CASE 3527: Application of EL PASO TO DRILL SEVERAL WELLS AT UNSPECIFIED UNORTHODOX LOCATIONS.

CASE NO. 3327

Application,
Transcripts,
Small Exhibits
ETC.

'67 MAY 22 AM 8 25

GOVERNOR
DAVID F. CARGO
CHAIRMAN

State of New Mexico
Oil Conservation Commission

LAND COMMISSIONER
GUYTON B. HAYS
MEMBER

P. O. BOX 2088
SANTA FE

STATE GEOLOGIST
A. L. PORTER, JR.
SECRETARY - DIRECTOR

LEGAL DIVISION
PHONE 827-2741

May 18, 1967

Case 3527

Mr. Emery C. Arnold
Supervisor, District 3
Oil Conservation Commission
1000 Rio Brazos Road
Aztec, New Mexico

Dear Emery:

Please send me a copy of the letter from El Paso Natural Gas Company requesting approval of non-standard locations for Project Gasbuggy for our files.

Did you approve two or three non-standard locations?

Very truly yours,

George M. Hatch

GEORGE M. HATCH
Attorney

GMH/esr

RECEIVED
MAY 19 1967
OIL CON. COM.
DIST. 3

George -
The "two" in my letter was in error & should have read "three". I have notified El Paso. Thanks
Emery

El Paso Natural Gas Company

El Paso, Texas 79999

May 11, 1967

ADDRESS REPLY TO
POST OFFICE BOX 990
FARMINGTON, NEW MEXICO 87401

E B
File

Mr. Emery C. Arnold
Oil and Gas Conservation Commission
1000 Rio Brazos Road
Aztec, New Mexico

Dear Sir:

Pursuant to Order No. R-3197, El Paso Natural Gas Company hereby requests approval for the drilling of GB1, GB2 and GBE (emplacement) at Ground Zero as indicated on the attached plat of Section 36, Township 29 North, Range 4 West, N.M.P.M., Rio Arriba County, New Mexico. The directional drilling will not be utilized in any of the three wells.

Your approval of this request is respectfully solicited.

Very truly yours,

D. N. Canfield

D. N. Canfield
Site Coordinator

DNC:ss
w/attachment

OIL CONSERVATION COMMISSION
1000 RIO BRAZOS ROAD
AZTEC, NEW MEXICO

'67 MAY 16 AM

May 15, 1967

COPY

El Paso Natural Gas Company
PO Box 990
Farmington, New Mexico 87410

Attention: Mr. D. N. Canfield

Dear Sir:

We have your letter of May 11, 1947 requesting approval of two non-standard locations of the following wells:

✓ GB #1	Loc.	1324 F/SL	1614 F/WL	Sec 36-T 29N-	R 4W
✓ GB #2	"	1218 F/SL	2070 F/WL	" " "	"
✓ GBE (emplacement)	Loc.	1218 F/SL	1770 F/Wl	Sec 36-T29N-	R 4W

The Secretary Director of the New Mexico Oil Conservation Commission has delegated to me the authority to approve these non-standard locations pursuant to the provisions of R-3197 and they are hereby approved.

Yours very truly,

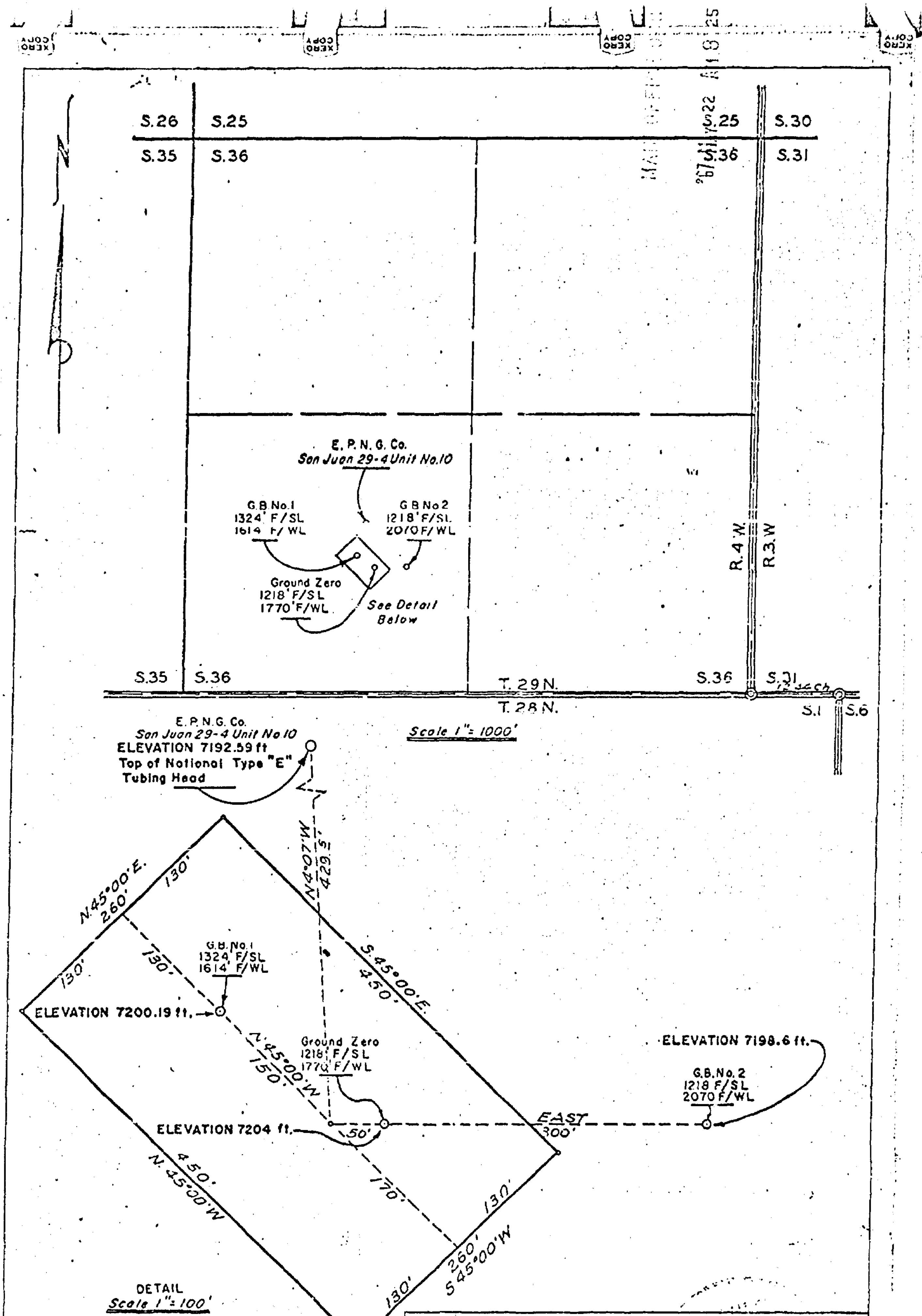
Emery C. Arnold
Supervisor Dist #3

ECA/me

CC: A. L. Porter, Jr.
Santa Fe

CC: William Cutler
EPNG
Farmington

5-22-67
Emery has notified the applicant that approval was for 3 non-standard locations.
[signature]



EL PASO NATURAL GAS COMPANY

EL PASO, TEXAS

PLAT OF

GASBUGGY GROUND ZERO

SCALE: As Shown	DATE: 1-25-67 Rev. 4-3-67	NO.
DRAWN BY:	CHECKED BY:	

GOVERNOR
DAVID F. CARGO
CHAIRMAN

State of New Mexico
Oil Conservation Commission

LAND COMMISSIONER
GUYTON B. HAYS
MEMBER

STATE GEOLOGIST
A. L. PORTER, JR.
SECRETARY - DIRECTOR

P. O. BOX 2088
SANTA FE

February 23, 1967

Re: Case No. 3527
Order No. R-3197
Applicant:
EL PASO NATURAL GAS CO.

Mr. Richard S. Morris
Seth, Montgomery, Federici & Andrews
Attorneys at Law
Post Office Box 2307
Santa Fe, New Mexico

Dear Sir:

Enclosed herewith are two copies of the above-referenced Commission order recently entered in the subject case.

Very truly yours,

A. L. Porter, Jr.

A. L. PORTER, Jr.
Secretary-Director

ALP/ir

Carbon copy of order also sent to:

Hobbs OCC x
Artesia OCC
Aztec OCC x
Other Mr. Ben Howell

BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

IN THE MATTER OF THE HEARING
CALLED BY THE OIL CONSERVATION
COMMISSION OF NEW MEXICO FOR
THE PURPOSE OF CONSIDERING:

CASE No. 3527
Order No. R-3197

APPLICATION OF EL PASO NATURAL GAS COMPANY
FOR AUTHORITY TO DRILL AND TO DIRECTIONALLY
DRILL SEVERAL WELLS AT UNSPECIFIED UNORTHO-
DOX LOCATIONS AND TO PRODUCE THEREFROM AND
VENT NATURAL GAS IN CONJUNCTION WITH
"PROJECT GASBUGGY," RIO ARRIBA COUNTY, NEW
MEXICO.

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at 9 a.m. on February 15, 1967, at Santa Fe, New Mexico, before the Oil Conservation Commission of New Mexico, hereinafter referred to as the "Commission."

NOW, on this 23rd day of February, 1967, the Commission, a quorum being present, having considered the testimony presented and the exhibits received at said hearing, and being fully advised in the premises,

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That the applicant, El Paso Natural Gas Company, seeks authority to drill several wells at unspecified unorthodox locations in the SW/4 of Section 36, Township 29 North, Range 4 West, NMPM, Choza Mesa-Pictured Cliffs Gas Pool, Rio Arriba County, New Mexico, for testing, instrumentation, and the detonation of a nuclear explosive to determine the feasibility of increasing the recovery of natural gas from low permeability reservoirs.

(3) That the aforesaid effort to determine the feasibility of increasing the recovery of natural gas from low permeability reservoirs by means of nuclear detonation is to be conducted by

the applicant in cooperation with the United States Atomic Energy Commission, the United States Bureau of Mines, and the Lawrence Radiation Laboratory of the University of California and is designated "Project Gasbuggy."

(4) That the applicant also seeks authority to produce and flare natural gas both before the detonation and afterward, as required, to establish producing characteristics of the formation at the test site and to otherwise properly evaluate the test.

(5) That the applicant further seeks the establishment of an administrative procedure for approval of the location of such wells as may be required at unorthodox locations and to directionally drill said wells as and when the applicant is able to determine the number of wells, the unorthodox locations, and the directional drilling that will be necessary to properly conduct "Project Gasbuggy."

(6) That the applicant proposes to drill a well or wells in the SW/4 of said Section 36 prior to any detonation of a nuclear explosive in order to conduct extensive coring and logging operations to determine the acceptability of the site for test purposes. The applicant also proposes to produce said wells and to flare said production in order to establish the exact producing characteristics of the formation.

(7) That the applicant proposes to drill an emplacement well within the SW/4 of said Section 36 at a site yet to be selected and for the detonation of a nuclear explosive therein in the Pictured Cliffs formation at a depth of approximately 4200 feet, if the aforementioned test wells establish that satisfactory conditions exist for the conduction of a nuclear explosion and test.

(8) That after the aforementioned detonation, the applicant proposes to drill a reentry well, and other wells as may be necessary, for the purpose of producing gas from and determining the extent of the fractured area and to produce and flare gas from the fractured area under the supervision of governmental authorities until such time as appropriate governmental agencies including the United States Public Health Service determine that said gas complies with all health and safety requirements.

(9) That in order to properly conduct and evaluate the aforesaid test to determine the feasibility of increasing the recovery of natural gas from low permeability reservoirs by means of nuclear detonations, it will be necessary for an as yet unspecified number

of wells to be drilled and to be drilled at unorthodox locations, to flare a minimal amount of gas before and after detonation, and possibly to directionally drill some of said wells.

(10) That the above-mentioned test is in the interest of conservation of the natural resources of New Mexico and should provide invaluable information toward determining the feasibility of increasing the recovery of natural gas from low permeability reservoirs by means of nuclear detonations; that the drilling of said wells at unorthodox locations, directional drilling of said wells, and the flaring of a minimal amount of gas are necessary parts of such study and will not violate correlative rights and may well result in the recovery of large amounts of gas that would otherwise be unrecoverable thereby preventing waste.

(11) That an administrative procedure should be established whereby the applicant can receive authorization to drill a well or wells in the SW/4 of said Section 36 at unorthodox locations and to directionally drill said wells if necessary when the applicant has determined the location or locations to be drilled and the necessity for and the manner of directionally drilling said wells.

IT IS THEREFORE ORDERED:

(1) That the applicant, El Paso Natural Gas Company, is hereby authorized to drill an unspecified number of wells in the SW/4 of Section 36, Township 29 North, Range 4 West, NMPM, Choza Mesa-Pictured Cliffs Gas Pool, Rio Arriba County, New Mexico, to drill said wells at unorthodox locations in said SW/4, and to directionally drill said wells if necessary:

PROVIDED HOWEVER, that the applicant shall apply to the Secretary-Director of the Commission for approval for each and every well to be drilled and shall apply to the Secretary-Director for approval for any directional drilling to be done and shall receive approval from the Secretary-Director for said wells to be drilled and for said directional drilling;

PROVIDED FURTHER, that should any of the aforementioned wells be directionally drilled, a directional survey shall be made of the well and a copy of the survey report filed with the Santa Fe Office of the Commission, Box 2088, Santa Fe, New Mexico.

(2) That Form C-105 shall be filed in accordance with Commission Rule 1105 and the operator shall indicate thereon true vertical depths in addition to measured depths.

(3) That the applicant is hereby authorized to produce and flare from wells drilled in the SW/4 of Section 36, Township 29 North, Range 4 West, NMPM, Choza Mesa-Pictured Cliffs Gas Pool, Rio Arriba County, New Mexico, in conjunction with "Project Gasbuggy" that amount of gas necessary to establish producing characteristics of the formations at the test site and to otherwise properly conduct and evaluate the test.

(4) That jurisdiction of this cause is retained for the entry of such further orders as the Commission may deem necessary.

DONE at Santa Fe, New Mexico, on the day and year hereinabove designated.

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

DAVID F. CARGO, Chairman

GUYTON B. HAYS, Member

A. L. PORTER, Jr., Member & Secretary

S E A L

esr/

Docket No. 5-67

DOCKET: REGULAR HEARING - WEDNESDAY - FEBRUARY 15, 1967

OIL CONSERVATION COMMISSION - 9 A.M., MORGAN HALL, STATE LAND OFFICE BUILDING
SANTA FE, NEW MEXICO

ALLOWABLE: (1) Consideration of the oil allowable for March, 1967;

(2) Consideration of the allowable production of gas for March, 1967, from thirteen prorated pools in Lea, Eddy and Roosevelt Counties, New Mexico; Consideration of the allowable production of gas from nine prorated pools in San Juan, Rio Arriba and Sandoval Counties, New Mexico, for March, 1967.

CASE 3527: Application of El Paso Natural Gas Company for authority to drill and to directionally drill several wells at unspecified unorthodox locations and to produce therefrom and vent natural gas in conjunction with "Project Gasbuggy," Rio Arriba County, New Mexico. Applicant, in the above-styled cause, seeks authority to drill and to directionally drill several wells at as yet unspecified unorthodox locations in the SW/4 of Section 36, Township 29 North, Range 4 West, Choza Mesa-Pictured Cliffs Gas Pool, Rio Arriba County, New Mexico, said wells to be used as required for testing and for the instrumentation and detonation of a nuclear explosive in conjunction with "Project Gasbuggy," which is to be conducted in cooperation with the United States Atomic Energy Commission, the United States Bureau of Mines, and Lawrence Radiation Laboratory of the University of California, to determine the feasibility of increasing the recovery of natural gas from low permeability reservoirs. Applicant also seeks authority to produce and vent natural gas both before the detonation and afterward, as required, to properly evaluate the test. Applicant further seeks the establishment of an administrative procedure for approval of the location of such wells as may be required at unorthodox locations.

CASE 3528: Southeastern New Mexico nomenclature case calling for an order for the creation of one pool and the assignment of an oil discovery allowable therein, and the creation, extension and abolishment of certain other pools in Lea, Eddy, and Chaves Counties, New Mexico:

(a) Create a new pool in Lea County, New Mexico, classified as an oil pool for Abo production and designated the Emerald-Abo Pool, comprising the following-described acreage:

TOWNSHIP 17 SOUTH, RANGE 36 EAST, NMPM
Section 15: SW/4

Further, for the assignment of approximately 47,220 barrels of oil discovery allowable to the discovery well, Elk Oil Company's Aztec State Well No. 1, located in Unit M of said Section 15.

(b) Create a new pool in Eddy County classified as a gas pool for Atoka production and designated as the Dagger Draw-Atoka Gas Pool, and described as:

TOWNSHIP 20 SOUTH, RANGE 24 EAST, NMPM
Section 3: W/2

(c) Create a new pool in Eddy County classified as a gas pool for Canyon production and designated as the Hackberry Hills-Canyon Gas Pool, and described as:

TOWNSHIP 22 SOUTH, RANGE 25 EAST, NMPM
Section 1: S/2

(d) Create a new pool in Eddy County classified as a gas pool for Canyon production and designated as the East Hackberry Hills-Canyon Gas Pool, and described as:

TOWNSHIP 22 SOUTH, RANGE 26 EAST, NMPM
Section 22: N/2

(e) Create a new pool in Lea County classified as an oil pool for Wolfcamp production and designated as the South Lusk-Wolfcamp Pool, and described as:

TOWNSHIP 19 SOUTH, RANGE 32 EAST, NMPM
Section 28: SE/4

(f) Create a new pool in Lea County classified as a gas pool for Devonian production and designated as the Paduca-Devonian Gas Pool, and described as:

TOWNSHIP 25 SOUTH, RANGE 32 EAST, NMPM
Section 18: NW/4

(g) Create a new pool in Chaves County classified as an oil pool for San Andres production and designated as the West Tobac-San Andres Pool, and described as:

TOWNSHIP 8 SOUTH, RANGE 32 EAST, NMPM
Section 26: SE/4

(h) Extend the Artesia Pool in Eddy County to include therein:

TOWNSHIP 19 SOUTH, RANGE 28 EAST, NMPM
Section 9: SE/4 NW/4 and NE/4 SW/4

(i) Extend the Atoka-Pennsylvanian Gas Pool in Eddy County to include therein:

TOWNSHIP 18 SOUTH, RANGE 26 EAST, NMPM
Section 15: N/2

(j) Extend the North Bagley-Upper Pennsylvanian Pool in Lea County to include therein:

TOWNSHIP 11 SOUTH, RANGE 33 EAST, NMPM
Section 3: S/2 SE/4
Section 9: NW/4

(k) Extend the Big Eddy-Strawn Pool in Eddy County to include therein:

TOWNSHIP 20 SOUTH, RANGE 31 EAST, NMPM
Section 19: SW/4

(l) Extend the Cato-San Andres Pool in Chaves County to include therein:

TOWNSHIP 8 SOUTH, RANGE 30 EAST, NMPM
Section 14: NE/4
Section 16: N/2
Section 17: NE/4

(m) Extend the Grama Ridge-Morrow Gas Pool in Lea County to include therein:

TOWNSHIP 21 SOUTH, RANGE 34 EAST, NMPM
Section 33: All

(n) Extend the Justis-Blinebry Pool in Lea County to include therein:

TOWNSHIP 24 SOUTH, RANGE 37 EAST, NMPM
Section 26: NE/4

(o) Extend the Middle Lane-Permo Pennsylvanian Pool in Lea County to include therein:

TOWNSHIP 10 SOUTH, RANGE 33 EAST, NMPM
Section 14: SE/4

(p) Extend the Lazy J-Pennsylvanian Pool in Lea County to include therein:

TOWNSHIP 14 SOUTH, RANGE 33 EAST, NMPM
Section 3: SE/4

(q) Extend the Malaga-Delaware Pool in Eddy County to include therein:

TOWNSHIP 24 SOUTH, RANGE 28 EAST, NMPM
Section 13: E/2 SW/4
Section 24: NW/4

(r) Extend the Osudo-Morrow Gas Pool in Lea County to include therein:

TOWNSHIP 21 SOUTH, RANGE 35 EAST, NMPM
Section 6: Lots 1, 2, 7, 8, 9, 10, 15, and 16

(s) Extend the Scanlon-Delaware Pool in Eddy County to include therein:

TOWNSHIP 20 SOUTH RANGE 29 EAST, NMPM
Section 30: NE/4 SE/4

(t) Abolish the West Mesa-Upper Queen Gas Pool comprising the following described acreage in Eddy County, New Mexico:

TOWNSHIP 16 SOUTH, RANGE 31 EAST, NMPM
Section 12: NW/4 & S/2
Section 13: N/2 & SW/4
Section 14: NE/4

(u) Extend the Mesa Queen Pool in Lea County, New Mexico, to include all of the Queen formation in the following area:

TOWNSHIP 16 SOUTH, RANGE 32 EAST, NMPM
Section 18: NW/4 & S/2

and to include the Upper Queen gas pay only in the following described area in Eddy County:

TOWNSHIP 16 SOUTH, RANGE 31 EAST, NMPM
Section 12: All
Section 13: All
Section 14: NE/4

CASE 3520. Northwestern New Mexico nomenclature case calling for an order creating certain pools in San Juan County, New Mexico:

(a) Create a new pool in San Juan County classified as a gas pool for Fruitland production and designated as the Pinon-Fruitland Pool, and described as:

TOWNSHIP 28 NORTH, RANGE 11 WEST, NMPM
Section 18: NW/4

TOWNSHIP 28 NORTH, RANGE 12 WEST, NMPM
Section 13: N/2 & SE/4

(b) Create a new pool in San Juan County classified as a gas pool for Gallup production, designated as the Ojo-Gallup Pool, and described as:

TOWNSHIP 28 NORTH, RANGE 14 WEST, NMPM
Section 31: S/2

TOWNSHIP 28 NORTH, RANGE 15 WEST, NMPM
Section 26: N/2 & SE/4
Section 35: NE/4
Section 36: N/2 & SE/4

(c) Create a new pool in San Juan County classified as an oil pool for Dakota production, designated as the Slick Rock-Dakota Oil Pool, and described as:

TOWNSHIP 30 NORTH, RANGE 17 WEST, NMPM
Section 36: S/2 SE/4

ir/

BEFORE THE
OIL CONSERVATION COMMISSION
STATE OF NEW MEXICO

APPLICATION OF EL PASO NATURAL GAS COMPANY FOR APPROVAL OF DRILLING, TESTING AND ALL OTHER OPERATIONS INCLUDED IN "PROJECT GASBUGGY," A PROPOSED TEST OF NUCLEAR EXPLOSIVE TO STIMULATE GAS PRODUCTION IN LOW PERMEABILITY SANDS, EXPECTED TO BE CONDUCTED ON SW/4 OF SECTION 36, TOWNSHIP 29N, RANGE 4W, N.M.P.M., RIO ARRIBA COUNTY, NEW MEXICO	)	CASE NO. 3527

El Paso Natural Gas Company is a Delaware corporation, authorized to do business in the State of New Mexico, hereinafter called "Applicant."

I.

Applicant, in cooperation with the United States Atomic Energy Commission, the United States Bureau of Mines and The Lawrence Radiation Laboratory of the University of California have studied the feasibility of increasing recovery of natural gas in place in low permeability reservoirs by detonation of a nuclear explosive and have concluded that the use of a nuclear explosive to frature the reservoir rock will substantially increase the recovery of gas from a low permeability reservoir and make production economically feasible from reservoirs which are noncommercial under present recovery methods.

II.

The joint feasibility study has selected as an appropriate place for such test the SW/4 of Section 36, Township 29N, Range 4W, N.M.P.M., Rio Arriba County, New Mexico, hereinafter called "test site." The test site and all land within a radius of one-half mile from the test site is public domain and is subject to United States Oil and Gas Leases which have been assigned to Applicant. San Juan 29-4 Unit Well No. 10-36 has been completed in and is producing from the Pictured Cliffs Formation, and is located 1650 feet north of the south line and 1700 feet east of the west line of said Section 36. The test site and surrounding acreage lies within the boundaries of the Choza Mesa Pictured Cliffs Gas Pool and is not presently subject to any proration order. The test site has been committed to the provisions of the San Juan 29-4 Unit Agreement and San Juan 29-4 Unit Operating Agreement. Applicant is Unit Operator for such unit and has submitted to the United States Geological Survey and to the Commission a unit plan of development including the operations contemplated for Project Gasbuggy. The owners of leasehold interests within said unit have agreed to the proposed operations.

III.

The Pictured Cliffs Formation in the vicinity of the test site has low permeability and, under current methods of well completion is expected to produce only a small proportion of the natural gas in place in the reservoir.

IV.

The proposed plan of conducting the test includes operations as follows:

(a) Drilling a test well (GB-1) to a depth approximately 100 feet below the base of the Pictured Cliffs Formation to determine by extensive coring the exact characteristics at the test site of the Ojo Alamo, Kirtland, Fruitland and Pictured Cliffs Formations.

(b) If the test site is found acceptable and additional information is desired, a second test well (GB-2) may be drilled within the test site to correlate reservoir information. Any such well, or wells, is expected to be produced and, in order to obtain exact measurements, gas produced will be metered to establish exact producing characteristics of the formation at the test site and vented. It is expected that the volumes vented, if marketed, would not repay the cost of making pipeline connection.

(c) If and when the test well(s) has established satisfactory conditions for conducting the nuclear explosion and test, an emplacement well (GB-E) will be drilled. A nuclear explosive will be detonated under direction of the Atomic Energy Commission.

(d) One or more reentry wells will be drilled, using such portions of the emplacement hole as are usable and/or a new location, for the purpose of drilling into the fractured area and producing gas therefrom.

(e) One or more test holes may be drilled at appropriate distances from the emplacement hole to determine the horizontal limits of fractures resulting from the explosion and to gather other data.

(f) By whipstocking, directional holes may be drilled from one or more of the above-mentioned wells to determine the extent of fracturing.

(g) After completion of the reentry well or wells, gas will be produced and vented under the supervision c. governmental authorities until such time as appropriate government agencies determine that gas produced from the test site complies with all health and safety requirements.

V.

Applicant requests that the Commission approve drilling in excess of one well on this 160-acre drilling block as an exception to Rule 104CII(b) and establish an administrative procedure for obtaining approval of locating any of the above-mentioned wells closer to the outer boundary lines of the tract and to quarter-quarter section lines or subdivision inner boundary lines than is permitted by the applicable spacing rules.

VI.

Applicant believes that the operations contemplated by this test will increase the total quantity of natural gas ultimately recovered from this pool and requests approval of venting volumes of gas required for the test and proper evaluation thereof.

WHEREFORE, Applicant requests that notice of this application be given as required by law and that this matter be set for hearing by the Commission at the regular State-wide Hearing on February 15, 1967, and that upon conclusion of said Hearing an order be issued approving drilling of additional wells upon the 160-acre test site, venting all volumes of gas both before and after the detonation as are required for conduct and proper evaluation of the test and establishing administrative procedure for locating wells closer to boundary lines than is permitted by the applicable state-wide rule.

EL PASO NATURAL GAS COMPANY

By Richard S. Morris

Ben R. Howell

of counsel

FORM 1397 1-66

PAN AMERICAN PETROLEUM CORPORATION

SECURITY LIFE BUILDING

DENVER, COLORADO 80202

PRODUCING DEPARTMENT
H. T. HUNTER
DIVISION PRODUCTION MANAGER

DISTRICT SUPERINTENDENTS
W. M. JONES
A. E. PIPER
T. M. CURTIS
JOINT INTEREST SUPERINTENDENT
S. B. RICHARDS

February 10, 1967

File: AMR-302-986.51

RE: Project Gasbuggy Hearing,
Case No. 3527. February 15, 1967

Case 3527

New Mexico Oil and Gas Conservation Commission
Post Office Box 871
Santa Fe, New Mexico

Gentlemen:

Please be advised that Pan American as a financial contributor to "Project Gasbuggy" supports the application of El Paso Natural Gas Company for authority to drill and directionally drill several wells at unspecified unorthodox locations and to produce therefrom and vent natural gas in conjunction with "Project Gasbuggy."

Pan American hereby requests the approval of this application by the commission.

Yours very truly,

S. B. Richards

cc: El Paso Natural Gas Company
Post Office Box 990
Farmington, New Mexico

BEFORE THE
NEW MEXICO OIL CONSERVATION COMMISSION
Santa Fe, New Mexico
February 15, 1967

REGULAR HEARING

IN THE MATTER OF: Application of El Paso Natural Gas Company for authority to drill and to directionally drill several wells at unspecified unorthodox locations and to produce therefrom and vent natural gas in conjunction with "Project Gas Buggy," Rio Arriba County, New Mexico.	Case 3527

BEFORE:

David F. Cargo, Governor
A. L. "Pete" Porter, Secretary-Director
Guyton Hays, Land Commissioner

Transcript of Hearing

MR. PORTER: The Commission will take up Case 3527.

MR. HATCH: Case 3527. Application of El Paso Natural Gas Company for authority to drill and to directionally drill several wells at unspecified unorthodox locations and to produce therefrom and vent natural gas in conjunction with "Project Gasbuggy," Rio Arriba County, New Mexico.

MR. PORTER: I would like to call for appearances in this case at this time. Mr. Morris.

MR. MORRIS: May the Commission please, I am Richard Morris of Montgomery, Federici, and Andrews, Santa Fe, New Mexico, appearing for the Applicant, El Paso Natural Gas Company. Also appearing for the Applicant will be Mr. Ben R. Howell and Mr. Robert A. Meyer, attorneys, for El Paso Natural Gas Company. After appearances, Mr. Porter, we would appreciate a very short recess to post some exhibits on the wall.

MR. PORTER: Are there any other appearances in the case.

MR. SMITH: R. V. Smith, Phillips Petroleum Company.

MR. PORTER: Mr. Smith, do you anticipate putting on any testimony?

MR. SMITH: No, sir, we do not.

MR. SOMMER: H. A. Sommer, Pan American.

MR. PORTER: Anyone else? Are there any people here from any of the Federal agencies who would like to make a statement or who would make a statement during the hearing?

MR. ANDERSON: John Anderson, Regional Oil and Gas Supervisor, U. S. Geological Survey, Roswell, New Mexico.

MR. WOODRUFF: Wayne R. Woodruff, University of California, Lawrence Radiation Laboratory, Livermore, California.

MR. PORTER: We certainly appreciate your being here.

MR. THALGOTT: Robert Thalgott, Atomic Energy Commission, Las Vegas, Nevada.

MR. KELLAHIN: Jason Kellahin, Kellahin and Fox, Santa Fe appearing for Continental Oil Company. We will have no testimony.

MR. PORTER: We will have about a five-minute recess.

(Recess)

MR. PORTER: Hearing will come to order, please. The Commission will recognize Mr. Ben Howell of El Paso Natural Gas Company.

MR. HOWELL: May it please the Commission, the application in this case is a request for drilling an indefinite number of wells at some indefinite locations within the Southwest quarter of Section 36 Township 29 North, Range 4 West and a request for permission to flare undetermined quantities of gas. This indefiniteness is inherent in the fact that this is an experiment and is the first experiment in which the United States Government is joining with industry and certainly the State Highway Department of the State of New Mexico has indicated its desire to participate in a test which we hope, will give a great many answers.

We have placed upon the wall at the extreme right a sketch. We do not intend to introduce this as an exhibit. Frankly, we don't have anybody in our organization who could testify under oath that he knows that is exactly what's going to happen. That sketch is taken from the feasibility study of Project Gasbuggy in which the Government Agencies and the company participate, and while not drawn to scale, does reflect the various formations and their sequence in the Basin, and does graphically portray the expected results.

We shall put on two witnesses; one witness, who is Mr. Richard Lemon and is the Manager of our Reservoir Engineering Department, to testify as to the existing reservoir conditions in the Pictured Cliffs Formation in this area.

We will also put on Mr. Leslie Truby who is Manager of our Production Department, who will give the details which are available as to the drilling program.

As the Chairman determined, there are present, representatives of Government agencies who are prepared to make statements covering a matter that, while public health is not directly the concern of this Commission, certainly we recognize that the Commission is interested in the fact that the public health and safety will be protected, and these gentlemen from the Atomic Energy Commission and the Lawrence Radiation Laboratory are available to make statements of the background conditions that will exist.

With this brief introduction, we shall allow the statements to be made, if you so desire, then proceed with our testimony.

MR. PORTER: Thank you very much, Mr. Howell. We are going to allow these gentlemen from the Atomic Energy Commission and the Lawrence Radiation Laboratory to make their statements first because it's very possible that Governor Cargo will not be able to be with us through the entire proceedings and we would like for him to have the benefit of their background statements. So which of you gentlemen would prefer to go first? You may come forward and sit in the chair to make your presentation. We won't swear you in. We realize that you are a representative of the Government agency and would have to get permission for that.

MR. THALGOTT: Robert Thalgott, I am the Assistant Manager for Operations of the Nevada Operations Office of the Atomic Energy Commission. We are stationed in Las Vegas, Nevada. My statement has to do with the studies and effort carried on prior to the detonation and the actions at detonation time. From a safety standpoint, there are two principal areas of possible concern from underground nuclear explosions. They are nuclear radiation and ground motion.

The radiation question is divided into, one, contamination in the atmosphere, and two, contamination of useable water supplies. The Atomic Energy Commission believes that the possibility of any radioactive contamination reaching the atmosphere is most unlikely. This conclusion is reached because of the depth of the burial of the gasbuggy device which is about 4,200 feet and the plan method of back filling the inplacement hole and other holes that may be drilled in the vicinity of the detonation. The depth of burial is approximately four times the depth which would be used for a contained detonation of the same yield at the Nevada test site.

For many years, the AEC has sponsored studies to determine the effects of the underground detonation on ground waters. These studies include the geology of the area involved, rates of movement of the ground water, possible rate of transport of contaminants, fixes of radio nuclides with the surrounding media and dilution factors.

To verify that radioactive material is not present these programs include post-shot monitoring of the test holes and in the vicinity of nuclear detonations, in addition to theoretic and laboratory work. With the background of more than 200 contained underground detonations, we have not detected radioactivity in ground water, except in areas immediately adjacent to the point of the detonation.

In our studies of the gasbuggy site, we feel that ground water supplies will not be adversely affected. However, as is customary, at locations where nuclear detonations have taken place, following gasbuggy, we intend to arrange for continued sampling of ground water to insure that contamination of the ground waters does not exist.

Another consideration in the safe conduct of underground detonation is the seismic affect or ground motion. Again, the AEC has been engaged in the major program to predict the ground motion at various distances from detonation of the given yield.

The program includes studies of the affects on known cultural features such as buildings, pipelines, and wells. Seismic measurements have been made on a large number of past tests and these measurements are used to refine ground motion preduction techniques.

These predictions will be reviewed and refined as new measurements and data are obtained. Studies by the AEC and its contractors do not anticipate damage from the gasbuggy detonation outside the test area. Our current predictions indicate that the ground motion will be insufficient to cause even plaster cracks and so forth at a distance greater than about two miles.

The results of all safety studies are carefully reviewed by the staff of the Nevada Operations Office, by independent consultants to the Atomic Energy Commission, and by the Lawrence Radiation Laboratory to assure that tests can be conducted with maximum safety. In the case of the gasbuggy, it is our opinion that no adverse affects on man or his environment will ensue.

