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AFWL-TR-71-144

THE INFLUENCE OF SOIL AND ROCK PROPERTIES ON THE DIMENSIONS OF EXPLOSION-PRODUCED CRATERS

> Larry A. Dillon Maj USAF

The Texas A&M Research Foundation

TECHNICAL REPORT NO. AFWL-TR-71-144

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#### FOREWORD

This report was prepared by the Texas A&M Research Foundation, College Station, Texas, under Contract F29601-70-C-0032. This research was performed under Program Element 61102H, Project 5710, Task SA102, and was funded by the Defense Nuclear Agency (DNA).

Inclusive dates of research were February 1970 through October 1971. The report was submitted 27 December 1971 by the Air Force Weapons Laboratory Project Officer, Major Neal E. Lamping (DEV-G). The former project officer was Captain Peter M. Terlecky.

This project was supervised by Dr. Louis J. Thompson whose help and encouragement made it possible. Mr. Steve Clark provided invaluable research aid. Captain Paul Knott provided and modified the computer plotting program.

Appreciation is extended to Mr. Robert W. Henny, AFWL; Mr. Luke J. Vortman, Sandia Laboratories; Mr. Robert W. Terhune, Lawrence Radiation Laboratory; and to Lt Colonel Robert L. LaFranz and the many helpful people of the US Army Engineer Nuclear Cratering Group for providing data.

This technical report is the result of research performed at the Graduate College of Texas A&M University in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Civil Engineering for Major Larry A. Dillon.

This technical report has been reviewed and is approved.

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### ABSTRACT

#### (Distribution Limitation Statement B)

Analysis of data from published cratering experiments shows the effect of soil and rock properties on the apparent dimensions of explosion produced craters. More than 200 cratering tests and related material properties were cataloged. The data consisted of 10 nuclear events whose yields varied from 0.42 to 100 kilotons and about 200 high explosive events whose yields varied from 1 to 1 million pounds of TNT. The different test sites included materials for which the density ranged from 60 to 170 pounds/cubic foot.

By regression analysis, using bell shaped curves, prediction formulas were developed for the apparent crater radius, depth, and volume as a function of charge weight and depth of burst for eight different types of materials. The bell curves were normalized using material properties and prediction equations were generated using all the data. These general equations were then studied to determine the specific effects of the material properties on resultant apparent crater dimensions.

Material properties are highly important in determining the size of explosion-produced craters and some of the more important properties are unit weight, degree of saturation, shearing resistance and seismic velocity. Previous investigators have been somewhat negligent in measuring material properties for past cratering experiments and no real data analysis can be made until the variables are either controlled or measured. Material properties which should be measured for future tests should at least include the above properties and if possible the material's energy dissipation and bulking characteristics. Better yet a reasonably simple theory of cratering is needed which will better define the material properties governing cratering mechanics.

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#### NOTATION

The following symbols are used in this report:

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A<sub>i</sub> = coefficient of bell curve in coded form; B<sub>i</sub> = coefficient of bell curve; C<sub>i</sub> = general coefficient; D = crater depth;  $D_a$  = maximum depth of the apparent crater; Dob = depth of burst;  $E_v = vaporization energy;$ G<sub>s</sub> = grain bulk specific gravity; H<sub>al</sub> = apparent crater lip crest height;  $L_a$  = linear apparent crater dimension (radius, depth, or cube root of volume); M = general material property; R = crater radius;  $R_a$  = radius of apparent crater;  $R_m^2$  = multiple correlation coefficient S = degree of saturation; SGZ = surface ground zero; TNT = the high explosive, trinitrotluene; V = crater volume;  $V_a$  = volume of apparent crater; W = weight of explosive;

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### NOTATION (Continued

ZP = zero point-effective center of explosion energy;

c = seismic velocity;

exp = exponential (e);

g = acceleration due to gravity;

ln = natural logarithm;

m = the divisor portion of the scaling exponent, 1/m;

 $\tan \phi$  = tangent of the angle of shearing resistance;

x,y = rectangular Cartesian coordinates;

 $\gamma$  = total unit weight;

 $\gamma_d$  = dry unit weight;

 $\rho$  = mass unit weight.

### SECTION I

### INTRODUCTION

Over the past several years, because of intensified studies of possible engineering applications of nuclear energy, increased attention has been devoted to the problem of cratering by explosives. One of the most obvious peaceful applications of nuclear explosives is that of earth excavation, as might be considered for the construction of harbors, dams, or canals. Prediction and design for survival of silo-launched missile systems has also added urgency to these studies.

Although most investigators have recognized that the size of a crater obtained from an explosive charge depends upon the media in which it is detonated, properties describing the media which relate to the dimensions of this crater are somewhat obscure. The primary purpose of this investigation, then, was to determine which engineering properties normally measured for earth and rock materials could be related to the size of a crater created by an explosive charge.

A large number of cratering experiments have been conducted in various media (15,60,87). These experiments primarily

provided data on the effect of explosive energy and depth of burst on crater dimensions. Although the experiments number in the thousands and although engineering material properties were measured for a good percentage of these experiments, very little has been reported which relate these material properties to the final crater geometry. Previous investigators seem to have been of two minds: (1) Because material properties vary greatly within one media in one location and because accurate measurement of these properties is often difficult, the best approaches are to ignore completely the material properties or to over simplify and let the material be described by one constant in a particular prediction relationship; and (2) because the cratering process is so complicated, extensive measurement of material properties both in the field and in the lab are required to describe the media to be subjected to an explosive charge. It would appear that the better solution lies somewhere between these two extremes.

#### SECTION II

#### GENERAL CONCEPTS AND TERMINOLOGY

This section of the report presents basic concepts concerning the parameters and mechanisms involved in the explosive formulation of craters. The effect of explosive weight, depth of burst and type of material are discussed. Terminology generally associated with the cratering process is also presented.

General Description of the Cratering Process (63). When an explosion occurs at or near the surface of a soil or rock-like material, a crater is formed (see Fig. 1). The size of this crater depends on at least four factors: (1) The energy released by the explosion; (2) the position of the explosive relative to the surface; (3) the material type; and (4) gravitational effects. The influence of the energy release is obvious, the larger the charge, the larger the crater. When the charge is on or above the ground surface, cratering effects are small. As the charge is placed deeper in the ground, the size of the crater increases, both in radius and depth, until a maximum is reached after which the crater size will decrease with increasing depth of burial. For deeply buried explosives, an underground cavity is formed. The surface itself may be raised and may eventually subside to form a depression crater. For materials which bulk during the explosion process, there is a region where rubble mounds will be formed. Mounding and



subsidence depend upon the material and depth of burst. The larger the material's energy-dissipative properties, the smaller the crater size will be. The size of the apparent crater is affected by the amount of fall-back material, that is, the material originally ejected which returns under gravity to the crater zone.

<u>Crater Terminology (22,27)</u>. A few basic terms and definitions are presented to provide an acquaintance with significant zones, dimensions and terminology used throughout the report. Again referring to Fig. 1, the cross section of a typical crater and the adjacent zones of disturbance are shown.

The <u>apparent crater</u> is defined as that portion of the visible crater which is below the preshot ground surface. The apparent crater would be the net design excavation for most engineering applications.

The <u>true crater</u> is defined as the boundary (below preshot ground level) between loose, broken, disarranged fall-back materials and the underlying rupture zone material which has been crushed and fractured, but has not experienced significant displacement or disarrangement. The true crater boundary is not a distinct surface of discontinuity, but rather a zone of transition between the rupture zone and fall-back materials.

The <u>apparent lip</u> is composed of two parts, the true lip, which is formed by the upward displacement of the ground surface, and the ejecta material deposited on the true lip.

The <u>visible crater</u> comprises the apparent crater and the apparent lip.

The <u>fall-back</u> consists of natural materials which have experienced significant disarrangement and displacement and have come to rest within the true crater.

The <u>ejecta</u> consists of material thrown out above and beyond the true crater.

The <u>rupture zone</u> is that zone extending from the true crater boundary in which crushing and fracturing have occurred.

The <u>plastic</u> <u>zone</u> is that portion of the cratered medium beyond the rupture zone in which permanent deformation has occurred.

The <u>elastic zone</u> extends beyond the plastic zone and is characterized by the absence of blast produced fissures, cracks, or permanent displacement of material.

The <u>optimum depth of burst</u> is that depth for a specified explosive charge which produces the largest crater. For any one charge in any one medium, there may be three optimum depths of burst depending upon whether the largest radius, depth, or volume is desired.

A <u>scaled dimension</u> refers to a particular crater dimension divided by the explosive weight of the charge to some power (usually between 1/4 and 1/3). If the proper exponent is sele ted, scaling between different sized explosive charges for a particular scaled depth of burst is then possible.

Crater dimensional data used in this report along with accompanying symbols and definitions is given in Fig. 2. A detailed description of all pertinent single-charge crater dimensional data can be found in reference 22.

<u>Cratering Mechanisms (27,38,46)</u>. The primary mechanisms or processes which produce craters in rock or soil may be categorized as: (1) Vaporization and melting of the material immediately surrounding the source of a nuclear explosion; (2) crushing, compaction, fracturing, and plastic deformation of the medium closely surrounding the explosive gas cavity; (3) spalling of the surface; (4) acceleration of the fractured material overlying the explosion by trapped gases; and (5) subsidence and fall-back of the material as the explosive pressure goes to zero and the force of gravity predominates.

The tremendous pressures resulting from an explosive detonation (10-100 million atmospheres for a nuclear explosive) generate a shock wave which propagates as a high-pressure discontinuity. This high-pressure discontinuity, or shock front, transfers energy to the medium, and in turn, alters the physical characteristics of the medium. In the immediate vicinity of a nuclear explosion, vaporization and melting of the material occurs. The peak pressure in the shock wave diverges and energy is expended in doing work on the medium. When the pressure and shear stress levels exceed the dynamic crushing strength of the material, work on the medium is manifested in crushing,



R<sub>a</sub> - Radius of apparent crater measured at preshot ground surface

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- D<sub>a</sub> Maximum depth of apparent crater below preshot
  ground surface
- H<sub>al</sub> Apparent crater lip crest height above preshot ground surface
- V<sub>a</sub> Volume of apparent crater below preshot ground surface

Dob - Depth of burst (distance to ZP from SGZ)

ZP - Zero Point-effective center of explosion energy

FIG. 2. DIMENSIONAL DATA FOR SINGLE CHARGE CRATER

heating, displacement, and deformation of the material. When the compressive and shear waves which propagate from the detonation encounter the surface, a tensile wave and another shear wave are reflected, and since the tensile strengths of rock and soil are much less than their compressive strengths, spalling of the surface occurs. Rock also tends to spall along pre-existing fractures and planes of weakness. The first two processes may be classified as short term mechanisms since they last only a fraction of a second. Gas acceleration, on the other hand, is a comparatively long-period process which imparts motion to the material around the explosion by the adiabatic expansion of gases trapped in the cavity. Finally the force of gravity pulls all the overlying fractured and crushed material into the cavity and pulls all the loose material thrown into the air by spalling and gas acceleration back into and around the crater. What remains is an apparent crater underlayed with crushed and displaced material.

Effects of Depth of Burst. The part each of the above mechanisms play in producing a crater is very strongly dependent upon the scaled depth of burst of the explosion and the medium in which the detonation occurs. Shown in Fig. 3 are typical crater cross sections in rock showing the effect of depth of burst. As summarized by Nordyke (46), Fig. 4, the contribution of each of the mechanisms to apparent crater depth as a function of the charge depth of burst is shown.

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#### SECTION III

#### **REVIEW OF PREVIOUS CRATERING RESEARCH**

There have been thousands of cratering experiments and hundreds of technical reports, articles, and books written as a result of these experiments and associated phenomena. Over 300 of these publications were reviewed for this study. This section presents a brief review of cratering experience and analysis. A brief history of recent cratering research and symposiums relating to that research is presented followed by the various prediction techniques available and the information found on the effects of material properties.

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<u>Nuclear Cratering Experience (13,45)</u>. There have been 10 nuclear detonations at the Nevada Test Site involving four different geologic media in level terrain which resulted in the creation of craters (or a mound as in the case of Sulky) which are considered applicable to explosive excavation. These detonations are listed as the first 10 events in Appendix I. Yields for these events varied from 0.42 kiloton for Danny Boy to 100 kilotons for Sedan (one kiloton = 1,000 tons equivalent weight of TNT).

<u>High-Explosive Cratering Experience</u>. Good summaries of past research in this area can be found in references 46, 81 and 87. Lists for the majority of the experiments can be found in references 15, 60 and 87. In all, these experiments number

in the thousands and involve more than 20 different soil and rock materials. They range in yield from 1 gram to 1 million pounds of TNT and include the full range of depths of burst. Considering each material, the largest number of these experiments were performed in a lightly cemented sand-gravel mixture known as desert alluvium. The number of experiments applicable for this research was considerably less than the total number available. For instance, original plans had included the Dugway cratering series in limestone, granite, and sandstone (76). Later review, however, determined that the crater dimensions reported were not those for the apparent crater as had been indicated by Vortman (87), but were mucked dimensions; i.e., all loose rubble in the crater was removed before crater dimensions were measured. Crater dimensions for this series, therefore, lie somewhere between apparent and true crater definitions. It was also necessary to eliminate hundreds of experiments reported by Sager (60) because other than spherical charges were used and because very few of the experimentors had reported material properties. A good conclusion that can be made regarding the various experiments and their data plots is that the data are highly scattered because explosive experiments in natural materials are difficult to control. The high-explosive experiments used in this research are shown in Appendix I beginning with event 9.

Symposiums Related to Cratering. The Plowshare Program

(the peaceful uses of nuclear explosives) was formally established in 1957 (30). At about the same time, the first contained nuclear experiment, Ranier, was executed (31). Ranier was a 1.7-kiloton explosion 900 feet below the surface. Because of the success of the Ranier event, numerous speculations were made as to the uses of underground explosions. The general range of ideas was first reported publicly in 1958 at the Atoms for Peace Conference in Geneva. This later became the First Plowshare Symposium. In 1959, the Second Plowshare Symposium was held in San Francisco and initial presentations on the uses of nuclear explosives for excavation and extrapolation of chemical explosive data for possible nuclear explosive application were presented (54).

In 1961, a Geophysical Laboratory - Lawrence Radiation Cratering Symposium was held in Washington D.C. (44). This was really the first somewhat all inclusive up-to-date presentation relative to cratering data and phenomena. Scaling laws, empirical analysis, theoretical calculations, nuclear cratering to-date, and explosive craters in desert alluvium, tuff and basalt were some of the more pertinent subjects presented. Nordyke presented his preliminary theory for the mechanics of crater formation; this theory is still being followed today.

In 1964, the Third Plowshare Symposium with its theme "Engineering with Nuclear Explosives" was held at the University of California, Davis Campus (74). Over 30 presentations were

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made that offered an up-to-date picture for using nuclear explosives for engineering purposes. By this time additional nuclear cratering data, including the 100-kiloton Sedan event, were available. Knox and Terhune (32) presented results obtained from using SOC, the two-dimensional computer model of cratering physics during the gas acceleration phase. A good portion of the data presented at the conference was later used by Teller (70) to write the book <u>The Constructive Uses of</u> <u>Nuclear Weapons</u>.

In January 1970, the most recent symposium, Engineering with Nuclear Explosives, was held in Las Vegas, Nevada (55). Over 100 presentations were made of which 17 were directly related to excavation. Since a number of the presentations relate to this research, they are discussed in the next two subsections.

<u>Prediction Techniques and Scaling</u>. To date there are basically two approaches being used for predicting crater dimensions. The first involves computer calculations of the mound and cavity growth used in conjunction with a free-fall, throw out model which gives an estimate of the crater radius and ejecta boundary. The second basic approach uses empirical scaling relationships. Another approach, although not so widely used but which deserves mentioning, is a quasi-static approach which considers cratering as an earth pressure problem.

SOC (spherical symmetry, one dimensional) and TENSOR

(cylindrical symmetry, two dimensional) computer codes numerically describe the propagation of a stress wave of arbitrary amplitude through a medium (6,12,32,36,37,71). These codes are hydrodynamic Lagrangian finite-difference approximations of the equation of motion which describe the behavior of a medium subjected to a stress tensor in one (SOC) and two (TENSOR) space dimensions. The code calculations handle both the initial shock wave phase, which creates spall velocities and the gas acceleration phase. The end product of the TENSOR code calculations is a chronological history of the cavity and mound growth resulting from an underground explosive detonation. The code calculations runs until the particle velocities no longer increase significantly from cycle to cycle. At this point, a free-fall throw out model calculation is used to determine the mode of deposition of that material which has been given sufficient velocity to pass the original ground surface. The ballistic trajectory of any given mass determines its final position on the surface. The throw out model calculation permits one to estimate crater radius and the maximum range to which significant material is thrown by the detonation. An estimate of the crater depth may also be made by considering the stability of the cavity walls and the bulking characteristics of the material which falls back into the crater opening. Since these codes assume that the material behaves hydrodynamically not only in the melted region but in the consolidated and

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cracked regions of the media, extensive laboratory testing is required to develop pressure-volume relationships for the material involved. The big advantage to this method is that it provides a visual graphical representation of the mound and cavity growth and fall-back. The disadvantages are that it requires an enormous amount of computer time to accomplish the computation and it requires extensive material testing to obtain pressure-volume relationships, rigidity modulus, tensile strength and distortional energy limits. Failure in the material is assumed to occur either when the tensile strength is exceeded or when maximum distortional strain energy is reached.

The second crater geometry prediction approach involves the use of scaling laws which relate crater dimensions from some reference yield to crater dimensions for any energy yield. The preponderance of cratering research (8,10,11,15,46,61,77,88) has been concerned with or utilized this prediction approach. This procedure in its simplest form is based on an empirical determination of the scaling exponent, m, as a function of soil type, using the assumed relationships

$$R = C_1 W^{1/m}; D = C_2 W^{1/m}; V = C_3 W^{1/m} .... (1)$$

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where R, D and W are the radius, depth and volume, respectively, of the crater,  $C_i$  are constants related to the soil type and depth of burst and W is the energy release. If a dimensional

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analysis is made, it would appear that m should be 3 for radius and depth and 1 for the volume if the effects of gravity and material friction are omitted; however when gravity of the material is considered, m becomes 4 for radius and depth and 4/3 for volume. The results of cratering experiments to date. however, have led to the development of m = 3.4 for radius and depth and m = 3.4/3 for volume. Although this relationship is very simple, the only way  $C_i$  can be determined is by performing a series of cratering experiments for the material in question. There is considerable actual data scatter, however, compared with the smooth curve this technique produces. The constants,  $C_i$ , therefore, appear to be variables which depends on material properties. At best, then, these relationships provide only a very rough estimate of cratering dimensions since all material properties are ignored.

A third method for predicting crater dimensions considers cratering as an earth pressure problem (42,78,79,80,81). This method considers expansion of the explosive cavity to some ultimate radius and pressure, at which time equilibrium is assumed to exist, at least for a while. For the cratered medium, it is assumed that a part of it, adjacent to the cavity, behaves as a rigid plastic solid, defined by a Mohr's envelop for the material. At a sufficient distance from the explosive charge the medium is assumed to behave as a linearly deformable, isotropic solid defined by a deformation modulus and a Poisson's

ratio. This method appears very reasonable, however it has only been applied to very small scale laboratory experiments. In addition, it does not consider surface spallation and does not seem to apply for surface bursts.

<u>Material Property Effects</u>. Although numerous observations and studies of cratering for both conventional and nuclear explosives have led to a fair understanding of the basic processes and phenomena involved, the physical characteristics of the cratering medium which significantly influence crater sizes and shapes were found to be largely unknown.

Whitman (89) postulated that crater dimensions were primarily related to soil type through the soil's shearing resistance. His study developed trends between cra+er size and soil strength for the weaker soils, but trends for the stronger soils and rocks were quite obscure.

Based on limited data, Baker (1) was able to relate material seismic velocity, angle of shearing resistance for sands, tensile strength for rocks, and relative consistency of clay to a radius modulus developed by Saxe (62) to relate a scaled normalized radius and the scaled depth of burial.

Chabai (11) made a dimensional analysis of scaling dimensions of craters and considered the following medium properties as being sufficient to describe the phenomena of cratering: density of undisturbed medium, yield strength of the medium, a viscosity or dissipation variable of the medium

and the sonic velocity in the medium.

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Westine (88) considered dimensional analysis and developed the following relationship:

$$R_a/Dob = f[W^{7/24}/(\rho^{7/24} g^{1/8} c^{1/3} Dob)] \dots (2)$$
  
in which  $\rho$  = mass unit weight, g = acceleration due to gravity  
and c = seismic velocity. Westine's plots of the data from  
five different materials show some reduction of the data  
scatter using his technique. The disadvantage in using this  
approach is that it implicitly assumes that an increase in unit  
weight and seismic velocity will result in a smaller crater  
Gimension.

Terhune (71) listed the following material parameters in the order of their importance for determining the cratering efficiency of the medium: (!) <u>Water content</u>; (2) shear strength; (3) porosity (compactibility); and (4) compressibility. He stressed the point that an increase in water content decreases the compressibility, drastically reduces the shear strength and provides an additional energy source in the form of a noncondensable gas.

#### SECTION IV

#### PURPOSE, SCOPE, AND PROCEDURE

The purpose of this research was to evaluate the data from published cratering experiments in an effort to show the effect of soil and rock properties on crater dimensions in conjunction with the burial depth and energy of the explosive charge. A secondary purpose was to show that no real analysis can ever be made of cratering data until controlled experiments are conducted or unless soil and rock property measurements are carefully made throughout the material field.

Of the thousands of cratering experiments that have been conducted, only a little more than 200 tests were selected for analysis. The remaining tests did not meet the general criteria established for this study. From the tests selected, those where the charge was detonated above the surface or the depth of burial was so great that a mound or slight depression developed, instead of a crater, were not used in the analysis.

The procedure used to accomplish the research was statistical analysis of data from existing cratering experiments. This involved the following: cataloging all crater and related material property data; selecting a proper regression model to develop empirical equations for apparent crater radius, depth and volume in terms of explosive weight and depth of burst for specific materials; integration of the various material properties

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into the model to develop the best equations for all the materials combined; and analyzing the best equations to determine the specific effect of the material properties used. An inherent part of the procedure was the development and use of computer programs.
## SECTION V

### EXPERIMENTAL DATA

This section presents the method and approach used to acquire and catalog the experimental crater and associated material property data necessary for this study. The cataloged listing is referred to and discussed in some detail. Sorting of the data to allow for better comparison and analysis is briefly described.

<u>Data Acquisition</u>. Using the Corps of Engineers' "Compendium of Crater Data" (60), Vortman's "Ten Years of High Explosive Cratering Research at Sandia Laboratory" (8/), and Circeo's "Nuclear Excavation: Review and Analysis" (13), as guides to previously conducted experiments, the original source documents were obtained and reviewed. This involved making visits to Sandia Laboratory and Air Force Weapons Lab, Albuquerque, N.M. and to Lawrence Radiation Laboratory and U. S. Army Engineer Nuclear Cratering Group, Livermore, California.

A review of the literature showed that there was a wide variation in the experiments as well as a wide variation in the parameters measured. The following criteria was established to determine if a particular cratering experiment was to be cataloged and used in this analysis:

 The explosive charge had to be single and spherical with a TNT equivalent weight of at least 1 pound.

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- The dimensions measured had to be for the apparent crater.
- 3. The experimental terrain had to be reasonably level.
- Sufficient material properties had to be measured or it had to be possible to estimate them with some degree of confidence from other recorded data.

Although crater dimensions were obtained for the various experiments with relative ease, soil and rock properties presented a very perplexing problem. For a number of the nuclear events, extensive soil borings and tests were reported. In other cases, only one soil test pit and limited testing was reported for a complete series of experiments. Somewhat arbitrarily, but keeping in mind the cratering phenomenology involved, those material properties which were thought to effect crater geometry were selected to be cataloged.

Data Cataloging. By considering all the data required to properly catalog each cratering event, formats and programs for computer input and output were developed. Every effort was made to keep the data for a particular cratering event to a minimum but yet make the data as complete as possible. For example, cataloging only the grain specific gravity, dry unit weight and moisture content of the media for a particular event allowed for computer calculation of various parameters such as total unit weight, degree of saturation, porosity, percent air, void ratio, etc. Data input to the computer was made to

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serve a dual purpose. It was used to produce the cataloged listing of crater data and as a basic data source for the analysis.

The listing of all data cataloged for this research is included in Appendix I. This appendix is divided into the following four segments:

- A list of all notation and definitions associated with the cataloged data.
- 2. The computer output crater data list.

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- The two line computer listing of all the cataloged material property data associated with the crater data list.
- The notes referred to in both the crater data and material property data listings.

It was initially thought that there existed many more measurements of cratering event material property data. In the final analysis, sufficient data was just not available to obtain measured values for each and every event or in most cases even for a series of events. Estimated values dominate the material property data section of the cataloged data. To differentiate, estimated values are indicated by a dollar sign in the data listing.

Viewing the crater data list, it can be seen that the approximate energy of the nuclear explosive cratering events was only estimated within 20 percent. This was due, apparently,

to the unsureness of the amount of nuclear material which actually participated in the reaction. As discussed by Vortman (87) for most high explosive events, cast spherical charges of TNT detonated at their centers were used for yields of 1000 pounds or less. For charges larger than 1000 pounds, cast blocks of TNT were stacked to approximate a sphere. For certain experiments liquid nitromethane was used. The liquid was placed in a spun aluminum sphere or in a mined cavity lined with an impervious material. For a number of the very small explosive tests, Military C-4 explosive was used. Equivalent weight of TNT factors for these latter explosives was based on the heat of detonation as reflected in Cook (14). There is, however, some question as to whether these equivalency factors are completely valid. There seems to be an optimum rate of burning for an explosive for a particular depth of burst in a particular material which will produce the largest crater. It is felt, however, that the equivalent weight of TNT shown in the crater data list for all events except the nuclear tests is within five percent.

Depending on the method used by the original investigators to measure crater dimensions, these dimensions are considered accurate only to within five percent. Again as discussed by Vortman (87), crater measurements have been determined using various techniques. These techniques have consisted of almost everything imaginable from conventional ground surveys to the

use of adjustable rods to aerial mapping. Lip heights and slope angles shown in the listing (although not specifically used in this research) were not reported by many of the investigators. Values reported, in many cases, reflect values measured from typical cross sections.

Material property values reported in the material property data list reflect those which were either reported by the investigator as an average for the experiment or series of experiments, or where possible, taken from boring logs and associated tests. In the latter case, a weighted average for a particular material property was computed for the vertical column in question. These weighted averages for the various borings were then interpolated or extrapolated to obtain the values reported for the explosive event location. Although the material property data list contains predominately estimated values, the majority of these estimated values were extrapolated from experiments in like or similar materials. It would have been advantageous to have been able to obtain specific measured values for each event. Where measured, material property values are considered accurate only to within 10 percent. Where values are estimated, it is believed that they are within 20 percent.

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<u>Data Sorting</u>. To allow for better comparison and analysis of the data cataloged, a computer subroutine was written and used. This subroutine provided for sorting on any three

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specified parameters at one time. The sorting scheme that was found to be most useful aligned the data by type of material, then by scaled depth of burst and lastly by explosive weight.

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## SECTION VI

#### EMPIRICAL DATA ANALYSIS

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This section describes the regression analysis technique used to develop a functional relationship between crater dimensions and explosive charge weight and depth of burst for a given soil or rock type. It also discusses the function constants obtained, presents plots of the actual data and presents the resultant regression curves to predict crater dimensions for nine groupings of the data.

<u>Regression Analysis (16,39)</u>. The data for this research were analyzed and the prediction formulas for crater dimensions were developed using applied regression analysis. First, the dependent variable (the variable for which prediction was desired) was selected and the independent variables (the parameters thought to have some influence on the dependent variable) were assumed. Next a form of the answer (the model) was assumed and the data applied to the model to obtain its coefficients. This was accomplished through the method of least squares surface fitting, whereby the sum of squares of the distances between the assumed surface and the actual data points was minimized. If the sum of squares is a minimum and the coefficients of the assumed model are determined, then this is the best fitting surface for the model and data used. Lastly through computation of a multiple correlation coefficient and

by an examination of the least squares residuals the prediction formula was evaluated.

Regression analysis has become a fairly common tool for analyzing experimental data and developing function relationships for that data. For this reason, it seems sufficient to mention only that an enormous amount of mathematical computation, including the solution of a large number of simultaneous equations, is required. Only through the use of a high-speed computer is this possible.

The computer program used was specifically written for this research. Although library regression analysis programs were available, it was felt that these programs were too elaborate and did not provide the flexibility needed for this research. The computer program written was intended to be a very flexible, minimum essential program that would adequately accomplish the data cataloging and sorting, the least squares surface fit and the evaluation of the fit. The multiple linear regression portions of the program were written using statistics books as guides (16,24). The matrix inversion, multiplication and print subroutines were available from previous research (75) and were modified for use here. As the research progressed, numerous changes, additions and deletions were made based on the scheme, procedure or purpose being tried at the moment. The program was originally written for the IBM 360/65 computer, but was later revised for use on the CDC 6600. Appendix II

contains a brief description of the program and its essential features along with a typical print-out of the essential portions of the program and its output after being run on the CDC 6600.

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Regression Approaches Considered and Tried. The number of regression approaches considered and tried was so numerous, it is superfluous to list them all. At the beginning, regressions of radius, depth, or volume as a linear function of depth of burst, explosive weight and various material properties were attempted. A second approach considered a linear crater dimension to be a function of various dimensionless parameters taken from Chabai's work (11). An attempt was also made to consider all material parameters which would reflect the amount of energy being dissipated during the cratering process. A closely related approach was to consider those material properties which would relate to the mechanisms of compaction, subsidence, spall and gas acceleration as proposed by Nordyke (46). In all of the above cases, sufficient material properties were not available to include all applicable terms thought to be important. An attempt was made to use available and applicable material parameters in a linear fit, but to no avail. When one considered a second order regression model, the number of parameters to be used suddenly becomes excessive for the data available and for the basic research purpose.

