLE VIII

NEUTRON ENERGY-DISTRIBUTION

NEUTRON ENERGY (ev)	NEUTRON DISTRIBUTION (Number of Neutrons)
0.2	3×10^{23}
$0.2 - 2 \times 10^{6}$	3×10^{23}
2×10^{6}	3×10^{22}

atomic species do not form radioactive products after neutron capture. The shaft and covolume will probably be made of steel so the composition given in Table IX is assumed for calculational purposes.

Cross section - The probability of neutrons interacting with atoms to form radioactive isotopes is referred to as the activation cross section. This is a function of neutron energy and the energy characteristics of the atoms. The microscopic activation cross section is usually given in tables for thermal neutrons (0.025 ev), therefore, the cross section for 0.2 ev neutrons (applying the 1/v relationship) is 0.389 times the value for thermal neutrons. Values for the microscopic activation cross section are given in Table X.

I. CALCULATION OF THE INDUCED NEUTRON ACTIVITY IN THE COVOLUME

The diameter of the covolume in the reference system is 70 ft., therefore, the surface area is:

$$\text{Surface area} = 4\pi r^2 = 4\pi\left(\frac{70}{2}\right)^2 = 15{,}400\ ft^2 \qquad (38)$$
$$= 1.43 \times 10^7\ cm^2$$

The source strength is 3×10^{23} neutrons/kiloton so the neutron exposure neglecting attenuation in the steel of the covolume is given by:

$$n = \frac{S}{Area} = \frac{3 \times 10^{23}}{1.43 \times 10^7} = 2.10 \times 10^{16}\ \text{neutrons/cm}^2 \qquad (39)$$

TABLE IX

STEEL COMPOSITION ASSUMED IN CALCULATIONS

ELEMENT	*%*
Fe	*97.4*
C	*0.1*
Mn	*0.4*
S	*0.03*
P	*0.03*
Si	*0.5*
Cr	*1.0*
Mo	*0.5*

PARENT NUCLIDE					RADIOACTIVE NUCLIDE		
Isotope	% Abundance	F	$\sigma_{act}{}^{th}$ (cm^2)	$\bar{\sigma}_{0.2}$ (cm^2)	Isotope	$T_{\frac{1}{2}}$	Radiations (Mev)
Fe^{58}	0.31	3.02×10^{-3}	$.9 \times 10^{-24}$	$.35 \times 10^{-24}$	Fe^{59}	47 days	β (.46, .26); γ(1.3, 1.1)
C^{13}	1.1	1.1×10^{-5}	$.0009 \times 10^{-24}$	$.0004 \times 10^{-24}$	C^{14}	5800 years	β (.16)
Mn^{55}	100	4×10^{-3}	13.4×10^{-24}	5.21×10^{-24}	Mn^{56}	2.6 hours	β (2.8,1.04,.65); γ(.82,1.77, 2.06)
S^{34}	4.2	1.26×10^{-5}	$.28 \times 10^{-24}$	$.10 \times 10^{-24}$	S^{35}	87 days	β (.17)
P^{31}	100	3.0×10^{-4}	$.23 \times 10^{-24}$	$.089 \times 10^{-24}$	P^{32}	14.3 days	β (1.70)
Si^{30}	3.05	1.5×10^{-4}	0.11×10^{-24}	$.043 \times 10^{-24}$	Si^{31}	2.7 hours	β (1.48)
Cr^{50}	4.3	4.3×10^{-4}	11×10^{-24}	4.3×10^{-24}	Cr^{51}	26.5 days	γ (.32)
Mo^{92}	15.9	8.0×10^{-4}	$<.001 \times 10^{-24}$	$<.0004 \times 10^{-24}$	Mo^{93}	7 hours	γ (.26, .69, 1.51)

TABLE X

PRIMARY TRANSMUTATIONS BY NEUTRONS

The number of neutron activation captures per cm^3 of surface for each atomic specie is given by:

$$R = \frac{n N \sigma_{0.2} \rho F}{A} \qquad (40)$$

$$R = 9.86 \times 10^{40} \sigma_{0.2} F/A \qquad (41)$$

where R = radioactive atoms/cm^3

n = neutrons/cm^2 of surface

N = Avogadros number (6×10^{23} atoms/mol)

$\sigma_{0.2}$ = microscopic activation cross section for 0.2 ev neutrons (cm/atom) ($\sigma_{0.2} = 0.389 \sigma_{thermal}$)

ρ = density of steel (7.8 gm/cm^3)

F = weight fraction of element of interest

A = atomic weight (g/mol)

The activity at the surface of the steel is:

$$\text{Activity} = \frac{d R/dt}{3.7 \times 10^{10}} = \frac{-\lambda R}{3.7 \times 10^{10}} = 1.87 \times 10^{-11} R/t_{\frac{1}{2}} \qquad (42)$$

$$\text{Activity} = 1.84 \times 10^{30} \sigma_{0.2} F/A \; t_{\frac{1}{2}} \text{ curies/cm}^3 \qquad (43)$$

Table X gives the required data for calculating induced activity, while Table XI gives the induced activity resulting from the primary transmutation. An examination of Table XI indicates that Mn^{56}, Si^{31} and Cr^{51} contribute the bulk of the activity. The first two have half-lives of less than 3 hours so

TABLE XI

INDUCED ACTIVITY IN COVOLUME

ELEMENT	*HALF-LIFE*	*ACTIVITY (Millicuries/cm^3)*
Fe^{59}	47 days	8.5×10^{-3}
C^{14}	5800 years	negligible
Mn^{56}	2.6 hours	75
S^{35}	87 days	0.98×10^{-6}
P^{32}	14.3 days	1.3×10^{-3}
Si^{31}	2.7 hours	0.43
Cr^{51}	26.5 days	286
Mo^{93}	7 hours	1.42×10^{-3}

they will be insignificant after a day or so. Cr^{51} is particularly troublesome since its half-life is longer (26.5 days). Thus, a steel containing less chrome is suggested.

II. INDUCED ACTIVITY IN THE SHAFT

Since the greatest part of the induced activity will occur during the first 10^{-8} seconds, the highest concentration of induced activity will be in the portion of the shaft nearest the covolume. The level of activity in the shaft will probably be orders of magnitude lower than in the covolume, therefore, it appears that induced activity will not be a problem in the shaft.