However, in the event that through some unforseeen mechanism there is an escape of radiation to the atmosphere the Atomic Energy Commission will, as a precaution, develop radiation predictions. This includes the direction of the cloud and anticipated; intensity of the radiation at various distances. The U. S. Public Health Service will be prepared to take action to minimize the exposure of personnel in the path of the cloud, should such unanticipated release occur. It is the policy of the AEC to conduct the nuclear test program, though such people cannot be subjected to radiation; and that if property is damaged as a result of the radiation, a fair and equitable settlement will be made.

I have provided, for your information, a copy of a report entitled "Safety Involving Detonation of Nuclear Devices," which was prepared in May of 1966 by the Nevada Operations Office of the AEC. This document discusses in great detail the matter I have covered briefly above.

I would like to say that although this document is less than a year old, we feel that conduction techniques have improved since its issuance. I would like to deviate from my statement here. We use every bit of the intelligence and capability of all of our system consultants, and anybody we can find, to assure ourselves that when a device is detonated underground it will contain. We review very carefully all of the factors, all of the knowledge of the immediate geology of the detonation point to be sure we have no fissures, that type of thing. We look at the method of covering the device, that is, the backfill. We look at everything we can think of to be sure that it doesn't come out, but when it comes to the actual time of detonation we prepare for this detonation just as if we were to explode the bomb on the surface. That way, we know that we are not going to get anybody in trouble except possibly ourselves.

So the rest of this statement concerns actions at shot time and without that explanation, I was afraid that you might think that we were just going to blow the whole end of New Mexico up.

I will return to this statement; Following previous reviews and preparatory meetings on the day preceding the detonation, the AEC Project Manager who is responsible for overall management of the project and it's safe conduct convenes an advisory panel for the purpose of a final review of the safety aspects of the project. The project manager's scientific advisor who, for gasbuggy, is furnished to the Commission by Lawrence Radiation Lab, is chairman of this panel. Members of the advisory panel have had extensive experience in the conduct of underground nuclear tests, and several members have had experience in atmospheric tests, which were limited prior to the test ban treaty. Based on the forecast, based on Meteorological Services Administration, formerly the Weather Bureau, including the prediction of radiation levels for the case of the worst dreadable release of radiation, and with the counsel of scientific advisors or members of the advisory panel, the project manager makes a decision. Preceding, or waiting improved conditions from a few hours before the detonation through detonation time, the test manager and his advisory panel continue to review the meteorological situation as to its acceptability.

As I have previously stated, it is a policy of the Commission to conduct each nuclear detonation with emphasis on safety being paramount. The detonation will only take place when the Commission-designated representative is assured that the experiment can be conducted within this policy. That concludes my statement.

MR. PORTER: Would you mind answering questions?

MR. THALGOTT: I will be very happy to.

MR. NUTTER: Dan Nutter, Chief Engineer for the Commission. Now, after the detonation there will be created according to the sketch there, a cavity in the ground which will contain gas. There will be, at the time of detonation, and immediately thereafter, there will be a high level of radioactivity in that cavity, is that correct?

MR. THALGOTT: That is correct.

MR. NUTTER: Now, eventually, some of that gas is going to have to be produced and initially vented to the air?

MR. THALGOTT: Yes.

MR. NUTTER: Now, we have heard of half lives of radioactive materials. Would you explain what half life of radioactive material means?

MR. THALGOTT: The half life of a radioactive material is that period of time which it takes to decrease the activity to fifty per cent of its original activity. That is, if, in abstract units, if you had a two year half life and you had a hundred of any unit, at the zero time in two years, you would have a unit of fifty.

MR. NUTTER: Then it's anticipated or it is a fact that some materials have much shorter half lives than other materials?

MR. THALGOTT: Yes.

MR. NUTTER: It is anticipated that this cavity will contain elements having high half lives and short half lives; the majority of the radioactivity, as I understand it, however, will be of relative short half life, is that correct?

MR. THALGOTT: Yes, sir. Mr. Woodruff is going to read a statement a little later which I think possibly might clear some of this up and I think he can answer these questions a little better than I.

MR. NUTTER: My line of question was going to be directed at the level of radioactivity at the time of the venting of the gas.

MR. THALGOTT: I think Mr. Woodruff --

MR. PORTER: Does anyone else have any questions? Thank you very much.

MR. PORTER: Mr. Woodruff.

MR. WOODRUFF: My name is Wayne R. Woodruff. I am a physicist with the Lawrence Radiation Laboratory of the University of California, and at the Livermore site, and I will be the test director for "Project Gasbuggy." I have been the test director for the University of California Laboratory in their weapons program for three years preceding this assignment at the Nevada test site.

I would like to read a statement about some of the activities we will carry on after the detonation. "Post shot re-entry drilling will be made in the device implacement hole with drilling containment equipment, a practice now employed at the Nevada test site. Some of this equipment is common to gas field operations such as blow up preventers. Gas is to be used as a circulating medium for the re-entry drilling and has to be flared.

Upon completion of the re-entry drilling there will be some reservoir evaluation measurements which will also necessitate the flaring of gas. During this time, a radioactive monitoring system will be maintained. Measurements of the amount of radioactivity present in the gas, or gas quality as it is called, constitutes one of the major objectives of the experiment. Because of the complex chemistry exchange reactions that exist in the environment of the nuclear stimulation process, ultimate radioactive concentration there is in the gas to be recovered and are difficult to predetermine.

It is very important to this and other proposed gas stimulation experiments to make radioactivity concentration measurements and to develop techniques to permit commercial uses. No gas from the stimulation experiment will be put into any gas line for commercial consumption unless compliance is assured with the radioactivity concentration standards to be established by regulatory agencies.

In closing, a comment should be made on the misconception that a gas fire results from nuclear detonation. Experience from the Nevada test site is that there is a reducing, not oxidizing atmosphere in the nuclear chimney, resulting from the iron present in the exploding cannister and implacement hardware in it. There is no oxygen to support combusion." I neglected to say that the iron from the casing also would contribute to the reducing atmosphere.

MR. PORTER: Does anyone have a question of Mr. Woodruff?

MR. NUTTER: In line with the questions I was asking Mr. Thalgott awhile ago, what are the isotopes that will be the most highly radioactive in the cavity immediately after the shot.

MR. WOODRUFF: Well, the ones, I think, that are most relevant to the gas are the gaseous fission products, the most prominent which would be isotope of (zenon), isotope of idine and isotope of crypton. By not performing tests immediately, those where the flaring of the gas is involved and a time like six months would probably be adequate, the Idine which is considered one of the biggest problems, would have decayed sufficiently that it should not be a problem.

MR. NUTTER: It has a relatively short half life then?

MR. WOODRUFF: Yes, sir, the zenon has even a shorter half life, measured in days so it would be also no problem. Crypton 85 would still be present because of its rather longer half life. However, it should not be present in quantities that should be of any consequence, as far as danger to off-site population.

MR. NUTTER: Now, the concentration of Crypton immediately after the explosion is much less than the concentration of the idine and zenon isotopes?

MR. THALGOTT: Well, it depends on the mechanism of the explosion. To give you an idea, at six months for Crypton 85 there would be something like twenty curies of crypton per kilaton of yield. There would be like one curie of carbon 14 and at six months the zenon and idine are insignificant.

MR. NUTTER: In the program that has been set out for this experiment, then would it be that the well would be opened up and vented to the atmosphere?

MR. WOODRUFF: Let me explain the post-shot program a little bit more in detail. What we would plan to do is as soon as we could after the detonation, re-enter the implacement hole. You must understand we plan to implace a device on pipe. We plan to fill the annular space between the casing and this implacement pipe with material, also the pipe itself. We then plan to attach a drilling rig to the implacement pipe with the appropriate containment equipment, re-enter the chimney as soon as we can, now, and withdraw small samples of gas for analysis back at the laboratory. As I mentioned in the statement, the gas quality experiment is one that is very important. This analysis will then indicate to us when we could then re-enter the chimney and begin to make the perimeter measurements that I referred to. Our initial estimate is it will be like six months.

Now, at that time, the problem of the idine will have decayed away or by that time it will have decayed away. Then at a time like this six months we will begin these reservoir perimeter measurements in which the flaring is involved. Now, during that time we will monitor the gas that goes into the stack so that as a result of the combustion and the dilution in the atmosphere and the meteorology of the situation and the population location, we can assure ourselves that there won't be any problem to the off-site personnel.

MR. NUTTER: Now, the services of the Weather Bureau will be employed at the time and their predictions will be taken into consideration prior to the shot, immediately prior to the shot, according to Mr. Thalgott?

MR. WOODRUFF: Yes, sir.

MR. NUTTER: Now, at the time that you begin to vent the gas to the atmosphere, six or eight months later, the services of the Weather Bureau will again be employed?

MR. WOODRUFF: Let me say they will be available and they probably will be employed. I want to point out that the reactions that, as I said, that take place in the chimney, they are so complex that quite frankly, we cannot make what I would call reliable predictions of what the situation is going to be. I think we can make pretty good estimates of it and if we are off, if we are being too conservative, for instance, maybe the activity problem won't be as severe as we have estimated, and as such one might be able to flare the gas and take into account no meteorology that it won't be even a problem to the on-site people immediately adjacent to the flaring.

MR. NUTTER: Now, when you said that you were going to reenter the implacement hole with containment equipment I take it that you mean blow up preventors in good working conditions?

MR. WOODRUFF: Yes, sir, at the Nevada test site we reenter the chimney area in a matter of two or three days after a nuclear detonation, so we feel that we are fairly well equipped to handle this kind of situation. We have done it, as Bob pointed out, since the resumption of testing, for some 200 events, so I think that we have developed a technique in that time that will permit us to make this re-entry drilling in a safe manner.

MR. NUTTER: Now, in the matter of acceleration or ground movement, what do you anticipate as far as ground movement, say, 10 to 12 thousand feet away from the zero point?

MR. WOODRUFF: One of the criteria that we use for ground motion is what we call particle velocity and this can be related to damage that might occur to cultural features such as buildings. Now, criteria that we use as a particle velocity of 10 centimeters per second represents the onset, or the threshold of damage to residential structures. This would be like plaster cracking, as Bob referred to it, or in the case of a concrete building, you might have a crack in the concrete block. We would expect that kind of motion at a distance of like 11,000 feet or something like that, two miles.

MR. NUTTER: Is there any house within two miles of this shot?

MR. WOODRUFF: Well, houses, there is a place used by the ranchers during round-up time, a couple of tarpaper shacks would be adequate description, although I think they are made out of wood, all from ground zero.

MR. NUTTER: There are no permanent homes?

MR. WOODRUFF: Not that I am aware of.

MR. NUTTER: There are some gas wells south of this area, I believe, the closest one is to the south.

MR. WOODRUFF: There is one about three thousand feet in Section 11 in the next, I guess you would call it, Township South West of ground zero.

MR. NUTTER: Do the studies of acceleration indicate that these wells would not be damaged?

MR. WOODRUFF: Well, you are getting into an area that's difficult to predict, and especially this is why I will have to hedge a little. We must obtain samples from the material in which the detonation is going to occur and make physical property measurements of these; and on this basis we will then make better, as Bob referred, seismic predictions. Now, as reported in the Oil and Gas Journal, a year or so ago, we have mocked up Christmas trees and that sort of thing in the Nevada test site in close proximity, no nuclear detonations and indeed have not found any damage to these detonations and some of these were as close as 500 feet from a 5 kilaton explosion.

These were tested for electronics and that sort of thing afterward and there was no difficulty experienced. However, one must recognize that these wells have been in for maybe ten years or so. They have been subjected to an oxidizing, rather hostile atmosphere and because of the possibility of them being in a weakened condition, especially subsurface, there might be some damage occur.

MR. NUTTER: Well, until the core drilling is complete and the actual nature of the rocks which will be penetrated and which will be subjected to the blast has been determined, it's impossible at this time to predict exactly what the acceleration and ground motion would be.

MR. WOODRUFF: We are prepared to make these estimates that I talked about, and, as I said, a range of 11,000 feet, we would predict roughly a ten centimeter per second particle velocity. I think that, again, the seismic damage question is another major objective of this experiment. Indeed, we want to find out what effect the experiment has on surrounding gas wells and the seismic damage prediction area is one that is still in its infancy.

A lot of the work needs to be done. This is especially as I mentioned, impacts on the future application of this thing because, again, many of the proposed areas for future stimulation experiments are in or near existing gas fields and this question to existing facilities is certainly a good one.

MR. NUTTER: This is one of the objectives?

MR. WOODRUFF: Yes, sir, I might point out there are roughly three major objectives for the experiment. One is the gas production, just what effect does the experiment have? Does it, indeed, increase the recoverability of the gas? The second is the question of gas quality. Can the gas ultimately be used commercially, or, if it can't what can we do about making it useable commercially? A third one is the area of seismic prediction. Another area which we feel is very important is the development of the engineering technology which makes this and other experiments an economically attractive thing to do.

MR. NUTTER: Thank you very much.

MR. PORTER: Does anyone else have a question. Governor Cargo?

GOVERNOR CARGO: I don't think so.

MR. UTZ: Are you prepared to make any estimate as to the volumes of gas that you might flare?

MR. WOODRUFF: No, sir, I am not. I think maybe Les, or Mr. Lemon could make better estimates of that. I would say that it could be two or three chimney volumes of gas, and the order of the magnitude of volume there is about a million cubic feet.

MR. UTZ: A million cubic feet per chimney volume?

MR. WOODRUFF: Yes, I think you must understand that the post-shot venting of the gas, the amount of the number of chimney volumes that would be vented depends entirely upon our ability to make these measurements and I think again, this is why we are doing the experiment, so we can make these measurements, draw down the reservoir and watch the pressure build-up and I wouldn't be prepared to venture a guess now. As I said, that's getting pretty much out of my field.

MR. PORTER: That's why the Applicant indicated indefinite volume, I suppose.

MR. HOWELL: That's right.

MR. UTZ: When this gas is flared, will it be burned?

MR. WOODRUFF: Yes, sir, that's the plan.

MR. UTZ: Does the actual burning of gas tend to reduce radiation?

MR. WOODRUFF: The mixture with oxygen would tend to reduce the concentration by about a factor of 200. In other words, you take in the normal consumption of gas that in order to reduce the carbon dioxide concentration down to whatever the standards called for, I think the normal dilution with air is like a factor of 200. So from the burning process you would expect like a dilution of a factor of 200 just to maintain the standards for the carbon dioxide.

MR. UTZ: That's all.

MR. PORTER: Does anyone else have a question of Mr. Woodruff? Mr. Woodruff, we certainly want to thank you and Mr. Thalgott for coming here and making your knowledge available to us concerning this experiment and we are certainly happy that New Mexico has been chosen as the site for the first experiment of that nature.

MR. WOODRUFF: It's been a pleasure and if there are any further questions we will be glad to come back and if you will just get hold of us we will try to do the best we can to answer them ourselves or see that we get the correct answers.

MR. PORTER: Mr. Hayes wants to know if you are going to invite the Commission up for the explosion?

MR. WOODRUFF: I was going to say, it would be a pleasure to have you come up any time. Especially now, it's a delightful time to trudge through the snow and mud. About a month ago I tried to bury a four-wheel drive vehicle out in it.

MR. PORTER: By the way, there was one other question that might be answered later, I don't know. Could you give us some indication of what your target date is for this detonation?

A Yes, sir, I will attempt to. We hope that the experiment can be conducted by about the middle of November.

I have to qualify this and say that the time at which we conduct the experiment is dependent upon the pre-shot reservoir evaluation and we have set aside a period of, like 90 days, for this and I believe Les will talk some more about that, and if this runs under or over a little bit the shot date could be adjusted some. I think you must recognize that we must set a shot date and work toward it, just as a matter of economy, and to try to advance. It quite often runs into the unnecessary expenditure of funds which are fairly short.

MR. PORTER: Is there someone else from one of the Federal agencies that would like to make a statement at this time? John Anderson, John, why don't you come down front? They can probably hear you better.

MR. ANDERSON: My name is John Anderson, Regional Oil and Gas Supervisor, United States Geological Survey, Roswell, New Mexico. The Geological Survey has a definite interest in this project. In the first place, the land on which the operations are to be conducted is federal land and is subject to an existing federal lease and an existing federal unit agreement which has been approved by the Director of the USGS by the Oil Conservation Commission, and by the State Land Commission.

Now, under this, land in the southwest quarter of Section 36 and other land that may be effected are subject to the San Juan 29-4 Unit Agreement. The wells in Section 36 and the gas in Section 36 and vicinity which may be effected by this project are not owned by the working interest owners and the royalty owners in Section 36, but are owned by all the working interest owners in the Pictured Cliffs participating area, and the royalty owners in the Pictured Cliffs participating area.

This situation has made it necessary that the project be operated as a unit project under a plan of development which has recently been approved by the survey and I believe is pending approval by the Oil Conservation Commission.

Under the terms of this lease and the San Juan 29-4 Unit Agreement, the Geological Survey has certain responsibilities in connection with the drilling of wells to a gas producing formation, the casing and cementing of these wells, stimulation by explosives or hydraulic pressures, the production of gas, its flaring and its marketing. In addition to our responsibilities under the lease terms and unit agreement, the Geological Survey acts as a technical advisor to the superintendent of the Jicarillo Indian Agency. The Jicarilla reservation lands are 3/4 of a mile east of the implacement hole. The Geological Survey is prepared to recommend to the Commission that it approve the project as requested by El Paso Natural Gas Company.

MR. PORTER: Does anyone have a question of Mr. Anderson? Thank you very much, John. You may be excused.

MR. HOWELL: I would ask Mr. Lemon and Mr. Truby to step forward, please to be sworn as witnesses and then have Mr. Lemon take the witness stand.

(Witnesses sworn)

RICHARD F. LEMON, called as a witness, having been first duly sworn, was examined and testified as follows:

DIRECT EXAMINATION

BY MR. HOWELL:

Q Please state your name for the record.

A My name is Richard F. Lemon.

Q Where do you live, Mr. Lemon?

A I reside in El Paso, Texas.

Q Are your qualifications on file with this Commission as a Reservoir Engineer?

A Yes, sir.

MR. HOWELL: Mr. Chairman, are they acceptable?

MR. PORTER: The Commission considers the witness qualified, Mr. Howell.

Q (By Mr. Howell) What is your present position with the company?

A I am manager of the Reservoir Engineering Department.

Q Generally, what are the functions of the Reservoir

Engineering Department Manager?

A I am responsible for all gas reserve and gas availability estimates for the Company.

Q Is that a continuing study?

A Yes, sir, it is.

Q Does that study cover this area in the San Juan Basin of New Mexico?

A Yes, for a large number of years we have followed the performance of the wells in the San Juan Basin.

Q Would you indicate the approximate number of wells that are connected to the company's gathering system in the San Juan Basin?

A Something on the order of 6,000 wells.

Q Approximately the number of wells which the company operates either as owner or as joint owner with others?

A Approximately 3,000.

Q Will you briefly discuss the general aspects of Project Gasbuggy?

A Project Gasbuggy is a joint undertaking of the United States Atomic Energy Commission, the United States Bureau of Mines, Lawrence Radiation Laboratory of the University of California and El Paso Natura Gas Company. The project was initiated to evaluate nuclear stimulation of the low permeability of the Pictured Cliffs formation in the San

Juan Basin, in an effort to increase the gas recovery.

Q Mr. Lemon, what have been the means of stimulation or increasing recovery that has previously been used?

A In the early days the wells were stimulated by shooting the open hole with nitro-glycerin. Generally, on Pictured Cliffs wells they used probably 1,000 quarts. Later hydrotracking or a process where you inject fluid and sand simultaneously has been used. In fact, that's the most predominent method now.

Q Would it be proper to describe this as a big shooting of a well?

A Yes, sir, I would say, in terms of the shots that are performed with nitroglycerin, this shot we have here would be on the order of 10,000 times greater.

Q Now, have you prepared an Exhibit No. 1?

A Yes, I have.

Q Would you hand the copies to the Commission that we have prepared for their use?

A (Witness complies)

Q Will you please go to the board and tell the Commission what Exhibit No. 1 delineates?

A Exhibit No. 1 is the map of the San Juan Basin area. The outside border here represents what would be called the Greater San Juan Basin area. The inner area here shown in blue and black and dotted lines here represents the Central Basin, most of the thousands of wells producing in the San Juan Basin are located within this Central Basin area.

The Central Basin is defined on the west and north and east by what is referred to as the Hog Back and I have indicated a dashed line here through the southern part. This whole perimeter here would be essentially the outcropping of the Pictured Cliffs and Mesa Verde Formations. The test site is located in the eastern portion of the Central Basin, approximately 55 air miles east of the city of Farmington and approximately twenty miles south of the community of Dulce. El Paso maintains camp at Gobernador which is about 8 miles to the west.

Q Do you know of any other inhabited buildings within a range of five miles of the proposed test site?

A I am not aware of any permanently inhabited dwellings.

Q While you are there, will you describe Exhibit 2 to the Commission and if you have copies, pass to the Commission copies of Exhibit 2. Have they been distributed?

A Yes, sir, they have. Exhibit 2 is a plat of 29 San Juan 29-4 Unit Agreement. The participating area within this unit is outlined in green. It consists of all of Section 36, the west half of Section 35, the east half of Section 6 and the west half of Section 8.

Q That indicates then that there is a rather small area in this unit which has been found to be commercially productive in the Pictured Cliffs formation?

A That is true. In addition to the green outline there are some wells outlined in brown which represent non-commercial wells which have been completed.

Q Now, immediately above the test site and to the north, there are a number of sections there that are diagonally hatched. What do those sections represent?

A The diagonally hatched section represents acreage that has been automatically eliminated from the San Juan 29-4 Unit.

Q Was the automatic elimination due to the surrender of the leases?

A Yes, it was. It was lack of development of these properties.

Q Now, immediately to the south what is the situation as to ownership?

A The participating area in the 28-4 unit consists of Section 11 and Section 12. These are half sections and El Paso owns the working interest in that unit.

Q Those are leases which have been committed to the unit agreement?

A That's correct.

Q Do you know whether or not the test site in the southwest quarter of Section 36 is within a prorated area or not?

A It is not in the prorated area. It shows the Mesa field which is not prorated.

Q Now, I think that's all for the minute at the board. I wish you would tell the Commission what criteria formed the basis of determination? What criterias were used in determining what would be an acceptable test site for Project Gasbuggy?

A If I may refer to the Project Gasbuggy Feasability Study, on Page 8 are listed six conditions for acceptability of the test site. First, low permeability depletion drive reservoir in which conventional stimulation methods are inadequate. Two; Reservoir having sufficient thickness to effectively utilize the anticipated effect of the proposed nuclear explosion, ideal thickness for 10 kilaton device is approximately 300 feet. Of course, now, we are talking about 20 kilaton device. Three: reservoir sufficiently deep to confine the explosion, but not so deep as to result in excessive implacement and testing expenses. Ideally the depth should range from 2,000 to 4,000 feet. Four: a site reasonably remote from habitation, but easily accessible. Five: sufficient drilling in the surrounding area to produce adequate production in subsurface data, yet not too highly productive as to be subject to liability for the possible damage in surface wells. Six: Uniformity of lease-hold ownership and/or withdrawal from leasing of unleased lands adjacent to the test site.

Q Have you prepared an Exhibit No. 3 which delineates the formation as lying above the Pictured Cliffs and between the surface and Pictured Cliffs Formation?

A Yes, I have.

Q Have you distributed copies of that to the Commission?

A Yes, I have.

Q Will you step up to your Exhibit No. 3, please, Mr. Lemon, and explain this exhibit to the Commission?

A Exhibit 3 is entitled Generalized Stratigraphic Cross Section, Project Gasbuggy Test Site Area. The index in the right hand corner shows the location of the test site and the wells in the area. The test site is the southwest quarter of Section 36 of San Juan Unit 29-4. Shown on this map are the traces which were used for setting up this cross section here. The trace AA Prime which trends to the northeast and southwest is represented by the horizontal line AA Prime. The trace BB Prime trends northwest-southeast through the well number 10 and is represented by the diagonal BB Prime. The center well, as I said, is the San Juan Unit 29-4 Number 10 Well.

Q What are the other wells that are shown on your cross section? Will you indicate both the location on the plat and where you show them on your cross section?

A Starting up in the upper lefthand corner, the first well is the Unit No. 4 well which is shown here on the map. It's in Section 35, in the northeast quarter. Coming around to the right in the righthand corner is Well No. 16 which is located in the northeast quarter of Section 36. To the south and lower righthand corner is the 28-4 Unit Well No. 7 which is located in the southeast quarter of Section 12. On the lefthand side, between the center well and the left margin is Well No. 6, which is located in the southeast quarter of Section 11. The well on the end opposite the A on the lefthand side of the horizontal is the San Juan Unit 28-4 unit No. 3 Well, which is located in the southwest quarter of Section14.

Q On Exhibit 3 have you transcribed logs which were actually taken from these wells?

A Yes, sir, the logs shown on this cross section represent the electrical well logs which were available, with the exception of this log on Unit No. 6 which was a radioactivity log over the lower portion of the well.

Q Well, from those logs have you determined the several formations and depths which they will be encountered?

A Yes, sir, the well logs have been arranged in such a form here as to give a three dimensional affect. The first formation that is encountered would be the: Ojo Alamo which would be found at a depth of approximately 3,400 feet. The next formation would be the Kirtland, which would be encountered a little below 3,600 feet. Fruitland would be encountered between 3,700 and 3,800 feet and Pictured Cliffs formation would be encountered at approximately 3,900 feet.

Q What lies below the Pictured Cliffs?

A The Lewis Shale is found below the Pictured Cliffs.

Q Would you describe, generally, the Pictured Cliffs formation as it exists in this area?

A Pictured Cliffs section here is approximately 300 feet thick and is composed of interbed of sand and shale deposits.

Q Is there any depth indicated from this cross section?

A Study of the well logs in this area indicates that tnere is a slight dip to the southwest.

Q Will you now proceed to Exhibit No. 4 and explain what Exhibit No. 4 relates to?

A No. 4 is electro logs on Well No. 10 which is the center well on this cross section Exhibit 3. The well was completed in 1956 for an initial potential of 1,348 MCF per day, after being sanded and fracked with 95, 600 gallons of water and 80,000 pounds of sand. On the lefthand portion of the Exhibit is indicated the geological sequence of the beds. The second column is the formation; with respect to the formations starting at Ojo Alamo we would expect a section of approximately 170 feet thick. The Kirtland 130 feet, Fruitland would be approximately 140 feet, the Pictured Cliffs section approximately 300 feet. This well is located approximately 430 feet north of the well which will contain the nuclear explosive.

Q From your study of well logs in the area, is it your opinion that Exhibit No. 4 reflects a typical Pictured Cliffs section over to the eastern portion of the Basin?

A Yes, sir.

Q Now, what reservoir properties have you found to exist in Pictured Cliffs rocks?

A Based on analysis of the available core, in the eastern portion of the San Juan Basin I have calculated the average porosity to be approximately 11 per cent, average water saturation 59 per cent, average gas saturation 41 per cent, permeability of .14 millidarcies. To give some idea of what Pictured Cliffs formation looks like, I have a piece of a core taken from a well in the eastern area of the Basin. At first glance, it looks quite solid, but actually there are small pores within the block, but because of the low permeability the gas cannot move to the wellbore, so what we hope to do is create a fracture network which will open up these zones to the wellbore.

Q Would you just hand the core to the Commission for their inspection?

A (Witness complies.)

Q Do you have available a core from any of these wells which are shown on your cross section?

A No, I do not.

Q I believe it's already been stated that one of the purposes of the pre-shot wells are to determine the reservoir characteristics and rock characteristics at this particular area?

A That is correct.

Q What is the formation pressure and temperature of the Pictured Cliffs reservoir initially?

A The average pressure was 1259 PSIA, which stands for pounds per square inch absolute, and 117 degrees Fahrenheit.

Q What formula did you use in your calculations and what data?

A Utilizing the customary volumetric formula compressibility, water saturation, an assuming that of the 300 feet of Pictured Cliffs section there, that 190 feet would be gas saturated. I have calculated that the gas in place under one acre would be 3 million cubic feet. Under 160-acre tract you would have 5.3 billion cubic feet.

Q Do you have available exhibits which reflect the cumulative production from the wells in this area?

A Yes, I have prepared Exhibits 5 through 10 which depict the pressure production history of the wells in this area.

Q There are copies available for distribution in the auditorium, I assume they have already been distributed. Please discuss these exhibits which are numbered 5 through 10.

A Exhibit 5 is the pressure production chart on the San Juan Unit 29-4 Well No. 10 which is located in the southwest quarter of section 36. That was the well I was referring to which will be the closest well to the implacement well. Also, I might add that this well is the center well on cross section Exhibit 3.

Exhibit 6 is the production chart on the 29-4 Unit Well No. 4 which would be located in the upper left quarter of the cross section there. Going around in kind of a cartwheel fashion will be these additional quarters.

Exhibit No. 7 is on the 29-4 Unit Well No. 16 which is located in the northeast quarter of Section 36.

Exhibit 8 is the chart on the 28-4 Unit Well No. 7 which is located in the southeast quarter of Section 12.

Exhibit 9 is the chart on the 28-4 Unit Well No. 6 which is located in the southeast quarter of Section 11.

Exhibit 10 is on the 29-4 Unit Well No. 2 which I don't have depicted on the cross section. However, it's on the map there. It's located in the southwest quarter of Section 35.

Q From a study of the production shown by these wells have you drawn any conclusions as to the ultimate gas recovery that would be anticipated within the life of the project up here, the life of the pipeline?

A A review of the performance data on these wells would indicate that the average recovery would be on the order of half a billion cubic feet per well.

Q As I take it, some of the wells are less than that and at least one of them is somewhat over that?

A Yes, sir, that's correct.

Q And that is an average figure?

A Yes, it is.

Q Now, about what is the ratio of recovery to the gas in place?

A Relating the one half billion to the five billion, the indicated recovery of the gas in place would be only ten per cent. I might point out that in arriving at that percentage it is based on the total gas saturation of the entire Pictured Cliffs section which would have sections in it that normally wouldn't be conventionally stimulated because of uneconomic, because they wouldn't be economical to stimulate.

Q Does the Pictured Cliffs section in this area have some lenticular areas in which there will be production inter-mingled with shale?

A Yes, sir.

Q As I understand your testimony, in many of these areas, the economics and cost of completion prevent making that gas available to the wellbore,under the present techniques?

A That's correct.

Q And your calculations are based upon the footage that would be made available to the wellbore by use of the best present methods?

A That's right.

Q Would you please describe the production tests which you intend to take on the pre-shot wells which we shall refer to as GB-1, the first well to be drilled, and GB-2, the second well to be drilled?

A Upon completion of GB-1 the well will be shut in for 7 day pressure build-up test, following that test the well will be produced for a short period of time in order to determine the producing characteristics of the well. These tests will be used to determine choke sizes which will be used for a constant rate isochronal type test. The constant isochronal test will be a series of four flow rates for a period of time, about six hours. The last flow rate of this series of isochronal tests, will be continued for a period of 24 hours at which time the well will be shut in.

Upon completion of GB-2, similar type tests will be conducted on that well and at the conclusion of these tests on GB-2 the test equipment will be moved back to GB-1 for a long time term constant rate tests of 30 days. After this test, the well will be shut in for pressure build-up. During the testing of GB-1 on this 30-day test we will observe the pressure performance and GB-2 so that we might observe any change in pressure that might occur due to the production of BG-1.

Q What data do you expect to accumulate and learn from these production tests?

A From these tests we would determine what the flow capacity of the formation is under natural conditions. We would be able to determine if any Wellbore damage had occurred during the completion of GB-1 and 2. And we might also obtain some idea of the drainage area being affected. All of this material would be used as a basis in evaluating the effects of the nuclear explosion.

Q In other words, in order to determine what the nuclear explosion did we want to find out exactly what existed before it took place?

A That's correct. We would be hopeful that the entire section of the Pictured Cliffs formation would be fractured. Of course, you would have the chimney area which would represent a sizeable wellbore enlargement, but too, we would have fractures existing out from this chimney area, and through these fractures we would hope to be able to drain, substantially, all the Pictured Cliffs Formation.

Q Now, in connection with the pre-shot tests which you have described, do you regard it as being practical to attempt to connect those wells with the pipeline?

A No, I would not.

Q For what reason?

A The existing line pressure in the area is 500 pounds. Because of the low flow rates anticipated on these naturally completed wells in order to compare the producing rates we would need a maximum flexibility that can only be accomplished by having minimum back pressure on the wells.

Q Do you anticipate any substantial amount of gas to be vented during this testing?

A No, I would anticipate the volume would be relatively small.

The tests are not going to be conducted for a period probably longer than thirty some odd days so the period of time is short besides the low volumes that we would expect.

Q I believe these wells will not have any stimulation either by fracking or shooting prior to this testing?

A That's correct.

Q So the gas produced will be at the natural flow of the reservoir?

A Yes.

Q I might ask you this, as to any gas that is produced from the chimney after the shot, have you any thoughts as to whether that gas would ever be produced if we don't have the shot?

A I think certainly it would be gas that wouldn't be produced otherwise.

Q In other words, some of this gas that will be produced after the shot would be the 90% that you estimate is going to remain in the rock if we don't do something?

A That's right.

Q Will you refer again to the criteria and let me ask you, without going through each item separately, if, in your opinion, the site which has been selected does meet the criteria as set out in the feasibility study?

A I believe it does, yes, sir.

Q Now, were these Exhibits 1 through 10 prepared by you, or under your direction?

A Yes, sir.

Q Do they correctly reflect the matters to which they relate?

A Yes, sir.

MR. HOWELL: If it please the Commission, we offer Exhibits 1 through 10 in evidence.

MR. PORTER: If there are no objections, the Exhibits will be admitted.

(Applicants Exhibits 1 through 10 admitted in evidence)

MR. HOWELL: That's all the questions for Mr. Lemon.

MR. PORTER: I asked our district supervisor, Mr. Arnold, who is also a geologist, if he agreed with your geology in Exhibit 3 that the Pictured Cliffs was below the Fruitland and he said as of now, he didn't know what it would be after the explosion. Does anybody have a question of the witness?

CROSS EXAMINATION

BY MR. NUTTER:

Q I missed that permeability when you gave that. What was that average permeability?

A .14 millidarcies.

Q Now, in the original drilling of wells in this area, were any drillstem tests made or any production tests made of any of these wells prior to artificial stimulation?

A In some cases they had taken natural gauges. The information is rather sparce though.

Q What do you anticipate one of these wells would produce naturally for the pressure that is there at the present time?

A It's rather difficult to answer it, but I would suppose probably a hundred MCF to maybe 200.

Q Even with a 95,000 gallon treatment on this middle well here the only potential is 1,345?

A That's right. I might point out, by referring to Exhibit 3 you will note that the initial potential on all of these wells is quite small. In fact, the one on the end, I think I show is around a hundred something. All of these wells have been rather heavily fractured and that's all the gas we got out of them, so I think it demonstrates the tightness of the formation so the anticipated volumes would be relatively small.

Q For the thirty day testing period?

A Yes, sir.

MR. NUTTER: I believe that's all. Thank you.

MR. PORTER: In other words, you can't get a commercial well here without some kind of stimulation?

A   That's true.

MR. PORTER: Does anyone else have a question? Witness may be excused.

(Witness excused)

LESTER G. TRUBY, called as a witness, having been first duly sworn, was examined and testified as follows:

EXAMINATION

BY MR. HOWELL:

Q   Will you please state your name for the record?