Of special note was the attempt to use Westine's technique

(88). Regression using this approach produced a high multiple correlation ratio. However, the residuals between the estimated and actual values of the dependent variables were found to be excessive. This was particularly true for the range of data where  $R_a/Dob$  was less than 2.

Regression Model Used. After much deliberation and due consideration of the literature reviewed, it was felt that the better approach for the solution of crater dimensions for one particular media was to consider a scaled linear crater dimension as a function of the scaled depth of burst. Although there seemed to be some question as to the proper scaling to use, the scaling exponent which appeared to most recently be used and justified was 7/24. This figure is the average of conventional cube root scaling (gravity effects excluded) and fourth root scaling (gravity effects included). The scaling exponent eventually used was 5/16 and resulted from a special study of the data cataloged for this research. The next question which arose was what model should be used for regression? After studying plots of the scaled data and after considering what happens to crater size as the depth of burst (or height of burst) is varied from one extreme to the other it became obvious that a curve reflecting the final dimension of a crater when plotted as a function of depth of burst (and height of burst) should be asymptotic at both extremes and reach its maximum value at the optimum depth of burst. This suggested the bell shaped curve

with its inherent advantages and disadvantages which will be discussed later. Using this approach, the regression suddenly improved for any one particular cratering media.

The general form of a bell curve is as follows:

$$y = B_1 \exp [B_2 (x+B_3)^2] \dots \dots \dots \dots (3)$$

That of the skewed bell curve used took the following form:

 $y = B_1 \exp [B_2 (x+B_3)(x+B_4)^2] \dots (4)$ 

in which x = the scaled depth of burst (Dob/W<sup>5/16</sup>) and where y =the scaled linear apparent crater dimension being considered: (1) Radius  $(R_a/W^{5/16})$ ; (2) depth  $(D_a/W^{5/16})$ ; or (3) cube root of volume  $(V_a^{1/3}/W^{5/16})$ . A big advantage to these curves is that  $B_1$  is the maximum height of the curve and it occurs along the abscissa at  $\mathsf{-B}_3$  for the standard curve and at  $\mathsf{-B}_4$  for the skewed form. In other words if y is equal to the scaled radius for the first case, then the maximum scaled radius is  $B_1$ , and it occurs at an optimum scaled depth of burst of  $-B_3$ .  $B_2$  sets the rate of change of the slope away from the  $(B_3, B_1)$  point. The (x+B<sub>3</sub>) term in the second case allows for skewing the standard bell curve. As can be seen, this introduces a second root to the equation. In the majority of surface fitting cases, this posed no problem since the second root and associated slope change were outside the range of the data. Whore the data was minimal and somewhat scattered, using the skewed bell curve proved infeasible.

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Since the above curves are not applicable to multiple linear regression, they were used in the rollowing coded forms. For the standard bell curve:

 $\ln y = A_{1} + A_{2}x + A_{3}x^{2} \dots \dots (5)$ where  $A_{1} = \ln B_{1} + B_{2}B_{3}^{2}$ ,  $A_{2} = 2B_{2}B_{3}$  and  $A_{3} = B_{2}$ ; or conversely:  $B_{1} = \exp (A_{1} - A_{2}^{2}/4A_{3})$ ,  $B_{2} = A_{3}$  and  $B_{3} = A_{2}/2A_{3}$ . For the skewed bell curve:

 $\ln y = A_{1} + A_{2} + A_{3} + A_{3} + A_{4} + A_{4} + A_{3} + A_{4} + A_{4}$ 

As can be seen for this later case, two sets of values for the constants  $B_4$ ,  $B_3$  and  $B_1$  are obtained. Examination of the numerical values obtained for a particular curve fit, however, quickly show the correct set to be used.

Determination of Best Scaling Exponent. For all the initial surface fits made, 1/4, 7/24 and 1/3 were used as the scaling exporents. For every set of data except one, 7/24 was found to produce the best fit of the data. Where the data consisted of a large amount of surface bursts, 1/3 was found to produce the best fit. This suggested using a variable exponent as a function of depth of burst. Numerous computer runs were made attempting to use an exponent which was a

function of depth of burst or an initial scaled depth of burst. Although a better fit was obtained for surface burst data, the over-all fit was never as good as that obtained from just using 7/24. Vortman (84) showed that the scaling exponent for surface bursts could vary from low of 0.23 for depth to 0.44 for radius depending on the material in question.

A special computer run was made to vary the scaling exponent from a value of 0.29 to 0.35. It was found that a scaling exponent of 0.31 produced the best fits for radius and cube root of volume while 0.32 produced the best fit for depth (there was very little difference, however, between the fits obtained from using 0.31 and 0.32). It was decided to use 5/16 (or 0.3125) as the scaling exponent for the remainder of the research. This figure represents the average of the 7/24 and 1/3 figures which have been used so predominately by other investigators.

Equations and Daca Plots for Specific Materials. Using equations (3) and (4) as the regression models (the standard bell curve and the skewed bell curve), the coefficients (B values) were generated to obtain the best fit of the data to empirically predict the scaled depth, radius or cube root of volume. This was accomplished for each of eight groups of material (or experiment) data and in addition for all the data combined. Linear dimensions used in these equations were in feet while W was in pounds of TNT. Listed in Table 1 are the B values

TABLE 1. EQUATION COEFFICIENTS FOR VARIOUS MATERIALS

of Data Predicted Within ±10% 12.5 60.09 93.8 52.6 47.4 25.0 25.0 60.0 28.0 59.4 57.9 45.0 78.1 0.06 85.0 ઝર Multiple Correlation Coefficient 101.4 95.8 0.66 98.8 99.3 97.6 97.5 101.2 97.2 95.7 95.1 99.4 97.4 97.5 95.2 Curve Coefficients -1.538 -1.622 -1.576 -1.352 -1.260 -1.213 -1.581 B4 -2.898 -2.783 3.222 -1.270 -2.348 -7.315 -1.266 -1.774 -2.737 -1.820 -10.605 -1.186 -1.290 1.151 -2.144 в В Associated Bell 0.030 5.715 0.092 4.229 -0.438 -0.495 -0.217 -0.789 -0.050 -0,062 5.942 -0.720 0.181 -0.564-0.053 <sup>B</sup>2 2.098 2.475 1.710 2.020 1.482 2.817 1.234 2.456 1.809 1.955 1.023 1.143 3.500 2.447 2.271 ъ Crater [ Dimension ( V\_a 1 V 1/3 ا ۷ ا 1/3 , v 1/3 ° م ഫ്ഷ പപ്പ Da Da a D a ഷ്മ Alluvium (Zulu Series) Clay Shaje Desert Alluvium Materiaï Basalt Sand

TABLE 1. EQUATION COEFFICIENTS FOR VARIOUS MATERIALS (Continued)

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		Associat	ed Bell (	urve Coef	ficients	Multiple	e .f Dot' Dundinted
Material	Crater Dimension	8,	B <sub>2</sub>	83 83	8 4	Coefficient Coefficient	<pre>% 01 Data rreutted Within ±10%</pre>
	R,	2.248	-0.802	-1.040		82.6	22.2
Various	ాద్	0.857	-0.748	-1.114		88.2	33.3
Rocks	رتا/3 م	1.772	-0.771	-1.052		89.7	22.2
	Ŗ	1.907	-0.272	-1.474		98.2	70.8
Playa (dir Vent	۳ ۵	0.829	-0.726	-0.879		99.3	66.7
Series)	رتار3 الم	1.489	-0.442	-1.090		98.5	66.7
	2	1.978	-0.710	-1.151		98.0	59.1
Playa (Tohonoan	م م	1.033	-1.608	-0.816		1.99.I	45.4
Series)	ب <sup>1/3</sup>	1.689	-0.925	-1.009		98.7	63.6
	R	2.136	-0.201	-1.817		87.8	37.5
All Data	ిద్	1.057	0.109	-6.325	-1.173	84 .6	22.3
Combined	ر1/3 ه	1.837	0.058	-6.618	-1.403	85.1	32.1

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obtained. The number of B values listed for a particular crater dimension for a particular material reflects which equation produced the best fit. Actual plots of the data used and the resultant empirical curves obtained are included as Appendix III.

A study of these data plots reveals several interesting facts. The smallest craters were produced in playa, the lighter weight, weaker material; next came the rocks, alluvium and sand; and lastly the largest craters were produced in the clay shale. The exact order for the different materials changes somewhat depending upon which crater dimension is being considered. A second important fact that can be noted is that in almost every case, nuclear events produced smaller scaled craters than their high-explosive counterparts in the same material. If attention is brought to bear on the surface burst data for the Air Vent Series, which also included the two 20 ton Flat Top events, it becomes obvious that a larger scaling factor would reduce the data scatter considerably. When this fact is considered along with a close look at other surface burst data, it would appear that surface and near surface bursts should be studied separately and should possibly have been eliminated from the data used in this research.

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<u>Discussion of Approach Used</u>. Since a good portion of the time spent on this research was in regression analysis, it seems appropriate to discuss this process and its applicability to

research of this type. In general, it is sufficient to say that multiple regression analysis for such a complicated problem as was encountered here is more of an art than a scientific approach. For regression analysis to be of real benefit, experience with its application and at least some knowledge of how the dependent variable behaves as a function of the various independent variables is highly desired. Otherwise, it becomes the problem instead of a tool to help solve the real problem. Statistics books, in general, tend to oversimplify the process (rightfully so if they are to teach the principles involved) but the real world just does not seem to be composed of only one or two independent variables. If a general series is assumed as the regression model, a very few variables, applied to say a fourth order fit, produces an excessive number of terms to be evaluated. This number of terms can quickly exceed the number of the observations or make it extremely difficult to obtain an accurate solution of the normal equations even using the computer. It is only when the behavior can be simply explained or when reasonably precise laws govern the behavior that regression analysis can be used with the assurance of gratifying results.

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Even though the idea of using the bell curve as the regression model was the key to any success achieved in this research, it did not, of course, fit all the data well. Several methods were tried in an attempt to skew this model to improve

the data fit, however each method had its inherent problems. Although the method chosen works satisfactorily, it no longer is a bell curve. It is asymptotic to the x-axis on only one end. If this end falls toward the deeper depth of burst portion of the graph then no real problem exists provided the "S" portion of the curve does not situate itself in the middle of the data as can be seen for the clay shale plots in Appendix III. Extreme care, therefore, must be taken when using this model to insure that the proper portion of the curve, did in fact, fit the data points provided.

As can be noted from the results of the surface fits, the standard bell curve fitted more of the data as well or better than the skewed form. It also, in general, produced a better fit for scaled radius data than it did for scaled depth and scaled cube root of volume data. If the assumption is made that the bell curve is truly representative of true crater dimensions, then this fact makes sense. The apparent crater radius is essentially equal to the true radius from depths of burst ranging from zero to past optimum. It is only at the deeper depths of burst that these two radii diverge. Of the three crater dimensions, poorer fits were obtained for apparent crater depth. Fall back is the important factor here, the volume (and in turn the height) of the fall back being dependent on bulking and other material characteristics. Judging from the data scatter, material properties are very critical for this

particular crater dimension. Judging also from the data plots, there exists a range of deep depths of burst in the explosion process where the material either responds or does not respond too well to being thrown out.

Obviously, from the above discussion, material properties are important in determination of crater size. Their inclusion into the bell curve prediction scheme is covered next.

# SECTION VII MATERIAL EFFECTS

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This section describes the method used to incorporate soil and rock properties into the bell curve regression models, the resulting general equations obtained and the analysis of these equations to determine specific material property effects. It also includes a discussion of material properties in general and of the material properties used in this research in particular. Lastly, it presents a brief discussion of the relationship between material properties and cratering mechanics.

<u>Incorporation of Material Properties</u>. After normalizing the crater dimensions and after determining that the bell curve was an appropriate regression model to use if material property effects were ignored, it was surmised that the position of the bell curve (i.e., the height, point of zero slope, etc.) was a function of the media material properties. In other words, the bell curve regression coefficients obtained for the various materials are really a function of appropriate material properties. This led to regression analysis involving inclusion of soil and rock properties.

Ideally, if sufficient data had been available at various material property conditions, then each coefficient (B value) of the bell curve could have been expressed as a function of these conditions. However, to make full use of the data, it was

necessary to assume that the coefficients of the coded bell curve, the A values, were functions of material properties. The B values are, of course, related to the A values as described by equations (5) and (6), but when the B values are shown in terms of material parameters, the resulting equation is so involved that it becomes meaningless. It was quickly determined that the coded bell curve constants were not linear functions of any one or more material properties. Reasonable regression began to occur when second order and interaction terms were included. This, however, reduced the number of material properties which could be considered at one time without increasing the number of parameters being used. Every effort was made throughout the research to keep the number of parameters to 40 or less. In the final analysis, the best prediction formulas were obtained using either equation (5) or (6) and the following functional relationships for their coefficients:

$$A_{1} = C_{1} + C_{2} \gamma^{5/16} + C_{3} S + C_{4} M + C_{5} \gamma^{5/8} + C_{6} E_{v}$$
(7a)  
+  $C_{7} M^{2} + C_{8} \gamma^{5/16} S + C_{9} \gamma^{5/16} M + C_{10} SM$ 

$$A_2 = C_{11} + C_{12} \gamma^{5/16} + \dots + C_{20} SM$$
 (7b)

$$A_3 = C_{21} + C_{22} \gamma^{5/16} + \dots + C_{30} SM$$
 (7c)

$$A_4 = C_{31} + C_{32} \gamma^{5/16} + \dots + C_{40} SM$$
 (7d)

in which  $\gamma$  = total unit weight of the material, in grams per cubic centimeter; S = degree of saturation, ranging from zero

to 1.0;  $E_v =$  vaporization energy of the material, in thousands of pounds per square inch per cubic inch (this factor is zero for all except the nuclear events); and where M may equal any one of the following: (1)  $G_s$ , the grain bulk specific gravity; (2) tan  $\phi$ , the material's shearing resistance; or (3)  $c^{1/3}$ , the seismic velocity of the material, in feet per second.

Appendix IV contains the equation coefficients (C values) for the various crater dimensions and combinations of material properties. Numerous computer runs were made to determine which material properties correlated best with crater dimensions and produced the best surface fit. As could be expected, those material properties which were predominately measured values correlated the best and these included the dry unit weight and moisture content and to a lesser degree the shearing resistance. Dimensional analyses by Westine (88) and Saxe (61) suggested the use of  $\gamma^{5/16}$  and  $c^{1/3}$ . These scaled values produced better regression than when their full values were used. Degree of saturation, S, and specific gravity,  $G_s$ , were selected after trying other related factors such as porosity, percent air and void ratio. They appeared to correlate better and have a little more meaning when considering their effect on crater dimensions.

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The vaporization energy of the material, E<sub>v</sub>, was used primarily to differentiate between nuclear and high explosive events. From actual experience (45) it was known that nuclear events produced smaller craters than would be predicted by

scaling from high explosive cratering events. This fact became evident when the nuclear events were analyzed with and without the  $E_v$  term as a parameter. To keep the number of parameters to a minimum,  $E_v$  was used in place of the normally expected S<sup>2</sup> term in the second order material property scheme utilized. The S<sup>2</sup> term was found to have the least effect of all the nine material property terms on the scaled crater dimension.

Also ar attempt was made to incorporate all the material parameters used into one 40 parameter equation, by considering the terms in previous surface fits which had the least effect on the dependent variable. This attempt, however, did not produce as good a surface fit as when only four material properties were used.

When this research was first undertaken, it was hoped that crater dimensions for at least 90 percent of the events could be predicted within ± 10 percent. After viewing the accuracy of the basic cataloged data, a goal of 80 percent of the events to be predicted within ± 20 percent was established. This second goal was more than met for radius and volume but not quite met for predicting depth. The final figures obtained do give, however, some indication as to the reliance of using material properties to predict crater dimensions and provide some validity to the assumption that investigation of the general equations obtained would allow a determination of the effect of soil and rock properties on crater dimensions.

Although an attempt was made to go back over the data to try and find specific explanations as to why specific events did not predict well, very little success was obtained. In general, it appeared that the accuracy of material property inputs was the predominate reason. Not using a better scaling factor for the surface bursts accounted for a small amount of discrepancy. Even Palanquin (a nuclear test) (82) which did not produce the crater expected and which in turn was blamed on a stemming failure, predicted well. The general equations using  $\gamma^{5/16}$ , S,  $G_s$  and  $E_v$  predicted Palanquin's radius and volume only eight and five percents higher respectively than those which occurred and actually predicted the depth 5 percent lower than the actual.

How well will the general equations obtained for the various crater dimensions predict future events? Judging from the data observed, there is an 85 percent chance of being within  $\pm$  15 percent for materials that fall within the range of the ones used in this research and for a scaled depth of burst less than 2.

<u>Effects of Material Properties</u>. After development of the general equations for crater dimensions, parametric studies of these equations were made to determine how crater geometry was effected as the various material properties were varied over their normally expected ranges. This was accomplished by writing a second, but much smaller computer program, to vary

the parameters in the final prediction equations to determine their effect on final crater geometry. Basically, this program read in the constants obtained for the prediction equations, varied the material parameters and scaled depth of burst within their expected ranges and computed the estimated values for scaled radius, depth, or cube root of volume. Since these studies produced pages and pages of computer output, only representative results are included here. These results are graphically presented in Appendix V.

<u>Material Property Definition</u>. Because the results and conclusions regarding the material properties used in this research are presented next, it seems appropriate to discuss just what is a "material property?" The term "material property" appears to have many meanings. These meanings, as they apply to engineering problems, can be catagorized into three areas: (1) Basic, (2) material test, and (3) theoretical.

<u>Basic</u> or primitive material properties are those that relate mass and volume. Examples for a single phase material are: (1) Density, (2) specific volume and (3) specific gravity. For a three phase material mixture, such as soil, where mineral particles comprise the solid phase and where water and air occupy the voids between the mineral particles, the basic material properties relate not only mass to volume for each phase but relate mass and/or volume of each phase to the total volume or total mass. Examples of such basic properties are:

(1) Dry unit weight; (2) total unit weight; (3) saturated unit weight; (4) moisture content; (5) void ratio; (6) porosity;
(7) percent saturation; and (3) percent air voids.

The second major category is material <u>test</u> properties. They are defined operationally. The results of specified and arbitrary tests yield these properties. Examples of such properties are: (1) Unconfined compressive strength; (2) Atterberg limits for soils; (3) splitting tensile strength for rock; (4) compressive strength of concrete at 28 days; and (5) Hveen stability of bituminous concrete. Such tests as these are usually standardized.

There may be some logic behind those test procedures that in some way model a mechanics problem, but in essence these test properties are empirical and arbitrary and may not relate at all to the mechanical behavior of the material in other situations. If they do, it is indeed fortunate and a tribute to some investigator's intuitive insight into material behavior.

The third type of material properties depend on a <u>theory</u> of material behavior that relates cause to effect. Usually the cause is stress, or possibly temperature, and the effect, strain or rate of strain. The coefficients in these theoretical relationships are the constitutive constants that describe idealized material behavior. The mathematical model used to describe a material may be as complicated as necessary to cover the range of interest of the material's behavior. Examples of

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very simple constitutive equations are those for rigid bodies, perfect fluids, linear elastic solids, perfect gases, and linear viscous fluids. The constants in these equations are called material properties. For example, in linear elastic theory, there are two material properties: the two Lame' constants. More complicated constitutive equations of nonlinear form that relate the stress tensor to the strain tensor and rate of strain tensor have been generated. In the case of plasticity theory, the constants relate the various invariants of the stress tensor at failure. In each of these cases, the theory must exist before a material property is measured. Without the theory, the property does not exist.

It would be ideal and very fortunate if valid relationships existed between the various categories of material properties, however, at best, we are fortunate that properties in one category may be indicative of properties in another.

<u>Material Properties Used in this Research</u>. The best regression equations were obtained as a result of using the total unit weight, the percent saturation, the specific gravity of the grains, the internal shearing resistance and the seismic velocity. Although these parameters may not really be the properties governing material behavior during cratering, they are at least indicators of the properties. None of these parameters except the specific gravity remain constant during the cratering process. They are all functions of the stress (or strain) level and their initial values are not necessarily indicative of their values during the actual explosive event. However, when used in conjunction with one another and in conjunction with the depth of burst, they provide some indication of the governing material properties. It was interesting, however, to study the effect these indicators did have on crater dimensions.

At the optimum depth of burst for granular materials, larger craters were produced at low and high degress of saturation than were produced at the intermediate values (Figs. 32-34). This was probably because granular materials with low moisture contents have very little cohesion. However, as the moisture content is increased, the material develops some cohesion and therefore greater strength. Whitman (90) showed that cohesion due to pore water increased as the rate of strain increased. The addition of water also increased the weight of the material. When the degree of saturation starts to approach 100 percent, the ability of the material to transmit the shock wave markedly increases. In addition, the strength of the material decreases considerably as the pore water starts to assume more and more of the pressare being exerted on the material. For clays and rocks (Fig. 35), any increase in the degree of saturation appeared to produce larger craters. Additional moisture in these cases did not improve their cohesion but only tended to increase their ability to transmit

the shock wave and to decrease their strength.

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Now, if other than optimum depth of burst is considered, the degree of saturation produced slightly different effects (Fig. 32). For deep depths of burst, an increase in the degree of saturation tends to always produce larger craters. For surface bursts, the effect of the degree of saturation was found to be the reverse of that determined for optimum depth of burst. Low- and high-moisture contents produced smaller craters, and there existed an optimum degree of saturation at which the largest crater was obtained. Since compaction is the predominate mechanism here, it follows that materials in this region would behave essentially as they do in normal engineering compaction problems.

Again, considering cratering events at or near optimum depth of burst (Figs. 36 and 37), it was found that the smaller craters resulted from low density and high density materials and that there existed an optimum density at which the largest crater resulted. This feature reflects again that better properties are necessary to predict crater dimensions. If unit mass, strength and the ability of the material to absorb the shock wave are all considered together, then this phenomenon seems plausible. Materials with low weight and strength appear to have high-energy absorption properties whereas dense, highstrength materials do not. Somewhere in the middle, then, there exists a material where these factors do not compliment

each other as much as they do for the two extremes. This density feature appears to hold true for all depths of bursts.

Because the effect of bulk grain specific gravity on crater dimensions is not so meaningful in terms of its application to the effects of material properties, it will only be discussed briefly. A change in grain specific gravity affects the total unit weight and degree of saturation and those were discussed above.

Not so easily explained as the effect of density and degree of saturation on cratering is the effect of the material's internal shearing resistance, tan  $\phi$ . It is very difficult to determine what the actual ranges of tan  $\phi$  are for a particular soil density and degree of saturation. Every effort, then, was made to stay within the area of the actual data to determine the effect of tan  $\phi$  on crater dimensions. In general, it appeared that as tan  $\phi$  increased for soil materials at the lower degrees of saturation and for the rocks, the size of the resultant crater also increased. If high degrees of saturation are considered for the soils, then an increase in tan  $\phi$  decreases the crater size. The only explanation that seems plausible for these effects is to consider the ability of the material to absorb energy in relation to tan  $\phi$ . Apparently the ability of the material to absorb energy increases more with an increase in internal shearing resistance than does the strength for the lower degrees of saturation. At the high degrees of saturation,

however, the energy absorption value apparently levels off and the strength increase is sufficient to produce smaller craters.

Because the parametric study involving tan  $\phi$  appeared to be somewhat meaningless unless values were considered in the same area as the actual data, a parametric study was not performed using the general equation which included seismic velocity. Again it becomes extremely difficult to determine the range of values in seismic velocity which would exist when the density and degree of saturation are assumed. In addition, there were fewer measured values for this parameter and it was included in the general equations with hesitancy. It was felt, however, that even though the data were not the best and this variable is stress dependent, it very likely would give some indication of the material's ability to transmit the shock wave. A cursory review of the data indicates that smaller craters result when the seismic velocity is either low or high and that there exists an optimum value where the largest crater will be produced.

It becomes very difficult to sum up all the possibilities, but in general it appears that for craters produced at or near optimum depth of burst, there exists an optimum unit weight, an optimum internal shearing resistance, an optimum seismic velocity with the degree of saturation at zero percent where the very largest craters will be produced for a particular explosive energy source.

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For practical considerations, it appears that the most important of the material indicators used is the degree of saturation (which is of course the result of water content). This study should be helpful in determining whether the addition of water to the medium will either enhance or decrease the size of a crater being considered for the explosive charge weight being used.

<u>Cratering Mechanics and Material Properties</u>. As a result of this analysis of the effects of material properties on crater dimensions, it appears very likely that a reasonably simple cratering theory should be possible. Hopefully the coefficients (material properties) in this theoretical constitutive relationship could be measured using simple laboratory or field techniques. In any case it would appear that these cofficients should in some way be related to the following material properties: (1) Energy dissipation; (2) total unit weight; (3) shear strength; (4) volume change; and (5) moisture.

These five material properties should be measured over the material field for each future test as a minimum material property requirement. The energy dissipation constant should account for the fact that smaller craters result in the lightweight, weaker materials. Unit weight in conjunction with depth of burst would give a measure of the total mass of the material which must overcome gravity. The shear strength constant would account for further energy dissipation. A volume change

constant would account for the change in density of the crater fall back which, in turn, effects the apparent crater depth and volume, Last but not least is the moisture. Vaporiation of moisture surrounding the explosive charge enhances the gas acceleration phase of cratering mechanics. In addition, moisture would modify the effects of all the other four properties proposed.

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#### SECTION VIII

## CONCLUSIONS AND RECOMMENDATIONS

If explosives are to be used for excavation purposes, then predictions of results must incorporate material properties. This study has shown that soil and rock properties are important in determining the size of explosion-produced craters and has provided some insight as to their specific effects. It has shown that previous investigators have been somewhat negligent in measuring material properties for past cratering experiments and that no real analysis of crater data can be made unless the variables are either controlled or measured. This study also has provided a means to predict crater dimensions for any material provided certain soil and rock properties are measured beforehand.

The final general equations obtained will predict the size of 85 percent of the cratering events within ± 15 percent. These equations predict apparent crater radius, depth, and volume in terms of (1) depth of burst, (2) the explosive weight and (3) the following material properties: total unit weight, degree of saturation, grain specific gravity, internal shearing resistance and seismic velocity. For nuclear explosions, the vaporization energy of the material is also included. These equations were developed from data which fell in the following ranges: (1) Explosive charge weights from one pound to 100

kilotons; (2) materials in which the unit weight ranged from 60 to 170 pounds/cubic foot; and (3) charge depths from zero to the point where no crater is produced.

It is not surprising that previous investigators have concluded that the effect of material properties on crater dimensions was somewhat obscure. This is particularly true if only linear and simple curvilinear relationships are considered. It is only when indicative soil and rock properties are considered in conjunction with one another for specific ranges of depths of burst that they become meaningful.

Of the six material properties used in the general equations, percent saturation and total unit weight appeared to be the most important indicators of the effects of material properties. This was due primarily because these two properties were calculated from predominately measured values while those for the other properties used were largely estimated. Prime examples of these effects are as follows: (1) For surface explosions, there exists an optimum percent saturation which will produce the largest crater; (2) for soils and for the explosive charge at optimum depth, zero moisture content produces the largest crater; in this case there is a least favorable percent saturation which will produce the smallest crater; (3) for rock materials and for all materials at deep depths of burst (at least twice the optimum), 100 percent saturation results in the largest crater, and (4) in general, there exists

an optimum unit weight which will produce the largest crater.

The bell curve provides a good model for predicting scaled crater dimensions in terms of scaled depth of burst. Where data indicate nonsymmetry, the skewed form of the bell curve can be used, provided it is done cautiously. The inherent advantage to the bell curve model is that the constants in this model immediately provide the maximum value for the scaled crater dimension under consideration and the optimum scaled depth of burst at which it occurs. This feature makes it useful for practical applications and allows quick comparisons between rock and soil property conditions.

As a result of the knowledge gained in this research effort, the following recommendations are made for future cratering experiments and associated studies:

- Sufficient material properties should be measured for each and every cratering event. As a minimum, unit weight, moisture content, grain specific gravity, shearing resistance and seismic velocity should be measured. In addition, some measure of energy dissipation and material bulking would be desirable.
- A method needs to be developed to measure the energy dissipation characteristics for soil and rock in which cratering experiments have and will be performed.
A method to measure and evaluate bulking or compaction needs to be developed.

4. A series of laboratory type experiments to consider specifically the effects of percent saturation on crater dimensions would be highly desirable. As a minimum, five levels of the degree of saturation for five levels of depth of burst for a particular dry unit weight would possibly suggest a more accruate relationship between crater dimensions and this very important material parameter.

This series could also be extended to include a variation in the dry unit weight and the inclusion of various types of materials.

- 5. For survival of silo-launched missile systems, where the primary interest is in near surface bursts, the surface burst data from this study could be supplemented with additional data and a regression analysis performed. This would allow the scaling exponent, as well as the material constant, to be a function of material properties. Thus, a more accurate prediction of crater dimensions could be obtained for this special case.
- A simple theory of cratering should be developed using the field equations of mechanics and a material

constitutive equation with sufficient complexity to account for soil or rock failure and energy absorption. Such a constitutive equation should also account for increase in strength as a function of pressure and the thermodynamic properties.