III. SURROUNDING EARTH

Induced radioactivity in the soil will be limited to the vicinity of the covolume since the transmutations are caused primarily by the prompt neutrons. In most soils the significant neutron induced gamma-ray emitting radioactive isotopes are Na^{24}, Al^{28}, and Mn^{56}. Batzel (15) estimated the level of activity induced in a typical medium surrounding a nuclear explosion. Table XII defines the typical medium. The soil contains 20% water, therefore, the neutrons are thermallized before capture with approximately 40% of the neutrons being captured by the soil and the remainder by the hydrogen of the water. The important radioactive nuclides produced, the percent of the neutron capture leading to these nuclides and the induced activity per kiloton are given in Table XIII. Figure 7 shows a comparison of induced

TABLE XII

TYPICAL MEDIUM*

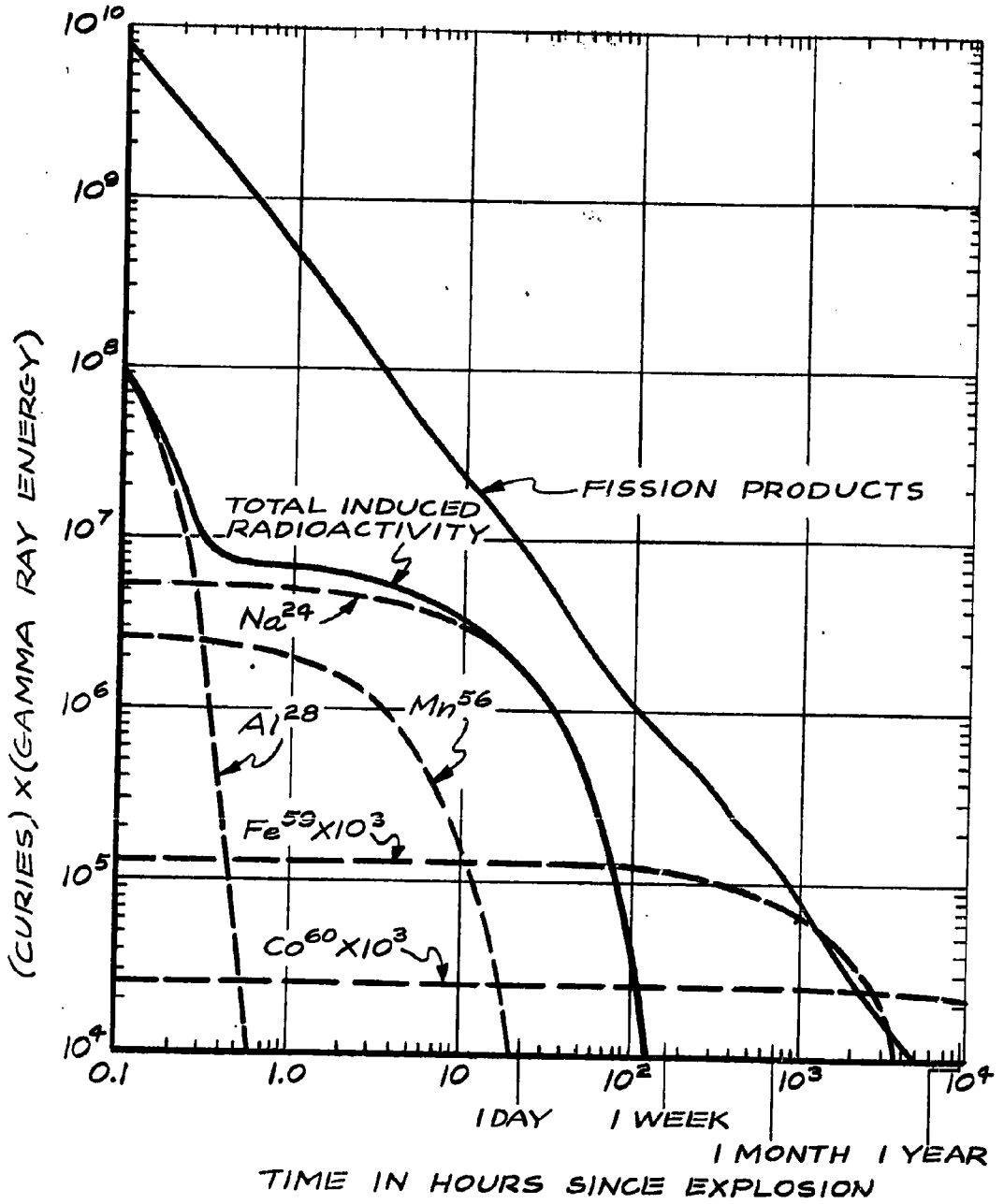
ELEMENT	ABUNDANCE BY WT %
Si	50
Al	14.5
Fe	9
Ca	6.4
H	5.1
Na	4.9
K	4.7
Mg	3.7
Ti	0.6
P	0.18
Mn	0.18
Co	0.0042

* Mason, Brian: Principles of Geochemistry, John Wiley & Sons (1952).

Element	Nuclide Produced	Half Life	Gamma Energy	Per cent of Neutron Captures Leading to Nuclide	Curies
Na	Na^{24}	15 Hours	4.0 Mev.	3.7%	1.3×10^{6}
Al	Al^{28}	2.3 Min.	1.8 Mev.	2.6%	3.5×10^{8}
Mn	Mn^{56}	2.6 Hours	1.8 Mev.	1.3%	2.6×10^{6}
Fe (0.33% Fe^{58})	Fe^{59}	45 Days	1.3 Mev.	0.015%	$\sim 10^{2}$
Co	Co^{60}	5.2 Years	2.5 Mev.	0.09%	~ 10

TABLE XIII

INDUCED RADIATION IN SOILS



INDUCED AND FISSION PRODUCT ACTIVITY vs TIME*

FIG. 7

* BATZEL, R. E., RADIOACTIVITY ASSOCIATED WITH UNDERGROUND NUCLEAR EXPLOSIONS, UCRL-5623 UNIVERSITY OF CALIFORNIA, LAWRENCE RADIATION LABORATORY (JUNE 23, 1959)

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radioactivity to fission product activity as a function of time. The induced activity contributes about 1% after 1 week and only 0.1% at about 45 days. Co^{60} and Fe^{59} are the most troublesome in view of their relatively long half life.

The induced activity in the soil will vary with the distance from the covolume surface. As a result of Plumbbob Observations (16) the following empirical equation was devised to give activity as a function of depth in the soil:

$$\text{Activity} = 10e^{-0.07874\,x} - 10e^{-0.11811\,x} + e^{-0.39370\,x} \qquad (44)$$

where x is depth in cm.

Figure 8 shows a plot of this equation with the function normalized to unit activity at the surface of the soil. This equation is similar to the thermal neutron flux distribution pattern and should represent the activity distribution for those activities produced principally by thermal neutrons. Since the contribution of induced activity in the soil to the total radiation dosage is extremely small, it is not considered a problem.

GROUND WATER CONTAMINATION

The degree of ground water contamination depends upon the quantity of fission products released and the chemical composition, geology and hydrology of the surround earth. Ground water samples (17) collected at the Nevada Test Site indicate no significant increase in radioactivity above background since the

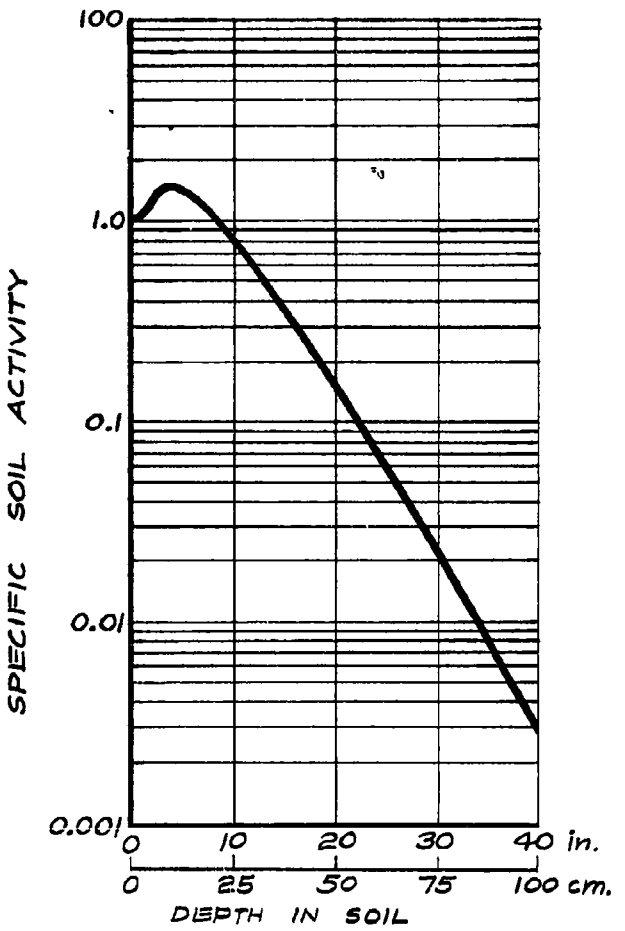


FIG. 8

ACTIVATION vs DEPTH PROFILE *

*MATHER, R.L., RESIDUAL GAMMA RADIATION FIELDS FROM INDUCED SOIL ACTIVITIES, USNRDL-TR-240 (APRIL 1958) U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORIES.