A   My name is Lester G. Truby.

Q   Where do you reside?

A   I reside in El Paso, Texas.

Q   By whom are you employed?

A   By the El Paso Natural Gas Company.

Q   Will you state for the Commission your education as an engineer?

A   I graduated from the Colorado School of Mines in 1948 with a degree in petroleum engineering.

Q   Are you a registered professional engineer in the State of New Mexico?

A   Yes, sir, I am.

Q   Now, what experience have you had in petroleum engineering since graduation?

A   After graduation from the school, I was employed by the Humble Oil and Refining Company as a petroleum engineer from 1948 to 1955.

During this time I was employed in off-shore production and drilling work in Louisiana for approximately two years. I then attended the Humble Reservoir Engineering School and remained there for approximately two years, working with the theoretical aspects of reservoir engineering and teaching in their company school. Following that, I was transferred to Southwest Texas and was associated with the application of reservoir engineering to well reservoir engineering, to well completions and projects of the type involving pressure maintenance and waterflooding work.

In 1955 I became associated with the Pacific Northwest Pipeline Corporation, working primarily w[illegible] the development of the gas supply of that company. In 1956 I was transferred to Salt Lake City and was assigned as General Manager of production operations which involved the production and exploration and gathering operations for that company. On the merger of Pacific with El Paso I was transferred to El Paso as manager of production.

Q Will you be the individual in charge of the drilling of GB 1 and 2 which is under the control, or participation let's say, of El Paso Natural Gas Company?

A Yes, sir, I will.

Q Now, I believe we have already identified the location of the first pre-shot well, known as GB-1, being in the southwest quarter of Section 36. What is its distance from the boundary lines?

A The GB-1 well location has been surveyed at 1,324 feet from the south line and 1614 feet from the west line.

Q Now, what is the reason for drilling this first well known as GB-1?

A This well will be drilled to evaluate the physical and chemical characteristics of the formations to a point 100 feet below the Pictured Cliffs Sands.

Q And do you contemplate additional wells drilled prior to the shot?

A Yes, sir, the GB-2 well will be drilled by El Paso Natural Gas Company. The AEC will supervise the drilling of the implacement hole and possibly a hole for seismic instrumentation. This latter hole would be used to determine the shot characteristics of the explosion and in no way concerned with the evaluation of the production of gas.

Q So, there is a possibility of as many as four wells being drilled prior to detonation?

A Yes, sir.

Q Now, will you describe the drilling program for GB-1, the first well?

A Perhaps, if I may refer to this sketch, from the Gasbuggy Experiment, I could depict the drilling of the wells from surface to total depth.

(Whereupon Exhibit No. 11 was marked for identification)

Q Have you prepared a plat which has been numbered Exhibit No. 11 which shows the location on the ground?

A Yes, sir, a plat was prepared, at my direction, showing the location of the GB-1 well and the potential or potentially proposed locations of GB-2 and the implacement hole.

Q Referring then to the sketch and when necessary, to Exhibit No. 11, will you go ahead and describe the drilling program as it is now set up for the first well, GB-1?

A Our well program calls for the implacement of thirteen and three eighths inch surface pipe at 500 feet and drilling out from underneath this pipe with a twelve and a quarter inch bit. This thirteen and three eighths inch pipe will be implaced in a seventeen and a quarter inch hole. The twelve and a quarter inch hole will be carried down to slightly above the top of the Ojo Alamo formation. We will be continuing to do so until we set the nine and five eighths inch casing.

At the top of the Ojo Alamo, 3400 feet, we will reduce the hole size to eight and three quarter inch and continue drilling ahead with a core bit and anticipate continuous coring operations from this depth to total depth. We will take a break for water tests approximately half way into the Ojo Alamo section. These water tests would be conducted by setting a packer at the very top of the section and actually running a string of tubing down inside the drill pipe to wash the mud cake off of the sand section, and then swabbing the well to get the flowing characteristics of the well at this point.

This detailed type of water test is to furnish information to the United States Geological Survey for their hydrologic studies of the area. This same type test will be run in the lower half of the Ojo Alamo formation with a packer set at the center of the formation. We will continue on drilling there with a core bit in the eight and three quarter hole, from the base of the Ojo Alamo to the top of the Fruitland formation. At this point, we will run a number of logs. We are in this reduced hole size and from the top of the Fruitland, at approximately 3,780 to 3,800 feet to 3,400 feet, and in that section of the hole we will run kip meters and micrologs to give us additional information on the dip of the formation and the permeability of the formation. Induction received potential logs will be run from total depth to the surface pipe to again review the stratograph. The various radioactive logs, including density and neutron porosity logs.

will be run at this point. Sonic logs will be run primarily again as a porosity tool, plus multiple space sonic logs will be run to evaluate or to check the natural fractures as may be encountered in the formation and as may be evaluated from this type of log.

After the logging program is completed at this point we would reem out the hole to a twelve and a quarter inch hole to the top of the Fruitland formation and set nine and five eigths inch casing.

Q Will the Pictured Cliffs formation be cased?

A No, sir, when we continue our drilling, we plan to drill out from underneath the nine and five eighths inch casing with an eight and three quarter inch bit, again using gas as the circulating medium. When I say eight and three quarter inch bit, we will again continue coring operations from the top of the Fruitland to a point 100 feet below the base of the Pictured Cliffs formation, which will be on the order of 4,250 feet to 4300 feet.

Q Do you have such an extensive logging program when you are coring the well through all of those formations?

A These logs would be used to supplement the core data plus to give us an opportunity to evaluate some of the post-shot holes with cores, and, in this manner, obtain a comparison before and after the shot. These logs may also be used for comparative purposes in other areas where nuclear stimulations may be used and assist in the evaluation of other projects.

Q Well, now in the cores what properties would be measured to determine core analysis?

A The chemical properties of the rocks would be determined by the Lawrence Radiation Laboratory, and routine tests of the reservoir characteristics sucn as porosity, permeability, and fluid saturation would be made. In addition to the chemical properties, the physical properties of the rock would be determined, such as compressibility, the ability of the fluid to transmit; shock and sound would be included in this analysis.

Q Is this an unusually extensive coring and logging program for this area?

A Yes, sir, the coring and logging program alone for this well will cost more than a conventionally completed Pictured Cliffs well at the site.

Q It might be termed over-cored and/or logged facetiously?

A From a strictly economic standpoint, extremely so.

Q For the purpose of obtaining exact information and data prior to the shot you do consider it necessary?

A Yes, sir, from the standpoint that this is a research project.

Q I wish you would discuss the effect of water encountered in any of these formations, beginning with the Ojo Alamo.

A The tests on the Ojo Alamo are to be performed at the request of the USGS in order to confirm their estimates of the movability of this water from one point to another. They have indicated to us there is extremely very little movement of any water in this area and these tests are to be utilized in their studies. We do not believe that the Ojo Alamo water has any significance to us from a production or production test standpoint in that the fractures radiating out from the chimney are not expected to reach that point.

As we drill into the Fruitland formation, while we don't expect mobile water in this formation, it's highly improbable, we must face the fact that it's possible; this is primarily the reason for setting the nine and five eighths inch casing in this first GB-1 well; in that, if water were encountered in the Fruitland formation, we would be able to case it off for further tests to the Pictured Cliffs with a seven inch liner. We would core to the top of the Pictured Cliff formation and if water were encountered, we would make rather expensive tests of the water to evaluate the mobility or ability of water to flow into the wellbore or its effect of flow from the nuclear induced fractures into the chimney.

Q Would you consider satisfactory water conditions in these formations as an important criteria for the test?

A Yes, sir, particularly from a production standpoint. For example, if the chimney would be filled with water in a matter of a year or less and we would consider that it was not practical to handle the water production with the gas, this could condemn this particular location as a site of the nuclear test.

Q Then if I understand you correctly, it's possible that in drilling this GB-1 first pre-shot test well, conditions might be encountered here which would require selecting another location?

A It's possible, yes, sir.

Q Then water conditions could be so unfavorable as one condition that would condemn it as a test site?

A That is correct.

Q Now, what other data besides the existence of water might be developed in this GB-1 that could make the continuance of the project unfeasible?

A In the event the reservoir and implace volume as calculated and indicated by Mr. Lemon were considerably less than estimated, this would have considerable bearing on the site. For example: if the core data of this exact site indicated 100 per cent or nearly 100 per cent water saturation in the available core space instead of 30 to 50 per cent, or estimated gas saturation, it may be necessary to reconsider the site.

Q And the exact saturation in this area can't be determined until you drill the test well?

A That is correct.

Q What tests of the natural flow of gas would be made while drilling?

A While drilling with gas after setting the nine and five eighths inch pipe we do plan to evaluate the natural flow of gas each time the core barrel is pulled. We will have facilities to direct the gas from a wellhead into a measuring device.

Q What measuring devices will you have?

A We have rigged up a test manifold that would involve the use of a conventional meter, run a positive displaceme meter and a critical flow proofer. This manifold is so designed that we can run the gas through all three of these measuring devices or any combination of them that we desire.

Q As a production man, do you consider it feasible to put the gas that might be produced during drilling and during the testing period into a pipeline?

A No, sir, during drilling, of course, the measurements are normally made at extremely close to atmospheric pressure, and during the test we anticipate that they would be made somewhere in the order of atmospheric fifty pounds back pressure, not knowing what pressure we need the flexibility to hold whatever back pressure on the formation appears to be indicated at the time the tests are run. We would have to put considerable compression facilities in this area to compress this gas for delivery into the pipeline.

Q You expect to conduct a lot of tests here at a lower pressure than the working pressure of the pipeline in that area?

A Yes, sir, the working pressure of the pipeline is approximately 500 pounds, in this area.

Q Now, passing to GB-2 will you tell us where it would be located?

A We plan that the GB-2 well will be located approximately 400 feet east of the GB-1 location. This site would be confirmed after reviewing the data obtained in GB-1 well.

Q What is the purpose of drilling GB-2?

A This well would be drilled to confirm the data obtained in GB-1, and obtain any information that we might skip or lose for some reason in GB-1.

In addition, this would give us a method to note the variation of the various reservoir qualities with horizontal distance. The data from these two wells would then be used to select the exact location of GB-1, the implacement hole, I should say.

Q Would you describe briefly the well program for GB-2?

A We plan to set nine and five eighths inch surface pipe at 500 feet and seven inch casing on top of the Pictured Cliffs Formation, after drilling down to this depth with mud. We would then complete the GB-2 well naturally or drill with gas throughout the Pictured Cliffs Formation.

Q Do you intend to run tubing after the well is completed?

A Yes, sir, in both wells and prior to the isochronal and thirty day test the GB-1 and GB-2 wells would be tubed as a naturally completed gas well in the area.

Q I believe it's already in the record that neither GB-1 nor GB-2 would be fracked or stimulated in any manner?

A Yes, sir.

Q Now, do you intend to turn these wells over to the Atomic Energy Commission and the government agencies for their control prior to the actual detonation?

A At the completion of the test with the tubing, and immediately prior to turning the wells over to the A.E.C. we would pull the reservoir pressure down in the wells pursuant to some additional logging program. We anticipate probably a fifteen day draw-down on these wells. The purpose of which will be to stimulate the gas to flow naturally into the wellbore, and after this drawdown, we would pull the tubing and set a packer in the formation and determine, to the best of our ability, the exact entry points of gas into the wellbores.

After completing this operation, the wells would be mudded up as in a conventional mud-drilled hole. Additional logs would be run and we would turn the wells over to the A.E.C. for instrumentation and stemming operation.

Q Now, will the wells continue to be capable of producing gas during the explosion?

A No, after this mudding up operation and the stemming operation, as contemplated or explained to us by the A.E.C., would include the setting of cement and sand and/or drilling mud in the wellbore to insure complete containment of the nuclear explosion.

Q I believe you have already testified about the possibility of an additional pre-shot well, which would be instrumented to measure seismic shock, and about the implacement hole. Would you give us a little data as to the present program, of the magnitude of the explosions that will be used in the implacement hole?

A It is my understanding from the A.E.C. that a 20 kilaton nuclear explosive will be utilized. This 20 kilaton referring to an equivalent of 20,000 tons of TNT.

Q Where will this explosive be located and what do you anticipate to be the effects on the formation?

A If I may refer to this schematic diagram, the explosive will be located at a point fifty feet below the Pictured Cliffs sandstone. The effect almost instantaneously with the explosion, the cavity will be formed in the rock. That is anticipated to have a radius of approximately 80 feet. Again, in a fraction of a second, this cavity would be lined with molten and crushed rock which would dissipate to the base of the sphere as noted on the sketch. Simultaneously, with the formation of the cavity fractures. Or, it is anticipated that fractures will radiate out from the shot point.

These fractures, based on calculations by the A.E.C. from the data obtained in their underground shots in Nevada would range to a point approximately 100 to 150 feet above the chimney and from 200 to 400 feet laterally away from the chimney. We are depending on these fractures from a production standpoint, at any rate, to show or give the successful attributes to the nuclear explosion. These fractures would be utilized as a flow channel for the gas to move from the tight matrick formation into the chimney formed by this cavity.

I should mention that once this cavity is formed the roof of the cavity will collapse. This collapse is caused by the overburden of the rock above, and forms this zone or chimney which is approximately 350 feet in height. The gas would then hopefully migrate to this area to the chimney through these fractures with pressure depletion, which may be accomplished by wells potentially drilled directly from GB-1, or two, into the chimney zone or drilling new post-shot wells in the immediate vicinity of the chimney.

Q At this time, are you able to determine or predict just what post-shot wells will be drilled?

A No, sir, that's in the province of the A.E.C. and would be determined definitely after the characteristics of the explosion were noted.

Q I believe you show that the fracturing expected does not go to any significant depth below the shot point?

A It is anticipated that the fracturing will extend 100 to 120 feet below the cavity, or cavity sphere, into the Lewis Shale Formation. This Lewis Shale is approximately 1000 feet thick in this area and is of no consequence relative to the test.

Q Are there any other comments you care to make or testimony you desire to add?

A No sir.

MR. HOWELL: I believe that's all my questions.

I did not introduce his exhibit, Exhibit 11.

Q Was Exhibit 11 prepared under your direction?

A Yes, sir, it was.

Q Does it correctly reflect the information which it purports to show?

A Yes, sir.

MR. HOWELL: We offer Exhibit 11.

MR. PORTER: If there are no objections the exhibit will be admitted.

(Applicant's Exhibit 11 admitted in evidence)

MR. PORTER: Does anyone have a question of the witness?

CROSS EXAMINATION

BY MR. NUTTER:

Q Mr. Truby, you were discussing all these tests that would be taken in the Ojo Alamo, particularly to determine if, indeed, it is a matter of static water there in place; second, as I understand it, if you determine that it is in a quafer, with water moving through it, another site could be selected, is that correct?

A Well, actually, I think the USGS does believe it is an aquafer, but their confirmation of the hydrology in this area would be with respect to this movement of water. Their current data would indicate no movement. I think they are thinking in terms with our discussion with them of 20 feet a year, say, moving away from this area.

Q Some movement would be permissive, but an excessive amount of movement would not and that's the purpose of the test to determine the amount of movement?

A They don't anticipate any but this is an additional test for confirmation.

Q Is Ojo Alamo utilized as a water source?

A Not that we know of in this area. We believe that it is fresh water but at the present time it is not being utilized.

Q How far away is it from being utilized?

A It was a considerable distance. We don't know of any water wells within at least five miles.

Q Now, your application, Mr. Truby, is for drilling and for directionally drilling wells. What would the purpose of the directionally-drilled wells be?

A This was for the administrative approval for the post-shot holes, in that it has been discussed and either GB-1 or both may be utilized for post-shot production by going in and cleaning out the stem and cutting a window and directionally drilling for fracture evaluation or gas production evaluation.

Q In other words, you would re-enter those holes and at some takeoff point drill down to look for fractures?

A Fractures and production, yes, sir.

Q Would you anticipate that GB-L or GB-2, either one, would penetrate into the chimney?

A We assume they will be both outside the chimney. Calculations indicate they will both be outside the chimney.

Q Again, the implacement well is to be a large diameter hole. Then I believe one of the Government witnesses testified that the device would be run on a string of casing inside that hole. Now, I didn't understand completely if that was to be drilled out and production made through that well or another well would be drilled for production from the chimney?

A I imagine it could be either, depending on the experiment, although this initial production was strictly to obtain a sample of the gas, or this initial re-entry into the implacement hole, depending on what the conditions indicate at this time; and as the project progresses, it could be utilized in that manner, I think.

Q On the directional drilling, the directional surveys will be run on these wells as they are drilled?

A Yes, sir, I didn't mention it, but on all these wells, even the GB-1 and GB-2, while we are not concerned with having the well absolutely vertical, we will run directional surveys from total depth to surface to give us the exact location of these wells after they have reached total depth.

Q It's the idea of your application here to obtain general approval of this program and then to obtain administrative approval of the various locations and directional drilling, is that right?

A Yes.

MR. NUTTER: I believe that's all.

MR. PORTER: Does anyone else have a question? You may be excused.

(Witness excused)

MR. HOWELL: I would like to make an additional very brief statement. Companies that are interested in this have expressed a great deal of interest. There are several companies that have expressed a desire to participate somewhat in the nature of a bottom hole contribution and joint effort, and I would like at this time to give credit to the various companies that have so indicated a desire. That would involve Aztec Oil and Gas Company, Mountain Fuel Supply Company, Colorado Interstate Pipeline Company, Austral Oil

Company. Incidentally, Austral, as you probably know, is sponsoring a project up in Colorado that may come along later for an experiment. Other companies are the General American Oil Company of Texas, Southern Union Gas Company, and its associated production company, Tenneco, Union Pacific Railroad and Pan American Oil Company.

MR. PORTER: El Paso ought to make money off this hole.

MR. HOWELL: I don't know with 900 feet of core in it. That concludes our case.

MR. PORTER: We had a number of appearances in the case. Would someone like to make a statement at this time.

MR. SMITH: Winston G. Smith, Austral Oil Company, Austral Oil Company, Incorporated, supports the application of El Paso with regard to its Gasbuggy project. We feel that this test will directly relate to Austral's proposed Rulesen test near Acron, California. Application for Rulesen has been made to the Atomic Energy Commission for the use of two 50 kilaton devices to be suspended in a hole to be fired, detonated simultaneously at depths of 7500 and 8500 feet. Rulesen is proposed to be a development project and we feel that if all testing is possible, as will be indicated by Gasbuggy, then we would look forward to commercially marketing the gas to be produced from the Mesa Verde formation.

MR. SOMMER: H. A. Sommer, Pan American Petroleum. I would like to enter into the record a letter which we will present to the Commission. Pan American, even though we don't have any acreage in this immediate area, feels this is a research type project that should be expanded. It has tremendous posibilities in all areas. The letter reads:

"The Oil Conservation Commission.

Please be advised that Pan American is an affirmative contributor to the project Gasbuggy and supports the application of El Paso Natural Gas Company to drill, and directionally drill several wells at unspecified and unorthodox locations, and to produce therefrom natural gas in conjunction with Project Gasbuggy. Pan American hereby requests the approval of this application by the Commission."

Signed by Mr. S. B. Richards, our Joint-interest Superintendent.

MR. PORTER: Thank you, Mr. Sommer. Does anyone else desire to make a statement? Commissioner Hayes suggests that this will come to you as quite a shock, but the Commission has decided to grant this application and an order will be forthcoming. It will be an unusual order, Mr. Howell, because of so many, what do you call them, "Indefinite factors" in the application, but we will go right to work on it.

MR. HOWELL: Thank you.

MR. PORTER: Thank you for your very thorough presentation.

STATE OF NEW MEXICO)
) ss
COUNTY OF BERNALILLO)

I, KAY EMBREE, Court Reporter, do hereby certify that the foregoing and attached transcript of proceedings before the New Mexico Oil Conservation Commission Examiner at Santa Fe, New Mexico, is a true and correct record to the best of my knowledge, skill and ability.

Kay Embree
Court Reporter

NVO-28

SAFETY INVOLVING DETONATION OF NUCLEAR DEVICES

UNITED STATES ATOMIC ENERGY COMMISSION
NEVADA OPERATIONS OFFICE

May 1966

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SAFETY INVOLVING DETONATION OF NUCLEAR DEVICES

UNITED STATES ATOMIC ENERGY COMMISSION
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May 1966

Prepared by the
Technical Reports Section
Management Engineering Department
REYNOLDS ELECTRICAL & ENGINEERING CO., INC.
Mercury, Nevada

INTRODUCTION

The objective in publishing "Safety Involving Detonation of Nuclear Devices" is to provide an updated version of the Nevada Operations Office Safety Program topics as presented in nontechnical terms to headquarters personnel of the U. S. Atomic Energy Commission (AEC) at Germantown, Maryland. The texts and illustrations used in this publication are derived from the contents of transcripts and filmslides utilized during this oral briefing on July 28 and 29, 1964.

The content of this publication is primarily directed to describing the long-range safety studies necessary to improve prediction capabilities and maintain pace with an active testing program. The day-to-day detonation safety activities necessary to support the testing program are described to the extent required to give an overall, though limited, version of event-related safety actions and procedures.

The activities of the AEC laboratories designing and testing the nuclear devices are not described in this publication. The laboratories' efforts, including safety efforts, are better described in other reports published specifically for that purpose.

SAFETY INVOLVING DETONATION OF NUCLEAR DEVICES

CONTENTS

CHAPTER XIII

STEMMING DESIGN AND SEISMIC NET OPERATION

Sandia Laboratory, Sandia Corporation *by Manager, Nuclear Burst Physics – Byron F. Murphey*

CHAPTER I

SAFETY RESPONSIBILITIES AND SPECIAL ACTIVITIES

By James E. Reeves, Manager
Nevada Operations Office
U. S. Atomic Energy Commission

SAFETY DEFINED

The dictionary defines safety as the "condition of being safe; freedom from damage or hazard." The status of safety knowledge and preventive capability is far from enabling the detonation of a nuclear device to be "free from danger or hazard." Hopefully, however, through the studies outlined in the following chapters, this state will be more nearly approached. There can be many different definitions of safety as it relates to nuclear device testing, but one which most adequately expresses the Atomic Energy Commission Nevada Operations Office (AEC/NVOO) safety philosophy is:

> A nuclear device can be detonated safely when it can be ascertained that the detonation can be accomplished without injury to people, either directly or indirectly, and without unacceptable damage to the ecological system and natural and man-made structures.

In assuring that NVOO can determine the safety of a detonation two concurrent efforts, project-associated and long-range, have been undertaken. Project-associated effort is best defined as that effort required to predict the hazards involved, to provide for the safe conduct of the project, and to provide an adequate post-shot record of the effects of the detonation. The project-associated effort requires input from the long-range effort so that the predictions may be accurate and the project conducted at the least possible safety expense. Long-range study effort is best defined as that effort which is necessary to provide more accurate predictions, to enable more economical safety precautions for future projects, and to prepare capabilities for both new programs and those which may not yet be envisioned.

SAFETY PROCEDURES

To provide and determine the safety of a particular detonation, several different actions are taken. First, an evaluation is made of the detonation design to be assured that the NVOO safety definition can be fulfilled. This evaluation includes consideration of such items as geology, hydrology, ground shock structural response, air blast, radiation, and so forth. The treatment of these items is described in the remaining chapters of this publication. The operational safety control features are then established, based on the evaluation of the detonation design, in order that all identified hazards may be controlled. In addition, every effort within limitations of official policy is made to convince interested parties and the general public that the project can and will be conducted safely. When contacting the public regarding a detonation, the technical and safety information should be available so an accurate account of the detonation can be given. It is also necessary that adequate supporting data be obtained to confirm that the project was conducted safely and to defend the Government against unjustified claims for damages and derogatory publicity.

The degree of effort that must be applied to the evaluation and preparation of operational controls for a specific detonation is dependent upon several factors, including:

(1) The device itself and its emplacement environment.

(2) The purpose of the detonation. (Is it planned for cratering, containment, etc.?)

(3) The geographical location and related populations, environments, and developments.

(4) The related political and local population attitude.

SCOPE AND SAFETY INFLUENCE

Paramount to determining the safety of a detonation is the ability to predict accurately, and provide protection from all potential hazards. The relative accuracy of the prediction capability affects all organizational elements involved in these detonations. A few examples of how safety can affect some of the organization elements involved in planning for and actually accomplishing a detonation include:

Planning— Unless accurate information regarding safety hazards is available at an early stage, much planning may take place on a project which may not turn out to be feasible from a safety standpoint. Conversely, a project could be erroneously dropped for suspected safety reasons due to limited capabilities in making the safety determinations.

Operations — Operations personnel must have a good understanding of most safety aspects to plan properly for close-in activities, roadblocks, evacuation procedures, and particularly to take safe emergency actions when unforseen developments arise following a detonation.

Scientific — The laboratories, for instance, must have general capability in all the hazard fields to accomplish advance planning and conceptual design of scientific experiments with knowledge of the hazards that may be involved.

Engineering — The phenomenology of nuclear explosions and their resultant effects must be developed and made known to the designers of facilities so the locations may be selected and designs developed to prevent or minimize damage to such facilities ars drilling rigs, construction equipment, power facilities, etc.

Public Information — All aspects of safety must be disseminated to the public in laymen terms with a high degree of accuracy and reliability, and without alarming the populace.

Legal — The safety implications in the legal field are obvious. Complaints and claims have been presented to the AEC due to testing at the Nevada Test Site (NTS), most of which can be easily disclaimed as not being the result of nuclear detonations. However, as we proceed to higher yields and to different locations, it will become increasingly necessary that causes of damage be more accurately defined in order that only legitimate claims be paid.

These are but a few examples of how safety affects most organizational elements. They are not solely applicable to NVOO or the laboratories; but also apply to Headquarters program divisions, s' 'f divisions, and other government agencies, such as the Department of Defense (D.O.D) and United States Public Health Service (USPHS). As testing expands, other government agencies with delegated responsibilities, such as the United States Bureau of Mines (USBM), Department of Interior, etc., will be brought into the act. In addition, it has been necessary to extend the efforts of organizations involved in safety studies beyond those required for safety purposes alone as a result of the Limited Test Ban Treaty.

As a result of the broad scope of influence of safety-oriented activities it is natural, and healthy, that differences of opinion develop between organizations involved in the nuclear detonation program. These differences are probably most apparent between the programmatic interests, such as Lawrence Radiation Laboratory (LRL). Los Alamos Scientific Laboratory (LASL), Defense Atomic Support Agency (DASA), etc., and the operational management organization (NVOO). Conflict of opinion on safety predictions have not interfered with the execution of any project. The greatest impact has been in the area of the long-range safety effort which has and will continue to result in different approaches toward solution of potential problems. Some may consider this as duplicate effort and may suggest curtailment of legitimate long-range studies. This duplication of effort, if it is that, should be looked on as a healthy condition which increases the assurance that some important safety problem is not overlooked or inadequately treated. In this vein, it is most important that as much of the long-range study effort as possible be placed in the hands of contractors, universities, other government agencies, etc., who, insofar as possible, cannot be accused of shading safety conclusions in favor of the programmatic gains in going ahead with a particular detonation.

SPECIAL SAFETY ACTIVITIES

The above has been a general discussion of safety philosophy and safety responsibility involved with the nuclear explosions. More information on the long-range and project-associated activities of contractors and government agencies involved in the safety program is presented in the following chapters. There are two activities, however, that are not presented in the following chapters that will be briefly described in the next paragraphs. These are the activities of the NVOO Safety Panel of Consultants and the Federal Aviation Agency.

The function of the NVOO Safety Panel of Consultants in the Safety Program is one of checks and balances. The Panel, composed of some of the most eminent people in the fields of geology, hydrology, rock mechanics, soil mechanics, earthquake engineering, etc., evaluates the programs conducted under the long-range study program and prepares safety evaluations for specific events and series of events, as requested. The NVOO relies most heavily on the Panel's efforts to assure that all considerations involved in long-range safety studies or in safely executing an experiment or series of experiments have been thoroughly studied and thoughtfully considered. To facilitate the use of the Panel, two sub-committees have been formed, each to meet on a quarterly basis with the full Panel meeting on an annual basis. Specific information is furnished the members two weeks prior to a meeting and general information on past events is furnished by a consolidated report (NVO-21, Consolidated Data on Selected Effects from Underground Nuclear Detonations) prepared primarily for that purpose. However, the report is of assistance to any and all agencies, laboratories, and contractors involved in the safe detonation of nuclear explosives. This is a brief description of the Panel's function and cannot begin to describe the value of its decisions and recommendations to the nuclear detonation program.

The other safety activity not specifically described in the following chapters is that which is provided by the Federal Aviation Agency (FAA) at no cost to the AEC. The service the FAA provides is to define and disseminate a "Notice to Airmen" to all pilots who may traverse an air space that could be involved in a nuclear detonation.

The FAA does not have the power to enforce a restriction on any air lane or air space but can only advise military and civilian aircraft to request safe routing instructions. An Air Space Advisory Plan is prepared within one or two days prior to the event since it is based on predicted cloud trajectory, forecast winds, estimated cloud height, and estimated radiation release. It is then revised as necessary a few hours prior to actual detonation time to account for actual meteorological conditions. Separate advisories are not prepared for each event, but only for those events expected to release material off-site, i.e., Plowshare, cratering, etc. If venting of the detonation occurs, the Air Space Advisory Plan remains in effect until cloud passage is essentially complete. If the detonation is essentially contained, the Air Space Advisory Plan is immediately removed. The FAA keeps records of inquiries or incidents concerning any commercial, private, or military aircraft that penetrates the area indicated in the Air Space Advisory Plan.

Much effort is still required in the field of safety. The remaining chapters in this publication will serve to emphasize that fact.

CHAPTER II

HYDROLOGIC CONSIDERATIONS

By Frank W. Stead, Research Geologist
United States Geological Survey
Denver, Colorado

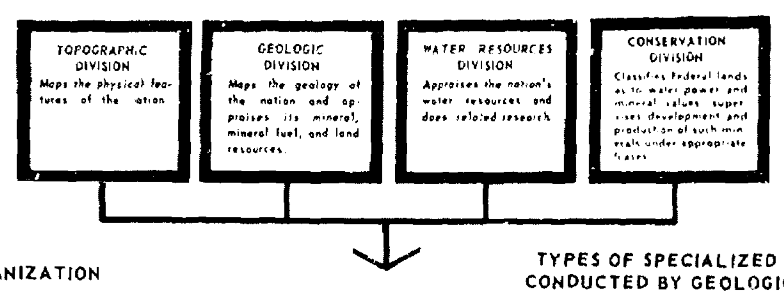
INTRODUCTION

The Geological Survey, as a scientific organization, does not make management decisions in the overall safety program of the AEC. The responsibility of the Geological Survey is to develop and present geologic and hydrologic information in the form most useful to decision-makers for selecting the best solution to a problem from among all possible alternatives. Much of the provided information is in the category of quantitative background data; such as, stream flow measurements, topographic maps and the chemical quality of water. Other information reflects the evaluation and interpretation of fragmentary raw data and is more in the nature of an educated guess than a quantitative measure. This would include the composition and structure of rocks at considerable depth, and the flow rate and direction of underground water.

The first part of this discussion is a brief outline of the types and uses of information provided by the Geological Survey. The second part concerns how this information fits the needs of the AEC in programs involving the safety of nuclear detonations. The third and final part presents the varieties and limitations of geologic and hydrologic information required for management decisions on the safety of nuclear explosions.

Types of Information

Various types of information are provided by the four technical divisions of the Geological Survey. Much of this work is interrelated and contributes to the public health and safety. The following organization chart presents a summary of specialized research subjects prepared for different divisions of the AEC.



AEC ORGANIZATION	TYPES OF SPECIALIZED RESEARCH CONDUCTED BY GEOLOGICAL SURVEY
DIVISION OF REACTOR DEVELOPMENT	RADIOACTIVE WASTE DISPOSAL STUDIES
DIVISION OF RESEARCH	GEOCHEMICAL AND GEOPHYSICAL RESEARCH
DIVISION OF BIOLOGY AND MEDICINE	BIOENVIRONMENTAL STUDIES
DIVISION OF RAW MATERIALS	URANIUM & THORIUM RESOURCES
DIVISION OF MILITARY APPLICATIONS (NVOO)	PROVISION AND EVALUATION OF DATA
DIVISION OF PEACEFUL NUCLEAR EXPLOSIONS (SAN)	SPECIAL STUDIES

The Topographic Division provides 90 percent of the general purpose topographic maps of the United States. Presently, two-thirds of the country is covered by adequate 1 mile to the inch or larger scale maps.

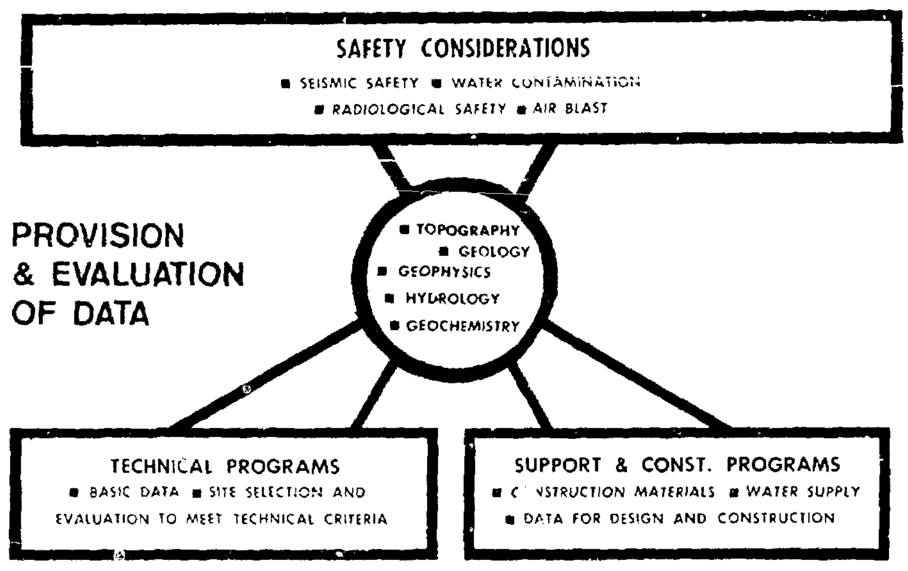
The Geologic Division provides both general purpose geologic maps and specialized geologic maps. Presently, less than 20 percent of the United States has adequate geologic map coverage at a scale of 1 mile to the inch, and less than 40 percent has coverage at a scale of 4 miles to the inch. Quite obviously, there are many areas of inadequate coverage in topographic and geologic maps of interest to the AEC.

The Water Resources Division provides data on the occurrence, quantity, and quality of ground and surface waters; again with the better and adequate coverage in the more populated and industrialized areas, and with scanty coverage in the less populated and desert areas of the western states.

The Conservation Division provides considerable geologic data on the federal lands. By law, all mineral, oil, and gas operations on leased public lands must provide to the Geological Survey whatever geologic information is deemed desirable.

Uses of Information

Information provided by the Geological Survey fits the needs of various AEC programs related to the testing or use of nuclear explosives, either at a major site such as the Nevada Test Site, or at a smaller site such as Project Gnome or Project Dribble. As shown by the following chart, the provision and evaluation of topographic, geologic and hydrologic data have multiple uses.