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## APPENDIX I

## CATALOGED CRATER DATA

<u>Notations and Definitions</u>. The following notations and abbreviations are used in the cataloged crater data and material property data listings:

ALLUV - desert alluvium;

- ATTBRG LIMITS Atterberg limits (see also LL and
  - PI) relating to the water content at which soil consistency changes from one state to another, see Wu (91);
- B indicates that there is no value following even though the computer printed zeros;
- BULK FACTOR bulking factor, a ratio of the unit weight of the material in the crater fallback to the preshot unit weight of the material, Frandson (19) analyzed this value for several materials;

CH - inorganic clays of high plasticity;

- CNF PRES, PSI confining pressure at which the confined compressive strength was obtained, in pounds per square inch;
- COHESION, PSI cohesion of the material, in pounds per square inch, based on Mohr-Coulomb failure theory;

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CONF COMP, PSI - confined compressive strength of the material, in pounds per square inch, at the particular confining pressure listed ir the next column;

CORE RECOV, PRCT - the amount of core recovered during coring operations, in percent; for rock it indicates the material's soundness;

CU FT - cubic feet;

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DRY UWT, LBS/CU FT - dry unit weight of the material in pounds per cubic foot;

ELEV, FT - elevation, in feet, which could have been converted to atmospheric pressures which Herr

(25) showed to be important;

EQUIV WT, LBS-TNT - equivalent of the explosive charge in pounds of trinitrotoluene;

EVT NO. - event number;

FLE STN, IN/IN - the strain at which failure occurred in either the unconfined or confined compression test, in inches per inch;

FPR MNT - Fort Peck Reservoir, Montana;

FT - feet;

KT - kiloton, one thousand tons equivalent weight
 of TNT (trinitrotoluene);

LIP HT, FT - apparent crater lip height, in feet;

LL, PR CT ~ liquid limit (see ATTBRG LIMITS), in percent; the water content of the soil which differentiates between the plastic and liquid consistencies of the soil;

LRL - Lawrence Radiation Laboratory, California;

- MELT, MPSI/CIN the energy required to melt the material, in thousands of pounds per square inch per cubic inch;
- ML inorganic silts and very fine sands, silty or clayey fine sands or clayey silts with slight plasticity;
- MOIST, PR CT moisture content, expressed in percent of the dry unit weight of the material;

MTCE - Multiple Threat Cratering Experiment;

NM - nitromethane;

NTS-A5 - Nevada Test Site Area 5;

NUC - nuclear;

- PI, PR CT plasticity index (see ATTBRG LIMITS), in percent, the water content difference between the liquid limit (LL) and the plastic limit; the plastic limit being that water content of the soil which differentiates between the semisolid and and plastic consistencies of the soil;

POISN RATIO - Poisson's ratio, ratio of the horizontal

stress to the vertical stress, which resulted from the theory of elasticity;

PRE-GDLA - Pre-Gondola;

REF NO. - reference number;

RMK, SEE NTE - remarks, see note;

SLP DEG - approximate angle the apparent crater slope makes with the horizontal preshot ground surface;

SM - silty sands, sand-silt mixtures;

SP - poorly graded sands, gravelly sands, little or no fines;

SP GR - bulk specific gravity of soil or rock grains;

TNS - tons;

TNSLE-S, PSI - splitting tensile strength of the material, in pounds per square inch;

UNC COMP, PSI - unconfined compressive strength of the material, in pounds per square inch;

USCS CLASS - the "Unified Soil Classification System" (73);

VAPOR, MPSI/CIN - the energy required to vaporize the material, in thousands of pounds per square inch per cubic inch;

WT-VOL - weight-volume;

YFC WSH - Yakima Firing Center, Washington;

\$ - indicates the value following is an estimated value.

<u>Cataloged Crater Data</u>. The crater data cataloged is computer listed in Table 2.

<u>Cataloged Material Property Data</u>. The two line computer listing of the cataloged material property data associated with the cataloged cnater data list is presented in Table 3.

<u>Notes</u>. The notes, referred to in either the catalog of crater data or the catalog of associated material properties, follow Table 3. TABLE 2. CATALOGED CRATER DATA

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APPARENT	0EPTH FT	205-00	116.40	78.50	-9.20	323.00	62+30	90-00	53,00	17-00	30 . 00	74.50	7.90	23.60	29+20	7.86	1.77	7.30	7.16	4.10	.38	2.30	. 45	6.70	1.70	- 63	- 83
	RADIUS	426.00	179.40	119.10	29.10	603.00	107.00	146.00	129.00	45.00	61-00	153.60	57.00	50.50	58.60	15.12	11-32	13.13	14.14	13.40	6.53	9.36	4.18	14.19	5.68	31-00	37.70
06PTH	aurst FT	355.00	170.75	280.00	90.00	635.00	110.00	67.00	17.00	-3.50	1.75	125.00	80.00	17.10	34.20	9.53	15.90	6.35	9.53	12-70	15.90	19.05	25.40	12.70	19-05	29-80	28.50
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EXPLOSIV	VIELD	31+-4KT	2.3+5KT	4.3KT	35+-15TNS	L00+-15KT	·2+08KT	1.2+1KT	1.2+1KT	L.2+1KT	•5+2KT	987410 LB	40120 LB	40240 LB	40070 LB	256 LB	256-LB	256 LB	256 LB	256 LB	256 LB	256 LB	256 LB	256 LB	256 LB	256 LB	256 LB
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ICATION	SITE	NTS-A20	NTS-A20	NTS-A20	NTS-A18	NTS-AIG	NTS-A18	NTS-A10	NTS-A10	NTS-A10	NTS-A16	NTS-ALO	NTS-A10	NTS-A10	NTS-A10	NTS-A10	NTS-A10	NTS-ALO	0T8-810	NTS-AID	OTV-STN	OTV-SIN	DIA-21H	NTS-ALO	018-21K	DTV-SIN	NTS-ALD
IDENTIF	SERIES/SHOT NAME	SCHOONER	CABRIOLET	PALANQUIN	SULKY	SEDAN	DANNY BOY	TEAPOT ESS	JANGLE U	JANGLE S	JOHNIE BOY	SCOOTER	STAGECOACH-1	STAGECOACH-2	STAGECOACH-3	SANDIA SR I-2	SANDIA SR I-4	SANDIA SR 1-8	€-I SANDIA SR I-J	SANDIA SR I-10	SAHDIA SR I-11	SANDIA SR I-12	SANDIA SR 1-15	SANDIA SR 1-16	SANDIA SR I-17	SANDIA SR II-1	SANUIA SR II-2
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TABLE 2. CATALOGED CRATER DATA (CONTINUED)

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CLATER DIMEN	VOLUME Cù FT	-1167.00	16.03	14.00	170.00	121.00	297.00	716.00	1077.00	1670.00	161.00	267.00	1044.80	355•60	363.60	299.83	129-30	37.40	1296.93	524° 40	942-70	293.30	1190.50	496,20	672.70	7200.00	
APPARENT	ЛЕРТН FT	-1.03	1.15	. 30	1.00	1.01	1.60	2.61	4.55	5.43	2.49	2.60	5.50	<b>3•</b> 95	2.60	2.05	1.70	1.40	5.85	5.50	6.20	3.40	6.00	4,55	4.00	10.90	
•	RADIUS	32,30	2.35	3.03	4.39	8.13	10.07	14.29	14.10	14.69	6.57	8.34	11.30	6.35	5.45	9.05	6.35	4.05	11.76	10.60	1 <b>1.</b> 05	8.30	11.75	9•20	9.85	22.70	
06PTH	BURST FT	26.10	25.50	23.30	22.60	19.70	19.00	16.40	16.10	13.10	0.00	00.0	6.35	3,18	1.65	. 83	0.00	63	6.35	3.18	4.77	.83	6.35	1.65	3.15	15.00	
E DATA	E QUIV #1 LBS-THF	256.00	256.00	256.00	256.00	256.00	256.00	256.00	25£.00	256.00	256.00	256.00	256.00	256.00	256.00	256.00	256.00	256.00	256.00	256+00	256.00	256.00	256.00	256.00	256.00	1119.00	
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ICATION	SITE	NTS-A10	NTS-A10	NTS-A10	NTS-410	NTS-410	NTS-A10	NTS-A10	NTS-A10	4TS-A10	NTS-A10	NTS-410	NTS-410	NTS-A10	NTS-ALC	NTS-A10	NTS-ALC	NTS-A1C	NTS-A10	NTS-A10	NTS-ALO	NTS-ASO	NTS-A10	NTS-416	NTS-410	NTS-A5	
IDENTIF	SERIES/SHOT NAME	SANUIA SR II-3	SANDIA SR II-4	SANDIA SR II-5	SANDIA SR II-6	SANDIA SR II-7	SANDIA SP. 11-5	SANDIA SR II-9	SANDIA SR II-10	SANDIA SR JI-11	SANDIA SP. II-12	SANDIA SR [1-13	MOLE-262	MOLE-203	rGL5-204	MOLE-205	40LE-2J6	HOLE-207	MOLE-212	107E-401	40LE-402	#01E-403	MOLE-474	40FE-485	407 E-4 US	PRE-8JGGY-TEST	
	REF NO.	9	53	07	40	07	0,	40	40	40	r 0	40	59	59	59	65	65	59	59	59	£3	65	65	ę 9	64	53	:
	E VT NO.	25	26	27	2\$	29	2	31	32	33	34	35	35	37	36	6£	С †	14	21	5	44	3 20	46	17	6 7	0`. 7	e U

RHK SEE NTE SLP LIP HT DEG FT \*\*\*\*\*\* 3.80 2.80 0.00 2.56 00.00 12.30 7560.00 8 0 8 0.00 2.78 0.00 0.00 0.00 0.00 00.00 5.00 6.80 04.6 6.70 0.00 10.20 15.90 17.20 14.50 1500.00 8 0 9 0.00 1890.00 B 0 B C.00 654.00 B 0 B 0.00 3500.00 8 0 8 0.50 2650.00 8 0 8 45.00 B 0 B 6080.00 B 0 B \$00.00 B 0 B 6950.00 B 0 B 2660.00 B v B 2620.00 8 0 8 7560.00 8 0 8 CRATER DIMENSIONS o 0 02 0 6030.00 8 0 29 33 56 NP 37 53 5830.00 B 7660.00 8 E530.00 8 VOLUKE CU FT 54220.00 135000.00 23200.03 75500.00 73900-00 53300.00 64.800.00 569100.00 277550.00 CATALOGED CRATER DATA (CONTINUED) EXPLOSIVE DATA DEPTH (CONTINUED) UEPTH APPARENT ( OF ADTUS OFPTH BURST RADIUS OFPTH FT FT 4.10 9.10 7.80 9.40 8.30 11.80 11.80 16.80 1.40 5.20 6.50 7.50 3.80 6.60 4.80 7.00 24.90 34.70 16.20 22.90 25.53 25.60 60.70 \$2.60 -1.30 11.90 21.60 19.70 20.70 22.70 21.20 21.10 4.63 15.65 16.70 15.00 16.92 12.15 44.66 57.00 36.30 49.00 46.10 22.10 10.67 20.90 15.80 50.30 95.20 09.00 20.60 68.00 16.60 19.80 18.50 18.90 24.70 9.60 4.80 16.60 9.60 4.80 42.70 41.60 21.40 25.50 16.20 19.60 19.60 19.60 14.70 58.80 58.00 50.20 42.49 16.33 66.10 71.70 1112.00 1110.00 1118.00 1100.00 950.00 1010-00 1112.00 1117.00 1100.00 950.00 1000.00 1000-00 1000.00 1000.00 1000.00 1000.00 39995.00 39876.00 43200.00 43400.00 43500.00 1000.00 00.00000 43600.00 165000.00 43160.00 EQUIV WT LBS-TNT TNT 39995 LB **6**, 9 8 -----TNT 40000 LB 5 NH 39250 LB NH 85.5 TONS 19.62 TNS 1000 LB 1011 ·LB 1800 LB 9 1000 LB 1000 LB 1000 LB 1000 LB 1000 68 1011 LB 1009 LB 1016 LB 1015 LB 1000 LB 950 LB 1000 LB 1000 LB VIELO 950 NN 39450 0656E HN TNT 39870 39840 TABLE 2. TYPE THT TNT TNT TNT TNT THT TNT TNT TNT TNT HZ HN X.X Ŧ X H ž ÿ DATE MEDIUM Motr BASALT BASALT BASALT BASALT BASALT 3 PRE-SCHOONER II IOAHO SEP65 RHYOLTE BASALT BASALT BASALT BASALT BASALT BASALT BASALT BASALT BASALT ALLUV ALLUV ALLUV ALLUV BASALT ALLUV ALLUV ALLUV ALLUV ALLUV 23 PRE-GDLA I-CHAR FPR MNT DCT66 SHALE NTS-A5 DEC62 NTS-AIS JUN60 NTS-A18 SEP60 NTS-A5 DEC62 NTS-A5 DEC62 NTS-A5 DEC62 NTS-A5 DEC62 NTS-A5 AUG63 NTS-A5 AUG63 66 PRE-BUGGY II-F3 NIS-AS AUG63 NTS-A5 AUG63 NTS-A16 JUN60 NTS-A18 AUG60 NTS-AI& JUL60 NTS-AL& JUNGD NTS-ALB JUNGO NTS-A18 AUG60 NTS-AIS JUL60 NTS-A18 SEP60 PRE-SCHOONER-A HTS-A18 FEB64 PRE-SCHOONER-D NTS-AI8 FEB64 NTS-A18 AUG60 PRE-SCHOONER-B NIS-A18 FE864 PRE-SCHOONER-C NTS-ALB FEB64 -----SITE IDENTIFICATION SERIES/SHOT 66 PRE-BUGGY II-F4 66 PRE-BUGGY II-F2 65 PRE-BUGGY II-F1 BUCKBOARD-11 BUCKBOARD-12 **BUCKBOARD-13** BUCKBOARD-10 BUCKBOARD-3 PRE-BUGGY-2 PRE-BUGGY-5 PRE-BUGGY-6 EUCK30ARD-2 BUCKBOARD-4 BUCKBOARD-5 BUCKBOARD-5 BUCKEGAR0-9 PRE-BUGGY-3 PRE-BUGGY-4 **BUCKBOARD-7** NAME 63 9 REF <del>С</del> 9 53 57 57 57 <u>6</u>5 65 1 51 57 50 85 85 **8** 0 EVT REF NO. NO. 35 85 **8**5 **8**2 50 55 85 52 53 15 55 56 58 65 68 11 57 5 3 5 29 63 **4**9 66 63 69 2 72 73 74 75 76

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RMX	NTE NTE																										
	LIP HT FT	13.70	13.90	13.00	3.80	3.10	3.70	4.30	00.00	00.0	00 • 0	0 • 0 0	00.00	00 • 0	00-00	0.00	0.00	0•00	00.0	0.00	0.00	3.00	0.00	00.00	00*0	0.00	0.00
SNOI	555 066	53	29	53	23	26	18	15	8	8	80	8 0 8	80	80	8	80	80	80	8 0 8	808	8 Û	80	8 0 8	808	80	80	8 0 8
) Crater dimens	VOLUME CU FT	241260.00	235300.00	133880.00	8100.00	97 00- 00	150.00	750.00	2•33 B	1.76 8	1.54 B	11.55 B	8.00 E	11.56 E	15.69 8	18.10 E	17.03 E	15.68 E	26+64 E	27.40 E	34.32 8	13.00 E	36.37 E	16.82 E	7.05 E	30.70 E	13.72 8
<b>TINUED</b>	06PTH F7	29.50	32.10	25.20	13.00	12.50	2.80	3.40	.91	.67	• 65	1.11	1.06	1.44	1.60	1.71	1.54	1.75	1.77	1.48	1.94	1.01	1.51	.80	.34	1.79	.67
A (CON	RADIUS	78.50	76.10	65.10	24.50	27.30	7.10	14.60	1.55	1.4.7	1,31	7.55	2.25	2.43	2.78	2.85	3.02	2.70	3.43	3.75	3.56	3.31	3.67	3.68	3.16	4.00	3.66
R DATA Depth	OF BURST FT	46.25	52.71	56.87	12.20	15.30	19.10	23.30	0.00	0.00	0.00	• 50	.50	• 50	1.00	1.50	1.00	1.00	2.00	2.50	2 . 00	2.50	2.00	3.06	3.50	3.00	3,00
GED CRATE	EQUIV HT LBS-THT	42590+00	44770.00	44530.00	1100.00	1100.00	1100.00	1100.00	9.00	8.00	0.00	6.00	6.00	00.8	8.00	8.00	8.00	00*0	5.04	00-2	5.00	6.00	6.00	9.00	6.00	0.00	A. 00
CATAL( Explosive	YIELD	19.36 TNS	20.35 TNS	20.24 TNS	1000 LB	1000 LJ	1000 LB	1005 LB	8 1 8	618	6 LB	9 L 8	8 L 8	8 L8	8 L 8	8 LB	8 LU	8 LB	5 LB	818	8 L 8	8 LB	8 L.B	8 L8	5,1,3	<i>ئ</i> ۲8	8 18
5.	TYPE	¥	HN	Ĩ	MN	WN	HN	MN	TNT	TNT	TNT	TNT	THT	TNT	TNT	TNT	TNT	TNT	TNT	TNT	THT	TNT	TNT	TNT	TNT	TNT	TNT
TABLE	HEDIUT	SHALE	PLAYA	PLÅYÅ	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	FLAYA	PLAYA						
	DATE HO YR	0CT66	NOV66	NOV66	JUN66	JUN65	JUNES	JUN66	NOV59	N0V59	6570N	N0V59	CSAON	N0V59	65A0N	JUNGO	65VON	92VON	N0V59	JUNGO	92VON	JURGO	6570N	65A0H	JUN60	657QN	0 V C S A C A
CATION	SITE	FP2 NNT	FPR MNT	FPR MHT	FPR MNT	FPR MNT	FPR MNT	FPR MNT	NTS-A6	NTS-46	NTS-A6	NTS-46	NTS-A6	NTS-A6	NTS-A6	NTS-A6	NTS-46	NTS-A6	NT S- A6	NTS-A6	HTS-26	NTS-A6	NTS-A6	NTS-A6	NTS-A6	NTS-A6	NTS-46
IDENTIFI	SERIES/SHOT NAME	E-GOLA I-BRAV	E-GOLA I-ALPH	E-GOLA I-DELT	E-GOLA I-SC-4	E-GDLA I-SC-2	E-GOLA I+SC-1	E-G01 4 1-SC-3	TOBOGGAN-EIA	TOBOGGAN-E1B	TOBOGGAN-EIC	TOBOGGAN-E2A	653-NADOULT	TOBOGGAN-E2C	TOBOGGAN-E3A	0306G4N-E3.5A	T08066AN-E38	T09066AN-E3C	1030GGAN-E4A	08066AN-E4.5A	1080GGAN-E4B	U3066AN-E4.53	T 09066AN- E4C	T 080GGAN-E5A	030GGAN-E5.5A	T 09066AN-E58	TOBOGGAN-ESC
	50	23 PR	23 PR	23 P.K	23 P9	23 PR	23 P.R.	23 PR	~	~	~	~	~	~	~	11 2	~	~	~	7 11	~	7 71	~	~	7 1(	~	۲.
	1 H H H H H	13	7.0	79	09	10	92	EP	48	<b>8</b> 5	<b>8</b> 6	87	68	60	96	16	92	53	46	56	96	26	96	66	100	101	102

in the second

CATALOGED CRATER DATA (CONTINUED) TABLE 2.

with sectors and the last

103       7       7000666M-E64       NIS-A5       NUM59       PLAYA       THT       B       B       0.00       4.50       1.50       .20       1.24       B       B       0.00       1.24       B       B       0.00       1.24       B       B       0.00       1.24       B       B       0.00       1.50       .20       1.24       B       B       0.00       1.50       .20       1.24       B       B       0.00
10         100066AM-E6A         NIS-A5         UNUS         LAY         TNI         B         L3         0.00         U.13         1.90         .20         1.24         B           10         7         100066AM-E6A         NIS-A5         UNUS         PLAYA         TNI         B         0.00         U.15         0.00         0.0
101         7         1000GGAM-E6A         NIS-A6         NUVUS         PLAYA         TH         6         6         0
103         7         1080GGAM-EGA         NIS-AS         NOVS9         PLAVA         TMT         B         B         O         U         130         130         130         20           104         7         TOROGGAM-EGA         NIS-AS         JUNG0         PLAVA         TNT         B         LB         B         0<
103         7         TOBOGGAM-EGA         NTS-AS         NUVS9         PLAYA         TMT         B <la< th="">         B&lt;.00         473         190           104         7         TOBOGGAM-EGA         MTS-AS         JUNB0         PLAYA         TMT         B<lb< td="">         B00         473         0.00           105         7         TOBOGGAM-EGA         MTS-AS         JUNB0         PLAYA         TMT         B<lb< td="">         B00         400         150         000           106         7         TOBOGGAM-EGA         MTS-AS         JUNG0         PLAYA         TMT         B<lb< td="">         B00         400         150         000           107         7         TOBOGGAM-ETA         MTS-AS         JUNG5         PLAYA         TMT         B<lb< td="">         B00         400         240           107         7         TOBOGGAM-ETA         MTS-AS         JUN65         PLAYA         TMT         B<lb< td="">         B00         400         240         240           107         7         TOBOGGAM-ETA         MTS-AS         JUN65         PLAYA         TMT         B<lb< td="">         B00         400         240         240         240         240         240</lb<></lb<></lb<></lb<></lb<></lb<></la<>
103         7         1080GGAN-EGA         NTS-A5         N0V59         PLAYA         THT         B         L3         0.000         470           104         7         TOR0GGAN-EGA         NTS-A5         JUN60         PLAYA         THT         B         L3         0.000         470           105         7         TO80GGAN-EGB         NTS-A5         JUN60         PLAYA         THT         B         LB         0.000         4000           106         7         T080GGAN-EGB         NTS-A6         JUN69         PLAYA         TNT         B         LB         0.000         4000           107         7         T080GGAN-EGA         NTS-A6         JUN69         PLAYA         TNT         B         LB         0.000         4000           107         7         T080GGAN-EGA         NTS-A6         JUN69         PLAYA         TNT         B         LB         0.000         0         000         0         000         0         000         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
103       7       TOBOGGAM-EGA       MTS-AS       NOVS9       PLAYA       TMT       B       LB       B.000         104       7       TOBOGGAM-EGA       MTS-AS       NUN60       PLAYA       TMT       B       LB       B.000         105       7       TOBOGGAM-EGB       MTS-AS       NUN60       PLAYA       TMT       B       LB       B.000         106       7       TOBOGGAM-EGS       MTS-A6       NUN59       PLAYA       TMT       B       LB       B.000         107       7       TOBOGGAM-EGS       MTS-A6       NUN59       PLAYA       TMT       B       LB       B.000         107       7       TOBOGGAM-EGS       MTS-A6       JUN65       PLAYA       TMT       B       LB       B.000       D0         108       9       MTCE-SIA       MTS-A6       JUN65       BASALT       TMT       4000 <lb< td="">       4000.00         110       9       MTCE-SIA       YFC       MSH       JUN65       BASALT       TMT       4000<lb< td="">       4000.00         111       9       MTCE-SIA       YFC       MSH       JUN65       BASALT       TMT       4000<lb< td="">       40000.00         111<!--</td--></lb<></lb<></lb<>
103         7         TOBOGGAN-EGA         NTS-AS         NOVS9         PLAYA         TMT         B         L3           104         7         TOBOGGAN-EGA         NTS-AS         JUNG0         PLAYA         TMT         B         L3           105         7         TOBOGGAN-EGA         NTS-AS         JUNG0         PLAYA         TMT         B         L8           106         7         TOBOGGAN-EGA         NTS-AG         NUVS9         PLAYA         TMT         B         L8           107         7         TOBOGGAN-EGA         NTS-AG         UNVS9         PLAYA         TMT         B         L8           107         7         TOBOGGAN-EGA         NTS-AG         JUNG9         PLAYA         TMT         B         L8           107         7         TOBOGGAN-ECA         NTS-AG         JUNG9         PLAYA         TMT         B         L8           107         7         TOBOGGAN-ECA         NTS-AG         JUNG9         PLAYA         TMT         B         L8           110         9         MTCE-S2A         YFC         WSH         JUNG5         BASALT         TMT         4000         L8           111         9
103       7       T0800G6.NM-E6.A       NTS-A6       N0V59       PLAYA       TNT         104       7       T0800G6.NM-E6.5A       NTS-A6       JUN60       PLAYA       TNT         105       7       T0800G6.NM-E6.5A       NTS-A6       JUN60       PLAYA       TNT         106       7       T0800G6.NM-E6.5       NTS-A6       JUN60       PLAYA       TNT         106       7       T0800G6.NM-E6.5       NTS-A6       JUN60       PLAYA       TNT         107       7       T0800G6.NM-E6.5       NTS-A6       JUN65       PLAYA       TNT         107       7       T0800G6.NM-E6.5       NTS-A6       JUN65       PLAYA       TNT         108       9       MTCE-S1(C1)       YFC       WSH       JUN65       BASALT       TNT         110       9       MTCE-S2A       YFC       WSH       JUN65       BASALT       TNT         111       9       MTCE-S2A       YFC       WSH       JUN65       BASALT       TNT         111       9       MTCE-S2A       YFC       WSH       JUN65       BASALT       TNT         111       9       MTCE-S2A       YFC       WSH       JUN65
103       7       1080GGAM-EGA       NTS-AS       NOV59       PLAYA         104       7       1080GGAM-EGA       NTS-AS       NOV59       PLAYA         105       7       1080GGAN-EGA       NTS-AS       NUN60       PLAYA         106       7       1080GGAN-EGA       NTS-AS       NUV50       PLAYA         106       7       1080GGAN-EGA       NTS-AS       NUV50       PLAYA         107       7       1080GGAN-EGA       NTS-AS       NUV50       PLAYA         108       9       MTCE-S2A       YFC WSH       JUN65       BASALT         111       9       MTCE-S2A       YFC WSH       JUN65       BASALT         111       9       MTCE-S2A       YFC WSH       JUN65       BASALT         111       9       MTCE-S2A       YFC WSH       JUN65       BASALT         112       9       MTCE-S2A       YFC WSH       JUN65       SAND
103       7       T080GGAM-EGA       NTS-A6       N0V59         104       7       T080GGAM-EGA       NTS-A6       JUN60         105       7       T080GGAM-EGB       NTS-A6       JUN60         106       7       T080GGAM-EGC       NTS-A6       JUN60         106       7       T080GGAM-EGC       NTS-A6       JUN60         107       7       T080GGAM-ETA       NTS-A6       JUN65         108       9       MTCE-S1(C1)       YFC       WSH       JUN65         110       9       MTCE-S2A       YFC       WSH       JUN65         111       9       MTCE-S2A       YFC       WSH       JUN65         111       9       MTCE-S2A       YFC       WSH       JUN65         112       9       MTCE-S2A       YFC       WSH       JUN65         113       9       MTCE-S2A       YFC       WSH       JUN65         113       9       MTCE-S2A       YFC       WSH       JUN65         113       9       MTCE-S2A       YFC       WSH       JUN65         133       5       ZULU       IT-M1       LRL       300       W065 <t< td=""></t<>
103       7       TOBOGGAN-EGA       NTS-A5         104       7       TOBOGGAN-EGB       NTS-A5         105       7       TOBOGGAN-EGB       NTS-A5         106       7       TOBOGGAN-EGC       NTS-A5         106       7       TOBOGGAN-EGC       NTS-A5         106       7       TOBOGGAN-EGC       NTS-A6         107       7       TOBOGGAN-EGC       NTS-A6         108       9       NTCE-S1A       NTS-A6         109       9       NTCE-S2A       YFC         110       9       NTCE-S2A       YFC         111       9       NTCE-S2A       YFC         112       9       NTCE-S2A       YFC         113       9       NTCE-S2A       YFC         114       9       NTCE-S2A       YFC         115       9       NTCE-S2A       YFC         113       9       NTCE-S2A       YFC         133       5       ZULU       I.NL       300         134       5       ZULU       I.NL       300         135       5       ZULU       I.NL       300         135       5       ZULU       <
103       7       T080GGAN-E6A         104       7       T080GGAN-E6B         105       7       T080GGAN-E6B         106       7       T080GGAN-E6B         106       7       T080GGAN-E6B         107       7       T080GGAN-E6B         108       7       T080GGAN-E6C         107       7       T080GGAN-E6C         108       9       MTCE-S1(C1)         109       9       MTCE-S2A         110       9       MTCE-S2A         111       9       MTCE-S2A         112       9       MTCE-S2A         113       9       MTCE-S2A         133       5       ZULU II-M11         134       5       ZULU II-M12         135       5       ZULU II-M12         135       5       ZULU II-M12         135       5       ZULU II-M12
103 105 105 105 105 105 105 103 111 1110 1110
103 104 105 105 106 110 112 112 113 113 135 135 135 135 135