Operation Plumbbob and Hardtack underground nuclear explosions. This is attributed to the formation of silica glass by the explosion and the ion exchange properties of fission products in normal earth minerals and the nature of underground water flow. The absorption or exchange of fission products from ground water by most naturally occurring minerals is important since this mechanism helps to retard the movement of the fission products. The movement is predictable in terms of the hydrology of an area and the distribution coefficient. The latter describes the distribution of the ion of interest between the water and the mineral. In general, ground water contamination (15) in tests to date has not presented any serious hazard.

It should be pointed out that the referenced tests were conducted under extremely favorable soil conditions. If for some reason the GASP facility must be located in soil with an unfavorable geology and hydrology, ground water contamination may present a problem if the containment is breached at levels in which ground water are encountered. Another possible source of contamination of the ground waters may be a result of induced activity of the soil. For this hypothesis, a breach of the containment vessel is not necessary. For our particular circumstances in which the covolume may be of the order of 15,000 feet below ground level, there is little, if any, chance of ground water contamination.

CHEMICAL REACTIONS

The primary propellant is hydrogen gas, which, as a result of the nuclear detonation, will contain other materials. These

include the fission products, vaporized bomb components and structural materials. The gas will consist of ions and electrons at the high initial temperature. However, as the temperature decreases the ions and electrons will recombine to form free elements or compounds. The formation and subsequent reactions of these compounds are of particular interest for determining decontamination procedures. There is a strong possibility of the elements in the gas as well as the components of the walls forming hydrides since they are in contact with high temperature and pressure hydrogen. If water is present, the hydrides could react to form oxides and hydroxides. This reaction would greatly influence the behavior of these materials.

Underground bomb tests (6) have demonstrated the formation of a number of chemical compounds. Gaseous hydrogen and some organics were found. The hydrogen was traced to the decomposition of water and organic materials. The formation of C_2H_6 and C_2H_4 were probably formed from the materials in the detonation chamber such as wood, cable installation and paraffin. Under ambient conditions, the gas in the GASP system will consist of hydrogen, water vapor, gaseous fission products and organics.

DECONTAMINATION

Preliminary studies of the radiological hazards associated with an underground nuclear detonation indicates the need for effective decontamination procedures since the facility must be

used several times to be economically practical. Decontamination must be accomplished in a minimum of time and within established constraints of health and safety. Decontamination problems in the GASP system depend to a large extent on the particular section of the launching system under consideration. Decontamination is discussed considering the following four parts of the system:

(a) Launching Site Area

(b) Shaft and Covolume

(c) Propellant Gas

(d) Treatment of Fission Product Wastes

I. LAUNCHING SITE AREA

The area surrounding the launching tube should be designed to facilitate the clean up of radioactive fission products resulting from fallout or washout. Among the factors besides those of physical and chemical nature of fallout (18) which influence the contaminability are the physical and chemical characteristics of the site surface. Materials, roughness, porosity, wettability, absorbability and chemical reactivity are surface properties affecting the retention of fission products. These properties are responsible for the degree to which a contaminant can be loosened, removed and transported by decontamination processes and/or the weather elements. Materials that can be decontaminated most readily are those whose surfaces are hard, smooth, non-porous and chemically inert.

The design of the facility should include such items as the paving of the area around the shaft with a hard-sloped surface. This will facilitate the scrubbing of the surface and collection of the fission products in drains leading to drainage basins, storage tanks, etc. The decontamination properties of many surfaces can be improved by a protective coating which seals pores, smooths rough surfaces and imposes barriers between the base material and fallout particles that would otherwise combine chemically. The leveling and clearing of the more distant sections are means for aiding decontamination operations. In some cases, the plowing under of the fallout may be sufficient. Here, the basic problem is the effect of the fission products on the natural environment and more particularly the possibility of them entering underground waters.

The problems encountered in decontaminating the area surrounding the shaft are similar to those associated with cleaning up after a bomb drop. Many of the techniques and procedures devised for the clean up of test areas and more recently airplane runways are applicable to this part of the system.

A variety of decontamination methods have been developed. Decontamination methods can be divided into two basic categories: non-destructive decontamination and surface removal decontamination. Representative methods (10) for each of these categories are given in Table XIV. An overall decontamination system may use one or

NON-DESTRUCTIVE DECONTAMINATION	
1. Water Flushing	*Firehosing, power-driven street flushers, etc.*
2. Steam Cleaning	*Washing with high pressure steam from a nozzle.*
3. Sweeping	*Dry sweeping with hand brooms or power brooms.*
4. Brush Scrubbing	*Scrubbing with water and detergent or chemicals or with water alone, using long-handled brushes, power street sweepers, etc.*
5. Hot Liquid Cleaning	*Washing with a high pressure stream of hot water from a hot liquid jet unit.*
6. Vacuuming	*Using industrial type vacuum cleaner or large scale airport runway vacuum cleaner.*
SURFACE REMOVAL DECONTAMINATION	
1. Abrasive Surface Removal	*Wirebrushing, star wheel cutters or sanders, sand-blasting or Vacu-blasting.*
2. Flame Treating	*Decomposition of surface with high temperature flames such as oxy-acetylene. This type of method is usually followed by an abrasive removal method.*
3. Chemical Treating	*Decontamination of surface with chemicals such as hydrochloric acid.*

TABLE XIV

REPRESENTATIVE METHODS OF DECONTAMINATION (19)

more of these methods, individually or in combination.

II. SHAFT AND COVOLUME

Decontamination of the shaft is necessary for reducing the radiation levels to permit repairs and installation of the components for the next unit. Partial decontamination must also be considered since it may be desirable to clean only those parts of immediate interest. Design features might include the coating of the steel shaft with a liner or insert of a material on which the fission products will deposit and later removed with the liner. Remotely controlled sand-blasting may be feasible for the slightly contaminated parts. Here, there is a definite dust problem and therefore, appropriate precautions must be taken. Other means include washing and spraying, utilizing built-in brush assemblies for scrubbing. The method used in decontamination and collection of the fission products must take into consideration the process for their ultimate storage or disposal.