Under technical programs conducted by the Los Alamos Scientific Laboratory (LASL), the Lawrence Radiation Laboratory (LRL), the Defense Atomic Support Agency (DASA) and other groups, the water content of the rock in the immediate vicinity of the nuclear explosion is needed to calculate the interactions between the explosion and the surrounding medium. Under support and construction programs, the available volume and chemical quality of water are needed for domestic and construction activities. Also needed would be the volume of water to be handled in design and construction of deep device-emplacement holes and shafts. Under safety considerations, the volume of water likely to be initially contaminated, and the probable rate and direction of movement of such contaminated water, are critically needed. Thus, required data consists of the volume of water and its mobility at the site of any proposed underground nuclear explosion, that are then used for a variety of purposes. Geologic information is essentially restricted to studies involving seismic safety and water contamination; little, if any, geologic data are needed in radiological safety and air blast studies.

STUDIES RELATED TO HYDROLOGIC SAFETY CONSIDERATIONS

Geologic Environment, Nevada Test Site

The balance of this discussion concerns the geologic information required in consideration of potential water contamination. A block diagram, 200 square miles in area, of the northern part of Yucca Flat (Figure 2.1) illustrates the geologic environment of the major part of the Nevada Test Site. Rainier Mesa, where the first underground nuclear explosions were detonated in tunnels, is at the northwest corner of the block. The small granite mass in which the Hardhat event was detonated at a depth of about 1,000 feet is shown in the north-central part of the block. Essentially all of the recent underground nuclear explosions have been detonated in deep drill holes in Yucca Flat proper.

Three major rock types are shown in Figure 2.1 as alluvium, volcanic tuff and basement rocks of Paleozoic age. Most of the area of Yucca Flat is blanketed by a variable thickness of alluvium that is composed of recent sands and gravels up to 2,000 feet thick. This alluvium effectively conceals the underlying volcanic tuffs and lava flows; it also conceals the still older Paleozoic rocks such as dolomites, shales, and quartzites.

In addition to adequate topographic maps that describe the surface of the location, and accompanying geologic maps which tell what is there--hydrologic safety and other technical considerations require more specific information; such as: first, the configuration of the rocks to considerable depth, including the thickness of the rock units, their depth below the surface and their structural attitude; second, the planes of weakness in the rocks such as faults, joints and cooling cracks; third, the detailed physical and chemical properties of the rocks, such as porosity, permeability and mineralogy, and more importantly the spatial variation of these properties; and fourth, the amount and location of water in the rocks, particularly the position of the water table below which rocks are water saturated.

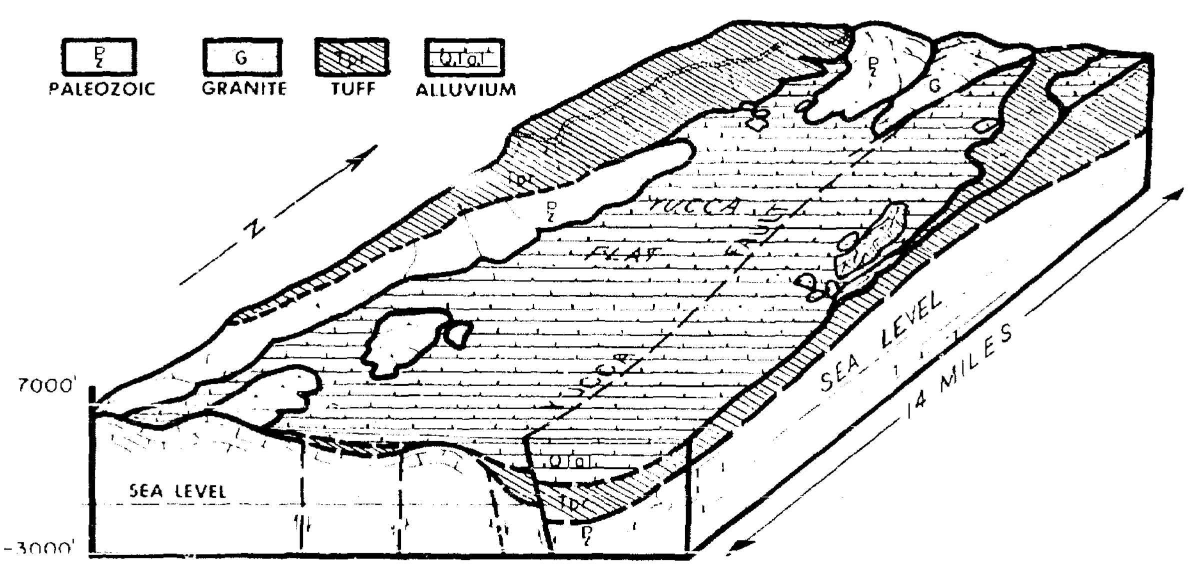


Figure 2.1. Block Diagram Illustrating Geologic Environment of Northern Yucca Flat, Nevada Test Site.

Ground Water, Yucca Flat, Nevada Test Site

Shown on the diagrammatic section (Figure 2.2) through central Yucca Flat, where the surface is about 4,000 feet above sea level, is the water table at about 2,400 feet above sea level and about 1,600 feet below the ground surface. The important fact is that the water table is essentially flat and does not tend to follow the ground surface. This is contradictory to the normal behavior of the water table in most environments. Enough deep test drilling has taken place at the Nevada Test Site to confirm this somewhat unusual behavior of the water table. Under the ridges to the east and west of Yucca Flat the ground-water table is in the Paleozoic rocks, where the ground-water flow is through dolomite or limestone characterized by numerous fractures.

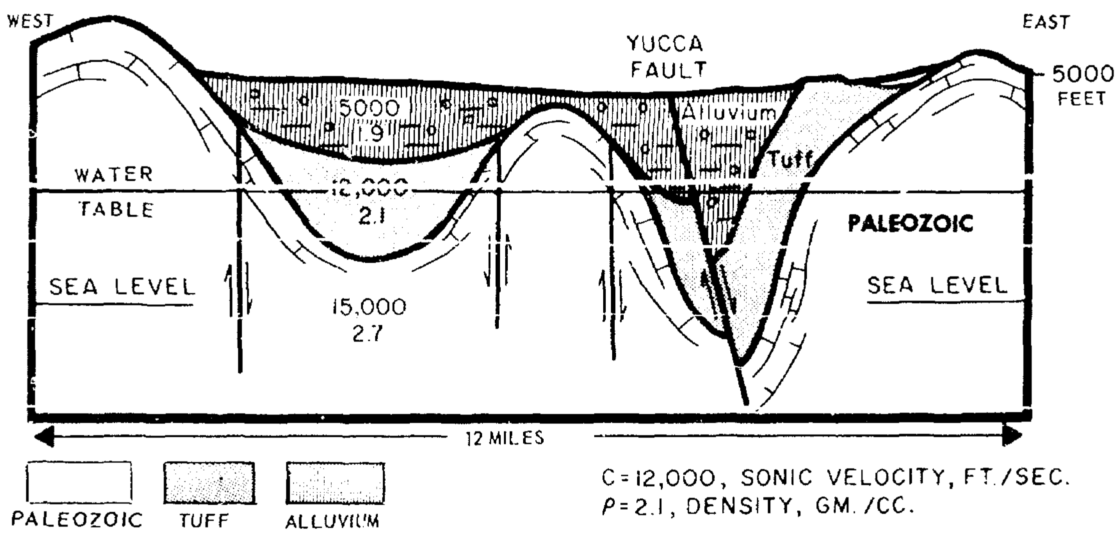


Figure 2.2. Diagrammatic Section through Central Yucca Flat, Nevada Test Site.

Initially, the Nevada Test Site was selected for surface and above surface testing of nuclear devices with essentially no consideration to the amount and location of ground water or to the possible long-term significance of widespread radioactive contamination of water at depth. Had the Geological Survey been asked to locate an area for underground testing where the water table was at 1,500 or more feet below the surface, it would have been difficult to find a better area than the Nevada Test Site.

Hydrologic Setting, Nevada Test Site and Vicinity

The present interpretation of the hydrologic setting of the Nevada Test Site is shown in Figure 2.3. Such interpretive information, continually re-evaluated as new data become available, is critically needed for evaluating the possibility of water contamination extending outside of the limits of the Nevada Test Site.

Shown in Figure 2.3 are the water table contours expressed in feet above sea level. In Yucca Flat, located in the northeast part of the Nevada Test Site where the ground surface is 4,000 feet above sea level, the water table is about 2,400 feet above sea level or about 1,600 feet below the surface. The surface drainage basins, outlined by dashed lines, are mostly closed basins without any surface drainage outlets. Quite obviously, the position of the water table and the regional movement of ground water are not controlled by the surface drainage pattern; the ground-water flows primarily through fractured Paleozoic dolomites at depth and passes under the high ridges surrounding Yucca Flat. As indicated by the arrows showing the direction of ground-water movement, ground water from the Yucca Flat area flows down gradient to the southwest, passes under Mercury, and ultimately reaches surface discharge areas in the Amargosa Desert near Death Valley Junction. The distance from Yucca Flat to the discharge areas in the Amargosa Desert is about 50 miles.

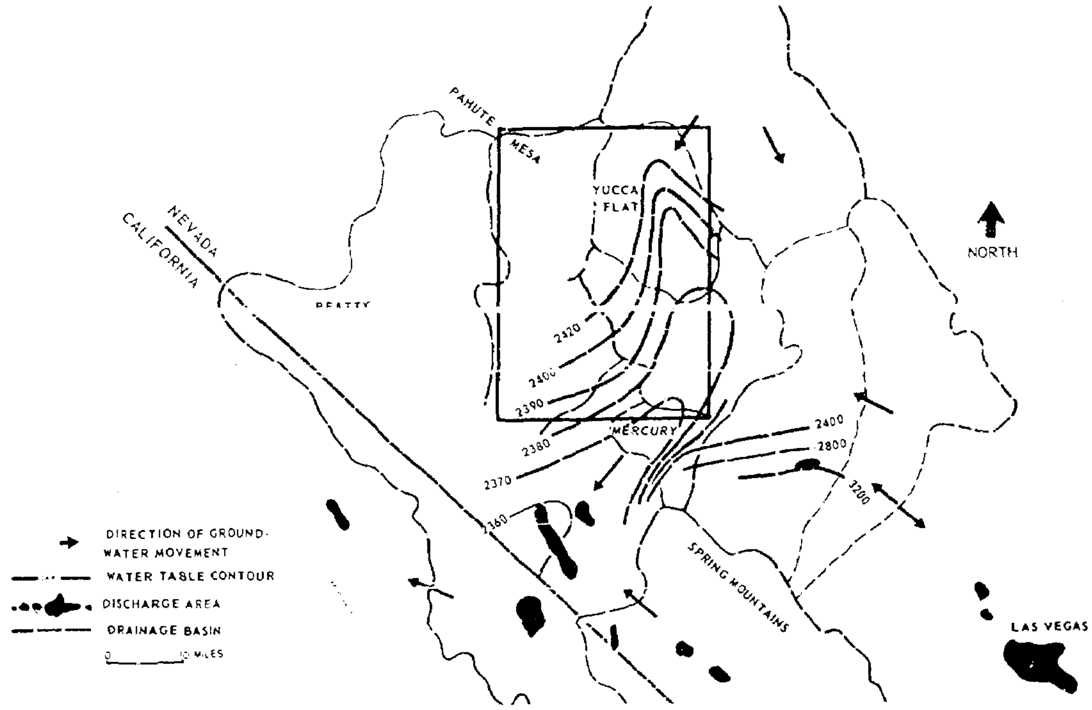


Figure 2.3. Hydrologic Setting of Nevada Test Site and Vicinity.

The best estimate of the ground-water flow rate is based; first, on the measured discharge volume in the Amargosa Desert; and second, on an assumption that this volume passes through a cross-sectional area, 4 miles wide and 1 mile high, in Paleozoic limestone and dolomites, under Mercury. The flow rate through the cross-sectional area is 3 to 6 feet per day. The travel time of ground water from Yucca Flat to the discharge areas is then about 100 to 200 years. Although the foregoing is by no means a quantitatively tight evaluation of the direction and rate of flow of ground water at the Nevada Test Site, neither is it a wild extrapolation. Even though the control points—observation and production water wells and other drill holes—are widely spaced, up to tens of miles apart, additional observation wells costing many millions of dollars would not significantly improve present understanding of the movement of ground water.

POSTSHOT DISTRIBUTION OF RADIONUCLIDES

Very few of the underground nuclear explosions to date have been detonated in saturated rocks below a water table; in even fewer cases has post-explosion exploration been sufficient to obtain meaningful samples. Such samples are needed; first, for determining the initial distribution and concentration of radionuclides in the rock and the contained water; and second, for determining any significant changes in the chemical and physical properties of the rock around the explosion.

Illustrated in Figure 2.4 is the postshot distribution of strontium 90 in ground water around two underground nuclear explosions, the 5-kiloton Logan event and the 19-kiloton Blanca event, at the Nevada Test Site. The post-explosion reentry tunnels are shown by solid lines and the device emplacement tunnels by dashed lines. The analytical data, in terms of curies of strontium 90 per milliliter of ground water, are shown for the few localities where samples of ground water draining into the tunnels could be collected a few months after the explosions.

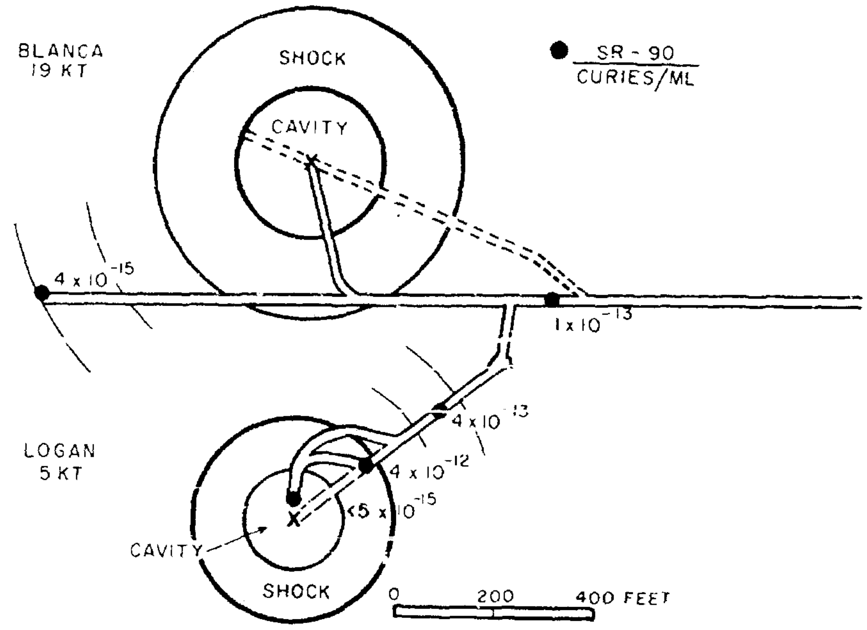


Figure 2.4. Postshot Distribution of Strontium 90 in Ground Water around Logan and Blanca Events.

Based on these scanty data, several points can be made. First, strontium 90, one of the few biological hazardous and long-lived fission products that must always be considered as a possible water contaminant, is not highly concentrated in the ground water; the highest concentration is just about at the continuous occupational maximum permissible concentration (MPC) for strontium 90 in drinking water. Second, the observed concentrations of strontium 90 most probably reflect the initial explosion-produced distribution and the reaching of chemical equilibrium in-place, as the water draining from the rock was volumetrically small and could not have traveled any significant distance. Third, strontium 90 is not widely distributed by direct explosive action and is largely contained within the zone immediately around the cavity, shown here as the shock zone. Fourth, no significant changes are present in the physical and chemical properties of the rock.

These previous points are not strongly founded either on fact or on theory. It is all too clear that there has not yet been developed sufficient knowledge on how fission products and other radionuclides are initially distributed, and on what actually may be the initial chemical forms and solubilities of these nuclides.

CALCULATION OF INITIAL DISTRIBUTION OF RADIONUCLIDES

The calculation of the initial distribution of a particular radionuclide, such as strontium 90, in ground water around an underground nuclear explosion requires additional geologic data. A generally applicable equation for such calculation or prediction is:

$$K_D = \frac{\text{Activity solid}}{\text{Activity water}} \times \frac{\text{Volume water}}{\text{Mass solid}}$$

where the first term is the distribution coefficient, K_D, for a specific radionuclide, the second term expresses the fraction of radioactive ions in the mineral phase divided by the fraction of radioactive ions in the water, and the third term is the water/solid ratio for a particular volume of rock.

The value of the distribution coefficient, K_D, can be determined in the laboratory by using a representative sample of a rock with its associated ground water, by adding trace amounts of a particular radionuclide — strontium 90, in this case — and by then measuring the amounts of the nuclide on the solid and in the water; for example, an average K_D value for volcanic tuff would be 100. For the second term, the total amount of an introduced nuclide must be known to apply this equation to a specific case, such as 1500 curies of strontium 90 from a 10-kiloton fission explosion. For the third term of the equation, the volume of rock into which this activity is introduced must be known or assumed; more specifically, the physical properties of the rock must be determined so that the total volume can be correctly proportioned between the volume of water in the pore spaces and the mass of the solid.

Now assume that a 10-kiloton fission explosion in volcanic tuff distributes 1500 curies of strontium 90 by direct explosive action in the shock zone around the cavity, and that the measured rock properties can be used to determine the volume of water and the mass of the solid. The equation can now be solved for the activity in the water:

$$100 = \frac{1500 \text{ Curies}}{\text{Activity water}} \times \frac{4.2 \times 10^{11} \text{ ml}}{23.3 \times 10^{11} \text{ g}}$$

Activity water = 2.7 curies

2.7 curies in 4.2×10^{11} ml = 6.4×10^{-12} c/ml of Sr^{90}

For this hypothetical case, the calculated concentration of strontium 90 in ground water is 6.4×10^{-12} c/ml, almost the identical concentration measured in the shock zone around the Logan event (Figure 2.4).

DISTRIBUTION COEFFICIENT VALUES

Shown in Figure 2.5 are about one thousand distribution coefficient values for cesium, mixed fission products, strontium and iodine as determined by radiochemical laboratories for various rock types at the Nevada Test Site. In general, these values reflect the best matching of the rock samples with their associated ground water or with solutions simulating naturally occurring water; this is necessary to prevent chemical mismatch and the provision of incorrect data.

The nature of the distribution coefficient is such that the higher the value, the more of a particular radionuclide is held on the solid by ion exchange mechanisms. It is immediately obvious that the range of values for a particular nuclide in a given rock type can be unpleasantly large. For example, strontium 90 in soils at Nevada Test Site has a range from 10 to 10,000, or three orders-of-magnitude; strontium in volcanic tuff has a range from 100 to 4,000. Needless to say, a prediction of the concentration of a hazardous radionuclide in ground water that has a three order-of-magnitude spread is not entirely satisfactory; it tends to push the use of such predictions toward the highly conservative and somewhat implausible end of the spectrum.

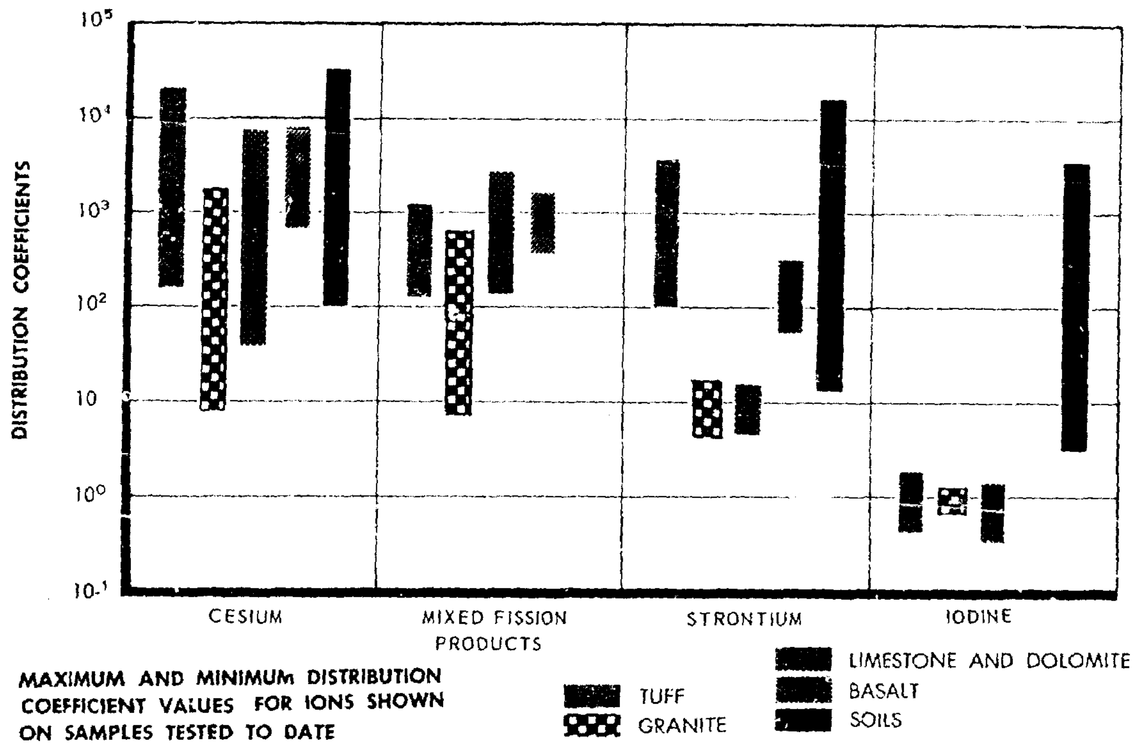


Figure 2.5. Distribution Coefficient Values Determined for Various Rock Types at Nevada Test Site.

TRANSPORT OF RADIONUCLIDES BY GROUND WATER

After determining the initial distribution of radionuclides, their transport by ground water can be calculated by relating the movement of a specific ion to the movement of the water. Thus,

$$\text{Flow (ion)} = \frac{\text{Flow (water)}}{1 + K_D\rho}$$

expresses the retardation or delay in movement of the nuclide in respect to the movement of the ground water; where:

Flow (ion) = Average rate of advance in feet/day.
Flow (water) = Average flow rate in feet/day.
K_D = Distribution coefficient (ml/g).
ρ = Ratio of mass to volume (g/ml).

Here, the only new information required is the average flow rate of ground water. For many sites of proposed nuclear explosions, the average velocity and direction of flow can be estimated either from existing hydrologic data or from a few supplemental observation wells.

However, straightforward use of this equation may be highly misleading. For example, dolomite either at the Nevada Test Site or at the Project Gnome site is not a porous medium in the strictest sense, and much of the ground-water flow in such dolomite may be through cracks and fissures rather than through the rock matrix as a whole. It follows that the ratio of the mass of the matrix available for ion exchange to the volume of the ground water—the term ρ in the equation—would be far too large by possibly an order-of-magnitude and would lead to erroneously low estimates of the rate of advance of a specific radionuclide.

A second difficulty with this equation is that laminar or tubelike flow must be assumed, with no spreading or mixing of the initial contaminated streamline. This assumption is far too rigorous and idealized for rocks, which tend to be highly variable, particularly when distances involves miles between locations. In a nonuniform and quasi-porous rock, considerable mixing and dilution of the streamline can be expected in three dimensions. Further, some parts of the original streamline will move more rapidly and some more slowly than the average flow rate.

DISTRIBUTION OF TRITIUM, NATIONAL REACTOR TESTING STATION

To illustrate the mixing and spreading of contaminated ground water under natural conditions, the distribution of tritium in ground water at the National Reactor Testing Station is shown in Figure 2.6. Starting about 10 years ago, tritium has been introduced into the ground water through the Idaho Chemical Processing Plant (ICPP) radioactive waste disposal well and has now moved about 5 miles down gradient from the point of injection. The average rate of ground-water flow based on regional hydrologic data is about 7 feet per day, in the southwest direction as indicated in Figure 2.6. The contours indicate the tritium concentration, in pirocuries per milliliter.

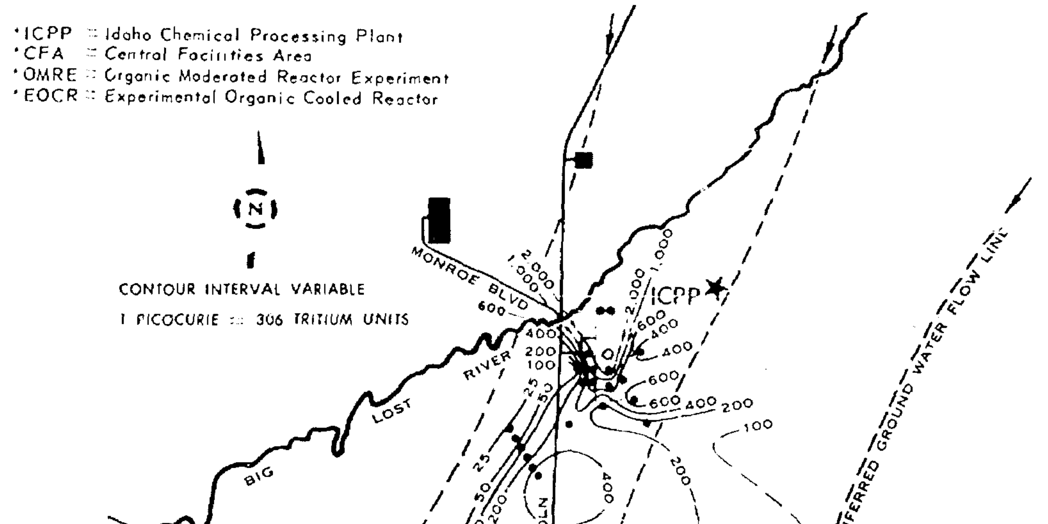


Figure 2.6. Tritium Activity in Picocuries at National Reactor Testing Station.

The most significant point shown here is the spread of tritium over an arc of about 90° in traveling a flow distance of a few miles. Obviously, laminar or tubelike flow does hold true in these rocks and using the flow equation as shown on page 12 would yield highly erroneous results.

A second point is the wide variation in ground-water flow rates between the input disposal well—the ICPP on the Figure 2.6--and the observation wells shown by the black dots. The flow rate averages 20 feet per day within a distance of a quarter of a mile from the input well, but can be as high as 120 feet per day.

Third, these data clearly indicate the importance of the longitudinal and transverse spreading of contaminated water and the care that must be exercised in using the average rate of flow of ground water in predicting the movement of a radionuclide.

This case clearly illustrates a major problem of how contaminated water spreads and becomes diluted in moving away from the point of initial contamination. Progress in solving this problem has been small and may or may not yield significant results in the immediate future. The necessary research is long-range and demands the best type of personnel and support.

TRACER TESTS TO DETERMINE RETARDATION OF RADIONUCLIDE MOVEMENT

For a particular test site, one of the best ways to determine how much a radionuclide might be delayed in its ground-water transport is to conduct a tracer test using two or more closely spaced water wells. Shown in Figure 2.7 is such a test conducted at the Project Gnome site, near Carlsbad, New Mexico.

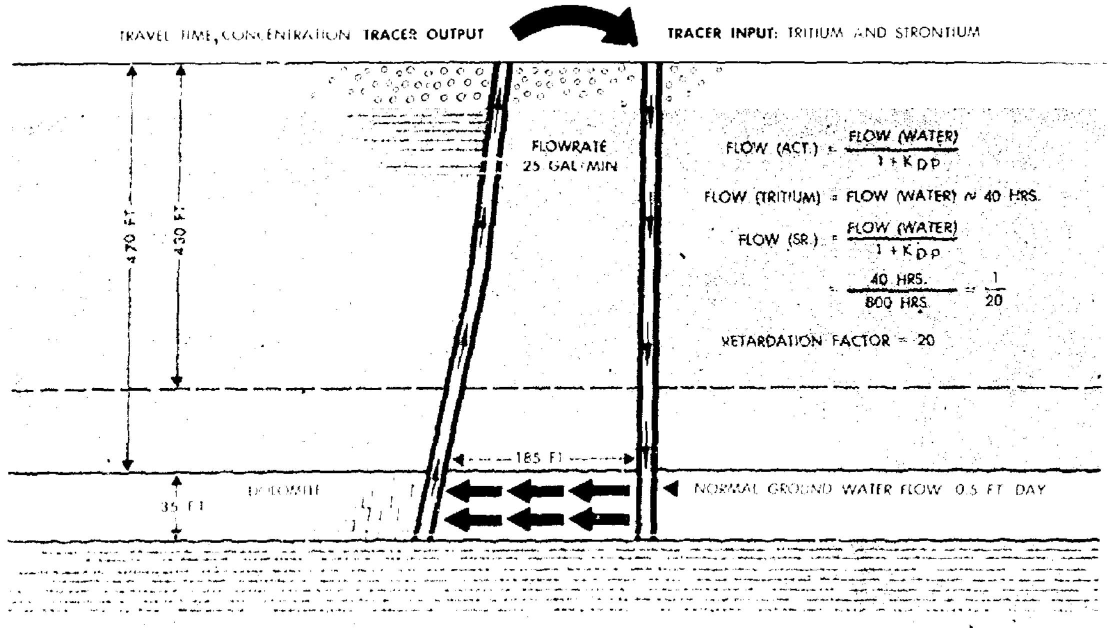


Figure 2.7. Tracer Test Conducted at Project Gnome Site.

As shown in Figure 2.7, water is pumped continuously in a closed circuit until stable flow conditions are reached. Trace amounts of tritium and strontium are then introduced through the input well, and the time of arrival of the radionuclides is measured at the outputput well. Tritium for practical purposes moves with the water, and provides the measure of the flow rate or travel time of the water between the two wells. In this case, tritium took 40 hours to travel between the wells, and strontium took about 800 hours; thus, the strontium moved one-twentieth as fast as the water, being delayed by chemical interaction between the moving water and the solid phase of the rock.

In actuality, such a tracer test using strontium determines by a relatively straightforward empirical approach the denominator of the flow equation shown on page 12; that is, the combined in-place value of 20 for 1 plus K_D (the distribution coefficient) multiplied by ρ (the mass-to-volume ratio). This retardation factor of 20 for strontium is in sharp contrast to the value of about 500 obtained by inserting laboratory values for K_D and ρ. This again demonstrates that many of the present methods used in evaluating the flow rates of ground water and the concurrent transport of radionuclides are limited to typically porous rocks, such as sands or sandstones. Present methods cannot be indiscriminately applied to rocks, such as granites and limestones where ground water frequently moves through fractures and cracks.

SURFACE WATER SAFETY CONSIDERATIONS

Illustrated in Figure 2.8 is a surface water problem, where fallout from a large nuclear cratering explosion might lead to contamination of surface water supplies. This may be recognized as a somewhat simplified version of Project Chariot, which was not executed.

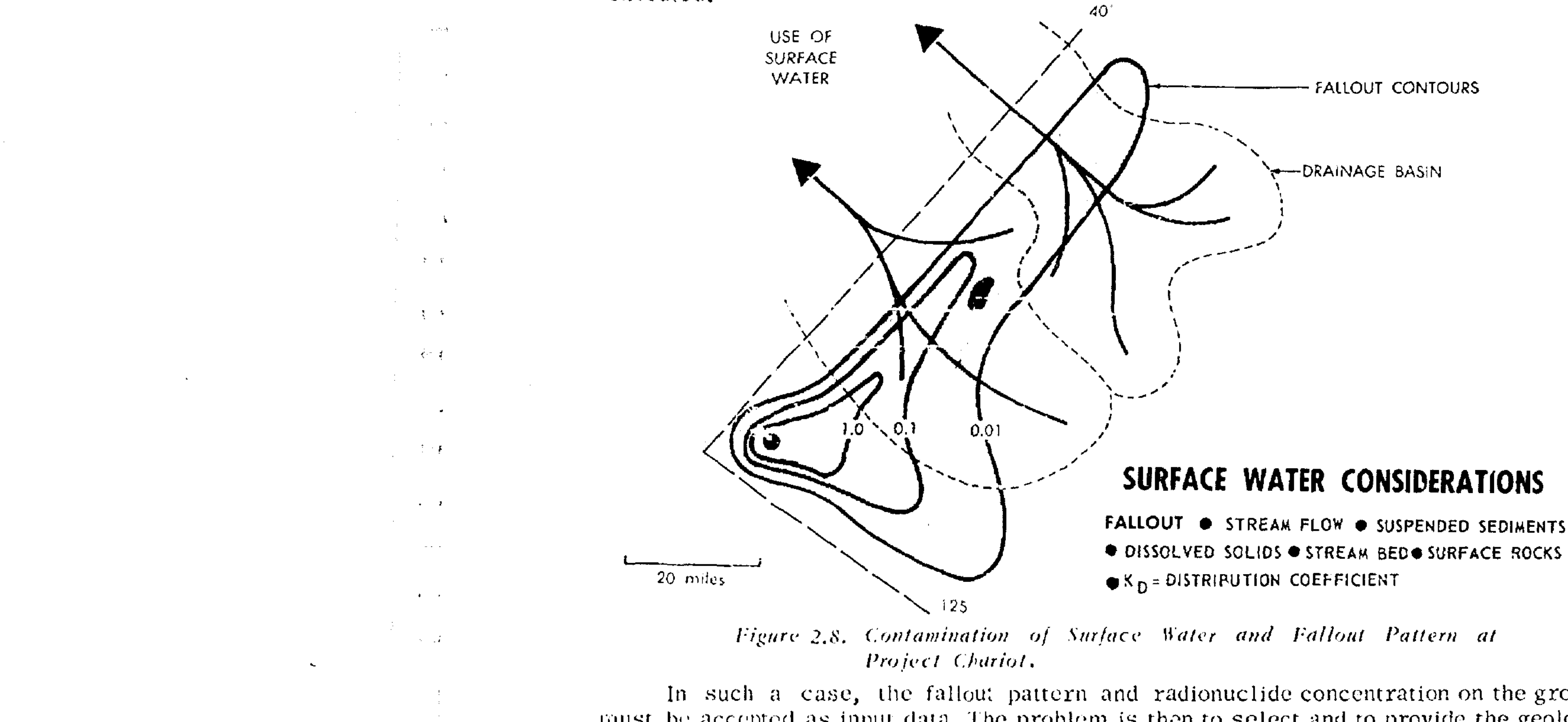


Figure 2.8. Contamination of Surface Water and Fallout Pattern at Project Chariot.

In such a case, the fallout pattern and radionuclide concentration on the ground must be accepted as input data. The problem is then to select and to provide the geologic and hydrologic data needed for evaluating the potential contamination of surface water. Summarized in Figure 2.8 as surface water considerations are some of the data needed over an area of several thousand square miles: First are the rainfall, runoff and stream flow. Second are the suspended sediments, dissolved solids and chemical and composition for the surface water. Third are the variations in stream bed characteristics, such as bare rock, mud and sand; fourth is the character of the land surface. Fifth are the distribution coefficients for various radionuclides for the whole and parts of the system.

Extensive field tests were conducted to confirm theoretical calculations by using typical fallout material from the Project Sedan nuclear cratering experiment at the

Nevada Test Site and also known amounts of radioactive cesium, strontium, and iodine. These radionuclides were spread over ten test plots in the proposed Project Chariot fallout area. Risking some broad generalizations, two distinct phases of potential water contamination can be discriminated: First, contaminating effects that are due to fallout directly on open-water surfaces with the radionuclides partitioned between the water and solid phases in accordance with the distribution coefficients for the system; this results in a wave of radionuclide concentration moving downstream with reasonable calculable attenuation and duration. Second, after the initial wave, further potential contamination depends on actual movement of radioactive particulates to the streams; that is, on the rate of erosion of the surface on which the fallout descends.