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LIP HT FT	•36	• 39	.30	.39	• • 6	.36	6**	45.	• 50	•52	.33	64.	.39	14.	6**	.43	.41	.21	.29	• 26	.30	.35	.31	•2•	.37	.34
SLP OEG	62	36	\$ 38	\$ 38	\$ 37	4E 3	\$ 35	36	33	32	36	\$ 32	\$ 35	\$ 32	33	\$ 28	\$ 28	31	30	31	36	32	35	35	33	36
VOLUME CU FT	17+55	13.78	12.85	12.40	9.18	3° 95	9.67	9*60	7.67	6.78	9•68	6.13	8.58	4.72	5•29	2.84	2.38	11.10	9.36	10.75	14.20	12.60	11.70	12.80	14.85	13.15
DEPTH Ft	1.91	1.55	1.49	1.51	1.26	.70	1•35	1.17	1.08	1.01	1-21	. 65	1.02	.78	.78	• € 0	• 4 0	1.28	1.15	1.39	1.43	1.40	1.41	1•39	1.52	1.44
RADIUS FT	2.55	2.50	2.47	2.41	2.27	1•99	2•25	2.41	2.24	2.13	2.38	2.25	2.44	2+07	2•19	1.63	2.05	2.48	2.40	2+34	2•65	2+52	2,42	2•55	2.63	2.54
BURST	1.60	1.75	1.75	1.60	1.95	1.99	2.00	2.00	2.00	2.00	2.00	2+00	2.00	2.01	2.11	2.11	2.11	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
EQUIV NT LBS-TNT	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1,30	1.30	1-30	1.30	1.30	1.30	1.30	1.30
VIELD	1 LB	1 LB	1 L8	1 LB	1 LB	1 LB	1 La	1 LB	1 LB	1 LB	1 LB	1 L8	1 LB	1 LB	1 LB	i : 8	1 LB	1 LB	1 LB	1 LB	1 La	1 LB	1 18	1 LƏ	1 LB	1 LB
ТүрЕ	4 - 5	4-0	5-0	4-0	4-0	<b>4-0</b>	4-0	4-0	4-0	<b>7-</b> 5	4-0	4-0	4-0	4-0	4-0	7-0	4-0	4-0	4-0 0	4-0	4-0	4-0	4-0	0-4 0	4-0	4-0
MEDIUM	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAN !	SAND	ALLUV	ALLUV	ALLUV	ALLUV	ALLUV	ALLUV	ALLUY	ALLUY	ALLUV
DATE HO YR	APR66	SEP65	SEP65	MAY66	A UG65	NOV65	AUG65	SEP65	00165	N0V65	0EC 65	FE866	FE866	<b>MAY66</b>	NOV65	OECES	SEPE6	10164	JUL 64	JUL64	JUL 64	JUL 64	10164	JUL 64	101.64	A UG64
SITE	LRL 300	LRL 300	LRL 300	LRL 300	LRL 300	LRL 300	LRL 300	LRL 300	LRL 300	LRL 300	LRL 300	LRL 300	LRL 300	LRL 300	LRL 300	LRL 300	LRL 300	NTS-A5	NI S-A5	NTS-A5	NT S- A5	NTS-A5	NTS-A5	NTS-A5	NIS-A5	NTS-A5
SERIES/SHOT NAME	ZULU II-SS20	ZULU II-15	ZULU II-8	ZULU II-SS21	2110 II-10	ZULU II-SS7	ZULU II-1	ZULU II-16	20LU II-19	20LU II-SS5	ZULU II-SSID	20LU II-SS14	20LU II-SS16	ZULU II-SS22	2ULU II-558	53-11 ULVS	20LU II-SS24	2ULU-18	2ULU-18	2ULU-1C	ZULU-24	2ULU-2B	ZULU-3A	2010-38	ZULU-3C	コヤーハース
	Ś	ŝ	ŝ	ŝ	Ś	ŝ	ŝ	ŝ	ŝ	ŝ	ŝ	ŝ	ŝ	ŝ	ŝ	ŝ	Ś	23	28	28	28	28	28	28	28	82
KO.	147	148	149	150	151	152	153	154	155	156	151	158	159	160	161	162	163	164	165	166	161	168	169	170	171	172
	EVT REF SERIES/SHOT SITE DATE HEDIUM TYPE YIELD EQUIVAT BURST RADIUS DEPTH VOLUME SLP LIPHT SE No. 25. Name and the yr dot r loss tail ft ft ft cuft deg ft mi	EVT REF SERIES/SHOT SITE DATE HEDIUM TYPE YIELD EQUIVAT BURST RADIUS DEPTH VOLUME SLP LIP HT SE No. 25. Name no yr mo yr do yr do yr dog ta u the state of the state of the state of the state state of the state state of the state state state of the state stat	EVT REF       SERIES/SHOT       SITE       DATE       MEDIUN       TYPE       YIELD       EQUIV WT       BURST       RADIUS       DEPTH       VOLUME       SLP       HT       SE         NO. %0.       NAME       NO       NO       YR       LBS-TWT       BURST       FT       FT       VOLUME       SLP       LTP       HT       SE         NO. %0.       NAME       NO       YR       LBS-TWT       BURST       FT       FT       CU FT       DEG       FT       NT         147       5       ZULU II-SSZ0       LRL 300       APR66       SAND       C-4       LB       1.50       1.91       17.55       39       .36       1         146       5       ZULU II-SSZ0       LRL 300       APR66       SAND       C-4       1 <lb< td="">       1.50       1.55       1.91       17.55       39       .36       1         148       5       ZULU II-15       LRL 300       SEP65       SAND       C-4       1<lb< td="">       1.30       1.75       2.50       1.55       13.70       .39       .39       1</lb<></lb<>	EVT REF       SERIES/SHOT       SITE       DATE       MEDIUM       TYPE       YIELD       EQUIVAT       BURST       RADUS       DEPTH       VOLUME       SLP       LIP HT       SE         NO. 320.       NAME       NO <yr< td="">       NO<yr< td="">       LBS-TWT       FT       FT       CU FT       OEG       FT       NT         147       5       ZULU II-SS20       LRL 300       APR66       SAND       C-4       1<lb< td="">       1.30       1.60       2.55       1.91       17.55       39       .36       1         148       5       ZULU II-15       LRL 300       SEP65       SAND       C-4       1<lb< td="">       1.30       1.75       2.550       13.78       30       .39       1       1       14       2       2.41       1.45       12.45       13.78       30       .39       1       1       14       2       2.41       1.45       12.45       13.78       30       .39       .39       .30       1       14       5       2.41       1.45       12.45       13.78       30       .36       1       14       1       1       1       1       1       1       1       1       1       2.45       1       1</lb<></lb<></yr<></yr<>	EVT REF       SERIES/SHOT       SITE       DATE       HEDUM       TYPE       VIELD       EQUIVAT       BURST       RADUG       DEFTH       VOLUME       SLP       LP HT       SE         NO.<	EVT REF       SERIES/SHOT       SITE       DATE       HEDUH       TPE       VIELD       EQUIVAT       BURST       RADUS       DEFTH       VOLUME       SLP       LPH J SE         NO.<	EVT       Ref       SERIES/SHOT       SITE       DATE       MEDUN       TYPE       VIELD       EQUIV NT       FT       FT       FT       CU FT       OEG       FT       NT         NO.<	EVT       Ref       SERIES/SHOT       SITE       DATE       HEDUN       TYPE       VIELD       EQUIVAT       FT       FT       FT       FT       FT       CUFT       DEG       FT       NIT         NO.<	EVT       REF       SERIES/SHOT       SITE       DATE       HEDUH       TYPE       VIELD       EQUIV NT       FT       FT       FT       CU FT       DEG       FT       NIT         NO.<	EVT         ERTES/SHOT         SITE         DATE         DATE	UN         SERIES/SHOT         STIE         DAT         MOLUNE         STIE         MOLUNE         STIE <th< td=""><td>VI         REF         SERIES/SHOT         SITE         DATE         MOL         TELD         CULT         DEC         FT         NUL         ST         FT         FT         FT         FT         FT         FT         FT         DEC         FT         DEC         FT         DEC         FT         NUL         NUL         ST         DEC         FT         DEC         FT         DEC         FT         DEC         FT         NUL         NUL         NUL         NUL         ST         DEC         T         DEC         FT         DEC         FT         DEC         FT         NUL         <t< td=""><td>VI         Ref         Series/shot         Site         Moute         Lip         Vi         Ref         Currin         Lip         Lip         Hi         Sec         FT         Mute         Site         Site&lt;</td><td>U/I         REFIGNATION         STEL         OATE         MOUNT         STEL         OATE         STEL         OATE         MOUNT         STEL         OATE         STEL         OATE         STEL         OATE         MOUNT         STEL         OATE         STEL         OATE         STEL         OATE         STEL         OATE         STEL         OATE         STEL         STEL</td></t<></td></th<> <td>VI         REE         SERIES/SHOT         SITE         DATE         DATE         NAME         NAME         NAME         SITE         DATE         DATE</td> <td>R.T.         Sertics/Sand         Site         Oate         Motion         Tech         Motion         Santa         Motion         Santa         Motion         Santa         Santa</td> <td>R. T. R. S. S.</td> <td>No.         State         State         State         No.         No.</td> <td>N. M. M.</td> <td>NUM         Support         Support         NUM         <th< td=""><td>W.Y. FOL         CARTEX/SHOT         STE         OW         WE         WOLVE         DEF         WOLVE         DEF         MALE           11         2         UU&lt;</td>         11-5523         RH 30         STE         00.77         SE         VE         VE<td>W.Y.         SCREEX/SMC         JIT         MORE         MET         MOLUNE         DUL         MOLUNE         MOLUNE         DUL         MOLUNE         DUL         MOLUNE         MOLUNE         DUL         MOLUNE</td><td>NU         Sector         Site         NIT         NIT&lt;</td><td>No.         Setting se</td><td>No.         Setta Service with ways         Setta with wass         Setta with with wass         Setta with with with wass         Setta with with with with with with with with</td><td>No.         Sectory and and         Sectory and and</td></th<></td>	VI         REF         SERIES/SHOT         SITE         DATE         MOL         TELD         CULT         DEC         FT         NUL         ST         FT         FT         FT         FT         FT         FT         FT         DEC         FT         DEC         FT         DEC         FT         NUL         NUL         ST         DEC         FT         DEC         FT         DEC         FT         DEC         FT         NUL         NUL         NUL         NUL         ST         DEC         T         DEC         FT         DEC         FT         DEC         FT         NUL         NUL <t< td=""><td>VI         Ref         Series/shot         Site         Moute         Lip         Vi         Ref         Currin         Lip         Lip         Hi         Sec         FT         Mute         Site         Site&lt;</td><td>U/I         REFIGNATION         STEL         OATE         MOUNT         STEL         OATE         STEL         OATE         MOUNT         STEL         OATE         STEL         OATE         STEL         OATE         MOUNT         STEL         OATE         STEL         OATE         STEL         OATE         STEL         OATE         STEL         OATE         STEL         STEL</td></t<>	VI         Ref         Series/shot         Site         Moute         Lip         Vi         Ref         Currin         Lip         Lip         Hi         Sec         FT         Mute         Site         Site<	U/I         REFIGNATION         STEL         OATE         MOUNT         STEL         OATE         STEL         OATE         MOUNT         STEL         OATE         STEL         OATE         STEL         OATE         MOUNT         STEL         OATE         STEL         OATE         STEL         OATE         STEL         OATE         STEL         OATE         STEL         STEL	VI         REE         SERIES/SHOT         SITE         DATE         DATE         NAME         NAME         NAME         SITE         DATE         DATE	R.T.         Sertics/Sand         Site         Oate         Motion         Tech         Motion         Santa         Motion         Santa         Motion         Santa         Santa	R. T. R. S.	No.         State         State         State         No.         No.	N. M.	NUM         Support         Support         NUM         NUM <th< td=""><td>W.Y. FOL         CARTEX/SHOT         STE         OW         WE         WOLVE         DEF         WOLVE         DEF         MALE           11         2         UU&lt;</td>         11-5523         RH 30         STE         00.77         SE         VE         VE<td>W.Y.         SCREEX/SMC         JIT         MORE         MET         MOLUNE         DUL         MOLUNE         MOLUNE         DUL         MOLUNE         DUL         MOLUNE         MOLUNE         DUL         MOLUNE</td><td>NU         Sector         Site         NIT         NIT&lt;</td><td>No.         Setting se</td><td>No.         Setta Service with ways         Setta with wass         Setta with with wass         Setta with with with wass         Setta with with with with with with with with</td><td>No.         Sectory and and         Sectory and and</td></th<>	W.Y. FOL         CARTEX/SHOT         STE         OW         WE         WOLVE         DEF         WOLVE         DEF         MALE           11         2         UU<	W.Y.         SCREEX/SMC         JIT         MORE         MET         MOLUNE         DUL         MOLUNE         MOLUNE         DUL         MOLUNE         DUL         MOLUNE         MOLUNE         DUL         MOLUNE	NU         Sector         Site         NIT         NIT<	No.         Setting se	No.         Setta Service with ways         Setta with wass         Setta with with wass         Setta with with with wass         Setta with with with with with with with with	No.         Sectory and and         Sectory and and

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	CRATER DIMEI	VOLUME CU FT	505.70	544.00	483-00	486.00	332+00	-1178.00	-2500.00	-2678.00	-2722-00	-1878.00	-1003.00	- 900- 00	24.02	26.10	22.79	28.33	442.00	517.00
TINUED)	APP4R5%T	ЛЕРТН FT	4.36	4.49	3.98	3.63	2.34	-3.61	-4.13	-4.11	-4.43	-2.67	-1.35	63	1.57	1.82	1.81	1.87	4.27	4.55
(CON		RADIUS FT	9.82	9• 94	10.32	10.98	11.02	22.90	26.40	22.60	22.30	22.00	23.40	24.70	3.41	3.41	3.26	3.52	9.36	10.12
R DATA	0EPTH	BURST	6.35	6.35	7.94	9.53	£5°6	12-70	1.2.70	15.90	15+90	19.05	22.20	25.40	0• 00	0.00	0•00	0.00	0.00	0.00
DGED CRATE	E	EQUIV HT L9S-THT	256.00	256.00	256.00	256.00	256 <b>.</b> 00	256.00	256.00	256.00	256.00	256.00	256.00	256.00	64.00	64.00	64.00	64.00	1000.00	1000-00
CATAL	EXPLOSIV	VIELD	256 LB	256 LB	256 LB	256 LB	256 LB	256 LB	256 LB	256 LB	256 La	256 LB	256 LB	256 LB	64 L8	64 LB	64 La	64 LB	1000 LB	1000 L3
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TABLE		MEDIUM	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA	PLAYA
		DATE HO YR	JAN64	JAN64	JAN64	JAN64	JAN64	JAN64	JAN64	JAN64	JAN64	JAN64	JAN64	JANG	JAN64	JAN64	JAN64	JAN64	JAN64	JAN64
	ICATION	SITE	NTS-A5	NTS-A5	NTS-A5	NTS-A5	NTS-A5	NYS-A5	NTS-A5	NTS-A5	NTS-A5	NTS-A5	NTS-A5	NTS-45	NTS-A5	NTS-A5	NTS-A5	NTS-AS	NTS-A5	NTS-45
		/SHOT ME	A7-11	82-II	11-3	46-II	11-98	II-16A	II-108	II-11A	II-118	11-12	11-13	4I-1I	III-14	111-18	31-11I	01-111	111-2A	III-28
		RIES	VENT	VENT	VENT	VENT	VENT	VENT	VENT	VENT	VENT	VENT	VENT	VENT	VENT	VENT	VENT	VENT	VENT	VENT
	ļ	Š	AIR	AIR	AIA	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR
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		ε VT N0.	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226

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CATALOGED MATERIAL PROPERTY DATA TABLE 3.

	SHOT ID	ENT.		AM	TERIAL		HT-VOL	RELATIO	JINSN	5				STRENG	THS	AND	S TR	SHINS				
1 A I	SERIES/SH NAME	01 6	FT	HEDIUH	USCS	NO.	SP GR	DRY UNT LB/CUFT	NOIS C	12	NSLE-S 1	IS4	CNC	COHP		STN NI	NO CON	F COMP	CNF	PRES	I U U U	NIN NI
	SCHOONE	~	5562	TUFF	ROCK	72	2.56	103.6	7.	i w 1 0	1400 6			15000		1050		25000		208		0600
~	CABRIOLE	F	6197	RHYOLTE	ŔĊĊŔ	59	2.63	153.1	<b>5</b> 1.	ŝ	862	360		12220	•	032		45980		5 000	•	7110
m	PALANDUL	z	6190	RHYOL TE	ROCK	64	2.62	155.0	s 1.	<b>5</b>	930 8	0		13370	•	5201	•	50000		2000		0120
\$	SULKY		5328	BASALT	ROCK	52	2.64	164.5	<b>8</b>	64 15	2640 E	•		14470	•	1038	÷	28000		200		2400
Ś	SEDAN		4320	γιιν	HS-3S	69	2+60	110.0	12.	5	7 8	•		11		0020		263		69	•	050
9	DANNY BO	<u>ب</u>	54,75	BASALT	ROCK	50	2.84	160.0	8	ŝ	1955 8	•		52245	•	034		40420		2000		655
~	TEAPOT E	SS	4226	ALLUV	NS-98	£4	\$ 2.58	\$ 95.0	<b>5</b> .	5 2	m	0	•	ŝ		1203	×	300	**	80		0360
٩	JANGLE !	2	6624	ALLUV	HS-98	54	2•55	91,0		•	n	0	•	ŝ		1200	s	300	÷	8		0360
500	JANGLE	S	4212	ALLUV	HS-4S	54	2+58	87.0	• 9 •	•	80 10	0	•	ŝ		002(	•	360	\$	80		0 S O
105	JOHNIE BI	0Y \$	5000	ALLUY	P-S-92	21	\$ 2.58	112.0	N.	9 8	8	•	8	0	80.1	0000	0	0	8	0	30.0	0000
¢	SCOOTER		4322	ALLUV	SP-SH	3	\$ 2.60	87.0		<b>\$</b>	9	0	w	5		1200	v	300	•	100		0001
	ADDN STR-	-STN PAR	AMETE	ßS		Ŭ	DULUS VAL	LUES		*1	יב ענוסט	ITTES	ATT	11 986	HITS			INTERNI	r F	ERGIE	и И	KEMKS
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EVT NO.	SERIES/SHOT NAME	ELEV	MEDIUM	USCS CLASS	REF NO.	SF GR DI	RY UNT B/CUFT	HOIST PR CT	TNSLE-	S TNSLE-	ONU G	COMP	FLE S IN/I	H CO	LF CONP PSI	R N C	RES FL	E STN EN/EN
10	STAGECOACH-1	11111	ALLUY	SP-SH		2.55	101.1	6.1		8		5	20.3	, s			100	. 1000
11	STAGECOACH-2	4323	ALLUV	HS-dS	86	2.55	99.7	8.0	•	8	*	ŝ	\$ • 02	\$ 00	360		100 \$	.1000
12	STAGECOACH-3	4332	ALLUV	HS-98	86	2+55	101.2	6.6	4	8	5 0	ŝ	<b>\$ .</b> 02	<b>\$</b> 00	300	•	180 S	.1080
13	SANDIA SR 1-2	4300	ALLUV	HS-98	99	3 25.22 2	130.0	8 8.0		8	•	3	<b>3</b> . C2	<b>3</b> ng	308	(4)	100 \$	.1000
14	SANDIA ok I-4	4300	ALLUY	HS-98	36	1 2,55 \$	100.0	\$ 8.0	*	8	<b>3</b> 0	4	<b>20.</b>	\$ 00	300	•	100 5	.1000
15	SANDIA SR I-3	4300	ALLUV	NS-92	36	\$ 2.50 \$	\$.00.0	\$ 8.0	ų	83	*	t.	<b>5 .</b> 02	<b>\$</b> 00	300	•	100 \$	.1000
16	SANDIA SR I-9	4300	ALLUV	42-92	<b>8</b> 6 1	1 2.55 \$	100.0	5 8.0	•	80	*	£.	<b>3 . 0</b> 2	2 00	300	•	100 \$	.1000
17	SANUIA SP I-10	4300	ALLUY	HS-92	86 1	: 2.55 \$	100.0	\$ 8.0	*	8	<b>\$</b> 0	4	\$ .02	<b>\$</b> 00	300	•	100 \$	.1000
13	SANDIA SR I-11	4300	ALLUV	P-SH	36	: 2.55 \$	100.0	D.8 J		8	<b>s</b>	£.	<b>\$ .</b> 02	<b>\$</b> 00	300		100 5	.1000
19	SANDIA SR I-12	4300	ALLUY	HS-dS	36	\$ 5.55 \$	100.0	\$ 8.0		8	•	æ	<b>\$ .</b> 02	200	300	•	100 1	.1000
20	SANDIA SR I-15	4300	ALLUV	HS-dS	86	\$ 5:22	100.0	\$ 8.0	•	8	<b>v</b>	£	1.02	<b>S</b> 00	300	•	2 0 3 3	.1000
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TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED) MATERIAL WI-VOL RELATIONSHIPS STREMGTHS AND STRAENS

SHOT IDENT.

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UES WAVE VELOCITIES ATTBRG LIMITS INTERNAL ENERGIES REMAS SHEAR SEISHIC SHEAR LL PI RECOV HELT VADOR SEE PSI FPS PR CI PR CI PR CI MPSI/CIN MPSI/CIN NOTE 100 1 .1000 100 1 .1000 100 1 .1000 100 \$ .1300 100 \$ .1000 100 1 .1000 00: 1 3 001 100 1 .1000 100 \$ .1900 100 5 .1000 100 5 -1000 8 0 8) 0 6) 0 6 0 8 æ œ 6 ພ 300 5 300 \$ 300 \$ 30.0 \$ 3 0 0 5 3005 3005 o 0 300 \$ 3005 3005 30.0 \$ CATALOGED MATERIAL PROPERTY DATA (CONTINUED) 95 B 95 e c 2000 B 0.0 B 0.0 S 95 P 95 P 95 P 95 P 95 P 95 8 2000 8 0.0 8 0.0 \$ 95 4 \$ .0200 \$ 4 5 .0200 5 4 5 .0200 2 4 5 .0200 5 4 5 .0200 \$ 4 5 .0209 5 \$ 0200 \$ 7 4 5 .0200 5 4 S.0200 \$ \$ 0200 \$ 7 4 5 .0200 0.0 \$ 3 0.0 0.0 0.0 0.0 5 0.0 5 0.0 5 2000 8 0.0 8 0.08 0.0 8 0.0 8 0.08 0.0 8 0.0 8 0 V 2000 9 2000 8 • **0 4** 0 1 • 2000 9 2000 8 0 1 **8** 0 **9** 14 0 0 9 2000 9 2000 8 8 2 2 8 2 8 2 8 2 2 B 0 8 2 œ ø 2 8 2 2 8 3000 \$ 3000 \$ 3000 \$ 3000 \$ 3000 \$ 3000 \$ 3000 \$ 3000 \$ 3000 \$ ALLUV SP-SH 66 \$ 2.55 \$ 100.0 \$ 5.0 \$ 8.0 \$ 8.0 \$ 8.0 \$ 8.0 \$ 0.0 \$ 8.0 \$ A.0 S 8.0 \$ 86 \$ 2.55 \$ 100.0 \$ 8.0 \$ 86 \$ 2.55 \$ 100.0 \$ 8.0 \$ 5 200 \$ 5700 \$ 5700 \$ \$ 0025 5700 \$ 57000 \$ 57000 3 \$ 00013 57000 \$ -----------86 \$ 2.55 \$ 100.0 \$ 36 3 2.55 3 100.0 3 36 \$ 2.55 \$ 100.0 \$ 86 f 2.55 \$ 100.0 \$ 86 \$ 2.55 \$ 100.0 \$ 86 \$ 2.55 \$ 100.0 \$ 86 \$ 2.55 \$ 100.0 \$ 06 1 2.55 1 100.0 1 HODULUS VALUES 16000 1 16000 \$ 16000 x 16090 \$ T6000 S 160000 \$ 160000 3 160000 4 160000 3 PHI COHESION POISN BULK SECANT YOUNGS PHI COHESION POISN BULK SECANT YOUNGS 05G PSI RATIO FACTOR PSI PSI HEDIUN USCS REF CLASS NO. 14 10 \$ 0 ₩ 0 1 0 يد 0 ⊷ • •• • . 0 5 0 TABLE 3. SP-SH SP-S4 P-S-98 SP-SH HS-92 HS-92 METERIAL SP-SH SP-SN HS-dS HS-92 ----γυλλ ALLUV 4300 ALLUV 4300 ALLUV ALLUV ALLUV ALLUV ALLUV ALLUV ALLUV C Ø 15 1 .4.3 1 .20 3 15 \$ .40 \$ 1.20 8 15 4 .4.1 5 1.2.1 8 1 4 4 40 5 1.20 8 0 15 1.40 3 1.20 8 15 5 .43 5 1.20 8 15 \$ .40 \$ 1.20 15 3 .40 \$ 1.20 15 2 .43 2 1.23 ADDN STR-SIN PARAYETERS 4300 4300 4300 4300 4300 4300 4300 4300 4300 7515 7515 SERIES/SHOT SANDIA SR I-16 \*\*\*\*\*\*\*\*\*\*\* SANDIA SR II-2 SANDIA SR II-5 SANDIA SR 1-17 SANDIA SR II-5 SANDIA SR II-8 SANDIA SR II-9 SANDIA SR II-1 SANDIA SR II-4 SANDIA SR II-6 SANDIA SR II-7 SHOT LOENT NAME 26 \$ 47.0 \$ 21 5 47.0 \$ 22 3 47.0 5 23 \$ 47.0 \$ 24 3 47.0 \$ 25 \$ 47.0 \$ 27 5 47.0 5 28 5 47.0 5 29 2 47.0 3 EVT NO. 21 ä 52 22 ŝ 8 S 29 26 27 5 31 No.

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TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED) MATERIAL WI-VOL RELATIONSHIPS STRENGTHS AND STRAINS

SHOT IDENT.

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CATALOGED MATERIAL PROPERTY DATA (CONTINUED) WT-VOL RELATIONSHIPS TABLE 3. MATERIAL

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CATALOGED MATERIAL PROPERTY DATA (CONTINUED) TABLE 3. HATERIAL

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CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

MODULUS VALUES WAVE VELOZITIES ATTARG LIMITS INTERNAL ENERGIES REMX: TOUNGS SHEAR SEISHIC SHEAR LL PI RECOV HELT PSI PSI PSI FPS PR CT PR CT PR CT PSI/CIN MPSI/CIN MOTE SP GR DRY UNT HOIST INSLE-S TUSLE-O UNC COMP FLE STN CONF COMP CMF PRES FLE STN Leader PR CT 951 PS1 IN/IN PS1 PS1 IN/IN 30 \$ .0700 30 \$ .0700 30 \$ .0700 30 \$ .0700 30 \$ .0700 30 \$ .0700 30 \$ .0700 30 \$ .0700 30 \$ .0700 30 \$ .0700 30 \$ .0700 14 23 0 θ o 221 205 205 205 205 16.0 221 221 155 16.6 138 STRENGTHS AND STRAINS 4000 \$ 2500 B 0.0 B 0.0 \$ 70 P 25 \$ .0040 25 \$ .0040 25 5 .0040 25 \$ .0040 25 4 .0040 25 \$ .0040 23 \$ .0049 23 \$ .0040 23 2 .0640 23 \$ .0040 25 \$ .0043 ₩ 0 \$ 0 **\$** 0 0 0 12 **\$**∙ 0 8 0 \$ **9** ¢ (3 0 8 2 3 9 2 8 19 8 5 8 2 8) -7 8 7 8) -7 5 8 8 5 4 1 13.0 \$ 9.0 \$ 3 0 6 3 0.6 9.3 3 12.7 5 9.3 \$ 9.3 5. 3.6.5 13.0 5 9.6 \$ 15000 \$ WT-VOL RELATIONSHIPS 61.6 61.8 61.8 61.6 61.6 61.7 61.7 61.8 61.8 61.7 61.7 MODULUS VALUES 38000 \$ 2.56 2.56 2.56 2.56 2.56 2.61 2.61 2.61 2.61 2.56 2.56 ----ы 0 ~ HEDIUM USCS REF CLASS NO. TABLE 3. PHI COHESION POISN BULK SECANT DEG PSI RAIIO FACTOR PSI DEG PSI RAIIO FACTOR PSI MATERIAL ¥ f ¥ f f ž ž f ź f ž PLAYA PLAYA PLAYA PLAYA PLAYA 5 \$ .30 \$ 1.00 9 PLAYA PLAYA PLAYA PLAYA TOBOGGAN-E4B \$ 4000 PLAYA T090664N-E4.58 \$ 4000 PLAYA ł ADON STR-STN PARAMETERS TOBOGGAN-52A \$ 4000 \$ 4000 0007 T09066AN-E4.5A \$ 4300 4000 4000 \$ 4309 0067 \$ 4360 -----ELEV FT 64 ы T090664N-E3.54 5 T080664N-E4A \$ \*\*\*\*\*\*\*\*\*\*\* TOBOGGAN-E2C T08066AN-E3A T08066AN-E38 T0806GAN-E28 TOBOGGAN-E3C SHOT IDENT. SERIES/SHDT NAME 43.0 EVT SE NO. 50 88 89 6 5 56 56 36 95 96 97 NO. 88 67

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CATALOGED MATERIAL PROPERTY DATA (CONTINUED) STRENGTHS AND STRAINS WT-VOL RELATIONSHIPS TABLE 3. MATERIAL

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20LU II-)	ŝ	•	1800	SAND	SP	t	\$ 2.65	110.	2 6.	₩ N	2	ß	<b>9</b>		σ	10.1	375 3		20	14	5	0100
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S-11 N1NZ	519	•	1500	SAND	SP	t	\$ 2.65	110.	9 7.	<b>v</b> 5	N	8	•		1	10.2	375 \$	-	92	14	*	0100
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CATALOGED MATERIAL PROPERTY DATA (CONTINUED) wt-vol relationships sp gr dry unt moist tasles tasled und comp fle stm pois tasles fle stm leacuet pr ct psi psi psi in/in psi psi in/in TABLE 3. MATERIAL A MEDIUM USCS REF 3