III. PROPELLANT GAS

After firing, the gas consists of hydrogen, water vapor (steam) organics, dust and gaseous and solid fission products. About 20% of the elemental fission products are gases at room temperature. The gaseous fission products include xenon, krypton, iodine, halogen acids and some hydrides. Knowledge about the fission products is important since the type and concentration

in the gas will dictate the subsequent treatment. The half-lives of the fission products vary from a fraction of a second to thousands of years. The short lived isotopes will rapidly become insignificant and are, therefore, unimportant process-wise. The longer half-life isotopes are controlling and are a predominant factor in determining the waste treatment or storage process.

The dust and suspended solid fission products can be separated from the gas using modifications of the methods commonly used in industry. These include cyclones, filters and scrubbing with a liquid. The selection of the separation method depends on the quantity of gas, concentration of solids, flow rates and size of the particulate. The size of the particulate is very important. Under GASP conditions the size may be very fine, thereby requiring a very effective separation process. However, it should be noted that the efficient removal of extremely fine particles from a gas stream is a particularly difficult problem in that specific isotopes may require almost complete separation. After removal of the solids, the gas can be recycled or sent to disposal for further treatment.

The most troublesome gaseous fission products are the iodines, particularly iodine-131 (8.1 days half-life). Chemical methods are usually used to remove the iodines from high level gaseous wastes. These include reaction on silver surfaces and absorption in caustic solutions. Another method of controlling the iodine hazard is to store the isotope long enough to permit

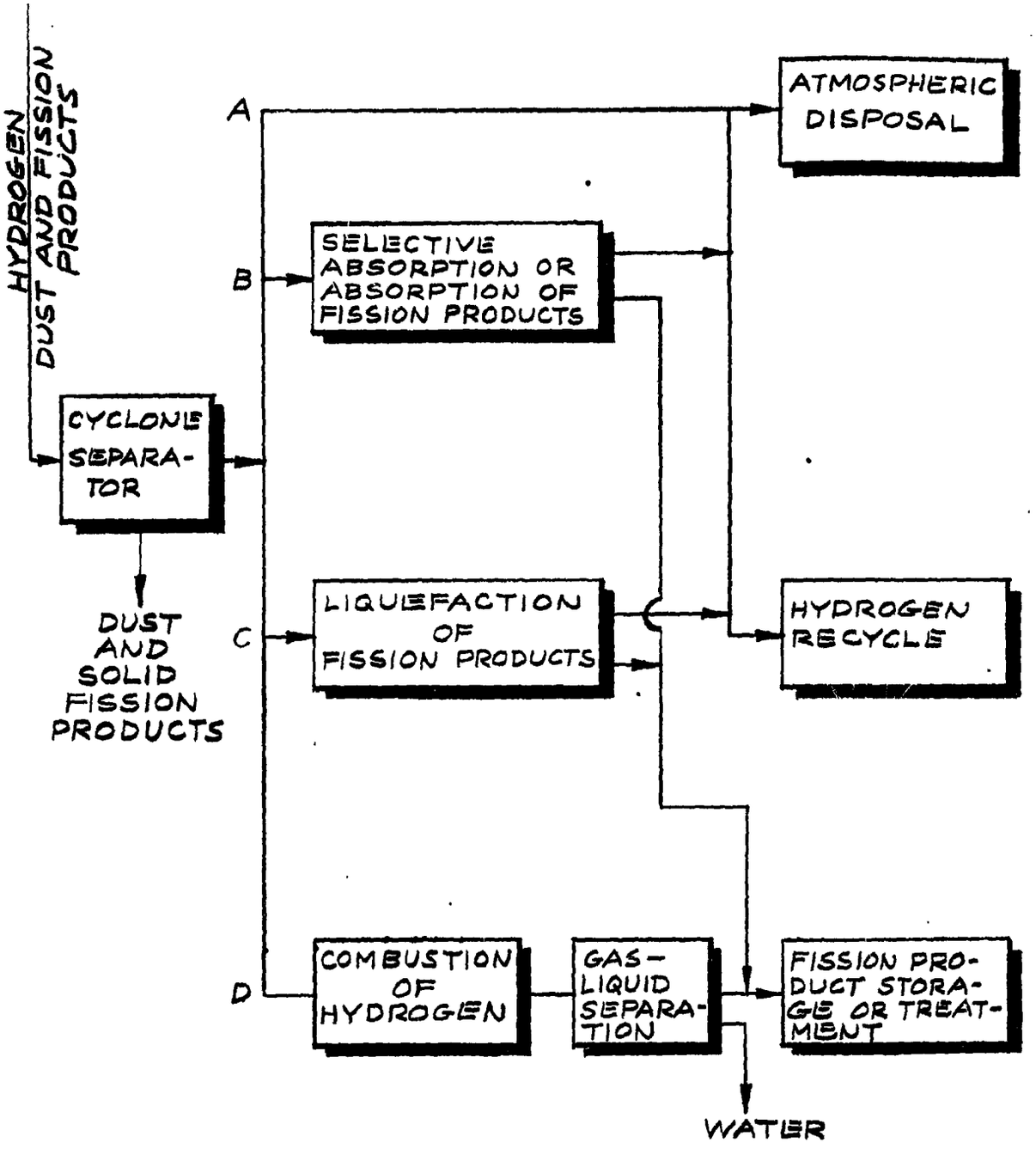
decay to an acceptable level before releasing the gas.

Several processes for treating the propellant gas are shown in Figure 9. In Process A, the gas goes to air disposal. Here the main consideration is the degree of hazard. After approximately 70 days most of the gaseous fission products have decayed to an acceptable level for disposal directly to the atmosphere. An accompanying hazard of air disposal may be the detonation of the hydrogen.

The gas in Process B goes to a unit or units for selective adsorption and/or absorption of the fission products. Considerable experimental information is available for the removal of gaseous fission products from gas compositions somewhat similar to those of the GASP. This problem was studied in connection with the Aqueous Homogeneous Reactor at Oak Ridge National Laboratory. After removal of the fission products, the gas can be recycled or sent for atmospheric disposal.

In Process C, the fission products are condensed and thereby separated from the hydrogen which is recycled or sent for disposal. The fission products are packaged and stored for ultimate disposal or use. The method or process for regenerating the adsorber or absorber will determine to a large extent the best means for the subsequent handling of the fission products.

The separation of the fission products from the gas in



POSSIBLE METHODS FOR TREATING PROPELLANT GAS

FIG. 9

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Process D depends on the combustion of the hydrogen followed by gas-liquid separation. The solubility of the fission products in the aqueous may preclude the use of this process.

The previously mentioned processes are to illustrate means in which the gas could be treated since further data are required before a complete process evaluation could be undertaken. Laboratory experiments may be necessary for supplying these data.

IV. TREATMENT OF WASTES

Once the surrounding area and shaft are decontaminated, the fission products must be stored or treated in a manner minimizing future dangers. This can be divided into two parts, namely, (1) preliminary treatment or storage and (2) ultimate storage. The first will be done at or near the launching site, whereas ultimate storage could be either at the site or at some distant radioactive waste disposal drea. Pretreatment includes methods of concentrating the fission products to provide more efficient ultimate storage. This treatment includes processes such as precipitation, scavenging, ion exchange, and calcination. Ultimate storage includes storage as a solid or liquid on tank farms, in deep wells, in salt domes, etc.

The type of decontamination procedure will determine to some extent the utility of a waste treatment method. For example, if the shaft is cleaned using sand-blasting, the best procedure might be to let the sand and the fission products fall into the

covolume and then cover them with concrete and steel. Another covolume at a slightly higher level could then be constructed to allow a subsequent launching. In any case, the study of waste treatment should follow the selection of the decontamination methods.