Bearing on geologic data, a better characterization of the land surface, than is provided by normal geologic mapping, is needed to discriminate bare soil, bare rock and vegetated areas together with their geochemical and physical properties.

SUMMARY

To summarize, this discussion has reviewed the types and kinds of geologic and hydrologic information required for evaluation of potential contamination of ground and surface waters, with some of the limitations on such information and some of the difficult problems remaining to be solved. In general, topographic, geologic and hydrologic data will be needed in varying detail over an extensive area for any proposed nuclear explosion. Most of this data will have multiple uses in the safety, technical and support programs.

Some of the problems remaining to be solved are common to other activities of the AEC. In particular, the disposal of radioactive wastes to the ground and the resultant possibility of contaminating ground and surface water. The solution of some of the more difficult problems, such as the rate and direction of flow of potentially contaminated ground water, must be sought on a long-term continuing basis by all groups competent and interested in such studies.

CHAPTER III

GROUND WATER CONTAMINATION PREDICTIONS

By Louis B. Werner, Project Manager
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INTRODUCTION

Contamination of water by debris from nuclear detonations has been regarded for some time as a potential hazard to man and has been the subject of past studies and control measures designed to safeguard the public. Current practice of limiting nuclear detonations to underground emplacement eliminates or reduces widespread radioactive fallout. But potential contamination of ground water must be considered. Operational safety evaluations are performed routinely to advise the test manager of the probable extent of water contamination, if any, and its practical significance with respect to current and future testing programs.

Field data demonstrating actual radionuclide contamination of ground water are scarce for any of several tests which have been fired in saturated media, and only limited field programs are underway to provide such data.

Nevertheless, analysis of known features of past shots shows that contamination of ground water *is a virtual certainty for certain shots, and will occur in future shots.* As a reminder of the magnitude of contamination potential, one can calculate that sufficient Sr^{90} is produced by one kiloton of fission yield to contaminate 1.7 million acre-feet of water to the maximum permissible concentration (MPC) set by the National Committee on Radiation Protection (NCRP) and the International Commission on Radiological Protection for this nuclide for potable water. However, it should be added that sorption on geologic materials, and in some cases the time required for movement of ground water and radionuclides, make it virtually inconceivable that this degree of water contamination would occur at water use points.

Radioactive contamination of ground water from controlled waste disposal practices has been observed at several locations. At Hanford, tritium concentration in ground water exceeds maximum permissable concentrations for drinking water for continuous nonoccupational consumption (1×10^{-3} $\mu c/ml$) at distances up to 6 miles from waste discharge points.

Examples of analogous contamination of ground water by chemical products illustrate the economic significance of uncontrolled disposal practices. At Rocky Mountain Arsenal near Denver, chemical wastes have rendered ground water in 6-1/2 square miles of land unsuitable for agricultural or domestic use. Land values alone in this instance are about 2.5 million dollars. There is no evidence at present that suggests that analogous unintentional nuclear contamination of water supplies has occurred.

In the interest of public safety the Nevada Operations Office has recognized the need for day-to-day operational evaluations of ground water contamination, and also, the need for improvements in the capability to predict contamination reliably. By this means, a more reliable basis also should be provided for evaluation of possible depreciation in value of natural water resources.

METHODS OF GROUND WATER CONTAMINATION PREDICTION

To estimate the probable extent of water contamination, it is necessary to combine information concerning phenomenology of nuclear detonations with nuclear, chemical, hydrologic, geologic, and biologic data. In presenting the method of estimating contamination of water, as well as the long-range study program, it may be helpful to consider the chronological sequence of events from formation of contaminants to possible contact with people.

Calculation of hazard requires that radionuclides be identified, quantities and concentrations be known, physical and chemical states be determined, and hazard criteria be provided which are applicable to the particular radionuclides produced and circumstances of the test.

CONTAMINANT PRODUCTION

Possible contaminants consist of fission products, fusion products, and neutron-induced activities. The location of these radioactive products is shown schematically by Figure 3.1 in the initial cavity shortly after detonation in an underground emplacement. Most products are present in the cavity in a gaseous state mixed with other cavity gases, such as water vapor. Melt lines the walls of the cavity. Radioactivities which are induced in the geologic medium outside the cavity walls may appear in the melt.

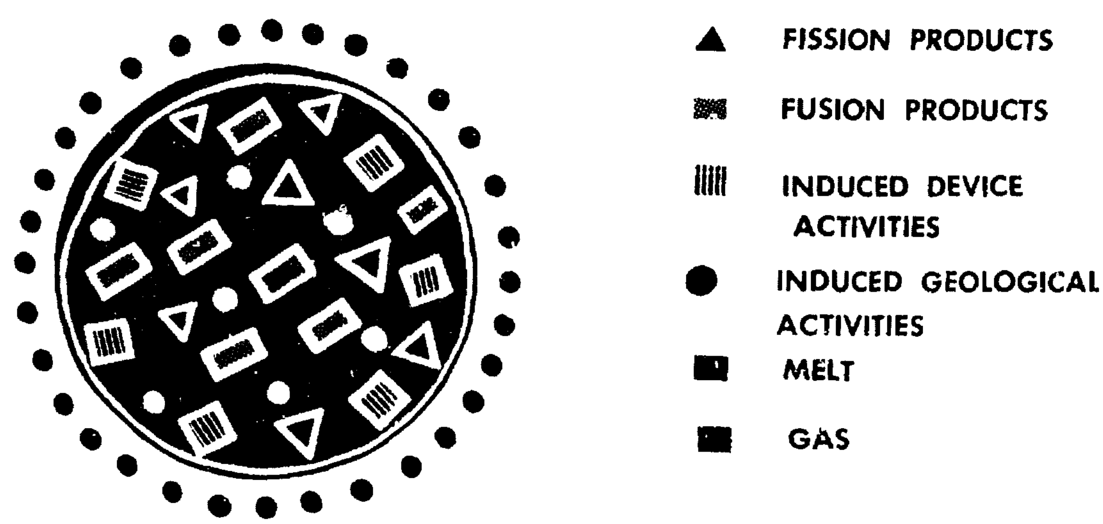

Figure 3.1. Schematic Showing Location of Radioactive Products in Initial Cavity Formation.

Radionuclides produced by fission are well-known and the quantities of each are readily calculated at various times. The following table lists nine fission products having the most contribution to radioactivity with over 0.5 year half-life.

	Half-life (years)	Activity (curies/KT)
Ce^{144}	0.78	5600
Pm^{147}	2.5	810
Ru^{106}	1.0	530
Cs^{137}	28.	180
Sr^{90}	30.	160
Sb^{125}	2.7	67
Eu^{155}	1.7	36
Kr^{85}	10.4	23
Sm^{151}	90.	5.1

These are radionuclide products of spectrum fission of U^{235}. It may be seen that Ce^{144} contributes more radioactivity than any other fission product. But for various reasons, this radionuclide is less hazardous as a potential water contaminant than Sr^{90} which contributes a lesser amount of radioactivity. Cs^{137}, which should be important, is so effectively sorbed by many minerals that concentrations in water and rate of transport by water are negligible under most conditions.

Of course, tritium is the important radioactive product of fusion reactions. It is reported in the unclassified literature that about 5,000 curies of tritium are formed per kiloton of fusion yield.

Excess neutrons from fission or fusion absorbed by materials of the device, or surrounding it, produce various activation products. The species and quantities of these products vary with elemental composition of device components, materials around the device, and the geologic medium. Neutron-absorbing materials may be added which result in nonradioactive products, and hence decrease relatively the amount of radioactivity produced as a result of neutron capture. Characteristics of the neutron flux are influenced by the device type. These characteristics are important, also. Results of a calculation are listed in the following table for a simple case of thermal neutron activation of a geologic medium having the average composition of the earth's crust.

	Half-life (years)	Activity (curies/KT)	Reaction
Fe^{55}	2.7	200	Fe^{54} (n, γ) Fe^{55}
Ca^{45}	0.44	80	Ca^{44} (n, γ) Ca^{45}
H^3	12.26	80	Li^6 (n, α) H^3
Co^{60}	5.27	8	Co^{59} (n, γ) Co^{60}
Eu^{152}	13.	5	Eu^{151} (n, γ) Eu^{152}

Yields of radioactivity may be seen to be about an order-of-magnitude lower than for fission products, but of course, become more significant in high fusion yield devices. Of possible interest among these nuclides is the presence of substantial amounts of Co^{60}. These estimates of yield have proved useful for general orientation and discussion, but of course are not valid for detonations in drastically different media, such as salt. Also, there may be circumstances in which shorter-lived radionuclides need to be considered.

Induced radionuclides from device and emplacement components, such as iron in casings, can contribute large amounts of radioactivity. Because of variability of design, each device and emplacement must be individually considered.

Spatial Distribution, Physical and Chemical States of Contaminants

Once the identities and quantities of contaminants have been determined; the question of their distribution in space and time arises, particularly with reference to location of water-bearing zones or aquifers. Recognized as two of the important mechanisms which may result in outward movement of radionuclides from the initial cavity are melt and gas injection into fractures, and the penetration of rubble and other porous media by gaseous radionuclides. These phenomena are related to entrance of contaminants into water-bearing zones and to rate of transport away from the shot point. An instant after formation, the cavity is presumed to contain gaseous materials at high temperatures and pressures. The results of an analysis of possible subsequent events are illustrated in Figure 3.2. This study was made as part of the long-range safety studies. Consideration of stresses about the cavity led to the conclusion that fractures in vertical planes would be formed. Rock melt lining the cavity is injected into fractures until depleted by injection and by running to the bottom of the cavity. Gas then enters fractures, further opening and extending them.

In Figure 3.2, the detonation is depicted as having occurred below the water table within a single stratigraphic unit that overlays a second water-bearing formation which also has been penetrated by fractures and presumably contaminated. Such penetration would be especially interesting if the deeper formation were more highly conductive and thereby provided a mechanism for more rapid transport of contaminated water to use points at some distance from the test site. Although this seems a reasonable conceptual description of phenomena which are believed to occur at this time, it is largely a qualitative one. The fracture frequency and extent of contaminant penetration are two important parameters that are shown in Figure 3.2 of which little experimental data exist. Much more basic data are needed from which to derive more quantitative descriptions.

Subsequent events are shown in Figure 3.3 as a vertical chimney results. Cavity collapse, which generally occurs in underground detonations, results in further dispersal of volatile radionuclides. Collapse takes place as roof support ceases, either by diminishment of support pressure by cooling of gas, or equalization of gas pressure around roof blocks by gas injection.

Those radionuclides, which are in a gaseous state, move progressively upward as gas in the cavity is displaced; condensing as the temperature is lowered through contact with fresh rock surface, or by radioactive decay of short-lived rare gas precursors to condensable daughter radioelements. As a result, certain radionuclides, such as Sr^{90} and Cs^{137}, appear to become distributed throughout a highly water-permeable mass of rock, probably in soluble form. Available evidence suggests that most radionuclides and over two-thirds of the total radioactivity are associated with the solidified melt. Much more data are needed on contaminant distribution and concentrations, and the chemical states of contaminants to estimate accurately the degree of solubility of various radiocontaminant in melt, rubble, and fractures when contacted by ground water.

Entry of Contaminants into Hydrologic Systems

After detonation in a saturated medium, various mechanisms can be visualized by which water enters the rubble chimney or cavity. One of these mechanisms, shown in Figure 3.4, results in a depression in water level if one assumes that water, which existed

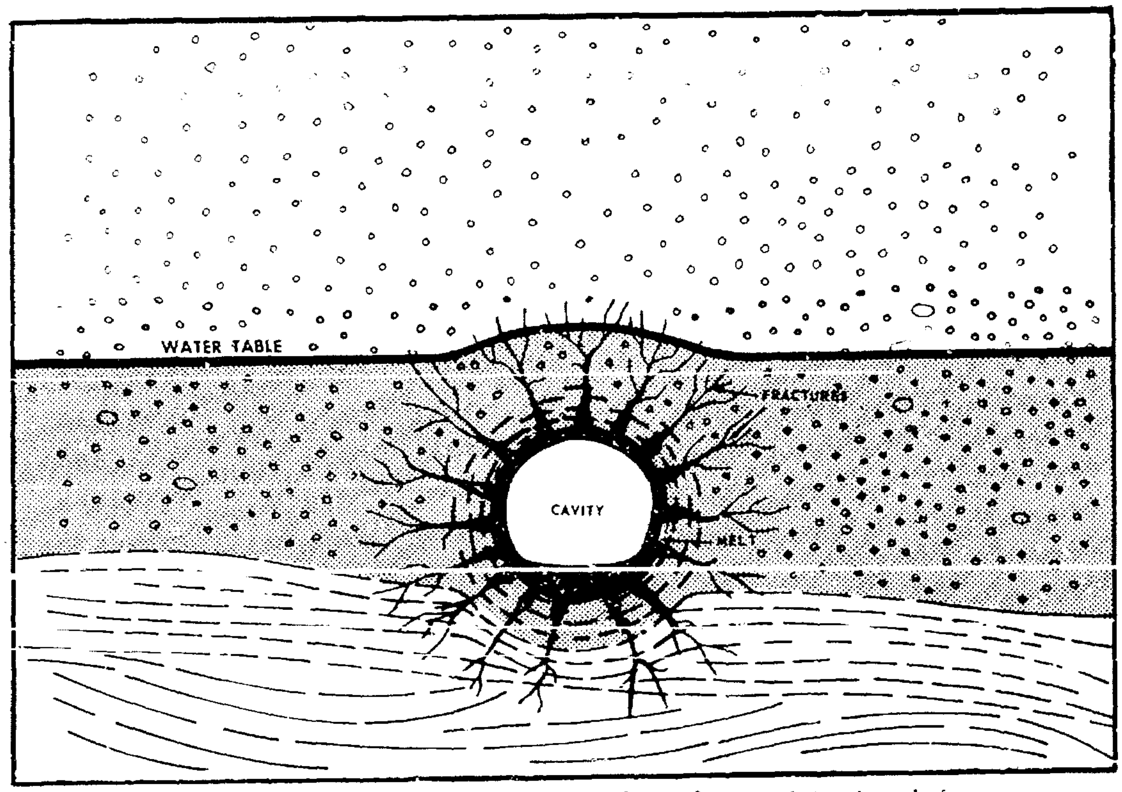

Figure 3.2. Spatial Distribution of Melt and Gas Injection before Collapse.

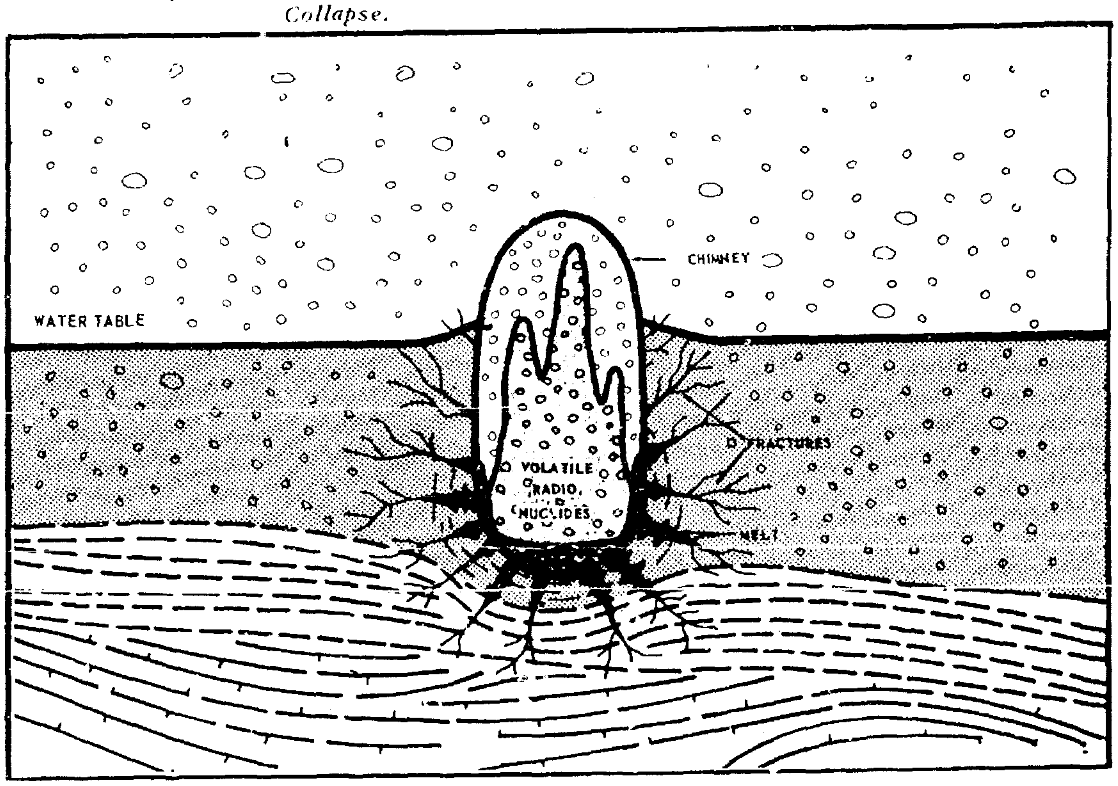

Figure 3.3. Spatial Distribution of Gas Penetration of Collapse Chimney.

in the region of the rubble chimney below the water table, was displaced by the detonation. As a result, water flows from the surrounding medium and filling of the cavity or voids in the rubble chimney occurs with the consequent dissolution of contaminant debris.

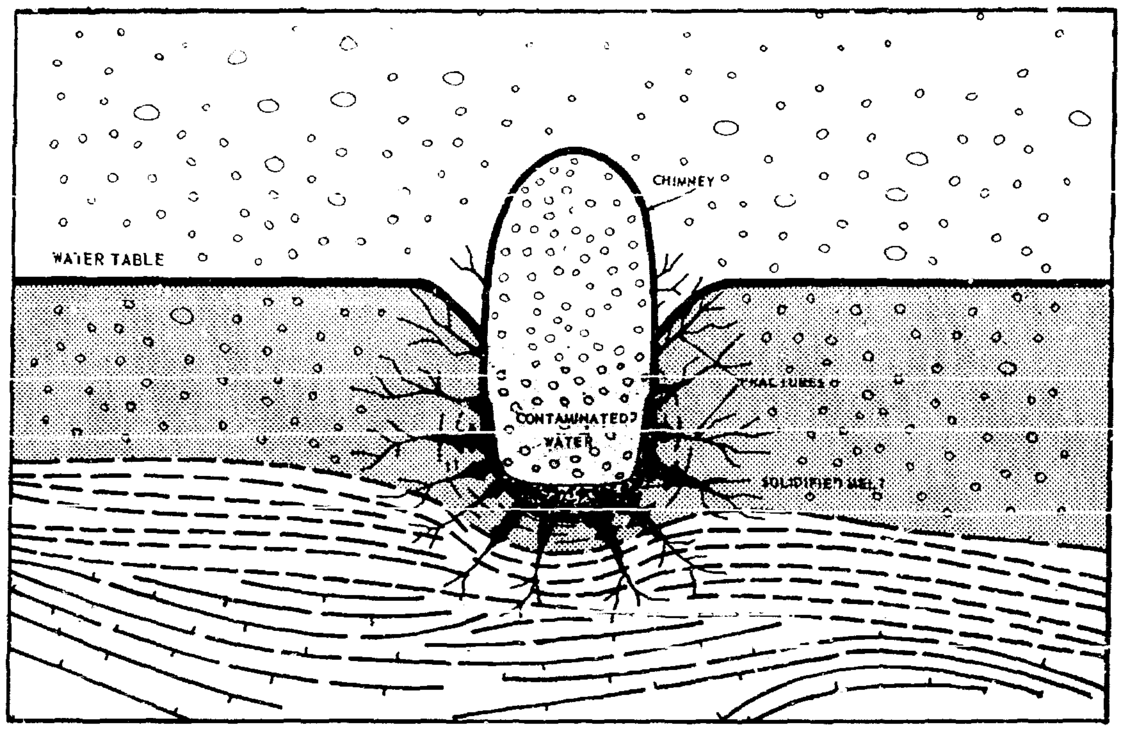

Figure 3.4. Entry of Contaminants into Water.

To consider dissolution of the solidified glassy melt, assume that 500 tons of melt are produced in a silicate medium per kiloton of yield for a pure fission device. After equilibration of the melt with ground water, the estimated concentrations of radionuclides in water are listed in the following table.

	T½ (years)	Concentration in Water (μc/ml)	Recommended Concentration NCRP (μc/ml)	Time for Radioactive Decay to Recommended Concentration (years)
Ce^{144}	0.78	1×10^{-3}	1×10^{-5}	~ 5
Pm^{147}	2.5	2×10^{-4}	2×10^{-4}	--
Ru^{106}	1.0	1×10^{-4}	1×10^{-5}	~ 3
Fe^{55}	2.7	4×10^{-5}	8×10^{-4}	--
Cs^{137}	30.	3×10^{-5}	2×10^{-5}	~20
Sr^{90}	28.	3×10^{-5}	1×10^{-7}	~230
Ca^{45}	0.44	2×10^{-5}	9×10^{-6}	~1
Eu^{155}	1.7	8×10^{-6}	2×10^{-4}	--
Co^{60}	5.27	2×10^{-6}	5×10^{-5}	--
Eu^{152}	13.	1×10^{-6}	8×10^{-5}	--

These values were derived by using about 100 ppm for solubility of amorphous silica and silica rocks, and assuming all cations to be dissolved to an equal extent. The required time is shown for decay of Ce^{144}, Ru^{106}, Cs^{137}, Sr^{90}, and Ca^{45} to MPC since these concentrations of radionuclides are in excess of MCP values. Further reduction in concentrations should occur, since sorption and precipitation processes were neglected. It is unlikely that melt dissolution offers a long-term deterrent to use of water.

Also, concentrations of radionuclides have been estimated in a rubble chimney filled with water by assuming that a mixed-batch process occurs in which radionuclides are uniformly distributed within the confines of the chimney. Entry of radionuclides into water may be estimated from consideration of two simultaneously occurring processes. These are the solution of radionuclides from the debris and the sorption of dissolved radionuclides onto the exposed surface of solids. Distribution of radionuclides between aqueous and solid phases have been measured in the laboratory and expressed as distribution coefficients (K_d).

Values determined for K_d in the laboratory may be used to calculate concentrations in chimney water; although results undoubtedly would be underestimated due to large-sized fragments found in rubble chimneys.

Figure 3.5 shows calculated Sr^{90} concentration as a function of device yield and K_d value in rubble chimney water. For materials shown, all concentrations, calculated with the listed assumptions, exceed NCRP recommended MPC's.

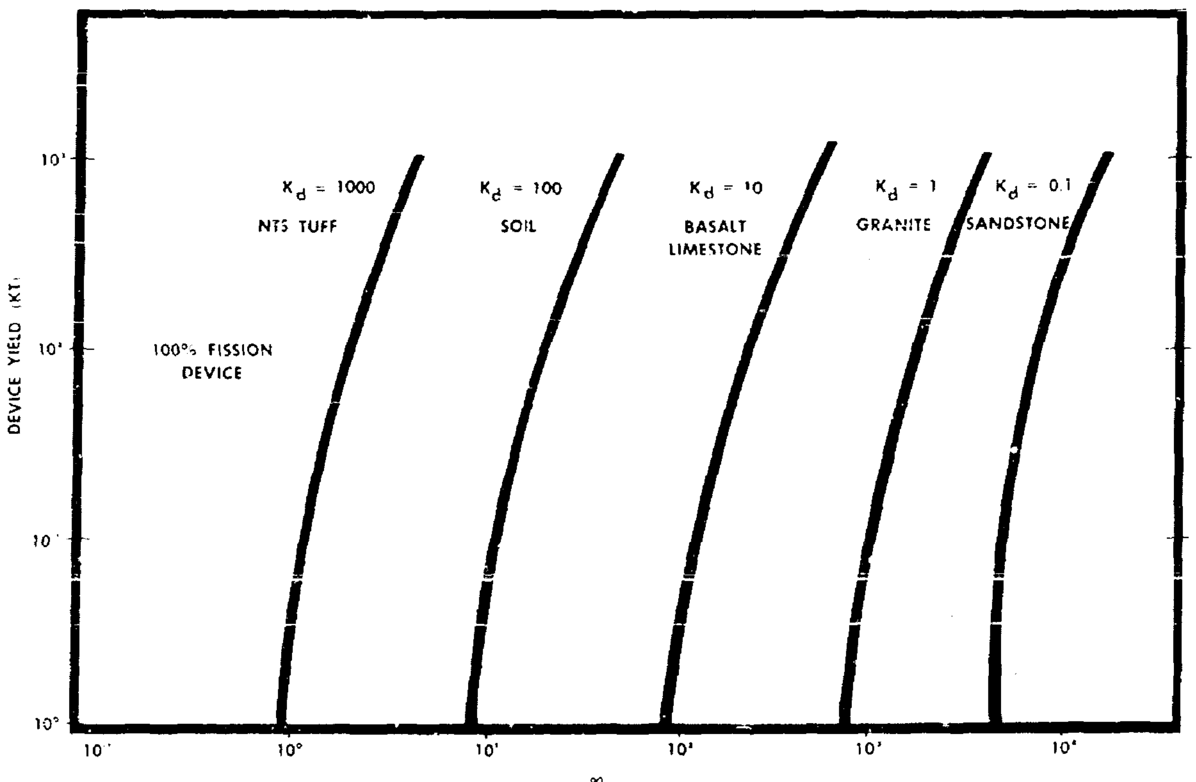

Figure 3.5. Calculated Sr^{90} Concentration as Function of Device Yield and K_d Value in Rubble Chimney Water.

Consideration of sorption does not apply in the case of tritium. Estimated concentrations of tritium are listed in the following table for a 90 percent fusion device in a rubble chimney filled with water.

Yield (KT)	Concentration Tritium ($\mu\mu$ c/ml)	Time to Acceptable Level (years)
100	6.0×10^5	~95
1000	1.2×10^6	~105

These data suggest that concentrations may result several orders-of-magnitude greater than MPC (1×10^{-3} μc/ml) from underground detonation of fusion devices.

Transport of Contaminants within Hydrologic System

Significant contamination of water takes place in the close vicinity of an underground detonation in a saturated medium. In applications in which early access to the rubble is desired or where dewatering of the environs is required, such as in mining applications, safe disposal of potentially large volumes of contaminated water would become a practical problem. In other cases, during the time required for contaminated water to travel to points of use, hazards decrease due to several factors. These are radioactive decay, decrease in radionuclide concentrations by dilution by uncontaminated water, and retardation of rate of movement due to sorption which delays appearance of radionuclides. Conditions of transport are depicted in Figure 3.6. A rubble chimney is shown filled with contaminated water flowing from left to right in the direction of original ground-water movement. Radionuclides, which are sorbed onto geologic media, move at a slower rate than water. If sorption coefficients and sufficient knowledge of the hydrologic system exist, an estimate can be made on the arrival time of contaminants at a location downgradient. Wide variations in velocity of regional water movement exist, and sorptive properties of the medium may be quite variable over the area under consideration. For example, carbonate rocks, such as the deep-lying Paleozoics at Nevada Test Site, are often highly conductive and generally may have lower K_d values than other media. Capability to reliably predict contaminant transport is particularly limited by lack of adequate information on the rate and direction of water flow, and the relative rate of contaminant transport.

In Figure 3.7, transport conditions are shown by a cross-section of a canal with the water level above the regional water table. Also identified are location of contaminants, fallback from the detonation, and the rupture zone. Water moves from the canal through contaminated fallback and the rupture zone into ground water. If the regional water table were higher than canal water level, the direction of movement of water would be through fallback into the canal. Therefore, contaminants would move into the canal water. Several important items of information are essential for calculation of effects for a canal situation. These are infiltration rate, rate and direction of water flow, and relative rate of contaminant transport.

Hydrologic Safety Criteria

Finally, if an estimate of radionuclide concentration has been made for some point in time and space, criteria must be applied to ascertain the significance of the estimated concentrations in terms of radiological hazard. In the past, various criteria have been used; for example, MPC for continuous, nonoccupational internal consumption, for 40 hours-per-week occupational exposure, or for emergency use of drinking water. Some aspects of the problem of availability and application of relevant criteria are shown in Figure 3.8, which depicts various uses of water and routes by which contaminants in

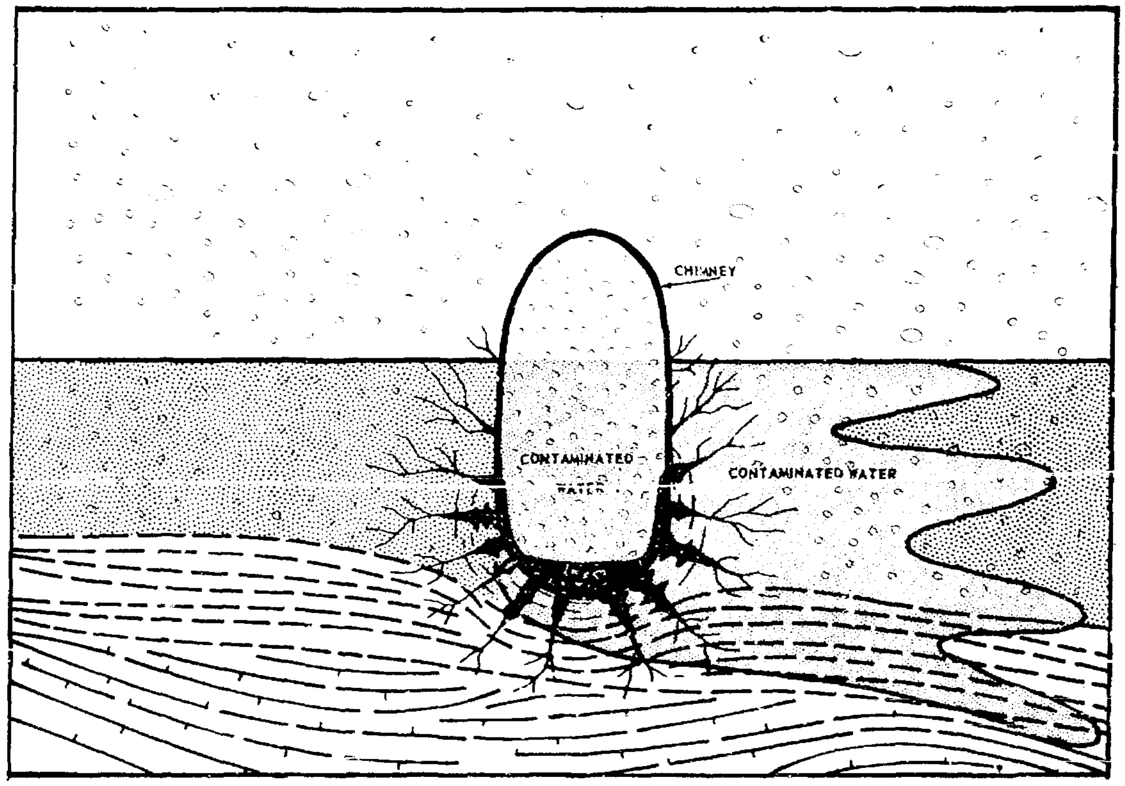

Figure 3.6. Transport of Contaminants from Rubble Chimney.

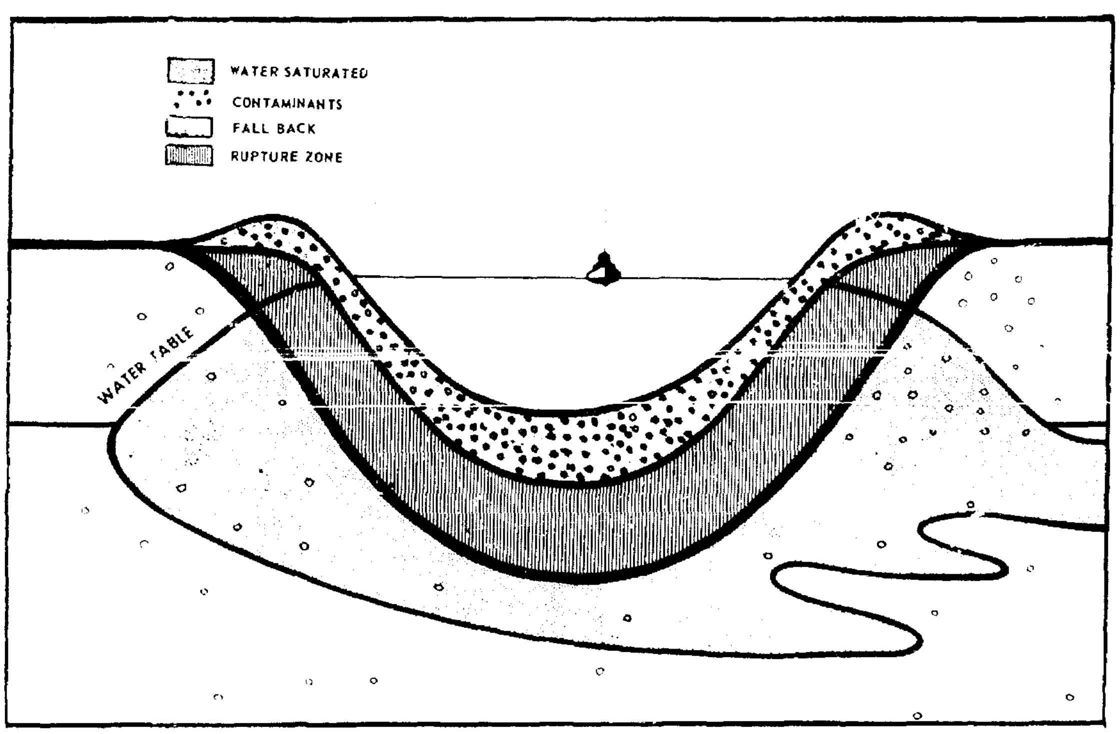

Figure 3.7. Cross-Section of Canal Showing Transport of Contaminants from Rubble Zone.

water reach man. Criteria, other than for domestic use of water, have not been formulated. Water use criteria could be conceivably more or less stringent than MPC for drinking water. For example, a case has been studied where agricultural use of river water, contaminated with reactor effluents to low levels of Cs^{137}, would have created a greater external radiation problem to farm workers because of sorption on soil than the internal hazard which would have resulted from use of the same water for drinking purposes. An important consideration is the potential concentration of radionuclides in the ecologic systems, particularly in food-chains leading to man as shown in Figure 3.8. Levels which might be quite safe for drinking water, pose a potential source of high concentrations of contaminants in ingested foods. To illustrate, concentration factors from 50 to 100,000 have been reported for various radionuclides in fish in the Columbia River and White Oak Lake. Little guidance is available for evaluating significance of such effects. The establishment of applicable MPC's and evaluation of significance of concentration factors are needed to provide adequate radiologic criteria.