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CATALOGED MATERIAL PROPERTY DATA (CONTINUED) ŝ TABLE

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	R STN N/IN	. 6100	.0100	. 0100	. 0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100	REHKS	SEE
	NF PRES FL PSI 1	2 9 2	3 71	2 77	14 5	14 5	14 \$	14 \$	14 5	14 5	14 5	14 5	ENERGIES	VAPOR MPSI/CIN
AINS	F COMP C PSI	128	88	96	74	96	156	11	70	96	96	96	INTERHAL	HELT MPSI/CIN
AND STR	STA CON	3 54 D C	0075 \$	6075	\$ 5200	0075	£ 015	\$ 5100	8 5100	0075	0075	<b>61</b> 55	s	- COKE
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	TNSLE-C	9	8	8	8	8	6	6 63	8	8	8	8	CITIES	SHEAR
	NSLE-S	8	~	2	2	N	2	2	2	N	~	N	VE VELO	ISHIC FPS
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RELATION	RY UNT B/CUFT	114.1	112.2	112.5	110.8	112.6	115.6	110.9	109.7	111.9	111.6	111.6	UES	SHEA
NT-VOL	SP GR 0	\$ 2.65	\$ 2.65	\$ 2.65	\$ 2.65	\$ 2.65	\$ 2.65	\$ 2.65	\$ 2.65	\$ 2.65	\$ 2.65	\$ 2.65	ULUS VAL	YOUNGS
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	ELEV	1600	1800	1800	1000	1600	100	1900	1000	1000	1800	1800	RANETEG	TIO FAC
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1N301 10	ES/SHOT NAME	9-II N	11-5521	01-II N	122-11	1-11 N	0 []-16	v II-19	11-S55	01SS-11	71SS-11	9122-11	N STR-STA	COHESIO
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SHOT IDENT.	NT.		ł	į	T A H	ERIAL		HT-V0	L RELATIO	JHSN	s			•,	STRENG	THS A	NJ STR	SHINS		1
ERIES/SHOT ELEV NAME FT	T ELEV	ELEV	>	T i	EDIUM	USCS	<b>P</b> <b>P</b> <b>P</b>	с С	LB/CUFT	AOIS PR CS		SI SI	TNSLE-		CONP	FLE S IN/I	1 N CO	F COMP C	NF PRES FI	E STN In/In
1900 \$ 2255-11 NT	22 \$ 1800	2 1600	8		SAND	ds	4	\$ 2.65	111.5	7.	*	Ñ	Ø	5	#	00. 2	75	32	14 5	.0100
14 II-SS\$ \$ 1800	3 5 1600	\$ 1600	0		SAND	SP	\$	\$ 2.65	110.6		•	2	6	•	10	1.00	\$ 52	61	14 5	.0100
ארט 11-559 <b>\$ 16</b> 01	9 \$ 160(	\$ 1600	ö	~	SAND	SP	t	\$ 2.65	111.9	<b>~</b>	¢ 2	N	8		12	1.00	75	96	14 5	.0100
14 11-SS24 \$ 1800	54 <b>\$</b> 160(	\$ 160(	ă	_	SAND	SP	4	\$ 2.65	111.4	~~~	5 N	2	8		11	1.00	¥ 52	88	14 5	.0100
ZULU-1A \$ 3161	\$ 318	5 316	ē.	×	LLUV	SP	٧Z	\$ 2.54	109.9	11.	<b>5</b>	2	8	<b>S</b> 0	ħ	\$ .02	60	196	42 3	• 02 00
ZULU-18 \$ 318	\$ 318	\$ 318	•	۲ ۵	LLUV	SP	82	£ 2°24	110.7	10.	<b>\$</b> 9	~	ß	5 3	£	1.02	8	191	\$ 2t	• 0200
ZULU-1C \$ 318	\$ 316	\$ 316	•	0 4	ורטע	SP	28	\$ 2.54	110.9	10.	<b>5</b> 10	~	8		4	\$ .02	00	191	12 5	. 05 00
ZULU-2A \$ 316(	\$ 316(	\$ 316(	ě.	۲ ۲	ררחג	SP	56	\$ 2.54	114.2	12.	<b>1</b>	1	63	<b>\$</b>	m	\$ .02	00	237	<b>4</b> 27	• 02 00
ZULU-28 \$ 318	\$ 318	\$ 318	•0	¥ 0	ררחג	SP	58	\$ 2.54	113.9	11.	*	4	8		n	\$ .02	00	202	\$ 21	• 02 00
ZULU-3A \$ 318	\$ 318	\$ 318	ē	۹ ۵	ורטע	SP	82	\$ 2.54	112.5	11.	*	7	8	<b>s</b>	~	\$ .02	00	195	42 \$	. 05 0 0
ZULU-38 \$ 3160	\$ 3180	\$ 3160	0	A	ררחא	SP	28	\$ 2.54	111.8	11.	15	4	8	<b>v</b>	<del>,</del> ,)	\$ .02	60	197	42 5	. 05 00
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CATALOGED MATERIAL PROPERTY DATA (CONTINUED)	IT-VOL RELATIONSHIPS STRENGTHS AND STRAINS	
TABLE 3.	MATERIAL	

Name:

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	E STU IN/IN	. 0500	• 02 00	. 05 0 0	• 02 0 0	. 05 0 0	. 25 0 0	. 05 0 0	• 02 0 0	• 02 0 0	.0500	.0500
	F PRES FL	\$ 27	\$ 27	42 \$	\$ 24	42 \$	\$ 24	\$ 25	\$ 24	42 \$	\$ 24	12 N N
TRAINS	ONF COMP CA PSI	211	224	724	190	190	191	191	190	190	190	197
THS AND S	FLE STN C	<b>5</b> .0200	5 .0200	5 .C200	5 . 026C	5 .0200	\$ • 0200		\$ .0200	£ .0203	\$ •0200	\$ •0200
STRENG	NC COMP I	æ	æ	4	*	2	t.	4	4	3	£.	*
	NSLE-D U	<b>9</b> 0	•	0	9	<b>\$</b> 0	•	<b>3</b> 0	8 0	<b>3</b> 0	0	<b>9</b>
	HSLE-S T PSI	4	1	8		1 8	18	1 0	1	1 8	1 8	19
Se IHSNI	HOIST F	10.9	11.3 5	13.4 \$	9.6	9.6	5.93	9.1.6	9.3 \$	9.3	9.8	9.6
RELATIO	DRY UNT LB/CUFT	113.8	115.3	115.2	103.9	105.7	109.4	10.2	107.2	105.7	107.2	105.9
NT-V01	SP GR	1 2 2 54	1 2 2 54	1 \$ 2.54	1 \$ 2.54	\$ 2.54	\$ 2.54	\$ 2.54	\$ 2.54	1 \$ 2.54	1 \$ 2.54	\$ 2.54
RIAL	USCS REF	SP 28	SP 26	SP 28	SP 26	SP 28	SP 28	SP 28	5P 26	SP 26	SP 26	SP 28
MATE	HEDIUN	ALLUV	ALLUY	ALLUY	ALLUV	ALLUY	ALLUV	ALLUV	ALLUY	ALLUV	אררטע	ALLUV
	ELEV F1	31.90	31.80	31.60	31.60	3180	31.60	3180	3180	31.80	31.60	3160
		•	•	•	••	*	•	*	•	•	••	••
THOT IDEN	SERIES/SHOT MAME	ZULU-JC	2010-40	214_U-48	ZULU-5A	2020-58	ZULU-6A	2ULU-68	ZULU-7A	2010-80	2ULU-9A	2010-90
	ž č NO NO	171	172	173	174	175	176	177	178	179	160	181

AC	IDN STR-ST	TN P.	ARAH	ETES	s		ИОР	אא צטוטנ	LUES		A N	VE VE	<b>31115</b> 5	4	1188	5	STIN.	ł		NTERNAL	ENERGIES	8	MKS
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÷2,	D	<b>\$</b> M	.43	4 14	• 22 •	8	•	30000	•	110000	w	4200	\$ 230	<b>70</b> B	••	80	0.0	8	0	с, с,	8	2	
39.	0	2 <b>2</b>	. 40		.22	8	3 0	3000	•	110000	•	4200	\$ 23(	9 O C	ċ	8	•••	0	0	0	8	ដ	
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39.	0	<b>*</b>	<b>1</b> .4.0	*	.22	æ	<b>9</b>	30000	<b>4</b>	110000	**	4200	\$ 230	9 90	÷.	8 5	0-0	<b>6</b> 1	9	6	<u>د</u>	Ñ	_

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SP GR DRY UXT HOIST HOLST INSLE-S INSLE-O UND JONP FLE STN JONF JONP DNF PAES FLE STN Langer pr CT PSI PSI PSI IN/IN PSI PSI IN/IN \$ .65 00 42 5 .0500 30 \$ .0700 30 \$ .0700 42 5 .0500 200 \$ .0090 200 \$ .0090 200 \$ .0090 200 \$ .0090 30 \$ .0700 200 \$ .0090 3 25000 \$ 25000 \$ 25000 \$ 25000 \$ 25000 \$ 103 205 205 197 197 205 CATALOGED MATERIAL PROPERTY DATA (CONTINUED) STRENGTHS AND STRAINS 3 \$ .0200 \$ 0 \$ 15000 \$ .0050 \$ 0 \$ 15000 \$ .0050 \$ 15000 \$ .0053 \$ 15000 \$ .0050 \$ 0 \$ 15000 \$ .0050 \$ 4 5 .0200 25 1 .0040 25 \$ .9043 25 \$ .0040 4 5 .0200 WAVE VELOCITIES ATTORG LIMITS **5**0 **5**0 **9** 44 0 0 M 1 0 **\$ 0 1** 8 1 8 1 8 8 7 8) 1 6 7 0 \$ 2.55 \$ 109.0 \$ 5.0 \$ 1400 8 0 \$ 2.56 \$ 109.0 \$ 6.0 \$ 1400 8 1400 8 1400 8 0 \$ 2.56 \$ 109.0 \$ 6.0 \$ 1400 8 0 \$ 2.56 \$ 109.0 \$ 6.0 \$ 6.0 \$ 9.8 \$ 10.5 \$ 9.8 \$ 15.9 \$ 16.1 \$ 16.1 3 WT-VOL RELATIONSHIPS 0 \$ 2.56 \$ 109.0 \$ 67.4 84.1 111.0 34.1 112.4 103.4 HODULUS VALUES 28 \$ 2.54 16 \$ 2.56 28 \$ 2.54 26 \$ 2.54 18 \$ 2.56 18 \$ 2.56 MEDIUM USCS REF CLASS NO. ; TABLE 3. MATERIAL ROCK ROCK ROCK ROCK ROCK 8 ŝ SP ř ž f ...... ALLUY ALLUV ALLUV TUFF TUFF TUFF TUFF TUFF 5 3050 PLAYA \$ 3050 PLAYA 202 AIR VENT II-2A \$ 3050 PLAYA ADDN STR-STN PARAHETERS 3160 3180 3180 5356 5348 5338 5321 5317 ELEV FT w 109 SANDIA-TUFF 11 ............. 290 AIR VENT I-1 SHOT IDEHT. SANDIA-TUFF 1 SANDIA-TUFF 2 SANDIA-TUFF 6 SANDIA-TUFF 7 SERIES/SHOT NAME 201 AIR VENT II-1 ZULU-10A ZULU-109 ZULU-111A 185 186 187 160 201 103 101

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INTERNAL ENERGIES REMKS YOUNGS SHEAP SEISMIC SHEAR LL PI RECOV NELT VAPOR SEE PSI FPS FPS PR CT PR CT PR CT HPSI/CIN HPSI/CIN HPSI/CIN HOTE 21 51 ŝ 22 22 22 22 3 5 5 7 77 • 8 0 8 0 8 0 8 0 9 9 8 0 83 0 80 8 0 8 5 80 6 0 70 8 d 0 0.01 708 708 2300 9 0.0 8 0.0 8 0 6 4000 8 0.0 8 0.0 3 70 8 0.0 \$ 70 P 0.0 % 70 R 0.0 \$ 70 8 0.0 \$ 70 2 0.08 3 0.0 **5 0 \* 0** 2300 8 0.0 8 0.0 8 2300 8 0.0 8 2500 8 0.0 8 0.0 9 0.0 8 0.0 8 2508 8 0.0 9 2500 8 0.0 B 4 000 9 6 000 t \$ 000 t 110000 \$ 4200 \$ \$ 0027 5700 \$ \$ 000% 4200 \$ 5700 \$ 5700 \$ 5700 \$ 5700 \$ \$ 0007 \$ 0007 110000 5 \$ 00000 \$ 600000 \$ 15000 % 15000 1 15000 1 100001 600000 \$ 600000 3 600000 F 0 \$ 300000 \$ 300000 3 00000 5 1400000 \$ 1400000 5 38000 \$ 1400000 \$ 38000 \$ 3 00065 1400000 5 1400000 5 ... 0 • **3** 14 0 \* ₩ 0 ., 0 ₩ 0 **9** 0 8 SECANT PSI 3 5 .40 5 1.22 8 3 5 .40 5 1.22 8 2 \$ .40 \$ 1.22 8 2000 \$ .15 \$ 1.10 8 2006 \$ .15 \$ 1.10 8 2003 1 .15 1 1.10 8 2000 3 .15 \$ 1.10 8 2000 \$ .15 7 1.10 8 7 3 .30 \$ 1.00 8 7 5 .30 5 1.03 8 7 5 .30 5 1.00 8 PHI COHESION POISN BULK Deg PSI Ratio Factor 184 5 39.0 5 105 3 42.0 5 166 \$ 42.0 \$ 187 \$ 42.0 \$ 146 3 42.0 5 169 \$ 42.0 \$ 200 1 29.0 1 201 \$ 29.0 1 202 1 29.0 1 39.0 39.0 -----1 132 1.03 17 N 10. ł

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

	N N N	0020	00.0	0100	0020	07 60	0100	0100	0020	0010	00.00	01 00	
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	CNF PRES	30	30	30	30	30	30	30	30	30	30	33	
TRA INS	ONF CCHP PSI	205	205	205	205	205	205	205	205	205	205	205	
S CNY SH	E STN C	.0040	C 7 D O .	.0040	• 0070	0700-	.0040	. 0040	.0040	.0040	. 0043	6400.	
HG TI		<b>\$</b>	4) 14	5	5	5	₩ \$	÷	<b>1</b>	\$	¥ 5	••	
STRE	NC COM	N	ŝv	N	N	2	N	N	N	N	N	N	
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CATALOGED MATERIAL PROPERTY DATA (CONTINUED) TABLE 3.

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- 2 GEOPHYSICAL DATA FRAM REF. 56.
- J GEOPHYSICAL DATA FRAM REF. 57.
- . MATERIAL PROPERTY DATA ALSO FROM REF. 34.
- 5 PREDOMINATELY SP-SH BUT ALSO INCLUDES GP-GM.
- 6 BULKING FACTOR FROM REF. 23.
- 7 UMAVAILABLE MATERIAL PROP. DATA ESTIMATED USING REFS. 53, 69 AND 86.
- UNAVAILABLE MATERIAL PROP. DATA ESTIMATED USING REF. 69.
- 9 UNAVAILABLE MATERIAL PROP. DATA ESTIMATEO USING REFS. 28, 53, 69 AND 86.
- 10 ESTIMATED VALUES BASED ON REFS. 28 AND 69.
- 11 ESTIMATED VALUES BASED ON REF. 2.
- 12 DATA ALSO OATAINED FROM REF. 35.
- 13 GEOPHYSICAL HEASUREMENTS FROM REF. 68.
- 14 FSTIMATED VALUES BASED ON REF. 64.
- 15 ESTIMATED VALUES BASEC ON REF. 2.
- 16-18. NOTE YUMBERS NOT USED.
- 19 VOLUME CALCULATED USING- VOL = 0.45(PI)(R)(R)(0).
- 20 ESTIMATEO VALUES BASED ON REF. 01.
  - 21 ESTIMATED VALUES BASED ON REF. 69.
- 22 ESTIMATED VALUES BASED ON REF. 72.

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## APPENDIX II

## THE COMPUTER PROGRAM

Description of the Program Elements. Considerable time and effort was expended in developing the program and its formats. Therefore it seems appropriate to include it as an appendix. A brief description of its essential features follows.

Main Program. - This portion of the program is nothing more than a calling program, i.e., it calls the various main subroutines to read, sort and print the data and to perform the surface fit of selected data.

Subroutine REDATA. - This subroutine reads and stores all crater and material property data into the computer data banks. Six cards are read for each cratering event. In addition, any note cards associated with an event are also read and stored.

Subroutine PRDATA and Related HEAD Subroutines. - This subroutine prints all crater and material property data along with calling the related CDHEAD, MPHEAD1 and MPHEAD2 subroutines to provide the necessary headings for the output data. This subroutine produces the cataloged data listing.

Subroutine SURFIT. - This subroutine is the main program for the conduct of the least squares surface fit and analysis. It primarily calls the various subroutines necessary to perform the surface fit and analysis. It also specifies the dependent
variable (radius, depth or volume), the scaling exponent and the number of independent variables to be used in the surface fitting process. In addition, it calls for or specifies printing of all pertinent matrices and coefficients.

Subroutine EQN. -This subroutine determines the type regression and the independent variables to be used in the least squares surface fit. It develops the vector of observations and the matrix of measured independent variables and normalizes these matrices to provide better matrix inversion and manipulation.

Subroutine CORCO. - This subroutine develops a simple correlation matrix between all the variables involved in the surface fit; dependent as well as independent.

Subroutine COEFF. - This subroutine takes the vector of observations and the matrix of measured independent variables and generates the vector and x-coefficient matrices. These latter matrices are, in essence, the normal equations which must be solved simultaneously to obtain the regression coefficients.

Subroutine ABPRN. - This subroutine prints the coefficients of the prediction equation. It also prints the decoded form of these coefficients when the model used was either a three or four parameter bell curve.

Subroutine PREDIC. - This subroutine calculates the estimated value of the dependent variable for each observation using the empirical equation generated and compares this value

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with the actual. It also calculates the multiple correlation coefficient and standard deviation for all the data being considered.

Subroutine MATINV. - This subroutine inverts the x-coefficient matrix to be used in solving the normal equations.

Subroutine MATPRN. - This subroutine prints a square matrix. It is used to print the x-coefficient matrix as well as the unit matrix which should result when the x-coefficient matrix and the inverse of the x-coefficient matrix are multiplied together.

Subroutines SIMALT and MULT. - These subroutines multiply a square matrix times a column matrix and a square matrix times another square matrix respectively. They are used to multiply the inverse of the x-coefficient matrix times the vector matrix to obtain the coefficients of the curve fit and to multiply the x-coefficient matrix times its inverse.

<u>Typical Program</u>. - A computer printout of the program as it was run during the latter stages of the research follows.

<u>Sample Data Output</u>. - The computer output for a simple regression analysis of scaled radius as a function of scaled depth of burst and one material property, total unit weight, using the skewed bell curve model follows the program.

```
PROGRAM MAIN(INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT, PUNCH, TAPE7=
           *PUNCH)
       HAIN PROGRAM
            CALL REDATA (NOATA)
CALL SURFIT(NDATA)
            STOP
            EN0
  C********
                                     *******
            SUBROUTINE REDATA(NDATA)
       THIS SUBROUTINE READS ALL CRATER AND MATERIAL PROPERTY DATA FOR EACH
CRATERING EVENT. SIX CARDS ARE READ FOR EACH EVENT(ITEM NO.) ALONG
  C
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       HITH ANY REMARKS(NOTE) CARDS. A BLANK CARD MUST BE INSERTED BETHEEN
DATA GARDS AND NOTE CARDS AND AT THE END OF THE NOTE CARDS.
COMMON H(200,28),SHOT(200,4),SITE(200,2),DATE(200,2),
          COMMON H(200,28),SHOI(200,4),STE(200,2),DATE(200,2),
*EMED(200,2),EXTYPE(200),YIELO(200,3),TNTHT(200),20B(200),
*RADIUS(200),DEPTH(200),VOL(200),HTLIP(200),
*RMKCD(200),ELEV(200),CLASS(200,2)
COMMON SPGR(200),UHT(200),PHOIST(200),SPTEN(200),DITEN(200),
*UCOMP(200),UCSIN(200),CCOMP(200),SONFP(200),CCSTN(200),PHI(200),
*COMES(200),POISN(200),BULK(200),SECMOD(200),YOUMOD(200).
           *SHEMOD(200), SEIVEL(200), SHEVOL(200), ATTLL(200),
           *ATTPI(200), CORE(200), EMELT(200), VAPOR(200), RMKHP(200, 2)
            CONHON IN0(200), NREF(200), ISL(200), HREF(200)
            COMMON /NOTE/ NCARD(10), RNTE(100), TEXT(100,19)
            1=0
      100 T=I+1
           READ(5,10) INO(I), NREF(I), (SHOT(I,J), J=1,4), (SITE(I,J), J=1,2),
*(DATE(I,J), J=1,2), (EMEO(I,J), J=1,2), EXTYPE(I), (YIELD(I,J), J=1,3),
           +INTHT(I)
            IF(INO(I).EQ.0)GO TO 200
            READ (5,20) DOB(I), RADIUS(I), DEPTH(I), VOL(I), W(I,1), ISL(I), W(I+2),
           "HTLIP(I),RHKCD(I)
            READ(5,30) + (1,3), ELEV(1), (CLASS(1,J), J=1,2), (REF(1), + (1,4),
           +SPGR(I), W(I, 5), UHT(I), #(I, 6), PHOIST(I)
          % KEAD(5,40) #(I,7) *SPTEN(I) *#(I,8) *DITEN(I) *#(I,9) *UCOMP(I) *#(I,10) *
*UCSTN(I) *#(I,11) *CCOMP(I) *#(I,12) *COMFP(I) *#(I,13) *CCSTN(I)
READ(5,50) #(I,14) *PHI(I) *#(I,15) *COHES(I) *#(I,16) *POISN(I) *
#(I,17) *BJ_K(I) *#(I,18) *SECHOD(I) *#(I,19) *YOUMOD(I) *#(I,20) *
           *SHENOD(I)
           READ(5,60) W(I,21),SEIVEL(I),W(I,22),SHEVOL(I),W(I,23),
*W(I,24),AITLL(I),W(I,25),ATTPI(I),W(I,26),CORE(I),W(I,27),
           *EHELT(I), W(I, 28), VAPOR(I), (RHKHP(I, J), J=1, 2)
       10 FORMAT(1X,214,6A4,2A3,2A4,2X,3A4,A2,F13.2)
20 FORMAT(5X,3F8.2,F13.2,42,13,A2,F6.2,A4)
       20 FORMAT(21X, 42, F6.0, 8X, 243, 14, 42, F5.2, 42, F6.1, 42, F5.1)
40 FORMAT(5X, 2(42, F6.0), 42, F7.0, 42, F6.4, 42, F8.0, 42, F7.0, 42, F6.4)
       50 FORMAT(5x,42,F5.1,A2,F7.0,A2,F4.2,42,F5.2,3(A2,F9.0))
       60 FORHAT(5X,2(A2,F7.0), A2,7X,2(A2,F5.1), A2,F4.0.A2,F6.0,A2,F7.0,A4,A
            GO TO 100
     200 NDATA=I-1
            J=0
      300 J=J+1
            READ (5,70) NCARD (J) , RNTE (J) , (TEXT (J, K) , K=1, 19)
       70 FORMAT(11.F4.0.18A4.A3)
            IF (NCARD(J) . NE. 0) GO TO 300
            RETURN
            EN0
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SUBROUTINE PRONTA(NDATA)
     THIS SUBROUTINE PRINTS ALL DATA READ INTO THE COMPUTER BY THE RECATA
C
     SUBROUTINE.
        COMMON W(200,28),SHOT (200,4),SITE (200,2),DATE (200,2),
*EMED (200,2),EXTYPE (200),YIELD (200,3),TNTWT (200),DOB (200),
*RADIUS (200),DEPTH (200),VOL (200),HTL IP (200),
*RMKCD (200),ELEV (200),CLASS (200,2)
COMMON SPGR (200),UNT (200),PHOIST (200),SPTEN (200),DITEN (200),
        *UCOMP(200), UCSTN(200), CCOMP(200), CONFP(200), CCSTN(200), PHI(200), *COHES(200), POISN(200), BULK(200), SECHOD(200), YOUMOD(200),
        *SHEHOD(200), SEIVEL(200), SHEVOL(200), ATTLL(200),
        *ATTPI(200),CORE(200),EMELT(200),VAPOR(200),RMKMP(200,2)
COMMON INO(200),NREF(200),ISL(200),MREF(200)
COMMON /NOTE/ VGARD(103),RNTE(100),TEXT(100,19)
         1=0
   100 CALL COHEAD
NLINES=7
   200 I=I+1
        WRITE(6,10) INO(I), NREF(I), (SHOT(I,J), J=1,4), (SITE(I,J), J=1,2),
*(DATE(I,J), J=1,2), (EHED(I,J), J=1,2), EXTYPE(I), (YIELD(I,J), J=1,3),
        +TNTHT(I),003(I),RADIUS(I), DEPTH(I), VOL(I), H(I,1), ISL(I;, H(I,2),
        #HTLIP(I),RMKCO(I)
         IF(I.EQ.NOATA)GO TO 300
         NLINES=NLINES+2
         IF (NLINES.EQ.59) GO TO 100
         GO TO 200
   300 1=0
   400 CALL MPHED1
         NLINES=8
  K=0
500 I=I+1
         K=K+1
         WRITE(6,23)INO(I),(SHOT(I,J),J=1,4),W(I,3),ELEV(I),
        *(ENED(1, J), J=1,2), (CLASS(I, J), J=1,2), MREF(I), W(I,4), SPGR(I)
       *W(1,5),UWT(1),W(1,6),PHOIST(1),W(1,7),SPFEN(1),W(1,8),DITEN(1),
*W(1,9),UCOHP(1),W(1,10),UCSTN(1),W(1,11),CCOHP(1),W(1,12),
        *CONFP(I),W(I,13),CCSTN(I)
IF(I.EQ.ND4TA)G0 T0 550
         NLINES=NLINES+2
         IF(NLINES.LT.30)GO TO 500
   550 CALL HPHED2
         NLINES=NLINES+7
         I=I-K
  560 I=I+1
         WRITE (6,30) INO(I), W(I, 14), PHI(I), W(I, 15), COHES(I), W(I, 16), POISN(I)
       *,W(I,17),BULK(I),W(I,13),SECHOD(I),W(I,19),YOUHOD(I),W(I,20),
*SHEHOD(I),W(I,21),SEIVEL(I),H(I,22),SHEVOL(I),
*W(I,24),ATTLL(I),H(I,25),ATTPI(I),W(I,26),CORE(I),W(I,27),
        *EHELT(I),*(I,28),VAPOR(I),(RHKMP(I,J),J=1,2)
IF(I.EQ.NOATA)GO TO 600
         NLINES=NLINES+2
         IF(NLINES.EQ.59)GO TO 400
         GO TO 561
  600 J=0
         IF (NCARD(J+1).EQ.0) GO FO 700
  620 WRITE(6,40)
         NLINES=2
  530 J=J+1
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IF(NCARD(J).GT.1)GO TO 650
      WRITE(6,50) RNTE(J), (TEXT(J,K), K=1,19)
      NLINES=NLINES+2
      GO TO 670
  650 WRITE(6,60) (TEXT(J,K),K=1,19)
      NLINES=NLINES+1
  670 IF(NCARD(J+1).EQ.0)G0 T0 700
      IF (NLINES.GE.60) GO TO 620
      GO TO 630
  700 WRITE (6,70) NDATA
10 FORMAT (*0*,214,644,2×3,244,2×,344,42,F13.2,3F8.2,F13.2,A2,I3,A2,F6
     *.2,A4)
   20 FORHAT (*0*, I4, 444, A2, F6.0, 244, 2A3, I4, A2, F5.2, A2, F6.1, A2, F5.1, 2(A2,
     *F6.0), A2, F7.0, A2, F6.4, 42, F8.0, A2, F7.0, A2, F6.4)
   30 FORHAT(+0+, 14, A2, F5.1, A2, F7.0, A2, F4.2, A2, F5.2, 3(A2, F9.0), 2(A2, F7.0
     *),2(A2,F5.1),A2,F4.0,2(A2,F7.0),A4,A3)
   40 FORMAT(*1*, 36%, *N O T E S*)
   50 FORMAT(+0+,F4.0,18A4,A3)
   60 FORMAT(* *,4X,18A4,A3)
70 FORMAT(*1*,*THE NUMBER OF DATA ITENS =*,15)
      RETURN
EN0
      SUBROUTINE COHEAD
C THIS SUBROUTINE PRINTS THE HEADINGS FOR THE CRATER DATA LISTING.
      WRITE(6,10)
   10 FORMAT (*1*,53X,*C R A T E R
                                       D A T A*//18X, *IDENTIFICATION*, 24X,
     **EXPLOSIVE DATA*, dx, *DEPTH*, 10X, *APPARENT CRATER DIMENSIONS*, 7X,*
     *RHK*/2X,*-----
                                                                  -----
     *----*)
                            0:
                                  _____
      WRITE (6,20)
   20 FORMAT(* *,* EVT REF SERIES/SHOT*,5x,*SITE DATE MEDIUM TYPE

* YIELD*,5x,*EQUIV WT BURST RADIUS DEPTH*,5x,*VOLUME SLP

* LIP HT SEE*/2X,*NO. NO.*,7X,*NAME*,14X,*MO YR*,28X,*LBS-TNT

* FT FT FT FT FT*,7X,*CU FT DEG FT NTE*/2X,*--- --- --
                                                                         SLP
     *----- ------
                     RETURN
      END
C********
               *************
```

```
SUBROUTINE HPHED1
   THIS SUBROUTINE PRINTS THE HEADINGS FOR THE FIRST HALF OF THE MATERIAL
С
C
   PROPERTY LISTING
       WRITE(6,30)
    30 FORHAT(*1*,43X,*M A T E R I A L P R O P E R T Y D A T A*//,*
* */10X,*SHOT IDENT.*,14X,*MATERIAL*,6X,*M
      * - VOL RELATIONSHIPS*, 29X, * STRENGTHS AND STRAINS*/2X, *------
      .
        *------------*)
       WRITE(6+40)
    40 FORMAT(* *,* EVT SERIES/SHOT*,5X,*ELEV MEDIUM USCS REF SP GR
* DRY UHT MOIST THSLE-S THSLE-D UNC COMP FLE SIN CONF COMP CNF PRE
*S FLE SIN*/2X,*NO.*,7X,*NAME*,9X,*FT*,11X,*CLASS NO.*,8X,*LB/CUFT
* PR CT PSI PSI*,6X,*PSI IN/IN PSI*,7X,*PSI IN/IN*/
*2X,*--
      +)
       RETURN
       ENO
C+++++++++
             SUBROUTINE MPHED2
   THIS SUBROUTINE PRINTS THE HEADINGS FOR THE SECOND HALF OF THE MATERIAL PROPERTY DATA
C
С
   HRITE(6,50)
50 FORMAT(*0*,*
                                                    */9X, *ADUN STR-STN PARAHETERS
      **,13X,*HOOULUS VALUES*,10X,*HAVE VELOCITIES*,2X,*ATIBRG LIMITS*,5X
*,* INTERNAL ENERGIES REHKS*/*
          INTERNAL ENERGIES REMKS*/*
      +----
                                               -----
      *CORE -----*)
   *CORE

WRITE(6,60)

60 FORMAT(**,* EVI PHI COHESION POISN BULK SECANT YOUNGS*

*,6X,*SHEAR SEISHIC SHEAR LL PI*,3X,*RECOV*,3X,*HELT

* VAPOR SEE*/* NO. DEG PSI RATIO FACTOR PSI *,7X,*

*PSI*,8X,*PSI*,7X,*FPS FPS*,4X,*PR CT PR CT PR CI MPSI/CIN MP

*SI/CIN NOTE*/2X,*---
      +----- -----+}
       RETURN
       END
C+++++
```