CLOSURE DEVICE

The closure device or mechanism is an important feature of the GASP system. A properly designed closure system will practically eliminate the escape of fission products without adverse effects on the propulsion of the missile. This section suggests several approaches, for consideration, as methods effecting closure. The mechanics of closure can be broken down into three principal parts, namely (1) actuation of closure device, (2) slowing down of the gas and/or sabot, and (3) closure. The following sections consider each part separately.

ACTUATION OF CLOSURE DEVICE

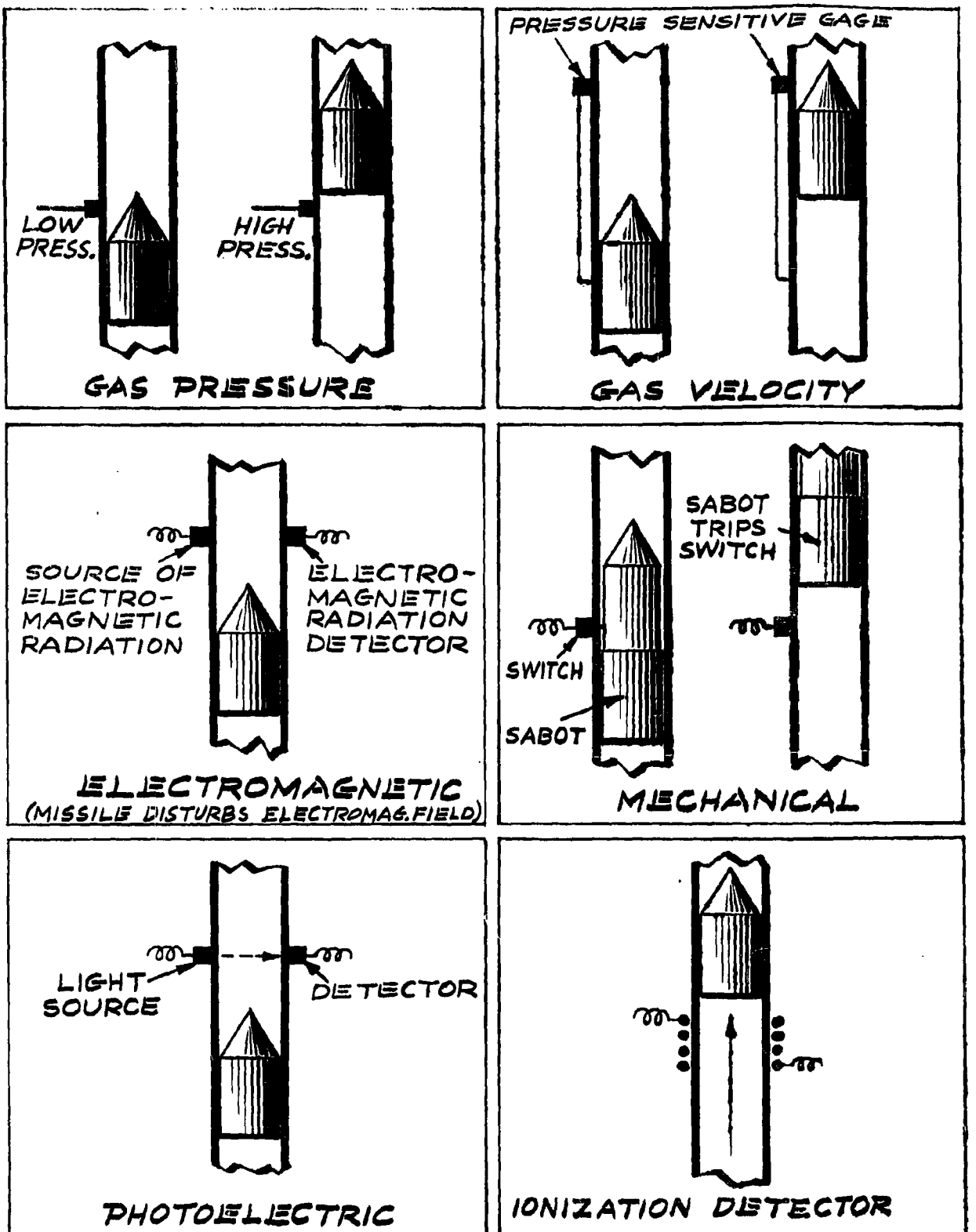
The rapidity of closure requires an exact timing of a sequence of operations to ensure a minimum release of gas and yet not interfer with the motion of the projectile. There are several approaches to actuating the closure device. One method consists of a standard electrical or mechanical timer which is started by the electrical circuit for setting off the nuclear detonation. This requires an exact prediction of the time required by the

projectile to reach the top of the shaft. It is extremely doubtful that this prediction would be sufficiently accurate. Improved accuracy may be achieved by defining time zero as the time when the missile passes a particular point near the top of the shaft. This would eliminate the uncertainties in predicting the moment of initiation of motion by the missile and the initial acceleration. Ideally, the actuation device should be near the top of the shaft and be actuated as a result of the passage of the projectile. Such a device can be based on one or more of the properties of the system. Some possible ideas are presented for consideration, (se Figure 10).

1) *Direct Pressure Measurement - The shaft pressure is atmospheric or less prior to passage of the projectile, but increases rapidly as the missile ascends. A blow-out disc or a pressure-sensing element would indicate when the missile passes a particular point and start the closure.*

2) *Bernoulli Effect - The velocity of the gas flow may also be used. The gas passing by a vane or port in the side of the shaft will decrease the pressure in the port. A differential pressure sensing gage may be used to indicate this and initiate action.*

3) *Temperature - The wall temperature increases rapidly with the passage of the missile. This can be used to determine when the missile passes a particular spot.*