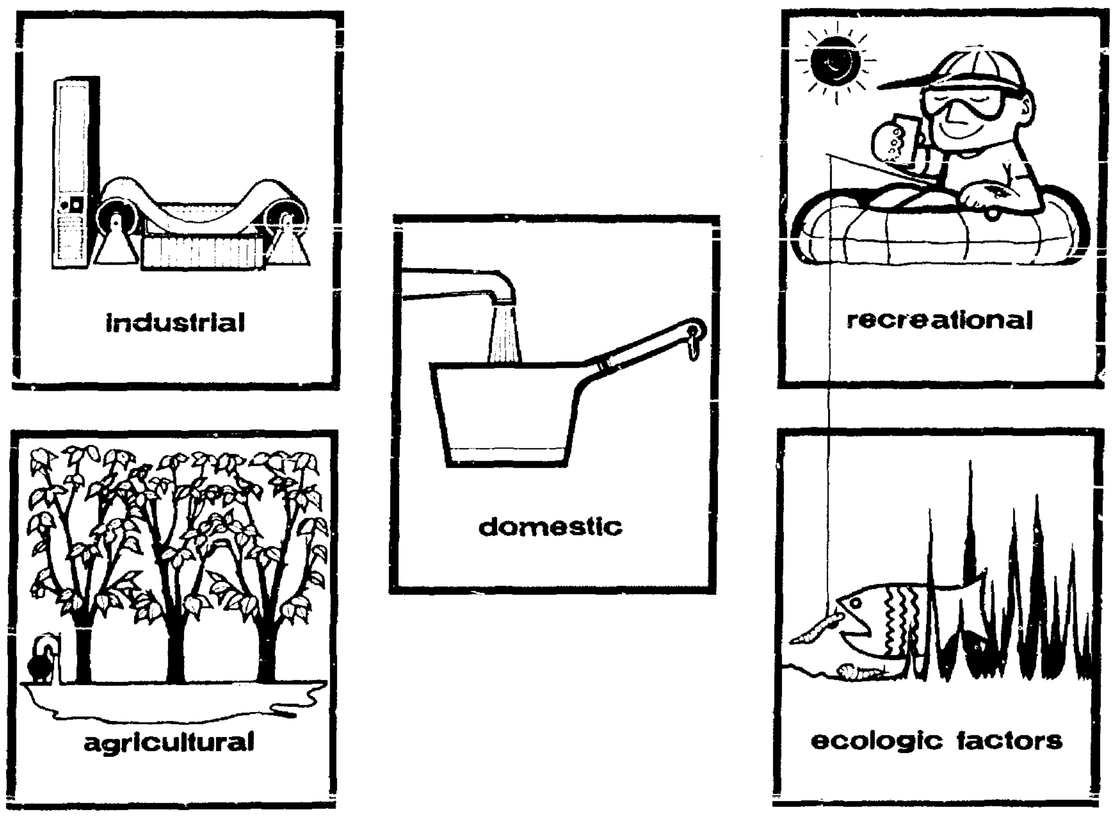

Figure 3.8. Radiologic Criteria of Water Usage and Contaminant Routes to Humans.

DATA REQUIREMENTS AND LONG-RANGE PROGRAM

It now should be apparent from the above discussion as to where some of the principal needs lie for additional data and basic studies. An attempt is being made to meet these needs in the ground water program by data acquisition, analytical and theoretical studies, and laboratory experiments. Data is being accumulated from the published literature and from operational agencies, such as U. S. Geological Survey, the Lawrence Radiation Laboratory (LRL), and the Los Alamos Scientific Laboratory (LASL).

Some of the long-range studies and data requirements in various program areas are discussed below.

Contaminants Produced by Detonations

An extensive effort is being undertaken by LRL to calculate quantities of radionuclides produced by Plowshare detonations. In weapons tests, there may be less attention being given to contaminant production. Innovations in device design and modifications of the device environment require constant review of potential contaminants of water, for example, as proposed by addition of oxidizing compounds. To the degree that sufficient information is not available, or cannot be obtained from other sources, it is proposed to extend estimation of yields of radionuclides produced by neutron activation of geologic materials to other media and neutron flux conditions. The method of estimation, which by necessity is an approximate one due to the complex nature of the time-space-energy variation of neutron fluxes produced by nuclear devices, should be checked against experimental data for accuracy. Information from the laboratories on the characteristics of these fluxes and the elemental composition of all significant quantities of materials in, or placed near, devices is essential for this work.

Spatial Distribution, Physical and Chemical States

The analytic study performed to estimate melt and gas injection into fractures appears to have provided some useful information on contaminant distribution. Predicted cracking radii are uncertain by a substantial amount, especially in the downward direction. This is significant in some cases with respect to initial contaminant distribution and subsequent water flow. Additional field data and theoretical studies of this type are needed. Physical chemical states, as related to solubility of explosion-radionuclides, will be estimated by using available data and from field sampling and laboratory analytical studies.

Entry of Contaminants into Hydrologic Systems

The question of the extent to which contaminants enter ground-water systems is determined only in part by their solubility properties. It is at least as important to know how water comes into contact with contaminants. Very little is known about the effects of a detonation on a hydrologic system and movement of water into explosion zones.

In view of the complexity of flow problems, it is proposed to find an approximate solution by modeling studies. Recommendations will be made for additional studies at sites, such as Bilby in Yucca Flat, where a detonation took place in a saturated medium.

Transport of Contaminants within Hydrologic Systems

This is simultaneously one of the most difficult and important problem areas with respect to offsite movement of water. Very little can be said quantitatively about the rate and direction of water movement, and hence of contaminant movement without intimate knowledge of the hydrogeologic system. For complex systems, analytic solutions are difficult. There is some hope that model and computer techniques will simplify calculations for certain cases where sufficient data are available.

Measurements of rate of movement of contaminants have been made on a field scale by well injection of radiotracers into ground water and pumping a nearby sampling well. If radionuclide retardation in the field could be determined by single-well tracer injection and pumping, costs of drilling a second well for sampling might be saved. This technique will be evaluated and supported by a limited number of laboratory experiments.

Work will also be done to evaluate surface transport of contaminants by wind and rain that may result in contamination of water supplies or recharge of contaminants to ground water.

Hydrologic Safety Criteria

MPC's or radioactivity concentration guides, which have been used to denote maximum acceptable amounts of radionuclides in water, are undergoing review and change by promulgating agencies. Studies are being conducted which may alter the bases upon which criteria are set. Recent results indicate a shorter biological half-life for retention of Sr^{90} in the body than had been thought earlier, and might justify raising the MPC for Sr^{90} significantly. In the future, information developed by the water contamination study will be compared with any new criteria established by regulatory agencies, and the significance of contamination of water supplies evaluated.

SUMMARY

In summary, phenomena from production of explosion-radionuclides to their ingestion by man have been reviewed sequentially, and factors discussed concerning the calculation of water contamination hazard. Much required information is lacking and remains to be developed. Input is required from other groups working on associated problems, and a long-range water contamination study is under way to improve the state-of-the-art.

Present capabilities do not permit accurate predictions, nor is it possible to calculate the error of current predictions. As an educated guess, the present accuracy of predicting concentrations at distant locations may be no better than many orders-of-magnitude. Nuclear detonations are potentially significant sources of contamination of water resources, but many factors tend to mitigate this potential. There are no data to suggest that adequate safety has not been achieved in past events.

Program objectives are directed toward achieving a better understanding of the parameters for controlling contamination and transport processes. This should be possible for a wide range of conditions to insure public safety and to do so in the most economical manner.

CHAPTER IV

GEOLOGICAL CONSIDERATIONS

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INTRODUCTION

The Geological Survey provides a variety of needed geologic information to evaluate the seismic safety aspects of a particular nuclear explosion. The required data range from being as detailed as possible close-in to the point of explosion to broadly generalized over an area of hundreds of square miles, or possibly stated better as hundreds of cubic miles. In contrast to potential water contamination considerations, which require data on the geochemical and flow properties of the environment, seismic safety considerations primarily require data on the physical properties of the environment.

A sharp distinction exists between safety considerations bearing on potential water contamination and those for seismic effects. Potential water contamination is long-term and can extend over tens if not hundreds of years; further, remedial action can be taken if contaminated water should be discovered moving in unanticipated directions after an explosion. Seismic effects are immediate at the time of explosion, and it follows that all geologic information, possibly useful in predicting structural damage, must be acquired well in advance of a proposed explosion. The amount of information obtained before an explosion cannot be cut back on the grounds that later remedial action can be taken.

GEOLOGY RELATED TO SEISMIC SAFETY CONSIDERATIONS

Geologic Environment, Nevada Test Site

The block diagram of Yucca Flat in Figure 2.1 illustrates some of the needed regional geologic data. In particular, the physical properties of these rocks are important, such as the location and orientation of faults or breakage planes.

For example, some of the faults shown on the front face of the block diagram break through and offset only the older Paleozoic rocks and have no effect on the overlying younger rocks. The major Yucca fault, along which very recent movements have occurred, clearly breaks through and offsets all the rocks. At the north edge of the block, the Yucca fault cuts through the small granite mass, in which the 5-kiloton Hardhat event was detonated at a depth of about 1,000 feet. To the east of the fault, the granite is concealed by the alluvium, and is downdropped at least 1,000 feet, possibly several thousand feet. The seismic energy moving outward from the point of explosion would be distorted by the asymmetry of the geologic environment for an underground nuclear explosion, such as the Hardhat event which was detonated at about point "G" in the granite mass. To the east, the seismic energy would initially propagate outward through a considerable thickness of alluvium and tuff; to the west, the energy would move through Paleozoic rocks with markedly different physical properties.

Velocity and Density for Yucca Flat, Nevada Test Site

The diagrammatic section through central Yucca Flat in Figure 2.2 shows the sonic velocities and densities for each of the rock types. These background data are required input for calculating the transmission of seismic energy, the resultant ground motion, and the possibility of structural damage.

It will be noted that the densities of the alluvium and the tuffs are about the same, and are in marked contrast to the much higher density of the underlying Paleozoic rocks. This density contrast permits us to interpret the depth to the older Paleozoic rocks from surface gravity data. For example, the buried ridge of Paleozoic rock immediately to the west of the Yucca fault was predicted on the basis of a gravity survey, and was confirmed by a shallow drill hole which penetrated Paleozoic dolomite at a depth of 100 feet.

Dependent on the point of an underground explosion, the ground motion and the possibility of structural damage might be much different over such a buried ridge of dense, high velocity rock than it would be over a deep trough filled with alluvium and tuff. Thus, it follows that the geologic character of the site of any structure near a major explosion must be provided in reasonable detail, and not broadly generalized.

Although gravity and seismic survey methods can be used successfully in many areas, it is imperative that some knowledge of the density and velocity distribution with increasing depth is in hand; otherwise, the interpretation of the raw geophysical data must assume a density and velocity distribution. It follows that in new or complex areas, a few deep exploratory drill holes are needed.

Surface Fractures in Yucca Flat

Moving closer to the point of explosion, some of the postexplosion effects and their relation to geologic structure are shown in Figure 4.1. The natural faults, with observable surface expression, are shown in solid black lines. Concealed faults, inferred from geophysical methods, are shown by dotted lines. Explosion-produced fractures, observable at the surface, are shown by dashed lines.

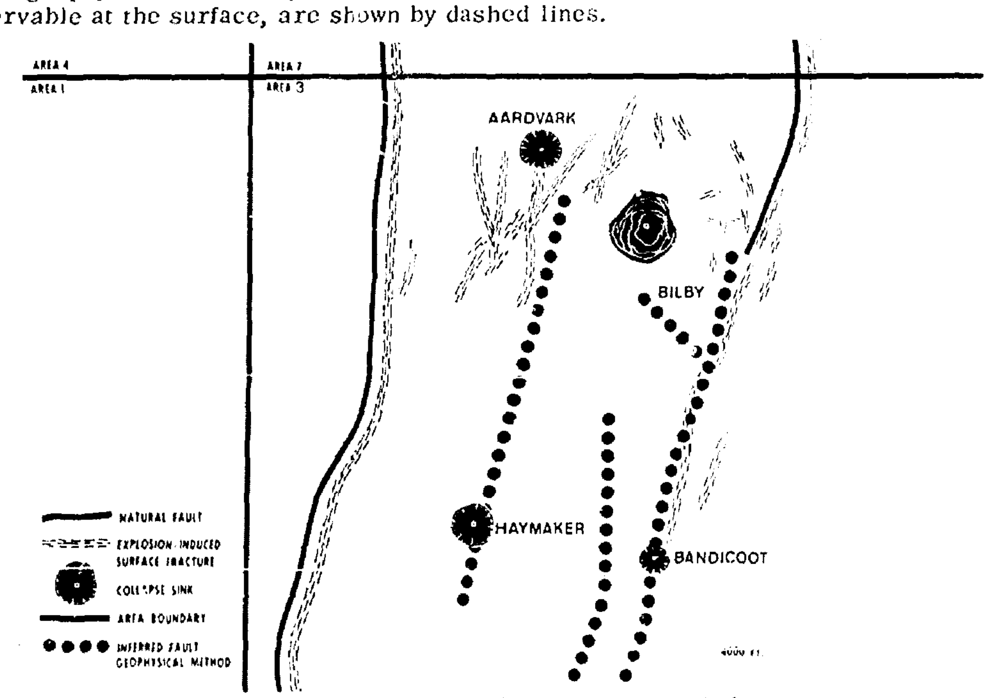

Figure 4.1. Surface Fractures in Yucca Flat Since Bilby Event.

It will be noted that the explosion-produced fractures tend to coincide with the pre-existing fractures, suggesting the possibility of renewed movement or differential compaction along the old fault planes.

Of more interest, the Bandicoot event, an underground explosion located almost on the subsurface fault inferred from geophysical data, vented to the atmosphere. This illustrates a major requirement in evaluating the possibility of venting, that is, the provision of the best possible three-dimensional interpretation of faults, joints, and other planes of structural weakness in the rocks around a proposed underground nuclear explosion. Such data are needed out to a radius of a few thousand feet from the explosion, and to a depth at least equivalent to the depth of burst.

Geologic Section, Areas 19 and 20, Nevada Test Site

Figure 4.2 shows a geologic cross-section of Pahute Mesa, covering a 200 square mile area in the northwest extension of the Nevada Test Site. This vertical section, where the test depth will be about 4,500 feet, illustrates the complexity of the volcanic rocks at depth and the numerous faults that cut through the rocks. This interpretation is based on one deep drill hole, in excess of 12,000 feet, and on a few 5,000-foot drill holes. Although some of the rock units can be projected into this area from adjacent areas, where they can be observed and geologically mapped; volcanic rock units, such as lava flows are not continuous in thickness or composition over any significant distance. As indicated, the velocity and density contrast among the various rock units is small. This lack of contrast sharply reduces the effectiveness of present geophysical methods, such as gravity and seismic surveys, for defining rock type and structure at depths of 1 to 2 miles. Every tidbit of information, no matter how indirect, from each of the widely spaced exploratory drill holes must be used in interpretation of the geologic setting at depth.

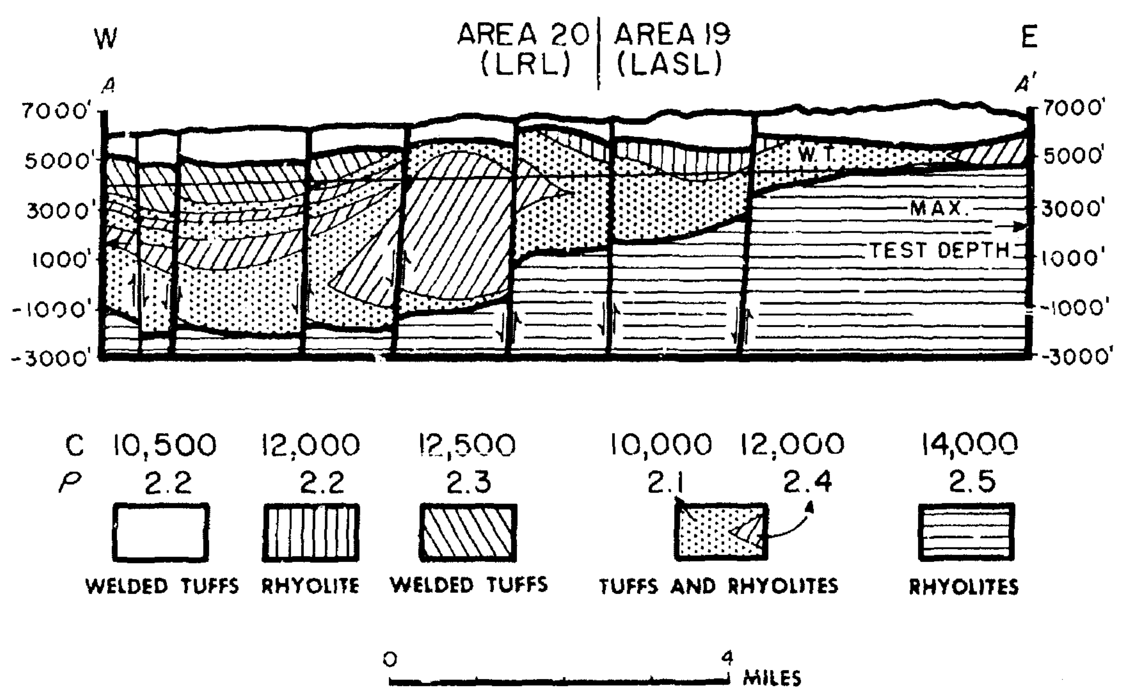

Figure 4.2 Geologic Cross-Section of Pahute Mesa, Nevada Test Site.

Favorable Areas for Testing in Areas 19 and 20, Nevada Test Site

Figure 4.3 is an interpretive map showing the favorable areas for the underground testing of intermediate-yield nuclear devices in Areas 19 and 20 of the northwest extension of the Nevada Test Site. The geologic cross-section along line A-A' on the map is given in Figure 4.2.

This map expresses the use of a wide variety of information, including surface geologic mapping, drill-hole sample data, hydraulic pumping tests, and surface and in-hole geophysical surveys. In essence this map shows the combination and interpretation of all currently available information, guided by two major criteria: first, the spacing of major fault planes at more than 2,600 feet apart at a depth of 4,500 feet, because the possibility of venting radioactive debris to the atmosphere along fault planes is a major seismic safety consideration; and second, the rock types, at depths between 2,000 and 5,000 feet below the surface, which have low transmissibility to ground-water movement. The latter is both a construction consideration and a hydrologic safety consideration.

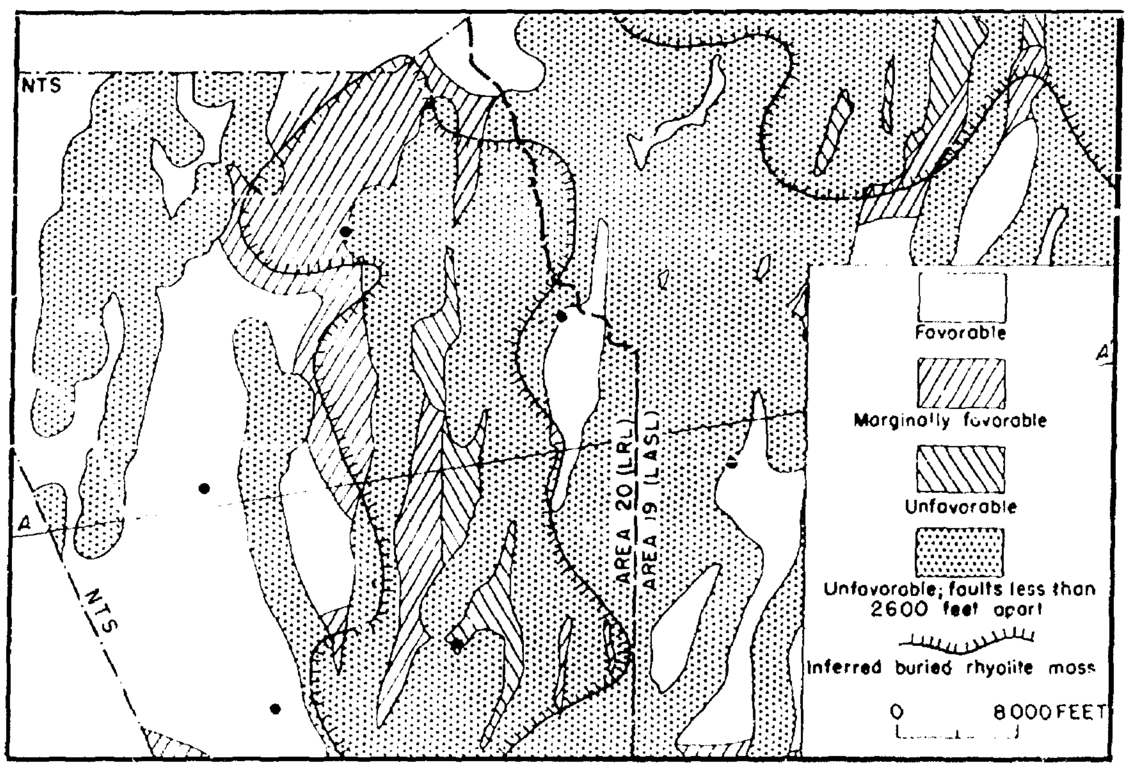

Figure 4.3. Favorable Areas for Test Sites in Areas 19 and 20. Pahute Mesa, Nevada Test Site.

Thus guided, the subsurface information has been projected to the surface to indicate the relative favorability of local areas for testing nuclear devices at depth. It is immediately obvious, by using these two criteria which are highly conservative and reflect the problems imposed by nuclear explosions of the maximum proposed yield, that most of the overall area is not favorable. If explosions of smaller yields are proposed, then much of the overall area indicated as marginally favorable could be considered favorable.

Geologic Section, International Mineral and Chemical Corp. (IMCC) Potash Mine to Project Gnome Site

Figure 4.4 is a geologic section from the Project Gnome site through the IMCC potash mines about 9 miles north of the 3-kiloton nuclear explosion. Most of this area, near Carlsbad, New Mexico, is covered by dune sands where a surface geologic map would not be particularly useful. Essentially all the data here shown come from deep exploration drill holes for petroleum and potash ore.

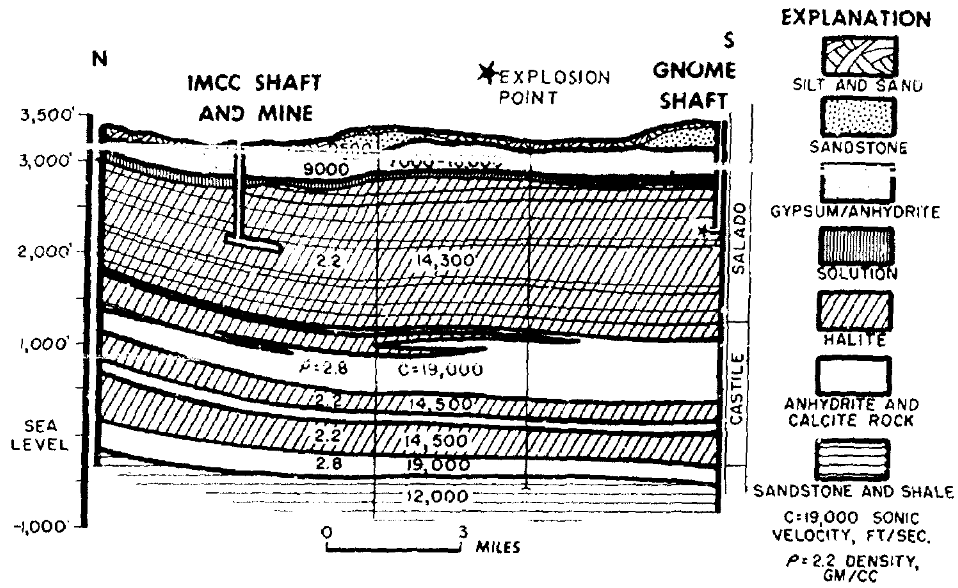

Figure 4.4. North to South Geologic Section through IMCC Potash Mine to Project Gnome Site.

Of particular importance to evaluation of ground motion from the nuclear explosion is the marked velocity layering, that is, alternating high and low sonic velocities with increasing depth. Such a geologic setting opens up the possibility of wave guide or ducting effects as the seismic wave energy moves out from the point of explosion. It will be noted that the depth of the Project Gnome explosion, at 1,200 feet below the surface, is very close to the depth of the IMCC potash mine, and that both the Gnome explosion and the IMCC mine are in essentially the same salt beds.

Such geologic sections providing structure, velocity, and density data are needed radially from the point of any proposed underground explosion to localities where ground motion might cause structural damage to mines, pipelines, oil and gas wells, and large surface installations.

Project Dribble, Velocity Sections

Figure 4.5 is the Project Dribble site in southern Mississippi showing the location of velocity sections radiating out from the Tatum salt dome in which the Salmon nuclear event was detonated. In this case, the velocity sections serve a two-fold purpose: first, to provide data for seismic safety considerations, that is, for predicting ground motion; and second, to characterize the symmetry of the environment as needed input for the long-distance seismic detection studies under the Vela Uniform program.

Fortunately, this area of several thousand square miles has numerous deep oil-exploratory drill holes as shown by the black dots. These drill holes provided extensive data at depth on the structure, stratigraphy, the physical properties of the rock units, and the location and amount of fresh water, saline water, oil, and natural gas.

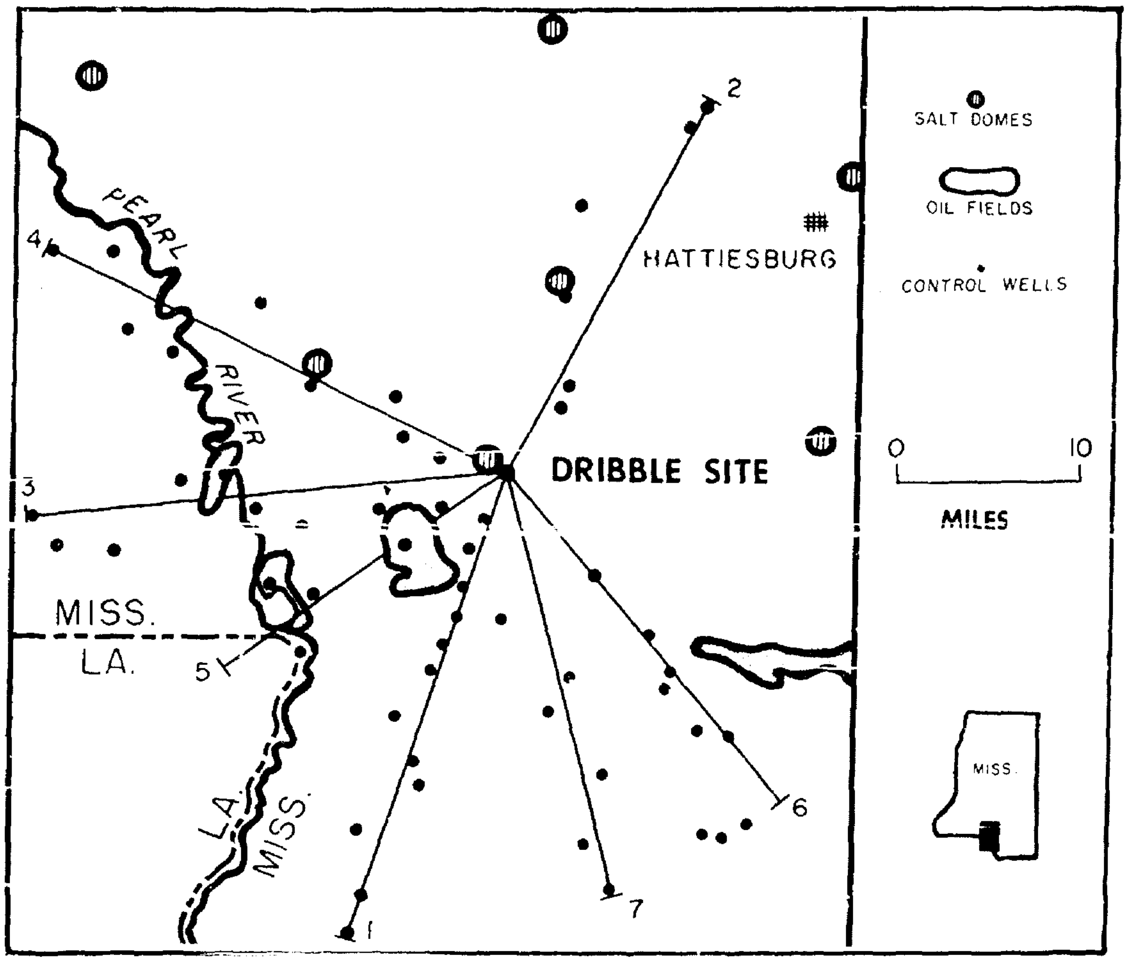

Figure 4.5. Project Dribble, Location of Velocity Sections.

Less than 8 miles to the southwest of the Project Dribble site is the Baxterville oil field with numerous productive oil wells. Velocity section No. 5 passes through this field and provides data for evaluating ground motion and possible structural damage.

Project Dribble, Section No. 7

Section No. 7 of Project Dribble is 24 miles long and about 2 miles deep as shown in Figure 4.6. It is typical of the eight velocity sections prepared for Project Dribble. The primary control data for this section came from the three exploratory drill holes whose location and total depth are indicated on the section; secondary data came from nine additional drill holes.

Geologically, this section shows part of a deep sedimentary basin, probably in excess of 30,000 feet to the underlying crystalline rocks. The sedimentary rocks in this

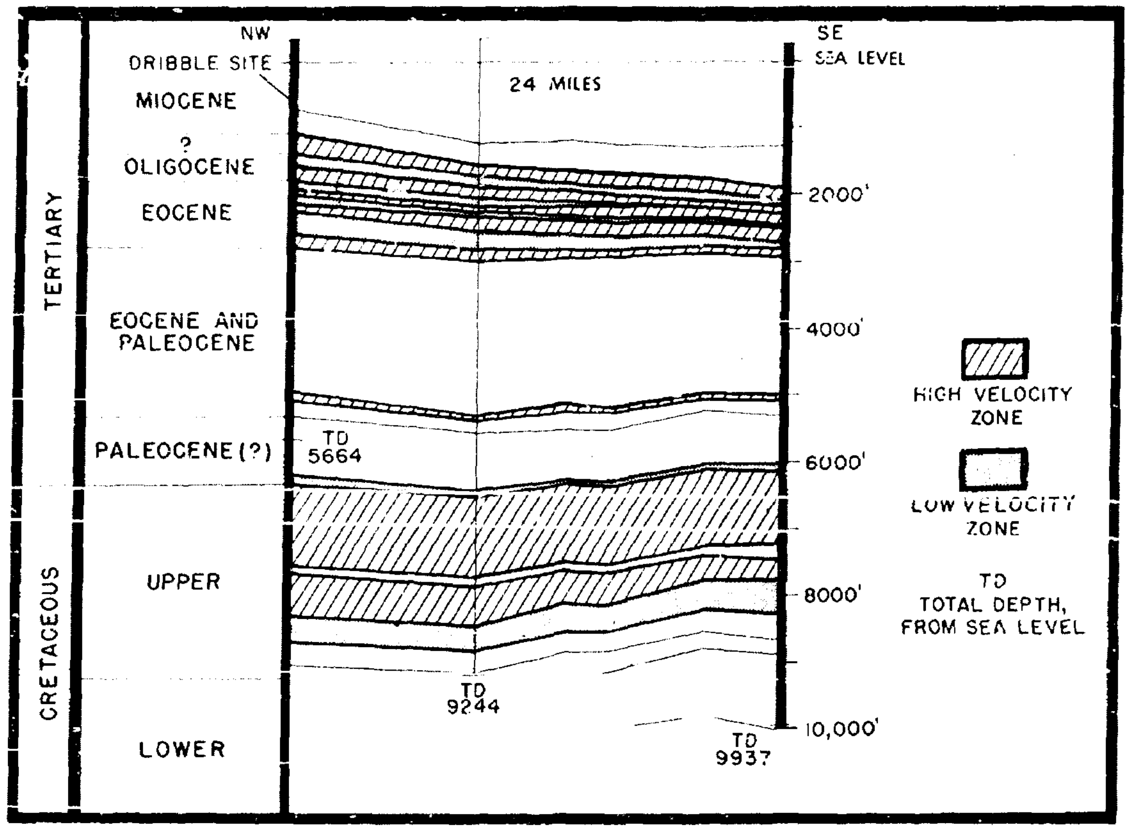

Figure 4.6. Stratigraphic and Velocity Cross-Section No. 7, Project Dribble.

basin are characterized by relative uniformity over long distances and by essentially no major faults, in marked contrast to the complex stratigraphy and structure of the volcanic rocks at the Nevada Test Site.

Only the continuous high velocity zones, greater than 10,000 feet per second, and continuous low velocity zones, less than 10,000 feet per second, are shown on the section. The zones not so indicated have variable sonic velocities and densities; that is, the velocity in a particular sedimentary bed or unit varies from high to low between adjacent drill holes.

Tatum Salt Dome

One of the best ways to assist in visualizing a complex geologic environment is to prepare a scale model, such as shown in Figure 4.7 for the Tatum salt dome. This model is at a scale of 500 feet to the inch, to a depth of three miles, and with a cross section out from the center of the dome about 2 miles long. The point of burst of the underground nuclear explosion — the planned 5-kiloton Salmon event — is indicated by the black dot on the 2,500-foot level.

By inspection, the position of the point of explosion in respect to the top and sides of the salt intrusive can be determined. As an aid in evaluating containment of the

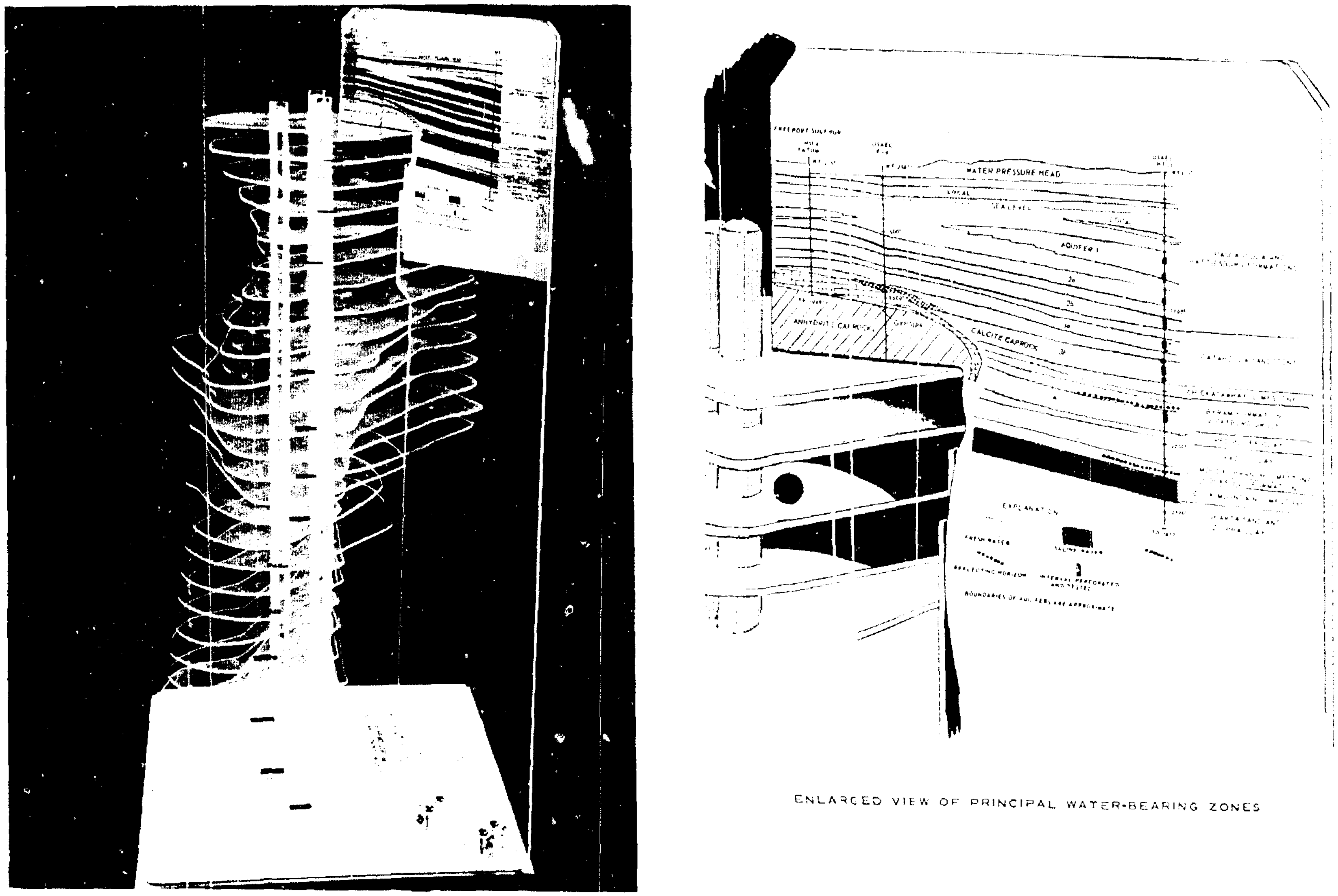

Figure 4.7. Scale Model of Tatum Salt Dome.

explosion, that is, the possibility of explosion-produced fractures extending outside of the salt mass, and thus providing channels for radioactive contamination, such a model showing the irregularity in shape permits rapid identification of the minimum distance from the explosion to the salt boundary.