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THIS SUBROUTINE DOES A LEAST SQUARES SURFACE FIT FOR RADIUS, DEPTH, AND VOLUME OF THE APPARENT CRATER
C
С
        DIMENSIONSEC(200), LX(41), LY(41), AU(200, 40), COL(200), XMEAN(40),
*VECT(40), XKOEF(40, 40), XK(1600), B(40),
        +HOLXK(40,4)),R(40,40),UHAT(46,40),DVAR(3)
         COMMON DUM (200.78), INO(200), IDUM(200.3)
Common /ATE/ UAN(40), ANS(40), EXPO
         EQUIVALENCE (XKOEF, XK)
    EQUIVALENCE (XKOEF,XK)
DATA BB,CC,DD,EE,SMAL/4HXKOF,4HPRNI,4HUNIT,4HCORK,1.E-96/
DATA DVAR/6HRADIUS,5H DEPTH,6HVOLUHE/
M=1 FOR RADIUS, 2 FOR DEPTH, 3 FOR VOLUME
L=1 FOR EXPO=0.250, 2 FOR 0.292, 3 FOR 0.3125, 4 FOR 0.333, 5 FOR VAR EXPO.
KK=1 FOR 3 PARAMETER EQN., 2 FOR 4 PARS., 3 AND 4 FOR 2 MAT. PROPS.,
5 AND 6 FOR 3 MAT. PROPS., 7, 8, 9, AND 10 FJR 4 MAT. PROPS.
C
С
С
         00 900 M=1,3
         L=3
         00 900 KK=4,10
         IF (KK.EQ.6.0R.KK.EQ.7)GO TO 900
         CALL EQN(COL, AU, ND, NP, L, CNORH, XMEAN, R, SEC, KK, N)
    33 WRITE(6,1) EXPO, DVAR(4)

1 FORMAT(*1*,*EXPONENT=*,F6.4,*

CALL MATPRN(R,NP,EE,CC)
                                                           FOR *, AG, * EVALUATION*)
         CALL COEFF (COL, AU, VECT, XKUEF, ND, NP, H)
         WRITE (6,2)
      2 FORHAT(*1*/* PRESENT CONTENTS OF VECT HATRIX*/)
         WRITE(6,5)(COL(I), I=1,NP)
      5 FORMAT (+0+, F12.4)
         CALL MATPRN (XKOEF, NP, BB, CC)
         00 100 I=1,NP
         00 100 J=1,NP
         HOLXK(I,J) = XKOEF(I,J)
   100 CONTINUE
         CALL HATINV(XK, LX, LY, NP, 40, SHAL)
         CALL MULT (UMAT, XKOEF, HOLXK, NP)
         GALL HATPRN (UHAT, NP, DD, CC)
  150 CALL SIMALF(XKOEF, VECT, ANS, NP)
WRITE(6,8)
      & FORMAT(*1*/* NORM. COEFS. OF THE PREDICTION EQUATION*)
    00 200 X=1.NP
00 WRITE(6,13) K,ANS(K)
10 FORMAT(*0*,*N(*,12,*)=*,F19.10)
 200
         00 90 K=1,NP
    90 UAN(K) =ANS(K)/XMEAN(K) + CNORH
         CALL ABPRN(UAN,NP,KK)
CALL PREDIC(COL,AU,ANS,INO,ND,NP,H,CNORM,SEC)
   900 CONTINUE
         RETURN
         END
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SUBROUTINE SURFIT(ND)

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SUBROUTINE EQN(COL,AU,ND,NP, L,CNORH,XHLAN,R,SEC,K<,H) THIS SUBROUTINE DETERMINES THE TYPE REGRESSION AND VARIABLES TO BE USED IN THE LEAST SQUARES SURFACE FIT AND DEVELOPS THE AU ARRAY C DIMENSION COL(N), AU(N0, 40), XMEAN(40), R(40, 40) REAL HEO DIMENSION MED(200), TYPE(6), SEC(NO) DATA TYPE/JH R, JH SP, JH S, JH H, JH C, JH CH/ COMMON W(200,28), SHOT(200,4), SIIE(200,2), DATE(200,2), \*EMED(200,2), EXTYPE(200), YIELD(200,3), TNTHT(200), DOB(200), \*RADIUS(200), DEPTH(200), VOL(200), HTL IP(200), \*RHKCD(200),ELEV(200),CLASS(200,2) COHHON SPGR(200),UHT(200),PHOIST(200),SPTEN(200),DITEN(200), \*UCOHP (200), UCSTN (200), CCOHP (200), CONFP (200), CCSTN (200), PHI (200), \*COHES (200), POISN (200), BULK (200), SECHOD (200), YOUHOD (200), \*SHEMOD(200), SEIVEL(200), SHEVOL(200), ATTLL(200), \*ATTPI(200), CORE(200), ENELT(200), VAPOR(200), RMKHP(200,2) COMMON INO(200), NREF(200), ISL(200), MREF(200) COMMON / AYE/ UAN(40), ANS(40), EXPO CNORH=0.0 GO TO(30,31,32,33,34),L 30 EXPO=1./4. GO TO 40 31 EXP0=7./24. GO TO 40 32 EXPO=5./15. GO TO 40 33 EXP0=1./3. GO TO 40 34 EXPO=1.0 40 CONTINUE DO 50 J= 1,NO 43 WUWT = ((1.+PMOIST(J)/100.)\*UWT(J))/62.43 SHUWT=WUWT\*\*(EXPO) SIG=1.0~(UHT(J)/62.43)\*((1.0/SPGR(J))+PHOIST(J)/100.) IF(SIG.LT.J.0) SIG=0.0 VMOIST=PMOIST(J) \*UWT(J)/6243. PROS=SIG+VHOIST VOURAT=PROS/ (1.0-PRJS) DESAT=VMDIST/PROS GO TO (210,220,230),H / TNT HT ( J) \*\* (EXPO) 210 Y=RADIUS(J) GO TO 250 /TNTWT (J) \*\* (EXPO) 220 Y=DEPTH(J) GO TO 250 IF(V∩L(J).LF.0.J) VOL(J)≈0.0 230 Y=VOL (J) \*\* (1./3.) / TNT HT (J) \*\* (EXPO) X= DOB(J) /TNTWI(J)\*\*(EXPO) IF(Y.LE.0.000)Y= .01 X= DOB(J) 250 IF(X.LE.0.)00) X=.01 YY=ALOG(Y) XX=ALOG(X+1.0) COL(J) = YYCNORM=CNORM+COL(J)/NO GO TO (110,120,130,135,140,140,150,150,150,150),KK 110 AU(J,1)=COL(J) AU(J,2)=X AU(J,3)=X\*X NP = 3

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GO TO 50 120 AU(J,1)=COL(J) AU(J,2) = XAU(J,3)=X+X AU(J,4)=X\*\*3 NP = 4 NP 44 GO TO 50 130 AU(J,1)=1.0 AA=SHUHT BS=DESAT AU(J,2)=44 AU(J,3)=83 AU(J,4)=A4++2 AU(J,5)=B8++2 AU(J,6)=44\*38 NMP=6 GO TO 180 135 AU(J,1)=1.3  $AU(J_{1}2) = SHUHT$ NMP=2 GO TO 180 140 AU(J,1)=1.J AA=SHUHT BB=DESAT CC=SPGR(J) AU(J,2)=AA AU(J,3)=BB AU(J,4)=CC AU(J,5)=A4+\*2 AU(J,6)=BB\*\*2 AU(J,7)=CC\*+2 AU(J,8)=44\*88 AU(J,9)=A4+CC AU(J,10)=88\*CC NHP=10 GO TO 180 150 AU(J,1)=1.0 AA=SHUHT 8B=0ESAT CC=SPGR(J) PHE=PHI(J)/180.0\*3.141593 IF(KX.EQ.9)CC=TAN(PHE) IF (K<.EQ.10) CC=SEIVEL(J) ++ (1./3.) AU(J,2) = AA AU(J,3) = B3 AU(J,4)=CC AU(J,5)=AA++2 AU(J,6)=VAPOR(J) AU(J,7)=CC++2 AU(J,8)=44+90 AU(J,9)=AA+CC AU(J,10)=88\*CC NMP=10 180 MS=NHP+1 NP=NHP#3 DO 300 HH=NS,NP 300 AU(J,HH)=AU(J,HH-NHP)\*K IF (KK.EQ. 3. OR. KK.EQ. 5)60 TO 47

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HS=NP+1
         HF=NP+NHP
         DO 400HH=MS, HF
   400 AU(J, HM) = AU(J, HH-NP) + X+ + 3
         NP=NP+NHP
    47 AU(J,1)=COL(J)
50 SEC(J)=DOB(J)/INTWT(J)++(EXPO)
    55 00 60 K=1,N0
COL (K)=COL (K)/CNORM
    60 CONTINUE
         00 79 J=1, NP
         XMEAN(J)=0.0
         00 70 I=1,N0
        XMEAN(J) = X MEAN(J) + AU(I, J) / ND
    70 CONTINUE
        00 80 J=1,NP
00 86 I=1,ND
AU(I,J)=AU(I,J)/XMCAN(J)
    80 CONTINUE
        CALL CORCO (AU, R, ND, NP)
        00 85 K=1, ND
        AU(K,1)=1.0
XMEAN(1)=1.0
   35
   190 RETURN
        END
C****************************
        SU3ROUTINE CORCO(X,R,ND,NC)
UIMENSION X(ND,40),R(40,40)
D0 100 I=1,NC
  00 190 J=1,NC
100 R(I,J)=0.0
        00 400 J=1,NC
00 400 I=J,NC
        1000=0.0
        TOP I = 0.0
        TOPJ=0.0
        801 I=0.0
801 J=0.0
        00 300 K=1,ND
TOPC=TOPC+X(K,I)*X(K,J)
        TOPI=TOPI+((K,I)
        TOPJ=TOPJ+X(K,J)
        BOTI=BOTI+X(K,I) **2
        80TJ= 80TJ+X(K,J) ++2
  R(I,J)=(TOPC-TOPI/NO*TOPJ)/ SQRT((BOTI-TOPI/NO*TOPI)*(BOTJ-TOPJ/NO
**TOPJ))
R(J,I)=R(I,J)
400 CONTINUE
  300 CONTINUE
        RETURN
        END
C****
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IF (KK.EQ.7) GO TO 47

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SUBROUTINE ABPRN (JAN, NP; KK)
        DIMENSION UAN(40), 8(40), 84(2)
        WRITE(6,8)
       FORMAT(*1*/* COEFFICIENTS OF THE PREDICTION EQUATION*)
     8
  00 200 K=1,NP

00 WRITE(6,10) K,UAN(K)

10 FORMAT(* *,*C(*,I2,*)=*,F19.10)

G0 T0 (310,320,800,800,800,800,800,800,800,800),KK

310 B(1)= EXP(UAN(1) - UAN(2)**2/(4.0*UAN(3)))
 200
        B(2)=UAN(3)
        B(3)=UAN(2)/(2*UAN(3))
        HRITE (6,88)
   88 FORMAT(+0+/+ COEFFICIENTS OF THE PREDICTION EQUATION*)
  DO 101 HM=1,NP
101 HRITE(6,11) HH,B(MH)
   11 FORMAT(*0*,*B(*,12,*)=*,F19.10)
        GO TO 800
  320 B(2) =UAN(4)
        BT=UAN(3)/UAN(4)
        BP= ABS(BT)
        UNRAD=8P**2.9-(3.0*UAN(2)/UAN(4))
        IF (UNRAD.GE.0.0) 60 TO 755
  WRITE(6,703) UNRAD
700 FORMAT(*9*,*UNRAD=*,F2G.10)
        UNRA0=0.0
       BSQT= SQRT (UNRAD)
 755
        B4(1) = (B\Gamma + BSQT) / 3.0
  B4(2) = (BT-BSQT)/3.0
00 900 JJ=1,2
813 B(4)=B4(JJ)
  812 B(3)=BT-(2.0*B(4))
        8NEG= A3S(3(4))
       B(1) = EXP(U4N(1) - B(2) + B(3) + HEG + 2)
        WRITE(6,55)
   55 FORMAT(*0*/* COEFFICIENTS OF THE PREDICTION EQUATION*)
  D0 191 HHH=1,NP
191 WRITE(6,22) HHH,3(HHH)
22 FORMAT(*U*,*0(*,12,*)=*,F19.10)
  900 CONTINUE
 800
       RETURN
       END
SUJROUTINE COEFF (GOL . AU, VECT . XKOEF, ND, NP, H)
   THIS SUBROUTINE GENERATES AND ASSEMBLES THE VECT AND XKDEF MATRICES
DIMENSION COL(ND), AU(ND, 40), VECT(40), XKOEF(40, 40)
ĉ
        ADATA=ND
       DO 10 I=1,NP
VECT(I)=0.
   10 CONTINUE
       00 30 I=1+NP
00 25 J=1+N0
        VECT(I) = VECT(I) + COL(J) + AU(J,I)
   25 CONTINUE
       VECT(I) = VECT(I) / ADATA
   30 CONTINUE
00 20 J=1,NP
00 20 K=1,NP
        XKOEF (J,K) =0.0
   20 CONTINUE
```

```
00 40 I=1,NP
        00 40 J=1.NP
00 35 K=1.ND
        XKUEF(I,J) = AU(K, I) * AU(K,J) + XKOEF(5,J)
    35 CONTINUE
        XKUEF(I,J)=XKOEF(I,J)/ADATA
    40 CONTINUE
    50 RETURN
        END
C+++++
                 SUBROUTINE PREDIC(COL,AU,ANS,IEV,ND,NP,H,CNORH,SEC)

THIS SUBROUTINE CALCULATES THE RADIUS, DEPIH, OR VOLUME USING THE

EMPIRICAL EQUATION GENERATED AND COMPARES THESE VALUES WITH THE ACTUAL.

DIMENSION IEV(N),COL(ND),AU(ND,40),ANS(NP),DVAR(3),SEC(ND),PAR(2)

DATA DVAR(6HRADIUS,6H DEPIH,6HVOLUME/
C
С
         WRITE(6,10) DVAR(M)
    10 FORMAT(*1*, 46, * PREDICTION AND EVALUATION*)
    WRITE(6,2)
20 FORMAT(*-*,10X,*PREDICTED VALUE*,12X,*ACTUAL VALUE*,12X,*PERCENT c
*RROR*,12X,*RESIDUAL*, 9X,*EVENT NO.*,6X,*SC 003*)
        CHEAN=0.0
        00 90 7-1,NO
    90 CHEAN=CHEAN+ EXP(COL(I) + CNORH)
        RTOP=0.0
        R801=0.0
        NL I NE S=0
        00 200 I=1,40
PREVAL =0.6
        00 100 J=1,NP
        PREVAL=PREVAL+AU(I-J) *ANS(J)
   100 CONTINUE
        PREVAL=PREVAL*GNORM
        ACTVAL=COL(I)*CNORM
        PREVAL= EXP(PREVAL)
        ACTVAL= EXP(ACTVAL)
        IF (ACTVAL.EQ.0.0) ACTVAL=1.0E-3
        RESID=PREVAL-ACTVAL
    RESID-REVAL -ACIVAL

ERROR=RESID/ACIVAL.+100.6

WRITE (6,30) PREVAL,ACIVAL,ERROR,RESID,IEV(I),3EC(I)

30 FORMAT(* *,6X,F17.6,3X,F17.6,15X,F8.2,6X,F17.6,9X,I5,2X,F15.4)

RIOP=RTOP+(PREVAL-CNOR4) **2
        RBOT=RBOT+ (ACTVAL-CNOR 1) **2
        NLINES=NLINES+1
        IF (NLINES.LT.50) G.) TO 200
        NLINES=0
        WRITE (6,50)
    50 FORMAT(*1*)
  200 CONTINUE
        RSQ=RTOP/RBOT*100.
        S=SQRT (R801/(ND-1))
WRITE (6,40) RSQ, DVAR(H).S
    40 FORMAT(*0*,*MULT CORR COEF =*,F9.2/* STAND. JEVIATION FOR *,A6,*=*
       *,F12.41
        RETURN
        END
C*********
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	SUBROUTINE BATTAY TATIKON (COLTA-INDIATSALST)		
	DIMENSION A(1600), IROW(41), ICOL(41)		
	N=NP		
	NP 1 = N + 1	GUNA	136
		GUNA	137
		CUNA	1 7.8
~		CILLIA	130
2	IKOH(I)=I	GUNA	124
	DO 75 ITER=1,N	GUNA	140
	HAXR= I YER	GUNA	141
	HAXC=1	GUNA	142
	TEAP= ABS(A(HAXR))		
	LTHTTC=NP1-TTER	GUNA	144
		GUNA	145
		CLUIA	116
		11 U INA	1.40
	1J=(J-1)*N101#1	GUNA	147
	IF (TEMP-( A0S(A(IJ)))) 10,15,15	GUNA	148
10	HAXR=I	GUNA	149
	L=3×4H	GUNA	150
	TEMP= ABS(4(IJ))	GUNA	151
15	CONTINUE	GUNA	152
		GUNA	153
		CUMA	101
~~		ANUP	104
20	IROH(NPI) = ITER	GUNA	195
	WRITE(6+200)	GUNA	156
200	FORMAT(+0+,+THIS IS A SINGULAR MATRIX AND IT WILL NOT INVERT+)		
25	IF (MAXR-ITER) 30,40,33	GUNA	159
30	0 35 J=1.N	GUNA	160
	MAXRJ=(J-1) + MRTM + MAXR	GUNA	161
		GUNA	162
		GUNA	163
		CUMA	100
	A(HAXRJ) = A(11J)	GUNA	104
35	A(LIJ)=1E4P	GUNA	165
	ITEMP=IRD#(MAXR)	GUNA	166
	IROH(HAXR) = IROH(ITER)	GUNA	167
	IRJH(ITER)=ITENP	GUNA	168
40	IF (MAXC-1) 45.55.45	GUNA	169
45	00.50.1=1-N	GUNA	170
		GIENA	171
			172
		GUNA	172
	A(I)=A(IMAXC) .	GUNA	173
50	A (IMAXC) = TESP	GUNA	174
	ITEHP=ICOL(MAXC)	GUNA	175
	ICOL(HAXC)=ICOL(1)	GUNA	176
	ICUL(1)=ITEHP	GUNA	177
55	$\mathbf{I} \in \mathcal{AP} = \mathbf{A} (\mathbf{I} \mathbf{I} \in \mathbf{R})$	GUNA	178
		GUNA	179
		CIINA	1 8 0
		CHMA	100
	11JH1 = (J - i) + NOTH + 11EX	GUNA	101
	11J=(J-1)•NDIA+11ER	GUNA	182
	A(ITJH1)=A(ITJ)/TEMP	GUNA	183
60	ICOL(J-1)=ICOL(J)	GUNA	184
	ITN=(N-1)*NJIM+ITER	GUNA	185
	A(ITN) = 1.0/TEHP	GUNA	186
	ICOL(N) = ITEMP	GUNA	187
		L HNA	1 8 8
	UU '/ x=++++ TE /[_TT[0] 66.76.66	CUNA	1 80
10	17 (1-1);;; (); (); (); (); (); (); (); (); ();	CUNA	103
65		GUNA	1.40
	00 70 J=2,N	GUNA	191

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	IJN1={J-J}*NIIN+J	GUNA	192
	I+HIGN*(1-L)*L	GUNA	193
	ITJH1=(J-2)*NDIK+ITER	GUNA	194
	A([JH1)=A([J)-A([TJH1)+TEHP	GUNA	195
70	CONTINUE	GUNA	196
	IN= (N-1) PNBIM+I	GUNA	197
	ITN#(N=1) BNDIH+[TEP	GUNA	194
		CINA	100
75		CUNA	200
		CUNA	200
		GUNA	201
	DU DU JAIRA	- UNA	202
• •		GUNA	203
80		GUNA	204
02		GUNA	205
90	DO 95 L=1,N	GUNA	206
	LI=(I-1)*N0IH+L	GUNA	207
	LJ=(J-1)*NDIH+L	GUNA	208
		GUNA	209
-	A(LI)=A(LJ)	GUNA	210
95	A(LJ)=YEH <sup>2</sup>	GUNA	211
	IRUW(J)=IROW(I)	GUNA	212
100	CONTINUE	GUNA	213
	DO 125 I=1,N	GUNA	214
	00 105 J×I,N	GUNA	215
	IF (ICOL(J)-I) 105,110,105	GUNA	216
105	CONTINUE	GUNA	217
119	IF (I-J) 115,125,115	GUNA	218
115	DO 120 L=1,N	GUNA	219
	IL = (L-1) *NOIH+I	GUNA	220
	JL=(L-1)*NIGH+J	GUNA	221
	TE-P+A(TL)	GUNA	222
	A(IL)#A(JL)	GUNA	223
120	A(JL) = TEMP	GUNA	226
		CUNA	225
125		GINA	226
		CILLIA	220
		CHNA	220
		CUNA	220
		GONA	229
6			
	SUBROUTINE MATPRN ( A , NP, B , RITE )		
	DIMENSION A (40,40)		
	N=NP		
5	FORMAT (*0*//)		
10	FORMAT(*0*.11(E12.3))		
22	FORMAT (#14 . 24H PRESENT CONTENTS OF	SUP	1277
	DATA YAZ/4HPRHT/		
	IF & RITE .NE. YAZ & GO TO F20	SUP	1280
	WRITE (6.22) B	SHP	1286
	IF ( N.GT. 11 ) GO TO 61	SUP	1286
	00 50 Tel.NP	301	
	WRITE (6.10) (A(T.J), Jai, NP)		
60	CONTINUE	500	1780
20		SHD	1200
6.0	NT # N/11911-10	305	1 6 7 0
90			

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		00 200 K = 1 , N1 , 11	SUP	1292
		KK = K + 10	SUP	1293
		$00\ 100\ !=1$ , N	SUP	1294
		$HRITE \ (5, 10) \ (\ 4 \ (1, \mathbf{J}) \ , \ \mathbf{J} \approx K \ , \ K K)$	SUP	1295
	100		SUP	1296
	200		SUP	1297
	200	x = x + 1 1	SUP	1299
		$\Omega \Omega$ $\Omega \Omega$ $\Gamma = 1$ . N	C.10	1 100
		WRITE $(6.13)$ (A(1.1), J=K , N)	SUD	1300
	300	CONTINUE	SUP	1362
	600	CONTINUE	SUP	1304
	500	RETURN		
		ENO	SUP	1306
Ç 1	****	***************************************		
		SUBROUTINE STHALL (A.R.C.NP)		
		DIMENSION A(40.40), B(40), C(40)		
		N=NP		
		N=NP		
		00 200 I = 1 , H	GUNA	124
		C(1) = 0.0	JUNA	125
	200	CONTINUE	GUNA	126
		DO 500 I = 1 , H	GUNA	127
		$00 \ 400 \ J = 1 \ N$	GUNA	128
		C(1) = C(1) + A(1,J) + B(J)	GUNA	129
	400	CONTINUE	GUNA	130
	500		GUNA	131
			GUNA	132
<b>^</b> •			CONT	133
6				
		SUBROUTINE HULT(A,B,C,NP)		
		UIMENSION A(40,40),8(40,40),6(40,40)		
		N-NP		
		80 100 [=1.x		. 7
		DO 200 J=1.N	OUAN	2 726
		Q = 0.0	01166	725
		00 300 L=1,H	QUAN	726
		$Q = Q + B(I,L) \cdot C(L,J)$	QUAR	727
	300	CONTINUE	QUAS	729
		A(I,J) = Q	AUG	729
	200	CONTINUE	QUAR	730
	100	CONTINUE	QUAR	731
		RETURN		
		END		

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的情况的历史。如此我们是我们的社会的问题,我们就是我们的社会上来的主义

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EXPONENT= .3125 FOR RADIUS EVALUATION

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PRESENT CONTENTS OF CORR MATRIX

16E-01 9.518t-0	09.60	1.000E+Ui	9.9846-01	9.031E-01	9.1235-01	7.1825-02	-3.376E-02
1C-01 9.03/C-0	.0.5	3. 300E "D	10+ 2000 • 1	7° - 7' 7 - 7 7	10-1007-6		20-30-6-0-
0 23220	6 7 0	0.0445.0	CU*3000 \$	0 0175-01	0.1962-31	1.255-02	-A.99AF.02
96-01 7.690E-0	7.64	9.0515-01	9.017E-01	1.00vE+00	3.3545-01	1.4926-01	2.479E-01
7E-01 7.77E-0	7.75	9.123E-U1	3.1055-01	9.954E-01	1.0005+00	7.2945-02	2.336E-01
8E-03 2.125E-0	2 5.41	7.132E-U2	3.637E-02	1.492E-U1	7.2945-32	1.JOOE+00	9.366E-02
2E-01 -2.645E-0	2 -2.67	-8.375E-02	-8.998E-02	2.479E-01	2.3366-01	9.366E-02	1.C00E+00

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PRESENT CONTENTS OF VECT MATRIX

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4ATRIX XKOF PRESENT CONTENTS OF

1.000E+00	1.0006+03	1.0005+00	1.0005+00	1.00JE+03	1.0005+03	1.000E×00	1.0005+00
1.0005+00	1.J05E+03	1.0045+00	1.005E+03	1.0035+00	1.0076+00	1.0016+00	1.003E+03
1.000E+00	1.00~5+00	1.529£+03	1.5286+03	1.5405+0]	1.8362+00	2.1695.00	2.162E+03
1.0006+00	1.408E+03	1.528č+3)	1.5326+03	1.8355+63	1.8342+00	2.156E+00	2.1536+63
1.900E+00	1.103E+0J	1.840€+00	1.8356+03	2.61uE+0]	2.5965+00	3.532E+ù0	3.514c+00
1.000E+00	1.J0/E+00	1. d36£+ JJ	1.8345+60	2.5906+03	2.5866+00	3.505£+00	3.4906+03
1.000E+00	1.JU1E+00	2.1695+00	2.1562+33	3.5325+03	3.5052+JJ	5.293E+0U	5.2586+03
1.000E+00	1.J03E+00	2.1522+00	2.1535+03	3.5146+03	3.430E+00	5.258E+00	5,2266+03

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PRESENT CONTENTS OF

1.000E+00	0.	-8.731E-11	5.821E-11	а,	1.7465-10	2.328E-10	2.328c-1J
0.	1.JOUE+00	1.746E-10	2.9165-11	1.1645-13	0.	э.	0.
2.328E-10	.0	1.0005+30	<b>.</b> 0	-9.3136-13	-3.3135-13	-3.7256-09	1.863Ē-0,
0.	0.	-3.313E-10	1.00CE+03	1.8635-04	1.8635-09	1.8635-03	-1.863E-03
<b>д.</b>	-1.363E-03	-3.1252-39	-1.863E-33	1.03JE+03		3.7256-09	-3.725E-04
<b>.</b> 0	9.313E-10	3.7252-09	1.363E-93	1.5635-03	1.0005+JJ	0.	Ĵ.
<b>д</b> .	-4.057E-10	1.8635-03	9.313E-13	<b>J</b> .	ŋ.	1.9005+00	1 8632-03
-4.657E-10	-9.313E-13	-2.7346-39	-1.863E-33	.0	1.863E-09	1.863E-09	1+000E+07

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NORM. COEFS. OF THE PREDICTION EQUATION

Marine Street

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- .764376745. =(1 )N
- -.6415280693 N( 2)=
- -6.1078288335 N( 3)\*
  - 3.4334176744 =(† )N
- 14-6954181835 N( 5)=
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- 6201062451.6. ≖(/ )N
- 10.3837296572 =(\$ )N