PRINCIPLES OF ACTUATION DEVICES

FIG. 10

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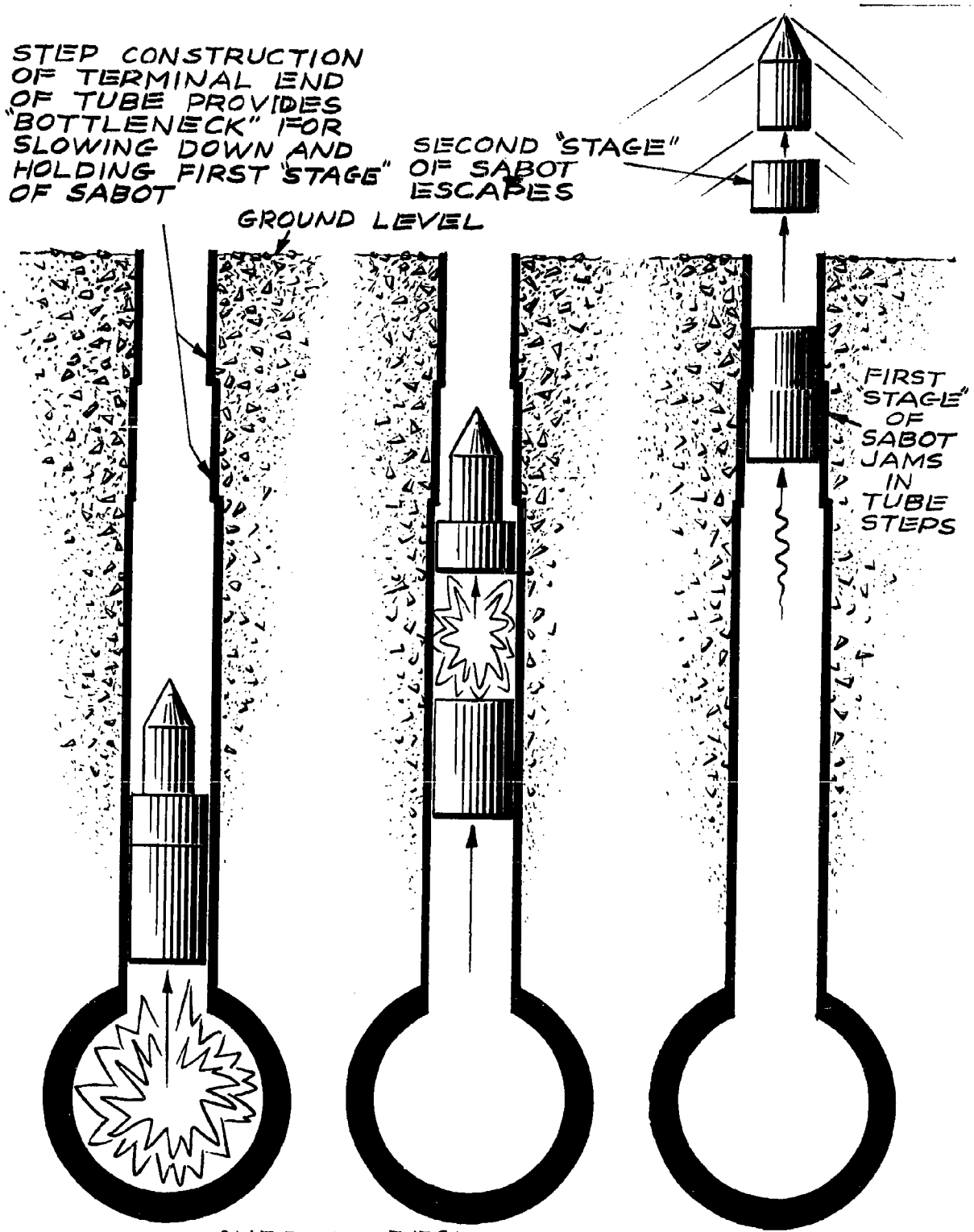
4) *Mechanical - The ramming of the sabot or the physical tripping of a switch could start the operation.*

5) *Others - These include systems based on electromagnetic radiation, electrical and optical properties. In these methods, the missile causes an unbalance of some sort in the actuation system.*

SLOWING DOWN OF SABOT AND GAS

If the system utilizes a sabot, there is the choice of permitting the sabot to exit from the shaft or using the sabot as a plug to help contain the gas. The latter, although more difficult engineering-wise, is more desirable from the standpoint of fission product containment. The bulk of the gas is behind the sabot and if it could be slowed down and stopped, this would give more time for final closure of the shaft.

One approach to slowing down the sabot is to constrict the shaft at the top. Naturally, the diameter of the sabot would be larger than that of the missile. A modification of this system is shown in Figure 11. Here the sabot consists of two parts. When the missile is near the top of the shaft a charge, carried by the sabot, detonates. The explosion separates the two stages of the sabot and helps to slow down the first stage. In principle, this is very simple, but the weight of the explosive materials is a problem. For example, if the mass of the sabot is about equal



CHARGE DECELERATION OF SABOT

FIG. 11

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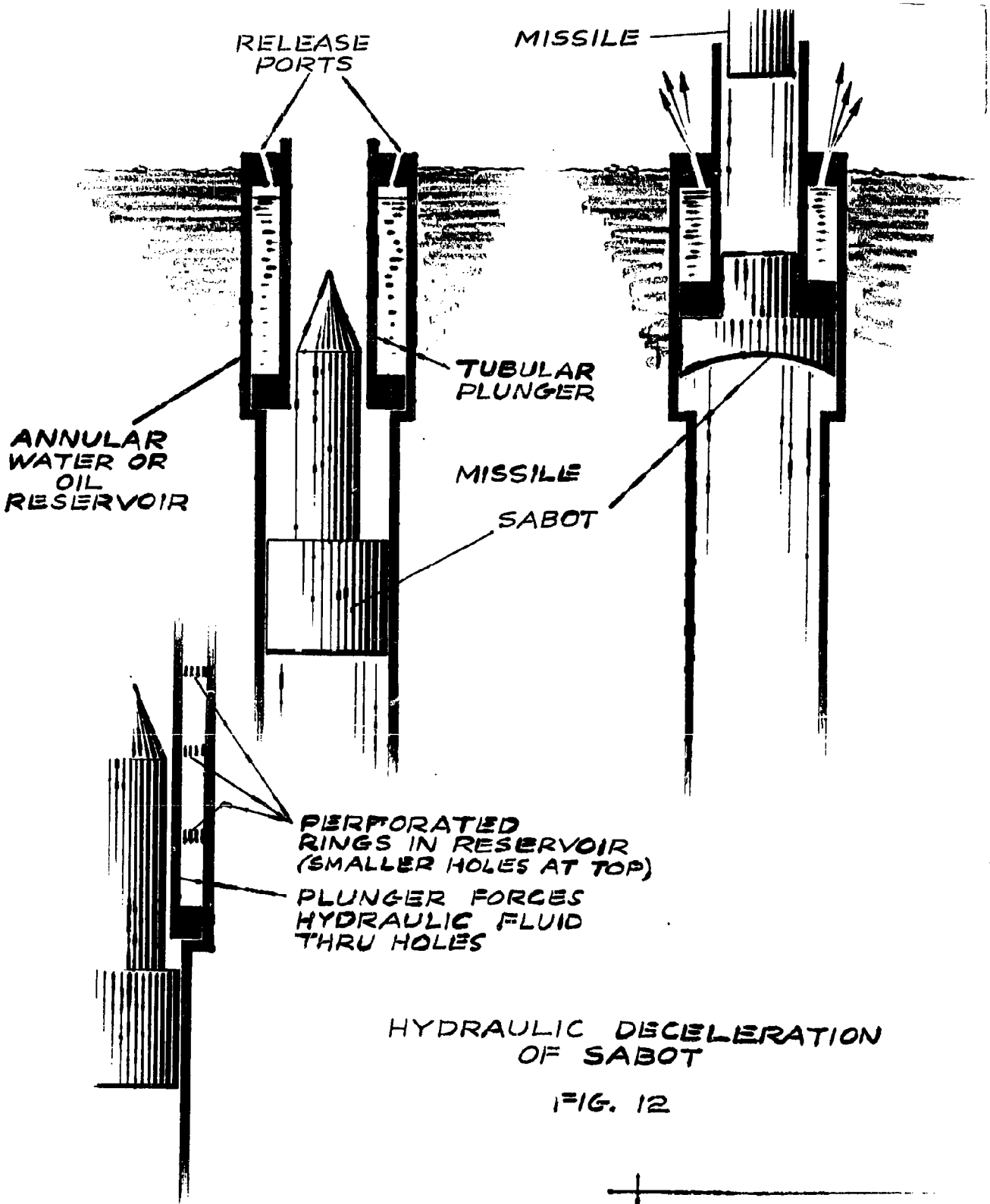
to that of the pay load, then the kinetic energy of a ten-ton sabot traveling at 40,000 feet per second is:

$$K.E. = 1/2 \frac{m}{g} v^2 = 1/2 \frac{20,000}{32} X (40,000)^2 \qquad (45)$$

$$K.E. = 5 X 10^{11} \text{ ft-lbs.}$$

This does not include the kinetic energy of the missile or the propelling gas. A ton of TNT is equivalent to approximately 2.8 X 10^9 ft-lbs of energy. Thus, the kinetic energy of the sabot corresponds to approximately 180 tons of TNT. This assumes that all the TNT's energy is used to slow down the sabot. The weight penalty may out-weight the benefits of the system. Also, there is a problem of finding an explosive that will not be exploded by the initial nuclear detonation blast wave, etc.