On the section across the top and down the side of the salt mass, the principal water-bearing zones are shown as fresh water and saline water. In terms of possible contamination of water, this illustrates another problem that must be considered. In addition to considering contamination by radionuclides, there is also the possibility of explosion-produced fractures breaking through between water-bearing zones and allowing contamination of fresh water by salt water.

SUMMARY

The geologic information needed in support of seismic safety considerations includes information on rock layering, the structures, the sonic velocities, and the densities of the environment to considerable depths below the surface, and radially outward to tens of miles. As demonstrated by the examples shown, the geologic environment of each proposed underground nuclear explosion tends to be quite different and must be determined on an individual basis. The properties of a new site cannot be generalized with sufficient accuracy where information at depth is lacking. In some areas, such as southern Mississippi, considerable geologic information at depth is already available because of previous petroleum and mining industry activities. In other areas, little if any information at depth is available, which would necessitate rather extensive geologic exploration at a proposed site.

The limitations on obtaining adequate geologic information at depths, such as 1 or 2 miles, are primarily economic rather than technical. Given sufficient funds for deep-hole exploration, the geologic environment of any proposed site of a nuclear explosion can be determined within a predetermined accuracy.

CHAPTER V

GROUND MOTION

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INTRODUCTION

Roland F. Beers, Inc., is assigned by contract the responsibility of providing NVOO with predictions of the shock and seismic effects of underground nuclear detonations. This work concentrates on predicting the type and magnitude of ground motion and how this motion will affect containment of the shot; and also, the extent of damage that may occur to underground structures. Relative numbers define the amount of ground movement from surface zero out to the limits of human perception. These predictions are made for wide variety of tests at the specific direction of the contracting administrator. In the past these predictions ranged from those for shallow cratering shots to deeply buried, high yield events. This involves studying variations in geology and emplacement, as well as yields.

The AEC Manual defines the safety responsibilities of NVOO. Weapons laboratories and interested agencies are fully aware of the need for adequate safety precautions. But the responsibility for safety ultimately falls upon the Atomic Energy Commission. In this respect the established policy of industrial operations is followed, where a system of independent control of safety is common practice. There is no interference with objectives of the scientific program or obstruction to the indispensable drive for achievement in nuclear progress. In short, the NVOO Safety Program provides an independent system of checks and balances. This is absolutely essential to insure confidence that nuclear testing will always move forward effectively, but remain safely under control.

Activities in support of the NVOO Safety Program generally consist of a mixture of established routine, improvisation and experimentation. The collected data and knowledge are cumulative. Each year brings improvement in the degree of reliability and confidence. Experience improves the acquired ability to overcome new and more formidable problems.

In coping with a static problem, success moves forward at an uneven rate. However, with dynamic problems in nuclear testing, pursuit of the moving target must progress rapidly to promptly intercept and grasp new factors.

The safest testing program must be very conservative. To obtain optimum test conditions, it is more realistic to strive for high accuracy in analyzing test designs prior to their detonation. New and valuable concepts develop, and innovations accelerate the rate of nuclear progress. Safety provisions must be adequate but commensurate with the expediency of the testing programs in the development of weapons and peaceful nuclear applications.

Substantial advances have been made in the past 2 years to increase confidence in predictions resulting from theoretical and experimental studies. The studies include shock waves, seismic propagation and the geology of shot environments. These factors are related to the problems of containment, seismic propagation and the terminal effects of ground motion. Data processing systems have been designed for these studies. Equipment has been installed and ground motion data have been processed from scores of events.

All these efforts have led to correlation between ground motion and distance for various yields in a variety of geological settings. Computer programs have been developed to calculate the effects where surface rock and soil are thrown upward, such as in the spalling phenomena. Other programs derive true ground motions from field records, and determine seismic waveform frequency- and energy-content.

Detailed engineering analyses have been made of more than a hundred shots. These serve as a basis for improving methods used in evaluating containment. Computer programs have been developed for use on models of containment and close-in terminal effects. Day to day current studies are thus based on the results of all available past tests. The objective is to deepen the understanding of all aspects of ground motion and venting, and to thereby insure greater reliability in achieving containment and avoiding damaging motions.

Theoretical studies have been pursued in five areas:

(1) The nuclear device as a source of energy.

(2) Thermodynamic equations describing the state-of-the device and state-of-the shot media.

(3) Processes of energy conversion.

(4) The source model.

(5) Models for transmission of seismic wave energy through various channels.

Weapons development tests often include complex emplacement plans. These consequently present new challenges in containment predictions which necessitate theoretical studies. Current studies also emphasize possible damage to mines, wells and underground openings. Additionally, there are possibilities of triggering slides on slopes and embankments. These are of particular interest in offsite tests. Increased effort is devoted to planning field measurement programs that will yield better ground motion data. Ultimately, this will improve the confidence in predicting ground motions over longer distances, larger yields and more varied geologic conditions.

The remaining discussion is concerned with containment and venting, ground motion, and damage to underground structures.

CONTAINMENT AND VENTING

When an underground detonation occurs, a cavity is produced. Fractured and disturbed materials, resulting from shock waves racing outward, are found outside the cavity. Their net effect is to produce fractures, plastic and elastic deformations of material, and possible damage to structures. Figure 5.1 shows the formation of a cavity with molten glass-like materials in a pool at the bottom. Radial fractures are developed in the surrounding material. These may provide ducts for the injection of solid particles and gases into the medium. At the free surface of the ground above the working point, reflection of the shock waves may produce upward separation and cracking of the surface layers, referred to as spalling. Spalling may extend from the surface down to some predictable depth and could provide channels for the possible escape of products of the detonation.

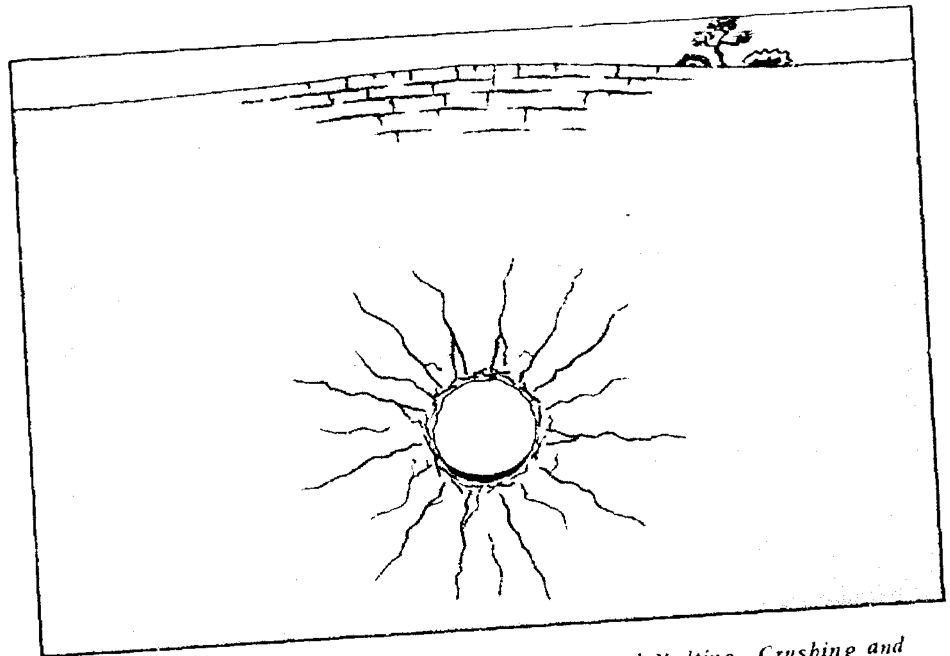

Figure 5.1. Formation of Cavity with Associated Melting, Crushing and Cracking.

Owing to the cavity size and fracturing of earth materials surrounding it, rubble usually falls into the cavity, creating a chimney above the shot point as shown in Figure 5.2. The dimensions of this chimney will vary depending upon the yield, depth of burial and nature of the rocks. Because of the bulking nature of the rubble, the upward migrating void of the chimney will tend to be filled. If filled sufficiently, further roof collapse will be choked off. When the degree of bulking is low, as in alluvium, the chimney height will be relatively large. If a chimney extends to, or nearly to the surface, a depression or subsidence crater above the shot point is normally formed as shown in Figure 5.3.

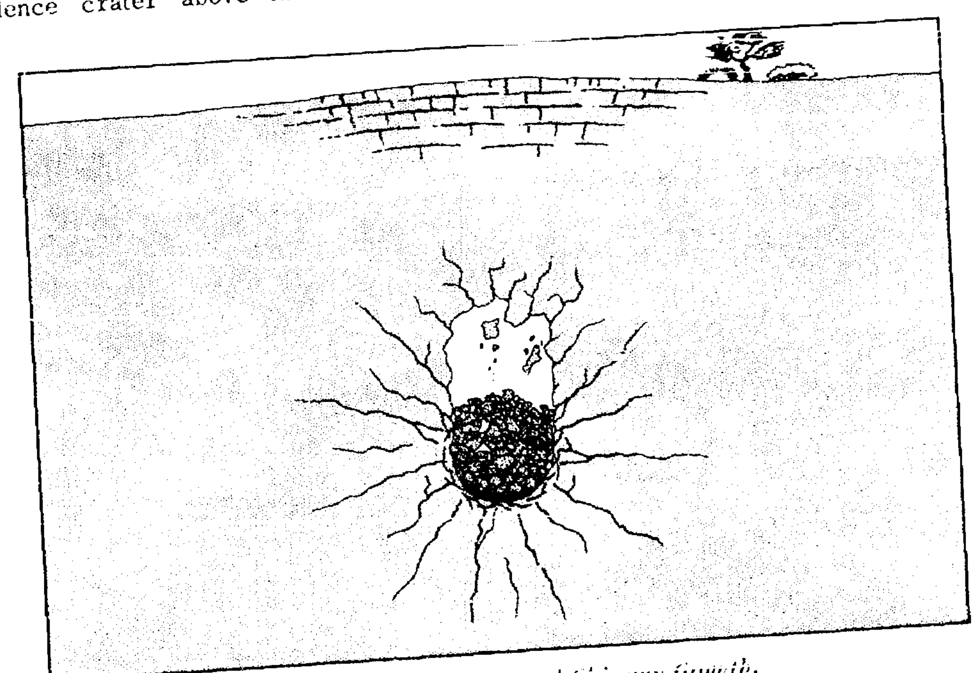

Figure 5.2. Cavity Collapse and Chimney Growth.

Figures 5.4, 5.5 and 5.6 show schematically a sequence of events for a typical hypothetical tunnel shot in rock with inclined bedding planes. Figure 5.4 shows sand plugs placed prior to detonation at intervals along the tunnel as stemming devices to delay passage of the shock waves down the drift. Figure 5.5 shows compressive shock waves rushing outward from the detonation, squeezing tight the sand plugs or other forms of stemming. As shown, stemming is vastly aided by implosive closure of the tunnel itself. Figures 5.5 and 5.6 show compositely several possible mechanisms of venting. Possible immediate mechanisms as shown in Figure 5.5, include radial fractures which may develop and extend to the surface. Such fracturing may be aided by preexisting geologic structures, such as faults (A), bedding planes (B), or surface cracks caused by spalling (C). Stemming of the emplacement tunnel may fail to operate correctly, possibly due to gases by-passing the sand bag stemming, or tunnel closure, by way of fractures (D) or preexisting bedding planes. Possible delayed mechanisms, as shown in Figure 5.6, include leakage through porous rubble of a chimney (E) or along fissures created by slumping in conjunction with chimney creation (F).

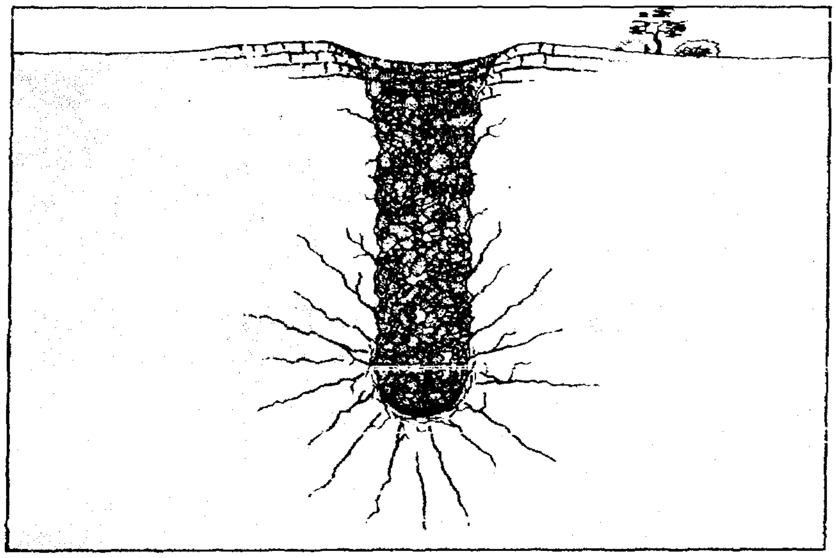

Figure 5.3. Chimney Extended to the Surface with Resultant Subsidence Crater.

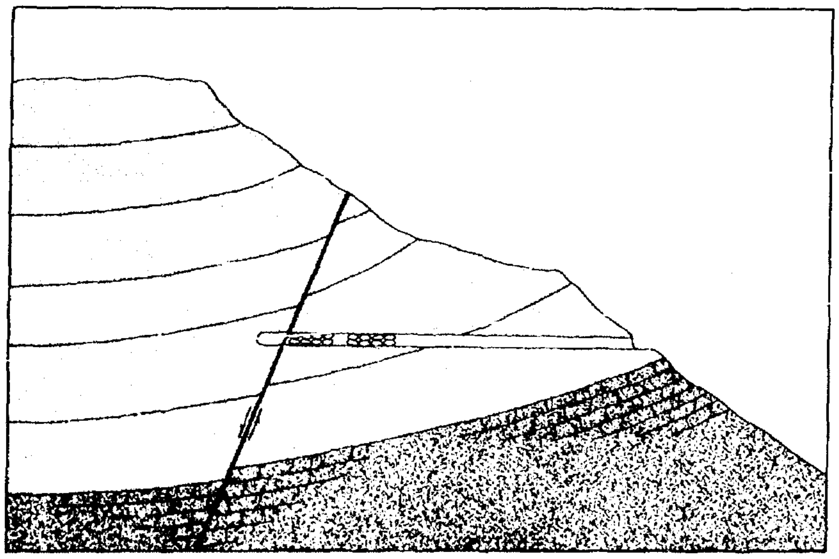

Figure 5.4. Emplacement Tunnel Stemmed with Sandbags.

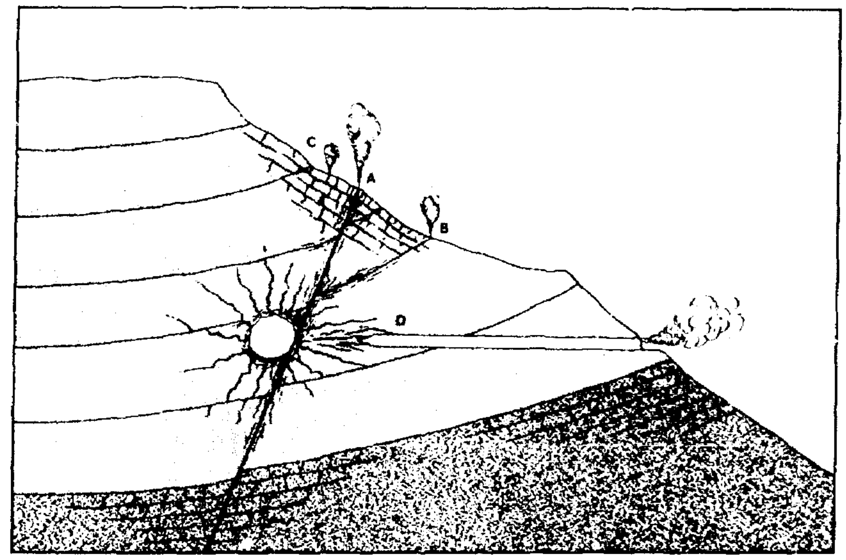

Figure 5.5. Composite of Possible Mechanisms of Immediate Venting.

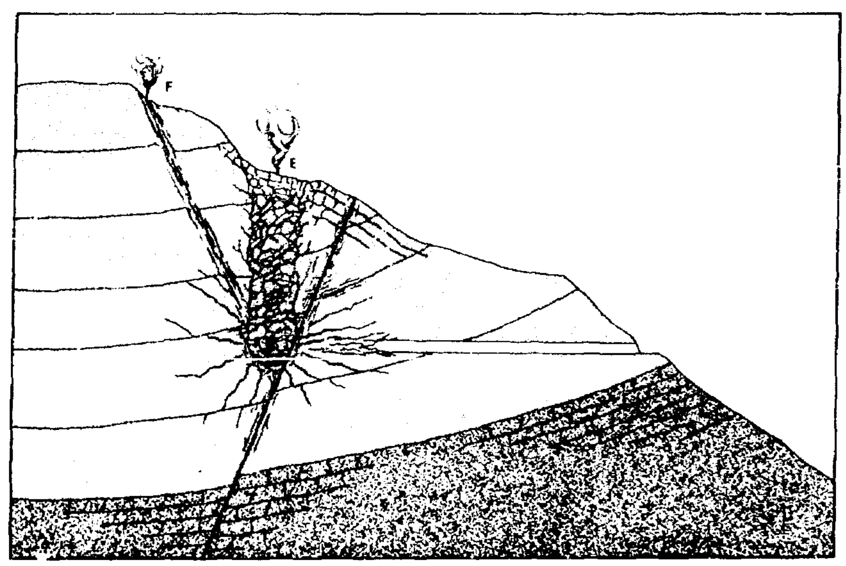

Figure 5.6. Composite of Possible Mechanisms of Delayed Venting.

The formation of surface spall, cavity, chimney and surface subsidence directly affects containment of fission products. Each of these phenomena and the associated venting mechanisms are closely controlled by physical properties of the medium, requiring that each geologic environment be treated separately. The U. S. Geological Survey and other agencies provide data to compile a complete and accurate account of the geology in local and nearby regions including the stratigraphy, lithology and physical properties of the rocks, location and orientation of joints and faults, and hydrology. Technical data must also be compiled from the event under study as to the design yield, maximum yield, burial depth, chamber emplacement size and configuration. Calculations are made as to the expected cavity radius, the elastic radius, the cracking radius, the extent of injection of radioactivity into the cracks, the chimney height and the depth of spalling.

From a safety standpoint, the basic objective is to avoid venting without excessive precautions for overcontainment. The total phenomenon and contributing mechanisms must therefore be accurately and thoroughly understood.

Today, the principal limitations on evaluations for containment are geologic uncertainties and a lack of sufficient empirical data. Data requirements to provide a firm basis for future efforts encompass the bulk of terminal effects associated with an underground nuclear detonation. Virtually no empirical information is presently available on phenomena such as radial fracturing, radioactive injection into fractures, spalling depths and the effects of geologic discontinuities. An understanding of these phenomena is crucial to a containment evaluation. The quantity of data on available subjects is insufficient to provide an accurate analysis of problem variables. Statistical methods for treating these variables require a fund of data and are essential if risk factors are to be understood. It is imperative to make a maximum effort in extracting all available information during postshot work.

Better theoretical models are developed by obtaining this empirical data which may be used to extrapolate past results into predictions for high yield devices. Future theoretical needs are:

(1) Methods of predicting pressure and temperature-time history as factors in cavity formation.

(2) Improved procedures for obtaining pressure profiles.

(3) Improved models for the fracturing and spalling phenomena.

(4) Comprehension of strain and displacement effects upon the *in situ* physical environment.

GROUND MOTION

Present methods of predicting ground motion are based upon correlation (regression lines) derived from the recordings of all available previous tests. Regression lines may be analyzed to scale amplitudes and other characteristics of ground motion with respect to yield and distance from ground zero. Also, ground motion effects may be predicted by applying analytical procedures based on equations of state-of-the shot medium. This provides an independent approach to the previously described empirical procedures.

Turning to general aspects of ground motion, only a fraction of the total energy of the nuclear device is converted into elastic waves which radiate outward from the inner zone of crushing, cracking and plastic deformation. These elastic waves temporarily disturb the media, but do not produce permanent changes in the surrounding earth. Seismologists classify the principal modes of such elastic propagation as compressional, shear, or surface waves. Measurements are in the form of particle acceleration, particle velocity and particle displacement.

Figure 5.7 shows a seismogram of various phases of elastic waves arriving at a given point at different times. These phases include body waves, of which P is the compressional mode and S is the shear or transverse mode. The surface waves include both Rayleigh and Love phases. The time of arrival and amplitude relations for these various waves will vary depending upon the distance from the source.

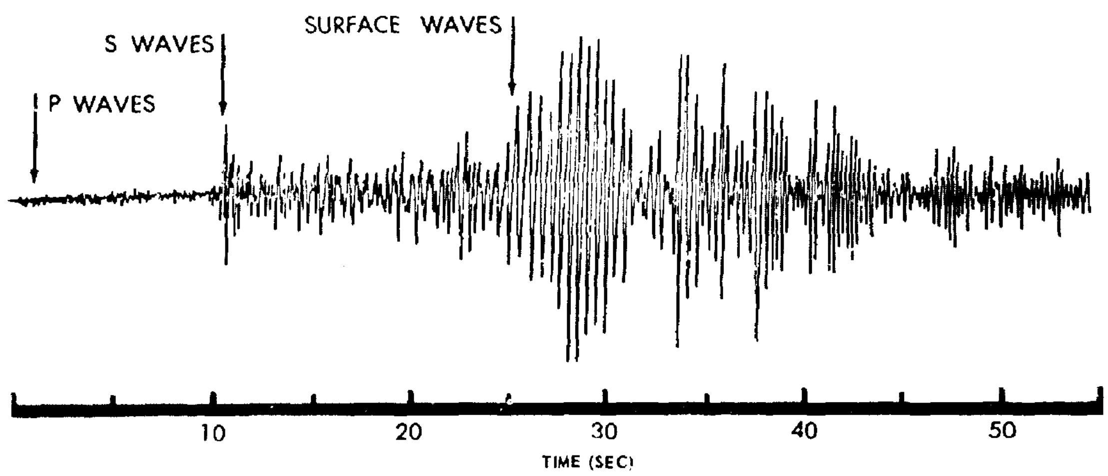

Figure 5.7. Seismogram of Various Phases of Elastic Waves Arriving at a Given Point at Different Times.

Figure 5.8 shows wave motions being recorded along three orthogonal axes. Peak motions that do not occur along one of these axes, must be determined by analyzing vector products. Ground motion is a complicated phenomenon, comprising a sequence of disturbances of different character at each point. They arrive by different paths and at different velocities in complex sequences at different times. Analysis of the individual waveforms requires separation and identification of the different phases. It also demands knowledge of the paths by which they travel, and an understanding of their attenuation and waveform changes with distance. This calls for complex computer and data-processing methods, using high-speed digital and analog equipment. Analyzing the separation of different phases is worthwhile, because they can be related to conditions along their paths of travel. In turn, this leads to a better understanding of how ground motion changes with distance and with geology.

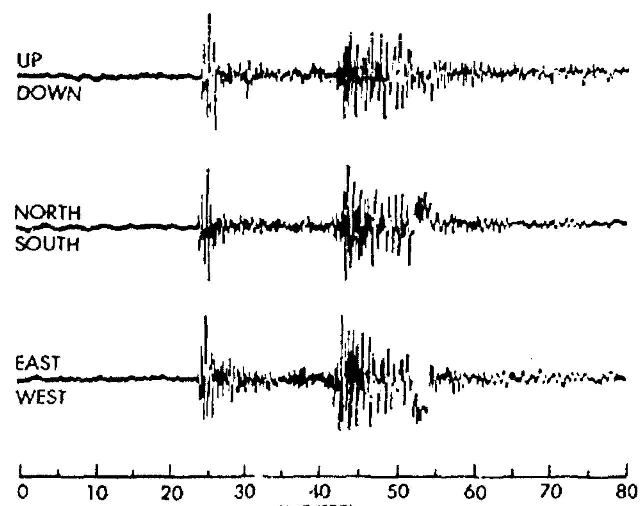

Figure 5.8. Wave Motions Being Recorded Along Three Orthogonal Axes.

Analyzing ground motion data in this orderly manner helps to predict damage to structures, to foresee perceptions of ground motion by the general public and to anticipate other effects. In estimating structural damage by ground motion, it is necessary to determine the frequency, directional characteristics, duration of the waveforms and total magnitude (including vector components). This type of information provides firms, such as John A. Blume and Associates with input data for making better estimates of these effects.

It is well known that the various waves arriving at a point are strongly influenced by the geology along the travel paths. Surface waves are of particular concern, especially in alluvium. Figure 5.9 shows a comparison of possible variations in magnitude of ground motion because of the lithology at the recording station. Typical regression lines are evident for both hard rock and alluvium. It may be noted that for a given yield of 100 KT, the alluvium acceleration is approximately double that received on hard rock. Thus the magnitudes of surface ground motion can be surprisingly high under certain conditions. In order to predict these motions accurately, detailed studies must be made to understand how magnitude, frequency and wave mode vary with yield, source conditions, geology and conditions at points of interest. To meet these needs, field instrumentation programs are designed. The programs must collect meaningful data for the construction of clear relationships between conditions of detonation and observed ground motion. Obviously, the arrays of instruments must be carefully planned to acquire enough data relating to cause and effect to establish reliable laws and relationships. Several lines of arrays are usually desirable, in order to detect asymmetry around the source.

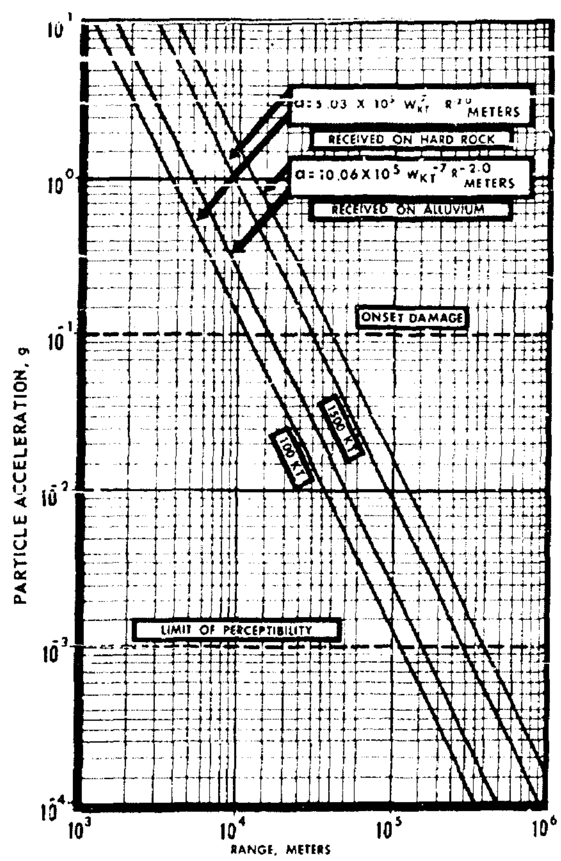

Figure 5.9. Surface Acceleration g, Total Vector.

Figure 5.10 shows the relationship of population centers to the location of planned instrumentation lines as being an important consideration for operational safety. These instrumentation lines must be picked with full knowledge of existing topographic and geologic conditions. Instruments are placed at locations suitable to screen out background conditions which may confuse the records.

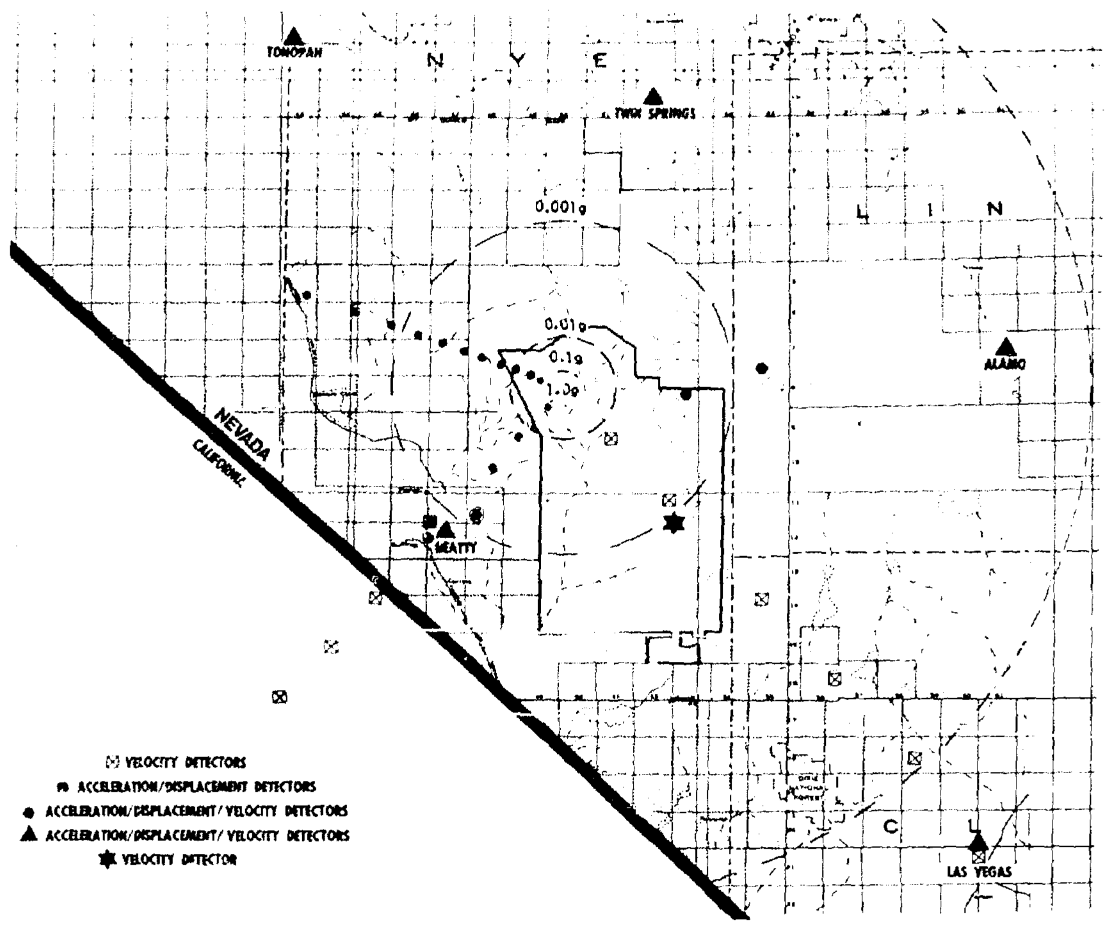

Figure 5.10. Relationship of Population Centers to Location of Planned Instrumentation Lines.

A second factor in planning instrument arrays is the selection of appropriate recording equipment. Such equipment must have the right sensitivity and performance characteristics to record the essential elements of ground motion. Moreover, the records must be in form for accurate, low-cost playback and analysis. Magnetic tape recording is preferred for these purposes.

Much thought has been given to the relative costs and accuracy of analog, digital and hybrid computer systems. The options are many. All technical and economic factors have been carefully weigned. The end result of data collection and processing is to show how peak ground motion varies with yield and distance, wave mode, shot medium and source geometries. The five principal objectives of record analysis are now standard operating procedures as follows:

(1) Correcting recorded ground motion for instrument distortion to achieve true ground motion.

(2) Using corrected instrument recordings to determine recorded peak values of ground motion.

(3) Deriving particle motions which have not been recorded; for instance, particle velocity by integration of acceleration records.

(4) Determining frequency composition of waves of ground motion.

(5) Making statistical analyses of amplitudes and periods as they change with distance.

All problems on the effects of ground motions are not so easily solved as the record analysis. Many complex situations require new methods of attack and demand an early solution. Some solutions to impending problems are cited herewith as examples:

Collection of Field Measurements from Intermediate-to-Large Nuclear Detonations

Recent studies have shown that predictions of ground motion and containment must continue to be based upon empirical methods. Theories are being developed from fundamental principles and hopefully these may someday be used to extrapolate beyond the range of actual measurements. There will be continued reliance in the immediate future on field measurements, with appropriate statistical treatment to give the highest accuracy and reliability. To obtain data helpful to understanding future events, new and more comprehensive instrumentation systems have been designed. These extend recording into larger dynamic ranges, wider spectral bands and over a greater variety of source and propagation conditions. Such data will be used in future predictions. Then too, the data will enable the testing of theories and models of the earth as it responds to underground nuclear detonations.

Development of Theories and Earth Models

Again current prediction procedures are based almost entirely upon empirical methods. Extrapolation from regions of actual measurement to other ranges is permissible to a limited extent; for instance, by a factor of 2 or 4. If carried too far beyond limits of actual experience, questions are logically raised as to the validity of the procedure. It must be said that extrapolation by lines of regression might be carried over greater limits if the relationships were supported by theory. Since the beginning of the NVOO Safety Program, efforts have been made to develop these essential theories. At the source, relationships are nonlinear, and therefore pose difficulties in finding solutions. Along wave propagation paths, in the seismic range, the difficulties are not with lack of linearity so much as with the confusing variety of possible wave path solutions. Taken together, these two circumstances account for the heavy dependence on empirical methods now in use.

Development of Computer Codes and Programs

Work is going forward to set up and test reliable analytical methods mainly by numerical computer methods. As valid solutions are found, they are compared with empirical results in regions of actual measurement. Little by little, this will allow more understanding and better reliability in predicting outside the range of actual tests. Improvements in prediction capability are being sought for two principal reasons:

(1) Increased accuracy and reliability on routine events.

(2) Projecting these qualities into unknowns, such as very large yields, very long distances of propagation and wider spectral bands of energy.