## COEFFICIENTS OF THE PREDICTION EQUATION

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<pre>151307 151304 151304 1513946 1513946 1513946 151493 15515 1516365 15515 1516365 15515 1516365 15515 1516365 15515 151525 1551 155 15 1</pre>	-22.55	627578	80	1.3675
1,4,946       2,0,6,7,7         1,10,0,15       2,2,0,5,9         1,10,0,15       2,2,0,5,9         1,10,0,15       2,2,0,5,9         1,10,0,15       2,2,0,5,9         1,10,0,15       1,5,14,0,5         1,10,0,15       1,5,14,0,5         1,10,0,15       1,5,14,0,5         1,10,0,15       1,5,14,0,5         1,10,0,17       1,5,14,0,5         1,10,0,17       1,5,14,0,5         1,10,0,17       1,5,14,0,5         1,10,17       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,14,0,5         1,17,71       1,5,16,0,5         1,114       2,5,14,0,5         1,114       2,5,14,	-24.85	711507	76	1.5129
1.10135       3.060042         1.10136       3.060042         1.163515       2.2954965         1.163515       2.2954965         1.163515       1.1636505         1.163515       1.1636505         1.16465       1.1636505         1.16465       1.1636505         1.16465       1.1636505         1.17126       1.1670540         1.17121       1.1670540         1.16465       1.1646740         1.171205       1.1670540         1.16465       1.1646740         1.1717       1.1670540         1.16465       1.1646740         1.1771205       1.1670540         1.16465       1.1646740         1.17771       1.1771205         1.16465       1.164756         1.17715       1.167565         1.117       1.164756         1.117       1.164565         1.117       1.16456         1.117       1.16456         1.117       1.16456         1.1166       2.1550650         1.1166       2.1550650         1.1166       2.1550650         1.1166       2.1560650         1.1166       2.1	-23.62	662351	11	1.6537
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2.75493       2.75494         3.85515       1.457497         3.85515       1.457497         3.85515       1.457497         3.85515       1.457497         3.85515       1.457497         3.85115       1.47741         3.81472       1.4579403         3.81472       1.4579403         3.81417       1.4579403         3.81417       1.4579403         3.81417       1.4579403         3.81417       1.4579403         3.81417       1.4579403         3.81417       1.4579403         3.81417       1.4579403         3.81417       1.4579403         3.81417       1.457940         3.81417       1.457940         3.81417       1.457940         3.81417       1.457940         3.81417       1.47726         3.81417       1.47726         3.81417       1.47726         3.81417       1.460733         3.81417       1.47726         3.81417       1.476073         3.81417       1.47726         3.81417       1.460733         3.81417       1.477612         3.81418       2.49727 </td <td>-21.20</td> <td>567976</td> <td>76</td> <td>1.0555</td>	-21.20	567976	76	1.0555
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082035       0.47015         082035       1.474315         214966       1.474315         214966       1.474315         251185       1.474315         251185       1.47505         251185       1.47505         251185       1.47505         251185       1.47505         25117       1.47156         25117       1.47156         25117       1.47156         25117       1.47156         25117       1.47156         25117       1.47156         25117       1.47156         25117       1.47156         25117       1.47156         25117       1.47156         25117       1.4756         25117       1.4756         25117       1.4756         25117       1.4756         25117       1.4756         25117       1.4756         25117       1.4756         25117       1.4756         25117       1.4756         25117       1.4767         25117       1.4767         25117       1.4767         25117       1.4767 <td< td=""><td>12.66</td><td>600647.</td><td>50</td><td>2.6117</td></td<>	12.66	600647.	50	2.6117
082035     1.474318       082045     1.467346       214966     1.599829       214966     1.599829       156185     1.67346       156185     1.67346       156185     1.476085       1609117     1.67346       1609117     1.67346       156185     1.476085       1609117     1.67346       1609117     1.476085       1609117     1.67346       1609117     1.67346       1609117     1.67346       1609117     1.67346       160934     1.476085       177711     1.97356       119675     1.476085       119675     1.975365       119675     2.05933       119675     2.05736       119675     2.53085       119675     2.55366       119675     2.55366       119675     2.55366       110112     2.55336       110112     2.55686       110126     2.55086       110126     2.55686       110126     2.55686       110126     2.55686       110126     2.55686       11012     2.55686       11012     2.55686       11012     2.55686 <t< td=""><td>-25.55</td><td>0104047-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1</td><td>10</td><td></td></t<>	-25.55	0104047-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1	10	
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55115     1.670503       56115     1.670503       609117     1.741250       609117     1.670504       609117     1.670504       609117     1.670504       609117     1.670504       609117     1.670504       609116     1.670504       609117     1.67153       600135     1.67153       600135     1.67125       019834     2.007715       019834     2.007715       019834     2.15506       019834     2.15506       019834     2.15506       1.90167     1.953105       1.90167     2.15506       1.90167     2.15506       1.90167     2.15506       1.90167     2.15506       1.90167     2.15506       1.90167     2.49506       1.110     2.49506       1.110     2.49506       1.110     2.49506       1.111     2.49506       1.111     2.49506       1.111     2.49506       1.111     2.49506       1.111     2.49506       1.111     2.49506       1.111     2.49506       1.111     2.49506       1.111     2.49506       1.111 <td>-24.36</td> <td>384863</td> <td>13</td> <td>.1467</td>	-24.36	384863	13	.1467
56185     1.676346       609117     1.876065       609117     1.8750       609117     1.8750       609117     1.8750       609117     1.8750       609117     1.8750       609117     1.8750       609117     1.8750       609117     1.8750       609117     1.8750       609117     1.8750       609114     1.97517       1.8750     1.997577       1.99757     1.997577       1.99757     1.997577       1.40047     2.059091       1.40047     2.15566       1.40114     2.45796       1.40114     2.45796       1.40114     2.45796       1.40114     2.45796       1.40114     2.45796       1.40114     2.45796       1.40114     2.45796       1.40114     2.45796       1.40114     2.45796       1.40114     2.45796       1.40114     2.45796       1.40114     2.45796       1.40114     2.45796       1.40114     2.45796       1.40114     2.45796       1.40114     2.45696       1.40114     2.45796       1.40114     2.45766	-5 - 6 8	074357	¥0	.1724
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666510 $1,40334$ $037771$ $1,995342$ $079334$ $2.07757$ $079334$ $2.077577$ $079334$ $2.077577$ $079334$ $2.077577$ $079334$ $2.077577$ $079334$ $2.077577$ $079334$ $2.077577$ $079334$ $2.075936$ $144702$ $2.53085$ $144702$ $2.53085$ $140034$ $2.45766$ $140114$ $2.45766$ $140114$ $2.45766$ $140114$ $2.45766$ $140114$ $2.45766$ $140114$ $2.45766$ $140114$ $2.45766$ $123652$ $2.39566$ $140114$ $2.45766$ $075317$ $2.596650$ $075317$ $2.596650$ $075316$ $2.396766$ $075316$ $2.596650$ $075316$ $2.596650$ $07560$ $2.96640$ $075316$ $2.596650$ $07560$ $2.596650$ $07560$ $2.596$	-9.64		: =	.6224
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009034 009034 009034 009035 144702 140047	. 61	.012256	36	1.1225
09935     2.1200.00       144702     2.135584       144702     2.530853       149575     2.530853       140114     2.69922       140114     2.69922       140114     2.672864       125635     2.593305       121726     2.593305       121726     2.593305       121726     2.593305       121726     2.593305       121726     2.593305       121726     2.593305       121726     2.593305       121726     2.593305       121726     2.593305       121726     2.593305       121726     2.594305       121772     2.395850       121772     2.395850       121772     2.395850       121772     2.49753       121772     2.49754       121772     2.49255       12172     2.49255       12112     2.49255       12112     2.49255       12112     2.49255       121112     2.49255       121112     2.49255       121112     2.49255       121112     2.49255       121112     2.49255       121112     2.49255       121112     2.49255       <	-3.24	067292	44	1.1225
064235     2.135594       14074     2.548217       139675     2.5530653       14004     2.6530653       140114     2.5530654       140114     2.453564       140114     2.457564       155317     2.3514740       155127     2.351305       155121     2.457264       155121     2.457305       155121     2.457366       155121     2.45736       155121     2.45736       155121     2.45736       155121     2.45736       155121     2.45766       155121     2.45766       155121     2.564431       155121     2.566493       155121     2.566493       155121     2.566493       155121     2.566493       155121     2.566493       155121     2.566493       155121     2.566493       155121     2.566493       155121     2.566493       155121     2.5566493       155121     2.5566493       155121     2.5566493       155121     2.5566493       155121     2.5566493       155121     2.5566493       155121     2.5566493       155121     2.5566493 </td <td></td> <td>059453</td> <td>42</td> <td>1.1225</td>		059453	42	1.1225
L44762 140047 140047 140047 140014 140014 1400114 14014 140114		******		2721-1
140054 13675 136675 140047 140114 140114 140114 140114 140114 140114 140115 140115 140115 140115 140115 140116	38.53		7 U	1 • 2 4 9 4
113675 2.059093 14014 2.49522 140114 2.49522 140114 2.49527 101725 2.45796 12517 2.49796 11725 2.4597 11766 2.4597 11766 2.464 130516 2.56846 130516 2.56846 2.56849 251454 2.56846 2.19635 2.19635 2.19635 2.19143 2.552	-15.44	396796	7	1.6724
140047 2.551875 140114 2.6799622 140114 2.6799622 125532 2.435279 17725 2.43527951 110168 2.5334740 127726 2.53305 101726 2.53305 101772 2.307528 101772 2.309153 101772 2.553305 101772 2.55350 101772 2.55650 101112 2.5555 101112  2.55555 1011112 2.55555 1011112 2.55555 1011112 2.55555 1011112 2.55555 1011112 2.55555 1011112 2.55555 1011112 2.55555 1011112 2.55555 1011112 2.555555 1011112 2.555	3.91	.080562	3	1.6735
Luull4 2.45952 Luull4 2.457264 125432 2.457264 17725 2.457365 110166 2.4593165 110166 2.475961 110166 2.47596 1303566 2.47596 1303566 2.456303 1303566 2.49630 130443 2.49599 14164 2.49599 14164 2.49556 14164 2.49566 14164 2.495666 14164 2.495666 14164 2.495666	-9.01	211829	50	1.6799
1753632 175317 175317 175317 17726 10166 1000 10166	-14.38	359509	16	1.6847
227101 227101 227101 227101 227101 227101 227102 2.593305 2.593305 2.59561 2.39572 2.39595 2.55635 2.55655 2.55655 2.55655 2.55655 2.55655 2.55655 2.55655 2.55655 2.55655 2.55655 2.55655 2.556555 2.556555 2.556555 2.55655555 2.5565555555555	-19-93	532750	13	1.6847
27101 117725 117725 117726 110168 110168 2.3091536 2.302522 2.302528 2.302528 2.302528 2.302568 2.302528 2.302568 2.302528 2.302528 2.302528 2.302528 2.302528 2.302528 2.302528 2.302528 2.302528 2.302528 2.302528 2.302528 2.302558 2.3055658 2.3055658 2.305568 2.305568 2.305568 2.305568 2.305568 2.305588 2.305588 2.305588 2.305588 2.305588 2.305588 2.305588 2.305588 2.305588 2.305588 2.305588 2.305588 2.305588 2.4925888 2.4925888 2.4925888888 2.4925888888888888888888888888888888888888	-12,50		51	1.5544
317725     2.475961       310168     2.309158       395771     2.30522       39576     2.30522       39536     2.305822       395906     2.3568401       355906     2.5698401       356038     2.5698401       359143     2.901112       359143     2.556850		57455744	24	2.0331
110166 2.309158 995771 2.309158 915316 2.302522 915316 2.302522 85906 2.560803 85906 2.560803 19143 2.19699 139143 2.492551 14164 2.492551		- 5662US	רי ה בי נ	2-1509
996771 2.302522 93536 2.376297 85906 2.366303 85906 2.508461 85906 2.508461 29143 2.19699 139143 2.492551 14164 2.492551	-12.45			60/1-2
395516 2.376297 931536 2.376297 85906 2.568433 85906 2.568433 859066 2.56850 196036 2.19699 196036 2.492551 14164 2.56532	-13.28	305751	, <b>1</b>	5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
93536 2.544431 865906 2.560833 56366 2.560803 196036 2.508461 2.596650 196036 2.19699 139143 2.492551 14164 2.492551	-15.11	382761	52	2-2144
855906 2.568833 855906 2.508461 2.59366 2.59650 2.96036 2.19699 339143 2.492551 14164 2.492551	-21.65	550895	56	2.2194
85906 2.508461 590366 2.596850 59143 2.19699 19143 2.492551 14164 2.492551	-16.16	382901	17	2.2451
79145 2.196950 39143 2.196990 19145 2.492551 14164 2.492551	-20.33	522555	21	2.2451
-99443 2.49254 -39143 2.49255 -49255	-24.89	646483	33	2.3158
101110°2 Contract 100°2	-13.70	300952	54	2.3866
44 FD4 C+43C751 C+43C751 C+43C751 C+43C751 C+43C	-15.09	161970	14	2.8107
	- 37 - 60		32	2.0461
57770 2.076465	-25-00		15	2.8931

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SC 008

EVENT NO.

RESIDUAL

PERCENT ERROR

ACTUAL VALUE

-30.12 23.27 -25.60 -19.49

PREDICTED VALUE

1.780141 1.004092 1.654633 1.654633 1.4534633 .736333 .7365533 .736645 1.236645 1.236645 1.236645 1.236645 1.236645 1.236645 1.236645 1.236645 .100524 **•**50106. .155803

2.21 3.39 110.969 110.969 3.52 3.52 3.52 3.52 114.26 114.2 -12.49 -5.79 -5.77 -4.63 -12.60 16.8--9.72 -5.30 15.69 -9.84 -5.4

2.432185

2.340057

922339 101404 119412 120739 138462 137450 143915

937166 .92267 .101537

2.330844

.266354

.349270

-.2108J8 -.230245 -.131652 -.159011 -.15914 -.078:45 .287678 .036232 .110921 .055621 -.129599 -.102769 .045736 .209648 .206928 .409237 .078359 .263941 .2533990 .129160 .129160 -.509512 -.229440 -.303009 --412103 -.219316

1.9439 1.9439 1.9439 0.0000 .9213 1.2896 1.2896 1.2898 1.3819 1.3819 9213 14742 1.8426 1.8426 1.8518 •4606 .4606

.1647

.134911 .208558 .045178 -.057216

.907934 1.048297 1.732173 1.824556 1.628516 1.628546

1.767339 2.064136 2.142892

.801198 .906325

853613

.256854 .777351

2.017603

1.888623 1.685941

.115622 .118257 .116702

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2.091311 1.633352 2.082398 2.008395 2.063672

119316

119273 118330 17521

2.247923 2.072385 2.192652 1.907054

PREDICTED VALUE	ACTUAL VALUE	PERCENI ERROR	RESIDUAL	EVENT NO.	SC 008
2.171915	2.637463	32.64	-534447	74	2 . 4 8 4 7
2.164354	1.506763	43.64	.657586	¢	1.5440
2.165760	2.678409	4 - 20	.067350	63	1.557u
2.138261	1.847234	16.32	.331027	61	1.6475
2.138006	1.553891	9.42	.184115	65	1.6975
2.118447	1.741729	21.63	.376718	12	2 - 7 444
2,353007	1.790521	14.66	.262467	11	2-0646
2.034238	1.232152	65.10	.802085	64	5-1479
2.037732	1.343216	51.71	.694516	۲,	2.1462
1.536155	1.759649	-12.70	223444	179	. 4636
1.567672	1.971544	-20.44	4. 872	175	.46.06
1.931955	1.969170	-23.62	458015	174	• 4606
1. 329205	2.026821	-4.82	097616	176	.9213
1.922785	2.072835	-1.24	150057	178	.9213
2.119270	2-130524	60.	.018746	181	1.3819
2.110963	2.257142	-5.12	138179	175	1.3819
2.142012	2.192652	-2.31	050639	184	1.6122
2.119466	1.999162	6.12	.120284	177	1.8426
2.119201	C19899.1	6 - 49	129231	189	1.8426
2.117747	2.22929J	-4.52	102543	182	1.8426
2.117556	2.211077	-4.23	093521	165	1.8420
2.117596	2.15580J	-1.77	038206	160	1.6426
2.117596	2.244743	-7.32	167144	164	1.8426
2.116421	2.229503	-5.17	113062	163	1.8426
2.116049	2.321631	-3.86	205582	166	1.8426
2.116950	2.349279	-9.99	232320	7 4 7	1-6426
<b>7.115568</b>	2.340057	-9.54	224489	172	1.8426
2.115557	2.441395	-13.35	325641	167	1.8426
2.116277	2.422972	-12.66	306636	171	1.3426
1.034682	.98451J	5.10	.050172	502	0.0000
2.072423	2.068287	.20	.004136	101	1.2233
2.396239	1.548733	35.35	.5471.99	4	1.2906
2.398621	2.651650	-20.86	553829	185	1.3028
2.141995	2.050610	4.46	.091365	189	1.6476
2.139082	2.457195	-12.35	318114	186	1.7006
2.159630	1.484946	46.11	.684684	2	1.4133
2.151905	2.140241	• 5.4	.011659	15	1.6119
2.091604	. 810739	157.39	1.280865	-	1.9056
1.J31640	. 355764	21.70	.192876	223	0.0000
1.051640	.929655	16.35	.151982	221	0.000
1.081640	.929655	15.35	.151982	222	0.000.0
1.051640	*959647	12.71	.121993	224	6.0000
1.092193	* 954594	14 - 41	•137599	203	0.000
1.092193	.979343	11.52	.112850	202	6-0000
1.059345	1.030066	5.76	,059263	227	0.0000
1.381640	1.080875	20.	.000764	225	0.0000
1.051640	1.1586.59	-7.44	087Cun	226	0.0000
1.05556	1.084500	. 45	· 00+0+00	228	0.000
1.035345	1.155745	-5 - / 4	066336	229	0000 • 3
1.101058	1.422070	-22.57	321011	504	ú.003U

PREDICTED VALUE

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PREDICTED VALUE	ACTUAL VALUE	PERCENT CKROR	RESIDUAL	EVENT NO.	SC 008
1.111492	1.312680	- 15 - 11	0.004448		
1.217545	1.187939	2444	202020-	200	10000
1.327690	1.347038				
1.562209	1.502602	24 - 2	050502	000	+ C 2 1
1.562209	1.562706		263000	202	
1.643195	1.736319	-5,35			, 626A
1.773327	1.693521	17.4	079866		.8415
1.360220	1.735947	12.92	.224272	263	1.1225
1.460220	1.757160	11.56	203059		1.1226
2.091433	1.824335	14.64	267098	222	1.4036
2.139909	1.948079	9 . 85	.191830	213	1.6847
2.139934	1.941009	10.25	.198926	212	1.6847
1.127969	.683999	54.91	• 443370	95	0-5004
1.127969	.767541	46.96	.360428	8 5 2	0.000
1.127969	.809312	39.37	.318657	100	00000
1.267006	1.174808	7 • 85	.092138		2611
1.267006	1.331449	-4.84	064443	87	. 2611
1.267006	1.268793	14	001786		. 2611
1.441149	1.409770	2 • 23	.031380		5221
1.441149	1.451541	72	010341	2.5	5221
1.441149	1.576853	-8.61	1357.44	20	. 5221
1.542907	1.448090	10.40	154817	10	7832
1+329067	1.790930	2.13	038137	76	1.0443
1.825067	1.858807	-1.60	029741	1	1.7463
1.829067	1.916242	-4.55	087176	200	2000.1
2.004529	1.728273	15.38	.276256	10	1.3053
2,004529	1.958013	2.38	.046516		1.305 4
2.114432	1.911021	10.64	203411	201	1.5654
2.114432	1.921464	10.54	.192968	99	1.5664
2.114432	2,088543	1.24	.025845	101	1.5662
2.141007	1.649953	29.76	10105	• •	
2.354433	.783205	162.42	1.97593		1000
2.058433	.992863	107.49	1.066273		
2.058433	1.253129	61.26		5 T T	4000.02
		03 • 60	405CA0.	166	2.0585
HULT CORR COEF = 88.49 Stand, deviation for Rac	1.3909 1.3909				

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APPENDIX III

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## DATA AND PREDICTION CURVE PLOTS













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#### APPENDIX IV

ามากมาร์ให้สัมธรรมของชีวสีรามสารทางได้จะระสายการสนับรายางสารการสมบัตร เป็นสารจะระบบ

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Cond Dr.

### GENERAL EQUATION COEFFICIENTS

IABLE	4. ULILIAL EQUATION		
Using	$\gamma^{5/16}$ , S and G <sub>s</sub>	Using <b>y</b>	$^{5/16}$ , S, G <sub>s</sub> and E <sub>v</sub>
C(1)= C(2)= C(3)= C(4)= C(5)= C(6)= C(7)= C(8)= C(10)= C(11)= C(12)= C(12)= C(13)= C(14)= C(15)= C(16)= C(17)= C(16)= C(20)= C(21)= C(21)= C(21)= C(22)= C(24)= C(25)= C(26)= C(27)= C(28)= C(29)= C(30)= R_m = 95.9	-31.8910003863 53.7596378609 -8.9711680343 .5549490163 -30.5239196038 -3.3733199735 -9415056768 14.0810150798 5.0934471223 -1.9052946210 -61.0822676775 10.5127003945 -2.7082997773 41.4257955425 44.6352964490 4.3584334973 1.7054916517 -9.6728410805 -42.7140631702 3.8425311344 71.0614236931 -8820397422 1.7405271634 -53.1325358655 -30.3299093539 -1.4850841324 4.1108960189 5.4834047720 26.7258983051 -2.6092817849 $\pm$ 10% $\pm$ 20%	C ( 1) = C ( 2) = C ( 3) = C ( 3) = C ( 3) = C ( 3) = C ( 5) = C ( 5) = C ( 6) = C ( 7) = C ( 10) = C ( 20) = C ( 30) =	$\begin{array}{c} 4.7431667917\\ -312.2659209015\\ 85.1020403634\\ 130.7525251740\\ 2.2953850824\\0000081432\\ -52.3758442797\\ -12.4911945922\\ 122.3636313152\\ -27.8147254654\\ -141.9455105232\\ 823.0531524578\\ -196.6141937964\\ -251.5265120348\\ -153.2196787518\\ .0000127300\\ 96.2318031404\\ 126.6088317324\\ -199.3081650438\\ 18.4750255695\\ 112.7398253173\\ -551.6962384152\\ 124.3090113793\\ 156.6485857970\\ 184.2976000126\\0000075942\\ -48.5622042860\\ -135.4375636622\\ 65.7358828222\\ 13.9867726702\\ -13.479357255\\ 112.247847897\\ -24.021462968\\ -38.983699801\\ -59.563255944\\ .000000488\\ 7.325651564\\ 39.158512632\\ 5.226829768\\ -8.697270163\end{array}$
		1 31/0 W1.CH.	111 - main

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TABLE 4 GENERAL EQUATION COEFFICIENTS FOR RADIUS.