A "hydraulic plunger" (Figure 12) is a second method. In this system, the sabot has a larger diameter than the missile. When they arrive at the plunger, the missile passes through and the sabot is trapped at the entrance to the plunger. The kinetic energy of the sabot is used to force the liquid through a series of ports or small channels. One modification of this is shown in the insert in Figure 12. Before the sabot hits, the top of the fluid is just even with the bottom retarder. When the sabot reaches the plunger, the fluid is forced through the holes giving a retarding force. The size of the holes will determine the magnitude of the force and would be designed to absorb the initial



HYDRAULIC DECELERATION OF SABOT

FIG. 12

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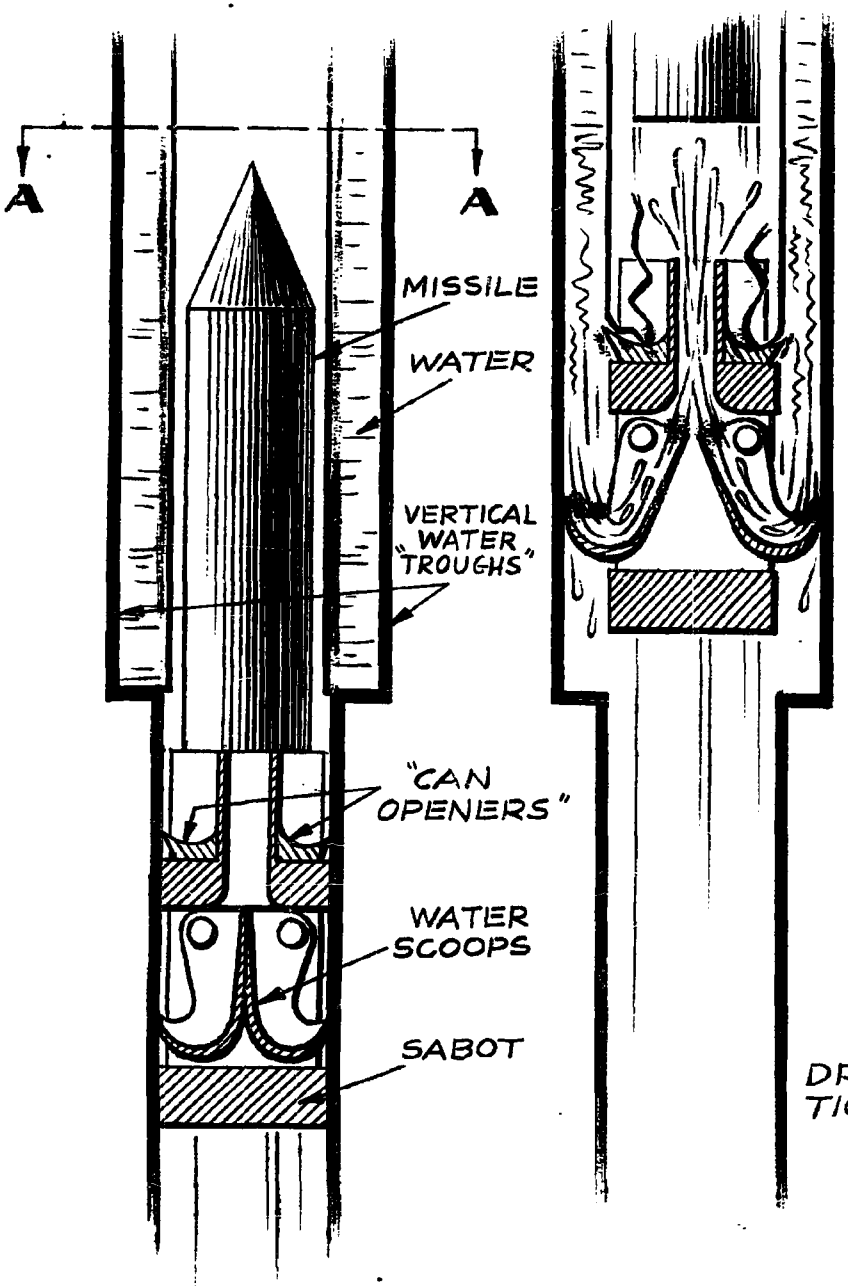
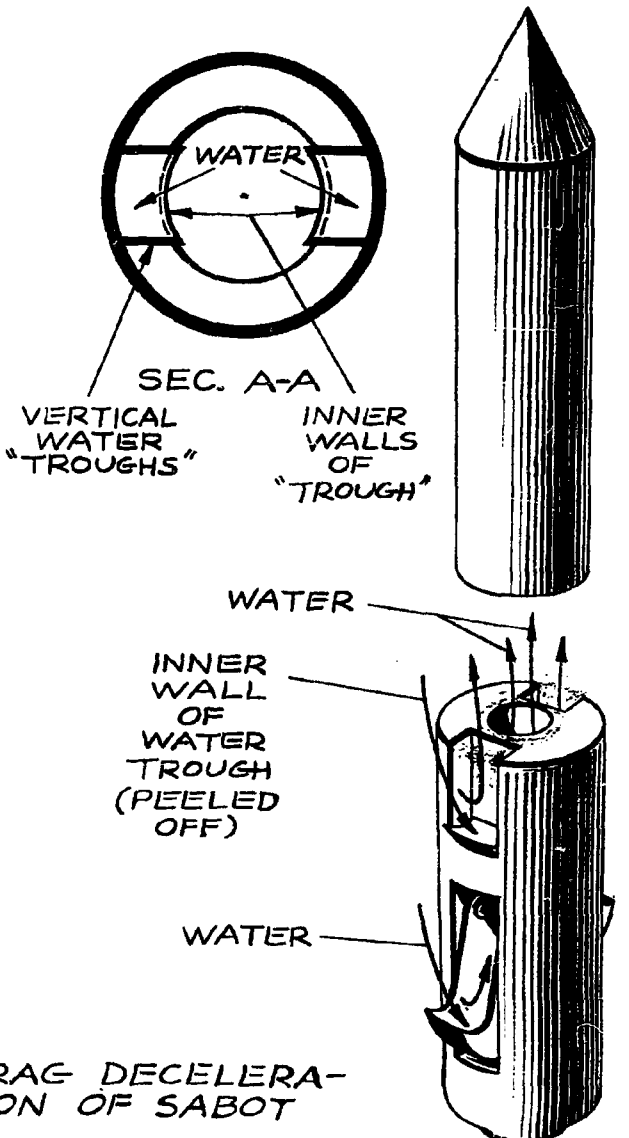
shock to effectively slow down the sabot. This will increase the available time for effecting closure of the shaft. The pressure increase in the liquid or the release of the fluid through a port could be used to actuate the closure mechanism.