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Using $\sqrt{5/16}$ , S, tan $\phi$ and Ev Using $\sqrt{5/16}$ , S, tan $\phi$ and Ev Using $\sqrt{5/16}$ , S, $c^{1/3}$ and E <sub>v</sub> C(1) = 18.8992452280 C(1) = -31.8938433251 C(2) = -31.8938433251 C(3) = 20.3800253443 C(2) = 17.2560192731 C(3) = 20.3800253443 C(4) = -4.4695237570 C(4) =0000027090 C(5) = 13.2362688240 C(5) =0000027090 C(6) =0000027090 C(7) = .447332000 C(7) = .447332000 C(7) = .447332000 C(7) =47332000 C(7) =47332000 C(7) =47332000 C(1) = 1.5946340224 C(10) =129487349 C(11) = .199.0532997158 C(11) =129.487349 C(12) = 323.2935371981 C(12) =27373482461 C(12) =2373482461 C(13) =16.5369735224 C(14) =64.5695519242 C(15) =485506629243 C(15) =485506629243 C(16) =0000105663 C(16) =0000105663 C(21) =2259601818 C(20) =16595754093 C(22) =361.8623322793 C(22) =361.8623322793 C(22) =361.8623322793 C(22) =361.48623322793 C(22) =99569248560 C(20) =0000127685 C(27) =3975240252 C(31) =48454457 C(33) =37.8928184431 C(33) =38928184431 C(33) =38928184431 C(33) =38928184431 C(33) =38928184431 C(33) =38928184431 C(33) =38928184431 C(33) =38928184431 C(33) =21639813553 C(39) =2163981747 C(39) =21639813558 C(39) =21639813558 C(39) =21639813558 C(39) =21639813558 C(39) =21639813558 C(39) =2215007438 R <sup>n</sup> =2215007438 R <sup>n</sup> =2215007438 R <sup>n</sup> =2215007438	TABLE 4.	GENERAL EQUATION COE	FFICIENTS FOR	RADIUS (CONTINUED)
C(1)= 18.899245280 C(1)= 29.3980672485 C(2)= -31.8938433251 C(2)= 17.2560192731 C(3)= 20.3800253443 C(3)= 10.0203963175 C(4)= -8.3982809715 C(4)= -4.4695237570 C(5)= 13.2362688240 C(5)= -33.2041384178 C(6)=0000027090 C(6)=00000274075 C(7)= .4473329001 C(7)=00027363973 C(8)= -17.5521678930 C(8)= -6.6328662697 C(9)= 6.8566842352 C(9)= 3.628382224 C(10)= 1.5946340224 C(10)=1239487349 C(11)= -199.0532997158 C(12)= -7.4095270897 C(13)= -116.5369735224 C(13)= -46.8808333927 C(14)= 64.5695519242 C(14)= 14.6150371805 C(15)= -128.5006629243 C(15)= 89.2867812633 C(16)=0000105683 C(16)=000006701 C(17)= -4.0691506255 C(17)= .0232794158 C(16)=0000105683 C(16)=000006701 C(17)= -4.0691506255 C(17)= .0232794158 C(20)= -1.0595754099 C(20)= .0819726642 C(21)= 225.6633484300 C(21)= 95.1305302502 C(22)= -361.8623322798 C(22)= 38.745913358 C(23)= 125.7880514578 C(23)= -20.664331679 C(24)= -76.6928891978 C(24)= -13.1284346475 C(25)= 140.4383152831 C(25)= -96.2455129465 C(26)= .0000176320 C(26)= .000127685 C(27)= 2.5802223123 C(27)= -0114900385 C(24)= -6.9956496680 C(30)=3975240267 C(24)= -6.995649680 C(30)=3975240267 C(30)= -6.9956496680 C(30)=3975240257 C(30)= -6.9956496680 C(30)=3975240257 C(31)= -24.6729413515 C(32)= 109.6418270782 C(32)= -13.6655896113 C(33)= -37.8928184431 C(33)= -24.6729413515 C(33)= -37.8928184431 C(33)= -24.6729413515 C(33)= -37.8928184431 C(33)= -24.6729413515 C(34)= 24.9124062737 C(34)= 3.5235047303 C(34)= 24.9124062737 C(34)= 3.5235047303 C(34)= 24.8140082327 C(35)= 27.6217414053 C(35)= -41.8140082327 C(36)=0001076457 C(36)=0000078407 C(36)=0001076457 C(37)=3086871023 C(37)=0011715210 C(37)=3086871023 C(37)=0011715240 C(37)=3086871023 C(37)=0011715240 C(37)=216398135685 C(39)= -22.3678557147 C(39)= -2.8343303865 C(40)= .2215007438 R <sup>2</sup> = 98.1 R <sup>2</sup> = 98.1 R <sup>2</sup> = 98.1 R <sup>2</sup>	Using y <sup>5/1</sup>	$\frac{6}{3}$ , S, tan $\phi$ and Ev	Using y <sup>5/16</sup>	, S, $c^{1/3}$ and $E_v$
C (2) = $-31.893843251$ C (2) = $17.2560192731$ C (3) = $20.3800253443$ C (3) = $10.0203963175$ C (4) = $-8.3982809715$ C (4) = $-4.4695237570$ C (5) = $13.2362688240$ C (5) = $-33.2041384178$ C (6) = $0000027090$ C (6) = $0000024075$ C (7) = $.4473329001$ C (7) = $0027363973$ C (8) = $-17.5521678930$ C (8) = $-6.63286626973$ C (9) = $6.8566842352$ C (9) = $3.6233822224$ C (10) = $1.5946340224$ C (10) = $12294733$ C (12) = $323.2945371981$ C (11) = $-122.373482461$ C (12) = $323.2945371981$ C (11) = $-122.373482461$ C (13) = $-116.5369735224$ C (13) = $-46.8808333927$ C (14) = $64.5695519242$ C (14) = $14.6159371805$ C (15) = $0000105683$ C (15) = $89.2867812633$ C (16) = $0000105683$ C (17) = $.0232794158$ C (16) = $0000105683$ C (17) = $.0232794158$ C (16) = $-1.0595754099$ C (20) = $.0819726642$ C (21) = $225.6633484300$ C (21) = $95.1305302502$ C (22) = $-361.8623322798$ C (22) = $38.7459133358$ C (23) = $125.7080514579$ C (23) = $22.0664331670$ C (24) = $-76.6928891978$ C (24) = $-13.1284346475$ C (25) = $140.4383152831$ C (22) = $-0010127685$ C (27) = $2.5802223123$ C (27) = $0114900339$ C (29) = $66.0886604123$ C (29) = $10.8695444627$ C (21) = $-37.8928184431$ C (23) = $-13.6140033792$ C (29) = $66.0886604123$ C (29) = $10.8695444627$ C (30) = $-3.78928184431$ C (33) = $8950301282$ C (31) = $-37.8928184431$ C (33) = $8950301282$ C (34) = $24.9124062737$ C (35) = $27.6217414053$ C (36) = $0000078407$ C (36) = $00100066210$ C (37) = $30868714237$ C (37) = $0011715210$ C (38) = $-22.3678557147$ C (39) = $-2.8343303859$ C (39) = $-22.3678557147$ C (39) = $-2.8343303859$ C (39) = $-22.3678557147$ C (39) = $-2.8343303859$ C (39) = $-22.3678557147$ C (39) = $-2.8343303859$ C (39) = $-22.3678557147$ C (39) = $-2.8343303859$ C (40) = $3.8323586654$ C (40) = $.2215007438$ R $_{m}^{2} = 98.1$ m $73\%$ within $\pm 10\%$	C(1) =	18.8992452280	C( 1)=	29.3980672485
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	C(2) =	-31.8938433251	C(2)=	17.2560192731
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	C(3) =	20.3800253449	C(3)=	10.0203963175
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	C(4) =	-8-3982809715	C(4)=	-4.4695237570
$\begin{array}{llllllllllllllllllllllllllllllllllll$	C(5)=	13,2362688240	C( 5)=	-33.2041384178
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	C(-6) =	- 0000027090	C( 6)=	0000024075
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	C(7) =	4473329001	C(7)=	0027363973
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	C(8) =	-17,5521678930	C(8)=	-6.6328662697
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	((9) = (0, 0)	6.8566842352	C(9)=	3.6233822224
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	C(10) =	1,5946340224	C(10) =	1239487349
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	C(11) =	-199,0532997158	C(11)=	-122.3373482461
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	C(12) =	323,2985371981	C(12)=	-7.4095270837
$\begin{array}{llllllllllllllllllllllllllllllllllll$	C(13) =	-116-5369735224	C(13)=	-46.8808333927
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	C(14) =	64,5695519242	C(14)=	14.6150371805
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	C(15) =	-128-5006629243	C(15)=	89.2867812633
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	C(16) =	0000105683	C(16)=	0000056701
$\begin{array}{llllllllllllllllllllllllllllllllllll$	C(17) =	-4.0691506255	C(17)=	.0232794153
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	C(18) =	94,5027765299	C(18)=	38,5678057694
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	C(10) =	-51.7359125275	C(19)=	-12.2559501818
$\begin{array}{ccccccc} C(21) = & 225.6633484300 \\ C(21) = & 225.6633484300 \\ C(22) = & -361.8623322798 \\ C(23) = & 125.7080514579 \\ C(23) = & 125.7080514579 \\ C(24) = & -76.6928891978 \\ C(24) = & -76.6928891978 \\ C(25) = & 140.4383152831 \\ C(25) = & 140.4383152831 \\ C(26) = & 0000176320 \\ C(26) = & 0000176320 \\ C(26) = & 0000127685 \\ C(27) = & 2.5802223123 \\ C(27) = &0114900349 \\ C(28) = & -96.9396721804 \\ C(28) = & -96.9396721804 \\ C(29) = & 66.0886604129 \\ C(29) = & 66.0886604129 \\ C(29) = & 66.0886604129 \\ C(30) = & -6.9956496680 \\ C(30) = & -6.9956496680 \\ C(30) = & -6.9956496680 \\ C(31) = & -68.9475372938 \\ C(32) = & 109.5418270782 \\ C(32) = & 109.5418270782 \\ C(33) = & -37.8928184431 \\ C(33) = & -37.8928184431 \\ C(33) = & -37.8928184431 \\ C(33) = &0000078407 \\ C(36) = &0000078407 \\ C(36) = &0000078407 \\ C(36) = &0000078407 \\ C(37) = &3086871023 \\ C(39) = & -22.3678557147 \\ C(39) = & -22.3678557147 \\ C(40) = & 3.8323586654 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 98.1 \\ R_m^2 = 97.7 \\ T3\% \text{ within $\pm 10\% \\ 95\% \text{ within $\pm 20\% \\ \end{array}$	C(20) =	-1,0595754099	C(20)=	.0819726642
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0(20) = 0(21) = 0	225 66 33484 300	C(21)=	95.1305302502
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	C(22) =	-361,8623322798	C(22)=	38.7459131353
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	C(22) =	125.7080514579	C(23)=	22.0664331670
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	C(24) =	-76-6928891978	C(24)=	-13.1284346475
C(26) =.0000176320C(26) =.0000127685C(27) =2.5802223123C(27) = $0114900343$ C(28) = $-96.9396721804$ C(28) = $-13.6140033792$ C(29) =66.0886604123C(29) = $10.8696441627$ C(30) = $-6.9956496680$ C(30) = $3975240252$ C(31) = $-68.9475372938$ C(31) = $-24.6729413515$ C(32) = $109.5418270782$ C(32) = $-13.6655896113$ C(32) = $109.5418270782$ C(32) = $-13.6655896113$ C(33) = $-37.8928184431$ C(33) = $8950301282$ C(34) = $24.9124062737$ C(34) = $3.5235047360$ C(35) = $-41.8140082327$ C(36) = $0000066210$ C(36) = $0000078407$ C(36) = $0011715210$ C(38) = $28.2818514475$ C(38) = $-2.1639813568$ C(39) = $-22.3678557147$ C(39) = $-2.8343303860$ C(40) = $3.8323586654$ C(40) = $.2215007438$ R <sup>2</sup> =98.1R <sup>2</sup> =97.773% within $\pm 10\%$ 95% within $\pm 20\%$	C(25) =	140.4383152831	C(25)=	-96.2455129445
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0(2)1=	.0000176320	C(26) =	.0000127685
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	C(27)=	2,5802223123	C(27)=	0114900349
$C(29) =$ $66 \cdot 0886604129$ $C(29) =$ $10 \cdot 8696441627$ $C(30) =$ $-6 \cdot 9956496680$ $C(30) =$ $-3975240252$ $C(31) =$ $-68 \cdot 9475372938$ $C(31) =$ $-24 \cdot 6729413515$ $C(32) =$ $109 \cdot 5418270782$ $C(31) =$ $-24 \cdot 6729413515$ $C(32) =$ $109 \cdot 5418270782$ $C(32) =$ $-13 \cdot 6655896113$ $C(33) =$ $-37 \cdot 8928184431$ $C(33) =$ $-8950301282$ $C(34) =$ $24 \cdot 9124062737$ $C(34) =$ $3 \cdot 5235047360$ $C(35) =$ $-41 \cdot 8140082327$ $C(35) =$ $27 \cdot 6217414053$ $C(36) =$ $-0000078407$ $C(36) =$ $-0000066210$ $C(37) =$ $-3086871023$ $C(38) =$ $-2 \cdot 1639813563$ $C(39) =$ $22 \cdot 3678557147$ $C(39) =$ $-2 \cdot 8343303863$ $C(40) =$ $3 \cdot 8323586654$ $C(40) =$ $2215007438$ $R_m^2 = 98.1$ $R_m^2 = 97.7$ $R_m^2 = 97.7$ $76\%$ within $\pm 10\%$ $95\%$ within $\pm 10\%$ $95\%$ within $\pm 20\%$ $95\%$ within $\pm 20\%$	C(28) =	-96,9396721804	C(28)=	-13.6140033792
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	C(29) =	66.0886604123	C(29)=	10.8696441627
$C(31) =$ $-68.9475372938$ $C(31) =$ $-24.6729413515$ $C(32) =$ $109.5418270782$ $C(32) =$ $-13.6655896113$ $C(33) =$ $-37.8928184431$ $C(33) =$ $8950301282$ $C(34) =$ $24.9124062737$ $C(34) =$ $3.5235047360$ $C(35) =$ $-41.8140082327$ $C(35) =$ $27.6217414053$ $C(36) =$ $0000078407$ $C(36) =$ $0000066210$ $C(37) =$ $3086871023$ $C(37) =$ $0011715210$ $C(38) =$ $28.2818514475$ $C(39) =$ $-2.1639813563$ $C(40) =$ $3.8323586654$ $C(40) =$ $.2215007438$ $R_m^2 = 98.1$ $R_m^2 = 97.7$ $R_m^2 = 97.7$ $75\%$ within $\pm 10\%$ $95\%$ within $\pm 20\%$ $95\%$ within $\pm 20\%$	C(30) =	-6.9956496680	C(30)=	3975240262
$C(32) =$ $109.5418270782$ $C(32) =$ $-13.6655896118$ $C(33) =$ $-37.8928184431$ $C(33) =$ $8950301282$ $C(34) =$ $24.9124062737$ $C(34) =$ $3.5235047360$ $C(35) =$ $-41.8140082327$ $C(35) =$ $27.6217414053$ $C(36) =$ $0000078407$ $C(36) =$ $0000066210$ $C(37) =$ $3086871023$ $C(37) =$ $0011715210$ $C(38) =$ $28.2818514475$ $C(38) =$ $-2.1639813553$ $C(39) =$ $-22.3678557147$ $C(39) =$ $-2.8343303869$ $C(40) =$ $3.8323586654$ $C(40) =$ $.2215007438$ $R_m^2 = 98.1$ $R_m^2 = 97.7$ $R_m^2 = 97.7$ $75\%$ within $\pm 10\%$ $95\%$ within $\pm 20\%$ $95\%$ within $\pm 20\%$	C(31) =	-68,9475372939	C(31)=	-24.6729413515
$C(33) =$ $-37.8928184431$ $C(33) =$ $8950301282$ $C(34) =$ $24.9124062737$ $C(34) =$ $3.5235047360$ $C(35) =$ $-41.8140082327$ $C(35) =$ $27.6217414053$ $C(36) =$ $0000078407$ $C(36) =$ $0000066210$ $C(37) =$ $3086871023$ $C(37) =$ $0011715210$ $C(38) =$ $28.2818514475$ $C(38) =$ $-2.1639813568$ $C(39) =$ $-22.3678557147$ $C(39) =$ $-2.8343303863$ $C(40) =$ $3.8323586654$ $C(40) =$ $.2215007438$ $R_m^2 = 98.1$ $R_m^2 = 97.7$ $R_m^2 = 97.7$ $75\%$ within $\pm 10\%$ $95\%$ within $\pm 20\%$	C(32) =	109.5418270782	C(32)=	-13.6655896118
$C(34) =$ $24.9124062737$ $C(34) =$ $3.5235047360$ $C(35) =$ $-41.8140082327$ $C(35) =$ $27.6217414053$ $C(36) =$ $0000078407$ $C(36) =$ $0000066210$ $C(37) =$ $3086871023$ $C(37) =$ $0011715210$ $C(38) =$ $28.2818514475$ $C(38) =$ $-2.1639813568$ $C(39) =$ $-22.3678557147$ $C(39) =$ $-2.8343303860$ $C(40) =$ $3.8323586654$ $C(40) =$ $.2215007438$ $R_m^2 = 98.1$ $R_m^2 = 97.7$ $73\%$ within $\pm 10\%$ $76\%$ within $\pm 10\%$ $95\%$ within $\pm 20\%$	C(33) =	-37.8928184431	C(33)=	8950301282
$\begin{array}{cccccc} C(35) = & -41.8140082327 \\ C(36) = &0000078407 \\ C(36) = &0000078407 \\ C(37) = &3086871023 \\ C(38) = & 28.2818514475 \\ C(38) = & -22.3678557147 \\ C(39) = & -22.3678557147 \\ C(40) = & 3.8323586654 \\ R_{m}^{2} = 98.1 \\ R_{m}^{2} = 98.1 \\ R_{m}^{2} = 98.1 \\ R_{m}^{2} = 98.1 \\ R_{m}^{2} = 98.1 \\ R_{m}^{2} = 98.1 \\ R_{m}^{2} = 97.7 \\ R_{m}^{3\%} \text{ within } \pm 10\% \\ 95\% \text{ within } \pm 10\% \\ 95\% \text{ within } \pm 20\% \end{array}$	C(34) =	24.9124062737	C(34)=	3.5235047360
$C(36) =$ $0000078407$ $C(36) =$ $0000066210$ $C(37) =$ $3086871023$ $C(37) =$ $0011715210$ $C(38) =$ $28.2818514475$ $C(38) =$ $-2.1639813563$ $C(39) =$ $-22.3678557147$ $C(39) =$ $-2.8343303863$ $C(40) =$ $3.8323586654$ $C(40) =$ $.2215007438$ $R_m^2 = 98.1$ $R_m^2 = 97.7$ $73\%$ within $\pm 10\%$ $76\%$ within $\pm 10\%$ $95\%$ within $\pm 20\%$	C(35) =	-41.8140082327	C(35)=	27.6217414053
$C(37) =$ $3086871023$ $C(37) =$ $0011715210$ $C(38) =$ $28.2818514475$ $C(38) =$ $-2.1639813563$ $C(39) =$ $-22.3678557147$ $C(39) =$ $-2.8343303860$ $C(40) =$ $3.8323586654$ $C(40) =$ $.2215007438$ $R_m^2 = 98.1$ $R_m^2 = 97.7$ $R_m^2 = 97.7$ 76% within $\pm 10\%$ $95\%$ within $\pm 20\%$	C(36) =	0000078407	C(36)=	0000066210
$C(38) =$ $28.2818514475$ $C(38) =$ $-2.1639813553$ $C(39) =$ $-22.3678557147$ $C(39) =$ $-2.8343303853$ $C(40) =$ $3.8323586654$ $C(40) =$ $.2215007433$ $R_m^2 = 98.1$ $R_m^2 = 97.7$ $R_m^2 = 97.7$ 76% within $\pm 10\%$ $95\%$ within $\pm 10\%$	C(37) =	3086871023	C(37)=	0011715210
$\begin{array}{cccccc} C(39) = & -22.3678557147 \\ C(40) = & 3.8323586654 \\ R_{m}^{2} = 98.1 \\ 76\% \text{ within $\pm$ 10\% \\ 04\% \text{ within $\pm$ 20\% \\ \end{array}} \begin{array}{cccccccccccccccccccccccccccccccccccc$	G(38) =	28.2818514475	C(38)=	-2.1639813563
$\begin{array}{cccc} C(40) = & 3.8323586654 \\ R_{m}^{2} = 98.1 \\ 76\% \text{ within } \pm 10\% \\ 94\% \text{ within } \pm 20\% \end{array} \begin{array}{cccc} C(40) = & .2215007438 \\ R_{m}^{2} = 97.7 \\ 73\% \text{ within } \pm 10\% \\ 95\% \text{ within } \pm 20\% \end{array}$	C(39) =	-22.3678557147	C(39)=	-2.8343303860
$R_{m}^{2} = 98.1$ $76\% \text{ within } \pm 10\%$ $94\% \text{ within } \pm 20\%$ $R_{m}^{2} = 97.7$ $73\% \text{ within } \pm 10\%$ $95\% \text{ within } \pm 20\%$	C(40) =	3.8323586654	C(40)=	.2215007439
76% within $\pm 10\%$ 94% within $\pm 20\%$ 73% within $\pm 20\%$	$R_m^2 = 98.1$		$R_{\rm m}^2 = 97.7$	
95% within ± 20%	111 76% withi	n + 10%	73% withir	1 ± 10%
	0/9 withi	n + 20%	95% withir	1 ± 20%

Using $\gamma^{5/16}$ , S and G <sub>s</sub>	Using $\gamma^{5/16}$ , S, G <sub>s</sub> and E <sub>v</sub>
C(1) = $53.3958631782$ C(2) = $-127.9226404562$ C(3) = $20.8301124395$ C(4) = $17.9316706900$ C(5) = $-48.4457154475$ C(6) = $-5180822422$ C(7) = $-24.1731506505$ C(8) = $15.8709481683$ C(9) = $91.6107413501$ C(10) = $-15.2484978757$ C(11) = $-44.9.1867152981$ C(12) = $368.5656181405$ C(13) = $-44.6720935833$ C(14) = $166.2532151665$ C(15) = $66.2414675220$ C(16) = $-3.7716040549$ C(17) = $17.9221947624$ C(18) = $11.5629558875$ C(19) = $-205.3794622239$ C(20) = $13.0681609205$ C(21) = $254.9573454245$ C(22) = $-134.8771751525$ C(24) = $-134.8771751525$ C(25) = $-51.6017664322$ C(26) = $1.9569970883$ C(27) = $2.9310692111$ C(28) = $1726515931$ C(29) = $94.4689354767$ C(30) = $-6.0438470627$ R <sup>2</sup> <sub>m</sub> = $93.6$ 39% within $\pm 10\%$ 65% within $\pm 20\%$	C(1) = $-43.6955704922$ C(2) = $-263.0260424584$ C(3) = $76.0756460918$ C(4) = $143.4022465293$ C(5) = $14.6854054001$ C(6) = $0000018621$ C(7) = $-47.1730917167$ C(8) = $-15.6964256288$ C(9) = $90.9027550405$ C(10) = $-22.2985600530$ C(11) = $87.0048968184$ C(12) = $660.3121352892$ C(13) = $-126.3905248215$ C(14) = $-354.1566836962$ C(15) = $-82.2950451513$ C(16) = $.0000200377$ C(17) = $112.9332700877$ C(17) = $112.9332700877$ C(19) = $-193.3862745518$ C(20) = $8.2417379757$ C(21) = $-598.9320341567$ C(22) = $-523.9584928841$ C(23) = $41.3421692588$ C(24) = $689.3555775093$ C(25) = $107.4665743070$ C(26) = $0000353688$ C(27) = $-160.9998103993$ C(28) = $-93.9073485683$ C(29) = $118.7384287103$ C(30) = $25.6274231778$ C(31) = $342.2023179307$ C(32) = $175.6525289593$ C(33) = $.3384907975$ C(34) = $-340.1575068641$ C(35) = $-340.1575068641$ C(35) = $-340.1575068641$ C(36) = $.0000144488$ C(37) = $71.4063952381$ C(38) = $33.5127395672$ C(39) = $-23.9273648252$ C(40) = $-15.1138557381$ R <sup>2</sup> = 96.0 m
	70% within + 20%

TABLE 5. GENERAL EQUATION COEFFICIENTS FOR DEPTH

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Justing 5/16	5 s tan 4 and F	Using 5/1	$6 \text{ s}^{1/3}$ and $\text{E}$
ος πις γ	, 5, ταπ φ απα ε <sub>γ</sub>	USING Y	, 5, C and L
C( 1)=	17.1253607120	C(1)=	21.7086303701
C(2)=	-37.3542155845	C(2)=	-42.8323530877
C(3)=	12.5105364460-	C(3)=	14.6236850659
C-( 4_) =	8.5029333445	C ( 4) =	.1510212043
C ( 5) =	14.7403694963	C(5)=	22.8611299509
-C(* 6)=	•0000029697	C( 6)=	.0000028213
Ç (* 7) =	-7.2058081245	C(7)=	.0096628854
C(8)=	-8.4253426900	C ( 8) =	-14.1319628653
C(9)=	3.3999072147	C(9)=	4996236563
C(10)=	<del>-</del> 1.8629595715	C-(10) =	.2047476495
C(11)=	-193.3918309651	C(11) =	-85.5758975793
C(12)=	330.9456858185	C(12)=	112.7124014239
C(13) =	-97.2329269833	C(13)=	-25.8772673551
C(14) =	33.0550538845	C(14) =	2.6748938295
0(15)=	-134.3558827033	U(15)  = 0	-45.0953840333
U(16) = 0(47) = 0		(16) =	
0(1/) = 0/100 = 0	4.4909080389 70 6556077575	C(1)  =  C(1)  =	70 40401510904
0(10) = 0(10) = 0			- 0776620835
0(19)-	7.6485959924	((20) =	7761101183
C(2t) =	210.4717738602	C(21) =	90.0293948233
C(22) =	-361,0416787948	C(22) =	-86,5807061319
C(23) =	113,5789573079	C(23) =	-16.6599345535
.C.(24) =	-63.5462262740	C(24) =	-4.1166825850
C(25)=	144.1389355682	C(25)=	27.0640857132
C(26) =	.0000298469	C(26)=	.0000219654
C(27)=	2.6975157247	G(27)=	.0528352713
C(28)=	-83.6172087730	C(28)=	6.2005227223
.C(29)=	54.6675138674	C(29)=	1.3423129952
C(30)=	-12.3071777705	C(30) =	•4649869039
C(31) =	-72.7217500189	C(31)=	-31.6097537754
C(32)=	116.2322451501	C(32)=	32.5439752743
C(33)=	-37.4935916521	C(33)=	11.4732120724
C(34)=	25.5528645197	U(34) = 0(35)	1.1107085605
C(35) = 0(35	-45 . 3802628657	U(35) = 0(7(3))	-12.490231/355
C(36)=		((36) = ((77) = ((77))	0000104875
		C(37) = C(37	
C(38) = C(30) =	-21 3464790174	C(30) - C(30	- 0.050707512
-C(40)=	6.0772500010	C(40) =	0721852584
- 2	703116333013	2	* U I & L U Z A Z U A
R <sup>⊆</sup> m = 94.5		$R_{\rm m}^{-} = 97.8$	
43% within	± 10%	45% within $\pm$	10%
66% within	± 20%	72% within ±	20%

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TABLE 5. GENERAL EQUATION COEFFICIENTS FOR DEPTH (CONTINUED)

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			113 -FUK .VU:	-9MC
Using -	$\gamma^{5/16}$ , S and G <sub>s</sub>	Using $\gamma^{5/2}$	<sup>16</sup> , s, g <sub>s</sub>	and E <sub>v</sub>
C(1) = C(2) = C(3) = C(4) = C(5) = C(6) = C(7) = C(10) = C(10) = C(11) = C(12) = C(12) = C(14) = C(15) = C(16) = C(17) = C(20) = C(20) = C(27) = C(28) = C(29) = C(30) =	$\begin{array}{c} -2 \circ 1752357203 \\ 13 \cdot 1141215646 \\ \cdot 5997600122 \\ -3 \cdot 6647026294 \\ -30 \cdot 4405669790 \\ -3 \cdot 4757992071 \\ -3 \cdot 8080378705 \\ 14 \cdot 9439527393 \\ 20 \cdot 8239905853 \\ -5 \cdot 9957649451 \\ -215 \cdot 7667550905 \\ 93 \cdot 1623369378 \\ -16 \cdot 5008692970 \\ 118 \cdot 9135549083 \\ 33 \cdot 8867065685 \\ 2 \cdot 7663678702 \\ -6 \cdot 3022129785 \\ 2 \cdot 7930 \cdot 38894 \\ -67 \cdot 2103550710 \\ 4 \cdot 0009580189 \\ 146 \cdot 3688958239 \\ -25 \cdot 5335254205 \\ 6 \cdot 3873929627 \\ -98 \cdot 0675342208 \\ -30 \cdot 2435268423 \\ -6234156121 \\ 9 \cdot 8235554535 \\ 1 \cdot 2453679293 \\ 37 \cdot 1186765414 \\ -2 \cdot 7689859994 \\ \pm 10\% \\ \pm 20\% \end{array}$	C(1) = C(2) = C(3) = C(3) = C(4) = C(5) = C(6) = C(7) = C(6) = C(7) = C(10) = C(11) = C(12) = C(12) = C(12) = C(12) = C(12) = C(14) = C(15) = C(16) = C(17) = C(16) = C(17) = C(16) = C(20) = C(21) = C(20) = C(21) = C(20) = C(21) = C(20) = C(21) = C(20)	$\begin{array}{c} -11.83\\ -347.04\\ 97.93\\ 156.84\\ -156.84\\ -16.14\\ 128.58\\ -30.98\\ -59.39\\ 875.96\\ -209.59\\ -334.69\\ -59.39\\ 875.96\\ -209.59\\ -334.69\\ -147.68\\ -147.68\\ -224.93\\ -134.86\\ -617.54\\ 122.24\\ 372.81\\ 163.41\\ -99.19\\ -133.49\\ 109.79\\ 133.51\\ 109.79\\ 13.51\\ 109.16\\ 152.11\\ -21.48\\ -150.23\\ -55.93\\ -55.93\\ -13.59\\ -9.81\\ \end{array}$	V 207236195 492941075 246661795 518890100 575210571 00070368 568518002 387586229 393232243 388871631 569012349 52548086229 393232243 388871631 569012349 53293740 146367155 153293740 146367155 153293740 146367155 153293740 146367155 153293740 146367155 153293740 146367155 153293740 146367155 153293740 146367155 153293740 146367155 153293740 146367155 153293740 146367155 153293740 146367155 153293740 146367155 153293740 146367155 153234833 15866705
		°m 65% within 89% within	± 10% ± 20%	

TABLE 6. GENERAL EQUATION COEFFICIENTS FOR VOLUME

INDEE U.			VOLUME (CONTINUED)
Using y <sup>5/-10</sup>	<sup>6</sup> , S, tan $\phi$ and E <sub>V</sub>	Using y <sup>5/16</sup>	, S, $c^{1/3}$ , and $E_v$
C ( 1)=	22.3706247625	C(1)=	20.4178474204
C(2)=	-38.9723779360	C(2) = 0	6.7210259119
C(-3)=	18.9610934544	((3) = (	11,9976882110
C(4)=	-5.7817278439	$((4) = (-1)^{-1}$	-2.8361992670
C(5)=	15.64131-96900	0(5)=	-1/.5564//18/1
C(6) =	0000019613	C(. 6)=	0000012370
C(7)=	-1.4903246793		.0043463631
C(8)=	-15.6027125598	C( 8)=	-9.5472334444
Ç( 9) =	7.4617827708	C ( 9) =	2.1150419147
<u>C(10)</u> =	.2976374547	C(10) =	023/115989
C(11) =	-205.6266042500	C(11) =	-88.7714888573
-C(12)=	332.7916277065	C(12)=	-1.0129467374
Ç(13)=	-107.5617213000	C(13)=	-40.4980903277
C(14)=	65.3451232219	C(14) =	10.4459006002
C(15)=	-131.0986024125	C(15)=	56.2397519725
C(16)=	0000133719	C(16) =	0000128355
C(17) =	-2.7122525642	C(17)=	0069710347
C(18)=	85.1580280890	C(18) =	36.2108467755
C-(19)=	-54.5527834882	C(19)=	-8.0426022638
C(20)=	2.9801404833	C(20) =	1288631602
C(21)=	224.1213882024	C(21) =	70.9874042555
<u>C(22) =</u>	-355.1369302715	C(22)=	39.8818213389
C(23)=	115.5598816362	C(23)=	5.8251333617
C(24) =	-82.6517911088	C(24)=	-10.3385864955
C(25)=	136.3420036065	C(25)=	-/3.6285916503
C(26)=	.0000208297	C(26) =	.0000259077
C-(27)=	3.61/2294428	U(27) =	• U24 U818545
C(28)=	-87.3706458740	0(28) =	-2%6011605495
C(29)=	69.9345875052	0(29) = 0(70	7.05554455247
C(30)=	-10.0936503159	((30) = (74)	23491/800/
C(31) =	-68.05/0038645	0(31) = 0(32) = 0	
C(32) =	105.8/9625/8/5	b(32) = b(32	
C(33)=	-35.1328556619	$((33)^{2})$	4.7047070077
U(34) =	28.20/1/99/15	0(34) = 0(75) = 0	
C(35)=	-39.6850247712	(132) = (132)	
6(36)=	0000087052		
C(37)=		0(3/) =	0138504243
C(38) =	25.7701411555	U(38) = U(38	-5.1011694//2
U(39)=	-24.3306349045		-1+320630/113
U(40)=	4.2180233191	0(40)=	• TOO A91 TI 0 2
$R_m^2 = 96.9$		$R_{\rm m}^2 = 97.8$	• • • •
66% within	± 10%	65% within ±	10%
92% within	± 20%	93% within ±	20%

TABLE 6. GENERAL EQUATION COEFFICIENTS FOR VOLUME (CONTINUED)

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## APPENDIX V

# MATERIAL PROPERTY EFFECTS PLOTS



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Percent Saturation, S





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Scaled Depth of Burst,  $Dob/W^{5/16}$ 

FIG. 37. CRATER VOLUME AS A FUNCTION OF CHARGE DEPTH AND DRY UNIT WEIGHT,  $Y_d$ , POUNDS/CUBIC FOOT, FOR SPECIFIC GRAVITY = 2.65 AND PERCENT SATURATION = 40



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UNCLASSIFIED Security Classification DOCUMENT CONTROL DATA - R & D (Security classification of fille, body of abstract and indexing annutation must be entered when the overall report is classified) ORIGINATING ACTIVITY (Corporate author) 28. REPORT SECURITY CLASSIFICATION UNCLASSIFIED Texas A&M Research Foundation College Station, Texas 77843 2b. GROUP 3 THE INFLUENCE OF SOIL AND ROCK PROPERTIES ON THE DIMENSIONS OF EXPLOSION-PRODUCED CRATERS. 4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Feb 70-Oct 71. February-1970-through-October-1971-Technical AUTHORIS) (First name, middla initial, last noine) [arry A./Dillon] Maj, USAF 76. NO. OF REES Feb 72 ONTRA ORIGINATOR'S REPORT NUMBER(S) F29601-70-C-0032 ment AFWLKJR-71-144 MA-NWER-SA-102 9b. OTHER REPORT NOISI (Any other numbers that may be assigned this report) 1 TRIBUTION STATEMENT Distribution limited to US Government agencies only because of test and evaluation (19 Jan 72). Other requests for this document must be referred to AFWL (DEV). 1. SUPPLEMENTARY NOTES 12. SPONSORING MILITARY ACTIVITY AFWL (DEV) Kirtland AFB, NM 87117 3. ABSTRACT (Distribution Limitation Statement B) Analysis of data from published cratering experiments shows the effect of soil and rock properties on the apparent dimensions of explosion-produced craters. More than 200 cratering tests and related material properties were cataloged. The data consisted of 10 nuclear events whose yields varied from 0.42 to 100 kilotons and about 200 high explosive events whose yields varied from 1 to 1 million pounds of TNT. The different test sites included materials for which the density ranged from 60 to 170 pounds/cubic foot. By regression analysis, using bell shaped curves, prediction formulas were developed for the apparent crater radius, depth, and volume as a function of charge weight and depth of burst for eight different types of materials. The bell curves were normalized using material properties and prediction equations were generated using all the data. These general equations were then studied to determine the specific effects of the material properties on resultant apparent crater dimen-Material properties are highly important in determining the size of explosions. sion-produced craters and some of the more important properties are unit weight, degree of saturation, shearing resistance and seismic velocity. Previous investigators have been somewhat negligent in measuring material properties for past cratering experiments and no real data analysis can be made until the variables are either controlled or measured. Material properties which should be measured for future tests should at least include the above properties and if possible the material's energy dissipation and bulking characteristics. Better yet a reasonably simple theory of cratering is needed which will better define the material properties governing cratering mechanics. DD FORM 1473 UNCLASSIFIED 347320" Security Classification

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