Another system utilizes a fluid (water or oil) surrounding the shaft behind an expendable barrier. (See Figure 13) The sabot has "can openers" at the top and scoops near the bottom. When the saobt enters this section of the shaft, the openers destroy the barrier thus allowing the scoops to contact the fluid slowing down the sabot while transferring the kinetic energy to the fluid. The scoops function exactly as the "air brakes" used in the Air Force's Test Sled. The purpose of Figure 13 is merely to portray the principle of utilizing a "drag force" system for slowing down a sabot. It is obvious that the stresses encountered shall be enormous. This presents a serious problem.

If the system does not have a sabot, then the problem is to slow down and contain the gas. Sequential throttling (2) is one method. Each stage effects partial closure, thereby reducing the load to the following stage. A large expansion chamber near the top of the shaft also has advantages. Here a series of louvers open up after passage of the missile to divert part of the gas stream. The expansion of the gas in the chamber reduces the temperature and pressure and, thereby, reducing some of the closure problems. The injection of a stream or shower of water





DRAG DECELERATION OF SABOT

FIG. 13

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into the system may have the additional advantage of diluting the concentration of fission product in the gas.

CLOSURE OR SEALING

The final step of the closure procedure is to seal the shaft. Sliding wedges, flaps or modifications of these are means of effecting closure. The prime requisite is speed since the closure must be made in times in the order of 0.01 second unless some additional times is obtained by slowing down of the gases. The use of an explosive is one way of ensuring rapid closures. The explosion causes a build-up of gas pressure and forces the wedges or flaps into place. The detonation is keyed to one of the actuation systems described previously. Figure 14 illustrates a system utilizing the propellant gas. The sabot plugs up the shaft and at least temporarily holds back the bulk of the gas. Some of the gas flows through channels located below the sabot and forces shut a system of sliding wedges or flaps to effect closure. After sealing, the gas should be contained for a period of time to permit the decay of the short-lived fission products. The temperature and pressure of the gas will decrease during this time, then the gas will be treated by one of the processes discussed in the section on decontamination.

EXPERIMENTAL PROGRAM

One of the objectives of the present program was to develop and outline an experimental program for studying various basic

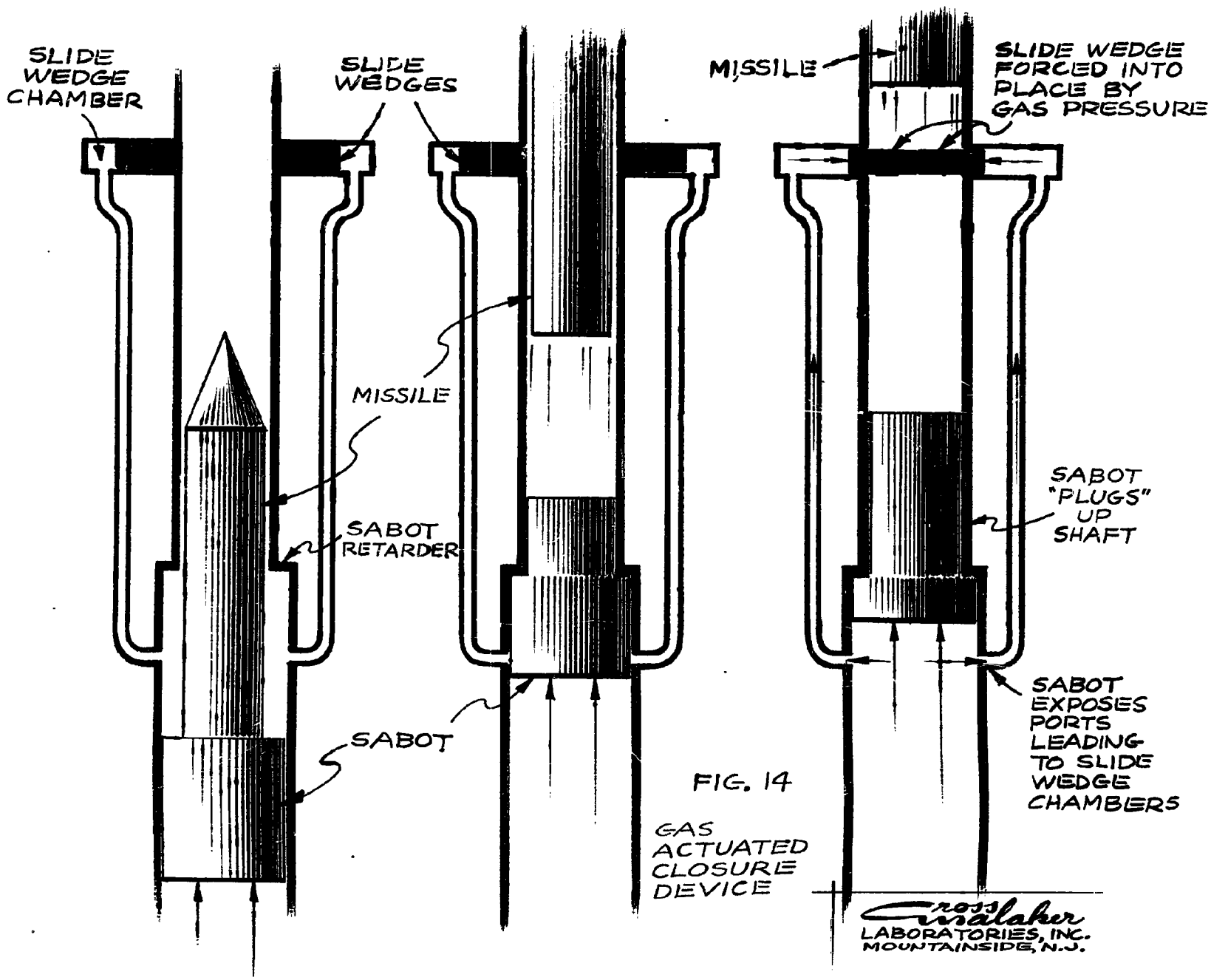

FIG. 14

GAS ACTUATED CLOSURE DEVICE

parameters of the GASP system. The ultimate "experiment" is a scaled down firing since this eliminates many of the test uncertainties. But before taking this step, laboratory test, if carefully planned and conducted, can be utilized for deriving qualitative relationships and a sounder basis for the design of a large scale test. The choice of the experimental approach is important if the results of the investigation are to be of value to the development of the GASP system.

A careful investigation of many experimental techniques indicate that the exploding wire phenomenon shows considerable promise as an experimental tool and as such, provides an excellent means of deriving invaluable data pertinent to the project. The basis for this recommendation is experimental evidence reported in recent literature on flow fields produced by exploding wires. It is interesting to note that the Committee on Cratering and Rupture (20) reported, "--developments of the exploding wire technique for the production of explosive pulses and controlled media, such as plaster of paris, should be utilized for the laboratory investigation of the cratering and rupture zone formation." This technique is applicable for studying such problem areas as contamination, covolume characteristics, shaft characteristics, shock waves and others.

A proposed program utilizing the exploding wire technique was developed and submitted under separate cover to the Project Officer.

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