The sources of improvement must continue from the recorded data of current events. Machine analysis of these data has been completely successful. Unit costs have been reduced by a factor of 2 or 3. Further reduction in costs is expected if and when improved instrumentation systems are in use. For example, recording by magnetic tape means a further reduction in unit costs by a factor of 3 or 4. Thus, the total cost reduction, including machine analysis and better instrumentation, might come to one-tenth the original cost.

Some problems cannot be solved except by computers. Some cases require digital machines, others respond to analog. A hybrid computer system appears very attractive for maximum flexibility in its operations and possible cost reductions.

Finally, there are many miscellaneous problems which, in the aggregate, will contribute to improvements in prediction capability. The output of these studies adds to the day-by-day understanding and leads to better results by trial-and-error methods. The ultimate goal is increased accuracy and improved reliability of predictions and evaluations.

DAMAGE TO UNDERGROUND STRUCTURES

Underground structures which frequently require evaluation of possible damage include nearby mines, pipelines and wells. As with other Beers, Inc. responsibilities, such evaluation rests heavily on the geology at the source, along the travel paths of seismic and shock waves and at the location of the underground structure. Such information is supplied by the U. S. Geological Survey and other agencies. In order to ascertain expected stresses on such structures, other technical data are necessary, including design yield, maximum yield, chamber emplacement size and configuration, distance to the structure and its structural characteristics. From these data, the peak pressure and particle velocity are calculated together with their variation in distance. This is done by using hydrodynamic calculations and empirical data, incorporating to as large a degree as possible the effects of the geologic environment. Empirical data from previous events, where similar structures existed, are investigated to determine damage criteria. Information is also obtained from earthquake data and routine blasting operations for consideration in anticipating effects of ground motion. These methods provide guidance on the possible extent of damage to underground structures.

To evaluate more accurately possible damage to mines, pipelines and other subsurface structures, more data are required on the local environment. These include topographic and geologic mapping, stability of side slopes and mine rock conditions. Improvements in these directions require:

(1) Abundant close-in measurements of the effects of past events.

(2) Similar yield of postshot survey information.

Obtaining this information is useful as the foundation of empirical laws to extend predictions beyond the limits of prior tests, and also to test the validity of theories and models supporting or substituting for the empirical relationships.

CHAPTER VI

MINE SAFETY PROGRAM

By Paul L. Russell, Staff Engineer
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Washington, D. C.

INTRODUCTION

The concern of the Atomic Energy Commission for the safety of private mines in the vicinity of planned nuclear detonations fully recognizes the legal responsibility of the U. S. Geological Survey and of the U. S. Bureau of Mines for private mining operations conducted under lease on Federal Lands. The technical competency in geology, engineering, and safety fully qualifies these agencies to conduct safety programs relative to other private mines regardless of their location.

In recognition of their legal and technical ability, representatives of the U. S. Bureau of Mines and U. S. Geological Survey make full use of their knowledge and abilities as key members of all mine examination and safety survey parties.

The U. S. Bureau of Mines, at the request of the Atomic Energy Commission, has accepted the responsibility for the overall coordination and execution of mine examination and safety surveys as defined under this section of the Safety Program.

Purpose of Mine Safety Program

The purpose of the Mine Inspection and Safety Program is to establish a system of controls from which to assess and evaluate any mine damage that may be alleged to be attributable to the detonation of a nuclear device.

In the event that damage should occur as the result of a nuclear detonation, information obtained would be used to support payment of claims for reasonable compensation. If on the other hand, claims are made for damage that can not be attributed to the nuclear explosion, then information from the program would be used to refute such claims.

Initial Planning

Public safety is considered the controlling factor in the conceptual planning of all nuclear experiments. Under the direction of AEC/NVOO, a Panel of Consultants nominated by the National Academy of Sciences, suitable Government agencies, and contractor organizations are requested to study each project from the standpoint of safeguarding the project participants and the public, and preventing damage to private, industrial, or other facilities. The staff of the NVOO Director of Operational Safety, together with other agencies involved, proposes a Mine Safety Program on the basis of information developed by this study.

PRESHOT AND POSTSHOT MINE EXAMINATION

Scope of Work

Using this proposed Mine Safety Program as a basis, meetings are held with each individual mining company that might be affected or concerned by the planned nuclear detonation. Specific problems of each mine operator are considered. If required, the basic Safety Program is modified to include special problem areas. Thus, in an area where several operating mines are involved, the Safety Program may differ at each mine. A willingness by the Government to modify its program to fit needs expressed by the mine operators is essential if industry cooperation for the program is to be obtained.

The scope of work required may vary according to a variety of factors. Location of the nuclear detonation in respect to the mines is of primary importance. Expected yield is also important, but in most cases this is of secondary importance since any nuclear detonation is viewed with alarm by most of the mining industry, and they want assurance that their particular property will not be damaged. This facet of human nature was evident in the Carlsbad, New Mexico area. Project Gnome was performed in this area with no damage to the nearby potash mines. Nevertheless, when the same test site was considered for use of Project Coach, mines furthest from the site requested an extensive safety program, while one of the close-in mines showed little interest in other than a minimal program.

The scope of work varies; depending upon the complexity of the problem, any or all of the following investigations may be required: shaft inspection, mine inspection, structure inspection, ground surface surveys, radiation surveys, seismic surveys, microseismic surveys, stratascope and roof sag instrument surveys, water level surveys, other instrumented surveys, photographic documentation, and reentry.

Company Cooperation

Little, if any, of this Mine Safety Program could be performed without the cooperation of mine owners or mining companies involved. In the case of idle or inactive mines, cooperation may consist only of permission for access to the property. In the case of large operating mines, extensive cooperation is desirable to obtain mine maps; details of operation, including rate of ore production; types and condition of shafts; water problems, if any; access to all shafts for detailed inspection; engineering advice concerning mine conditions from a structural and geologic viewpoint; knowledge of critical areas; assistance in locating and installing various types of instrumentation for safety evaluation purposes; and a variety of other information and assistance aimed at providing the best possible system of controls for use in evaluating damage, if such should occur.

All Government work is performed on a noninterference basis, where possible. However, certain operations, such as inspection of an ore production shaft, may require loss of production as many mines work 24-hour shifts, 7 days a week. In such cases, compensation may be required, depending on company policy.

Since the problem of mine safety is a mutual one, company cooperation is usually easy to obtain. However, the extent varies with company personnel and with company policy. Diplomacy and tact by the Government agencies involved is a must if full benefits are to be achieved.

Other Government Agency Cooperation

The number of agencies involved in any particular safety program varies according to the scope of work required. No one agency is capable of performing all of the areas of work necessary.

Where operating mines are involved, the following agencies have participated in the Mine Safety Program: U. S. Geological Survey; U. S. Bureau of Mines; U. S. Coast and Geodetic Survey; U. S. Public Health Service; local State Inspector of Mines; Sandia Corporation; Holmes & Narver; Edgerton, Germeshausen & Grier, Inc.; and representatives of the specific mine involved. This list is somewhat shorter where small inactive mines are involved.

Each agency provides one or more services within its areas of specialization. The services performed by the group as a whole provide a rather broad range of information to assess the effect of any particular nuclear detonation in any particular mine. Much of the information derived is important in prediction of effects from future nuclear tests.

DESCRIPTION OF PROGRAM

Obviously, a detailed description of each individual type of investigation cannot be given at this time. The Project Gnome Mine Safety Inspection Report consisted of nine volumes and weighed 26 pounds. The following discussion briefly describes each phase of the investigation.

Shaft Inspection

In underground mines, this structure is the most important single unit of the mine. All men and supplies must enter the mine through the shafts, and all ore reaches the surface through the shafts. Shaft excavation is slow and expensive, with costs ranging from hundreds to thousands of dollars per foot in a few cases. Shaft linings may seal out underground water that would otherwise prevent mining.

Possibility of damage to shafts is greater than to mine tunnels and repair is more expensive. Usually a structural engineer conducts the shaft inspection as this is considered one of the most important, if not the most important phase of the mine inspection program. A mining engineer and/or geologist, a photographer, and a company engineer ride or climb through every foot of shaft, to note cracks in the lining or in the rock walls, inflows of water and volume, weakness in any timber or steel structural members, and and other features that might be affected by the planned nuclear detonation. Preshot and postshot photographs are taken of major features noted. Shaft construction drawings, if available, assist in this work.

At least one and possibly two preshot inspections are made and at least one postshot inspection. A preshot inspection is made as close to shot time as possible and a postshot inspection is made as soon as possible after the nuclear detonation. Inspection notes, maps, and photographs are compared to determine the effect, if any, of the nuclear detonation on the shaft. Pumping records are compared with preshot records for some weeks after the shot to determine if water inflow increases or decreases.

Mine Inspection

Most producing mines are too large to permit detailed inspections, such as those made in the shafts, and it is not warranted. The same inspection procedures are followed as for the shafts, but only areas of obvious weakness or areas deemed critical by mine management are documented. Figures 6.1, 6.2, 6.3, 6.4, 6.5 and 6.6 are representative of preshot and postshot photographic documentation.

Figure 6.1. Preshot Stalactites in Idle Mine Section.

Figure 6.2. Postshot Stalactites in Idle Mine Section.

Figure 6.3. Preshot Support Pillar after Final Mining.

Figure 6.4. Postshot Support Pillar after Final Mining.

Figure 6.5. Preshot Timber Failure in Stope Area of Sheelite Mine.

Figure 6.6. Postshot Timber Failure in Stope Area of Sheelite Mine.

Structure Inspection

The surface plant is considered a part of the mine for the purpose of this survey. A registered structural engineer is provided by a participating agency and critical surface and underground structures are documented preshot and postshot.

Ground Surface Surveys

In some instances control ground surface profiles are made to determine whether surface subsidence into the mine increases following a nuclear detonation.

Radiation Surveys

The U. S. Public Health Service provides a radiation monitor to accompany all inspection parties. Background radiation on the surface and underground is recorded preshot and postshot for purposes of comparison. If radiation could conceivably migrate underground, these surveys are continued for months, or possibly years, following the nuclear detonation.

Seismic Surveys

Seismic instrumentation is used to record acceleration and displacement on the surface and underground that result from the nuclear detonation. In addition, seismic recording of normal mine operations may be made for comparison with those received from the nuclear detonation.

Microseismic Surveys

Tests have shown that when rocks are stressed, the microseismic rate — that is the number of microseisms generated per unit of time — increases with the applied stress. The increase in the rate is most pronounced as the ultimate strength is approached.

This characteristic of rock is used to determine the relationship of the stresses produced by normal blasting for ore production in mines with the stress developed in the same test area as a result of nuclear detonation. Figure 6.7 represents the microseisms produced by the Gnome nuclear event. Note that in the case of the nuclear detonation, both the noise level and the time required to return to normal background level was less than for normal ore blasting.

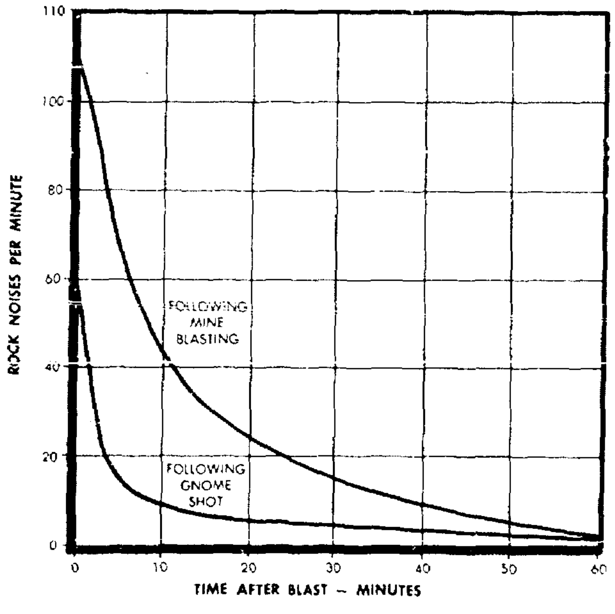


Figure 6.7. Rock Noise Rate Following Mine Blasting and Gnome Shot.

Strațascope and Roofing Sag Instrument Surveys

Convergence stations may be used to measure roof sag and differential roof sag in areas where pillar robbing will ultimately result in caving. The purpose of such stations is to determine normal convergence prior to a nuclear detonation and determine convergence rate change, if any, following the nuclear detonation. Holes are drilled upward into the roof stone and visually examined by using a stratoscope as shown in Figure 6.8. Using this same instrument, pictures are made of cracks or bedding separations. Using the information obtained, metal measuring points are installed in other holes drilled into the roof and floor as shown in Figure 6.9. Using an instrument called an extensometer, the distance between roof and floor pins is measured to 1/1000 of an inch, and rate of convergence or roof sag calculated. Figure 6.10 shows the roof convergence rate at one of the potash mines in New Mexico for a period before and after the Gnome nuclear detonation. No change was noted in convergence rate following the Gnome test.

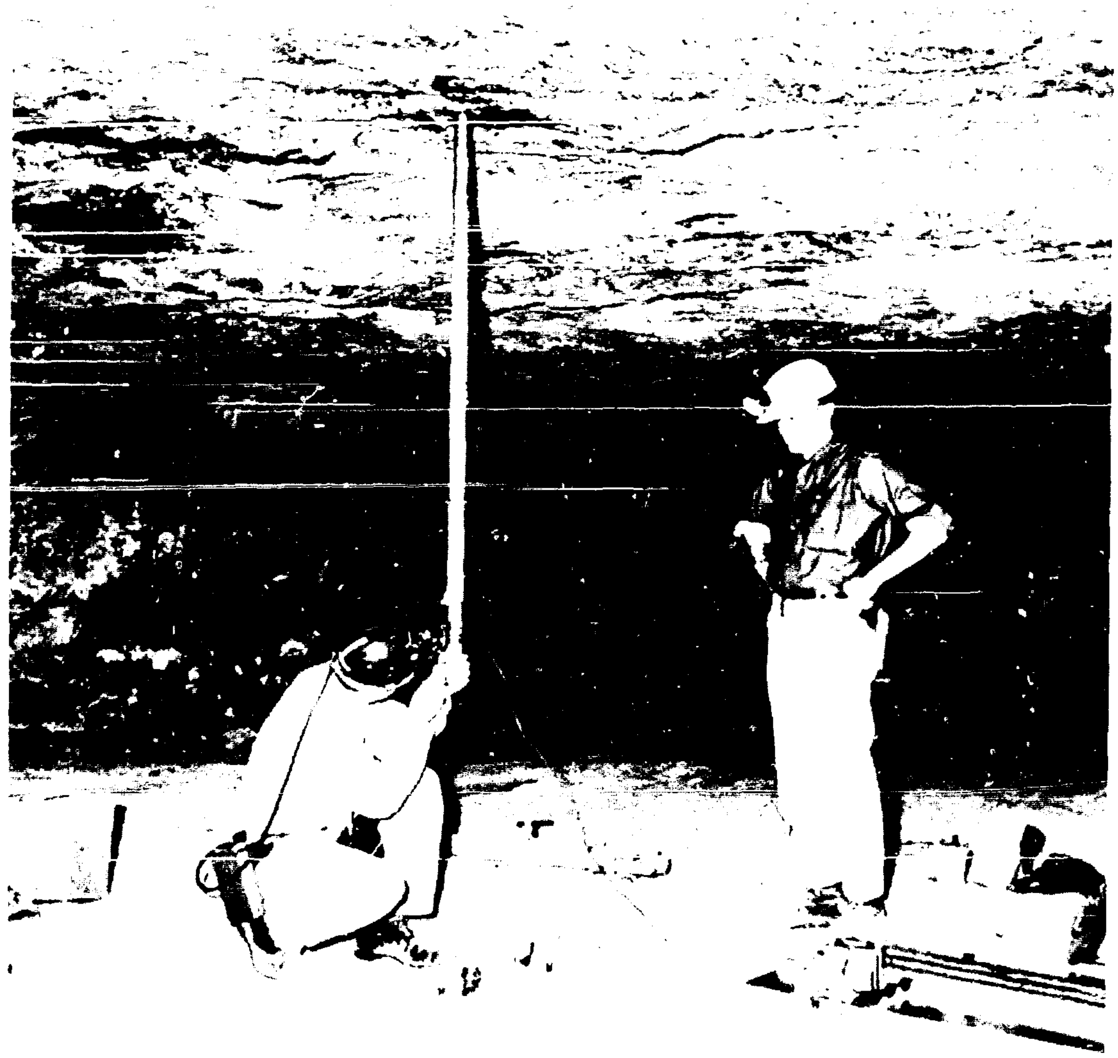


Figure 6.8. Method of Using Stratascope.

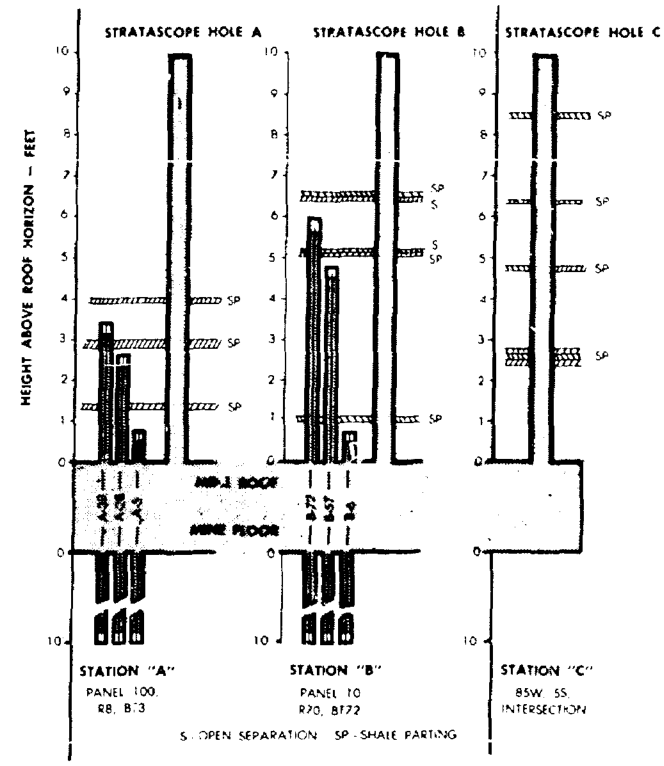


Figure 6.9. Mine Section Showing Location of Sag Pins.

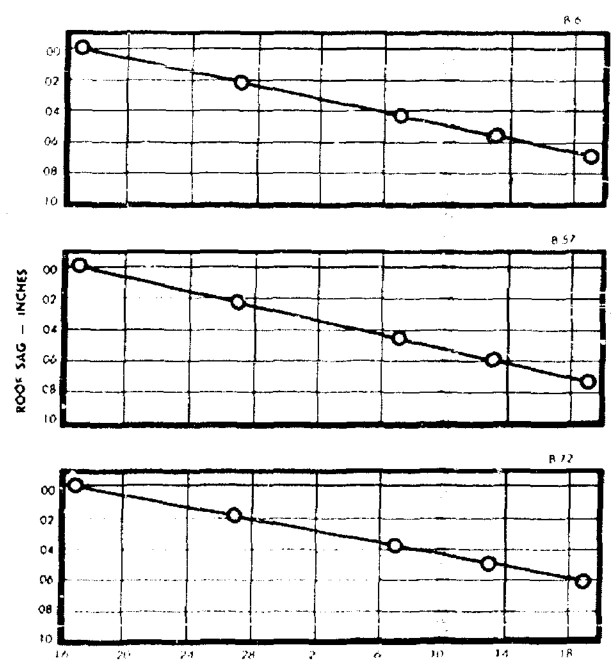


Figure 6.10. Rock Sag Rate Following Mine Blasting and Gnome Shot.

Water Level Surveys

Measurements of water table levels and rate of flow are recorded in mines and shafts, where possible. These records assist in determining possible damage in shafts, especially those which are inaccessible for visual and photographic documentation.

Other Instrument Surveys

Existing conditions in certain areas may require instrumentation of a special nature for a particular purpose. An example of one such case was the monitoring of vibrations produced by the Gnome event at a potash refinery in New Mexico. In this case the plant was old, and contained a high pressure boiler plant and numerous high pressure steam lines. No damage was noted.

Photographic Documentation

Preshot and postshot photographs provide one of the best records in determining just how any particular area reacted to a nuclear detonation. This tool is used to document almost every phase of the Mine Inspection and Safety Program.

Reentry

Mine management or union regulations may require that all workmen be removed from underground mines located near a nuclear detonation. At company request in such cases, reentry or postshot inspections are performed before men return to work underground. Reentry teams make preshot and postshot inspections for the purpose of noting any change that may have resulted from the nuclear detonation. These reentry teams usually consist of representatives of the following agencies: U. S. Bureau of Mines, Safety Division; U. S. Geological Survey; U. S. Public Health Service; structural engineer (Holmes & Narver); a State Inspector of Mines; and one or more representatives of mine management. These teams make a preshot inspection the day preceding the shot and a postshot inspection immediately following the shot.

PUBLIC AND INDUSTRY ACCEPTANCE

The Mine Inspection and Safety Program has been an effective one, and generally well received by the industry. Perhaps it has been too well received in some cases, since AEC often receives requests for examination of mines so remote from the location of a nuclear detonation that damage is inconceivable.

The first reaction by many of the larger mining companies is that they really do not expect damage, but why not do this whole thing somewhere else. However, once they accept the idea that a nuclear detonation is to be made, full cooperation to develop and participate in the Safety Program is forthcoming. The attitude of the mining industry will change and the work will become easier as experience is gained in the use of nuclear explosives and evidence is demonstrated in the ability to predict effects from such detonations. However, a demand for work in this area is expected to continue for some period of time.

CONCLUSION

The U. S. Bureau of Mines takes an active part in the Mine Examination Program and feels that this is a dual roll in protection of both the Government and the mining industry. This Program has been successful because of the splendid cooperation received from other participating agencies and from the mining industry.

CHAPTER VII

STRUCTURAL RESPONSE TO GROUND MOTION

By John A. Blume, President
John A. Blume & Associates, Research Division
San Francisco, California

RESPONSIBILITY AND OBJECTIVES

John A. Blume & Associates Research Division is assigned by contract the responsibility of providing NVOO with predicted effects of expected ground motion on structures and facilities. This includes providing for temporary bracing, where damage is probable, in order to reduce or prevent losses and claims. The basic long-range objective is to conduct research and to compile this data in a manual that contains data for the reliable predictions of structural response to ground motion from underground explosions; and also, the methods to minimize the extent of damage, if any, by temporary bracing or other means.

Although a comparative newcomer to the NVOO Safety Program, this organization has over 30 years experience in structural dynamics and in the response of structures to ground motion induced by earthquakes. Much of this background is expected to be of value in the structural response portion of the NVOO Safety Program.

There is a great deal to be gained by the careful application of data from the field of earthquake engineering and from the results of previous detonations conducted above the ground. However, the degree of accuracy inherent or necessary in these two areas is not such as to be adequate for response resulting from underground experiments or for future commercial applications of nuclear explosive energy. To state this in another way, no one can be held responsible for an earthquake and for what it might do to someone else's property, whereas man-made ground motions do carry certain legal and financial responsibilities.

Although there will be little room for error, too much conservatism could unduly curtail the effective uses of atomic energy. Therefore, the indicated procedure is to conduct new studies and to gather all possible empirical and other data leading to greater accuracy with less gaps in knowledge than in earthquake and blast procedures.

Initially, while conducting research and assembling basic data, current prediction methods and their limitations will be called upon occasionally to make response predictions for specific events. This will be done capably from available data within the present state of knowledge.

Of course, there are various *rule of thumb* methods for predicting damage thresholds to ground motion. Most of these are empirical, but are based unfortunately upon a very limited number of tests and experiences, many of which were conducted under such low energy levels and short distances, and without consideration of so many important parameters as to make one seriously doubt the value of extrapolations into higher levels. Peak velocity is a favorite and convenient criterion for damage. It is one of the best available when using a single parameter. However, a single parameter is not considered adequate or compatible with the nature of the Safety Program. Peak acceleration is another popular criterion, especially when modified by frequency, as in earthquake procedures. But acceleration can be very misleading as a sole consideration, also. Exceptions resulting from dynamic response phenomena can be many, and can be of serious magnitude.

Comparisons to earthquake history are useful, but of limited value and of unknown or debatable confidence levels.

The basic problem is not one of statics but of dynamics, with energy, vibration, highly variable ground motion, and highly variable structures. The possible number of combinations of parameters and situations staggers the imagination. Since all possible combinations cannot be evaluated individually, in time they all can be handled mathematically and practically by placing them into logical categories.

Applying Examples of Earthquake Data to Safety Program

Some data and sketches from research in earthquake engineering will illustrate certain points pertinent to the structural response portion of the NVOO Safety Program.

Figure 7.1 shows ground motion for a major earthquake. *Acceleration*, in the upper portion, was recorded in 1940 by the U. S. Coast and Geodetic Survey. This El Centro, California earthquake of 1940 is perhaps the best example of earthquake motion to date recorded anywhere in the world. The horizontal scale for all three portions of the figure is elapsed time, in seconds, from the start of the recording instrument. *Gravity units* refer to the acceleration of gravity, or the rate of change of velocity of a falling object. This particular record has a peak acceleration of about 0.33 g. *Ground velocity* values were obtained in inches per second as shown in the center portion by careful integration of the acceleration record. *Ground displacements* were obtained in inches as shown in the lower portion by another integration from the velocities. It is to be noted that the waves become smoother and of longer duration from acceleration, through velocity, and to amplitude. However, there are many different wave patterns occurring simultaneously throughout these 30 seconds of violent motion. The work in structural response will need similar complete time history records of ground motion. These records of ground motion would be obtained by the U. S. Coast and Geodetic Survey and processed by Roland F. Beers, Inc.

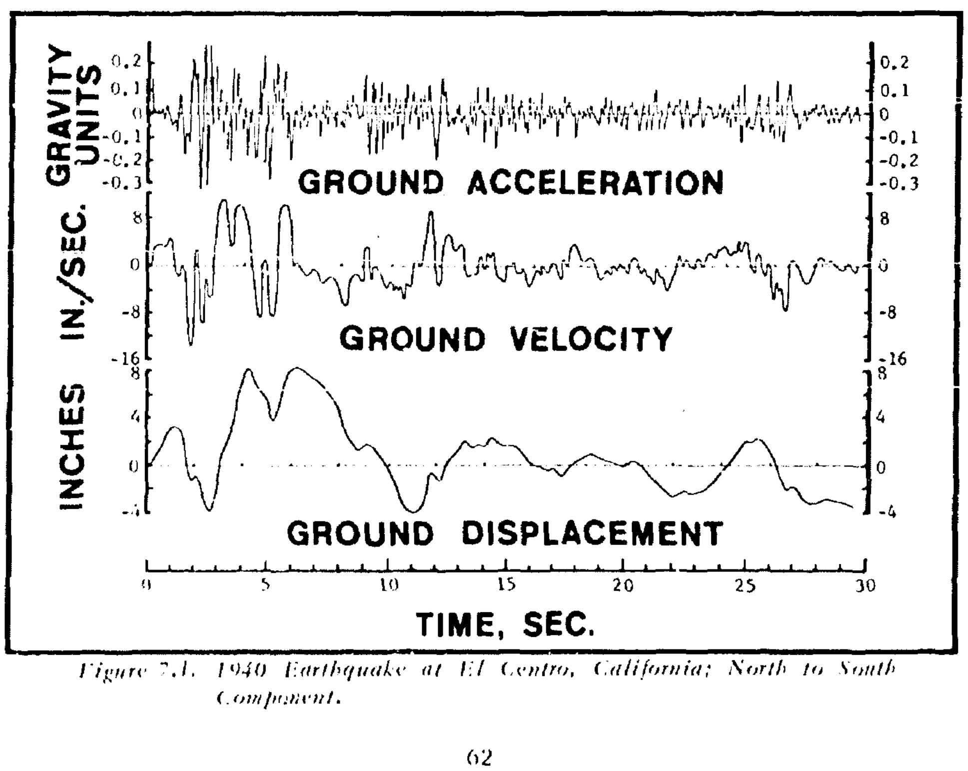
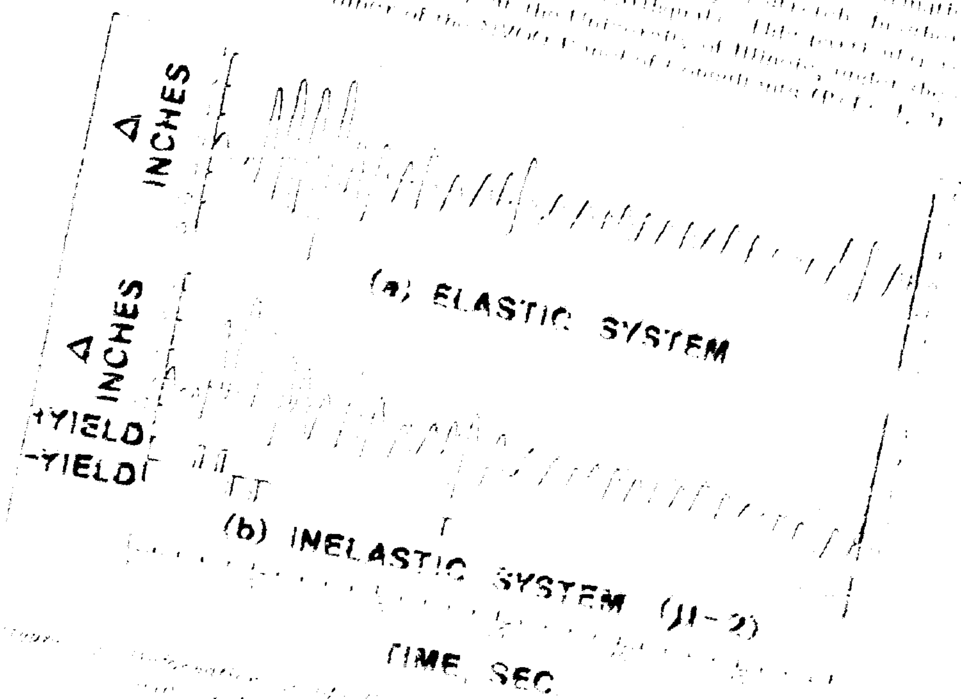


Figure 7.1. 1940 Earthquake at El Centro, California; North to South Component.

Figure [illegible] shows the response, in terms of [illegible], of two idealized simple vibrating systems exposed to the ground motion of Figure [illegible]. The upper diagram is the response of an elastic system, or one that is strong enough not to be permanently stretched by this earthquake. The lower vibration diagram is for a somewhat weaker elastoplastic system that is stretched beyond its elastic limit by this earthquake motion. Five excursions into the plastic range are to be noted in the lowest part of the Figure 2.3, two act yield to one side of the original (pre-earthquake) position and three act yield to the other side. The final plastic deformation [illegible] structure with about 1 inch of permanent displacement, or stretch. In other words, this building would be 1 inch out of plumb after the earthquake. This result was [illegible] obtained by the aid of a computer at the University of Illinois, under the direction of Dr. N. M. Newmark, a member of the [illegible] (Ref. [illegible]).



[illegible]

cept the rocking block (No. 6), the time required for free motion from one side to the other and back again, or the *period of vibration*, is constant (unless motion is otherwise forced by an outside agency such as the ground). However, the period of vibration decreases for the rocking block (No. 6), that is the frequency increases rapidly as the rocking amplitude decreases.

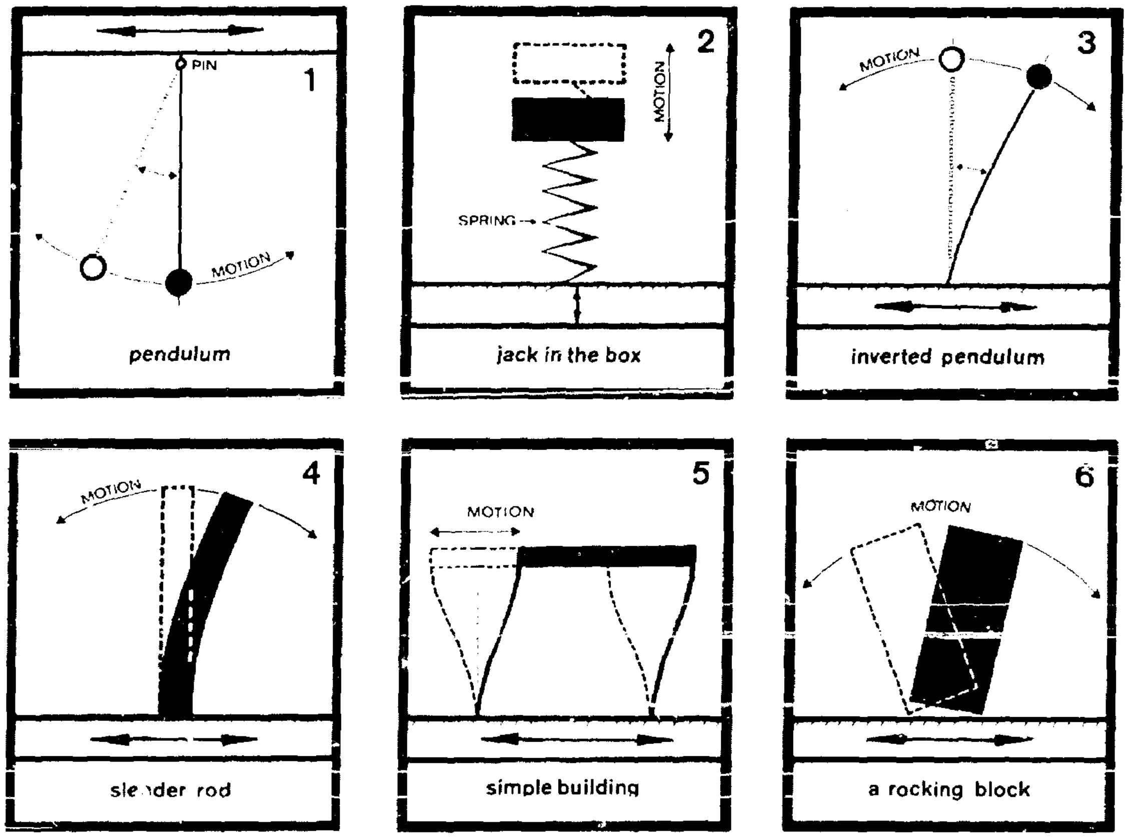


Figure 7.3. Idealized Vibrating Systems.

When a disturbing force, such as ground motion, happens to have periods or frequencies that correspond, or nearly correspond, with any of the natural periods of a structure, the structure's motion can build up to many times that of the ground motion. This happened recently in Alaska, and it can possibly happen to structures affected by ground motion induced by underground nuclear explosions.

The idealized vibrating motions illustrated in Figure 7.3 are simple systems. Actual structures, such as buildings and bridges, are much more complex dynamically and structurally. For example, in a typical high rise building there are not only a great many natural modes of vibration, but other complications from the interaction of architectural elements (such as partitions, plaster, stucco, glass, etc.) with the structural frame, but also between the structure and the ground upon which it bears. It could be said that a simple pendulum is to a modern tall building as an amoeba is to the complex human body.

Figure 7.4 indicates the first three natural modes of vibration of a more complex system — a multi-story building. Any or all of these modes (and more) can vibrate at the same time. The nodes, or loops, of each mode oscillate back and forth, each mode in its own period of vibration. A vibration record taken in a building undergoing all three of these modes simultaneously would indicate complex wave forms. Different types of

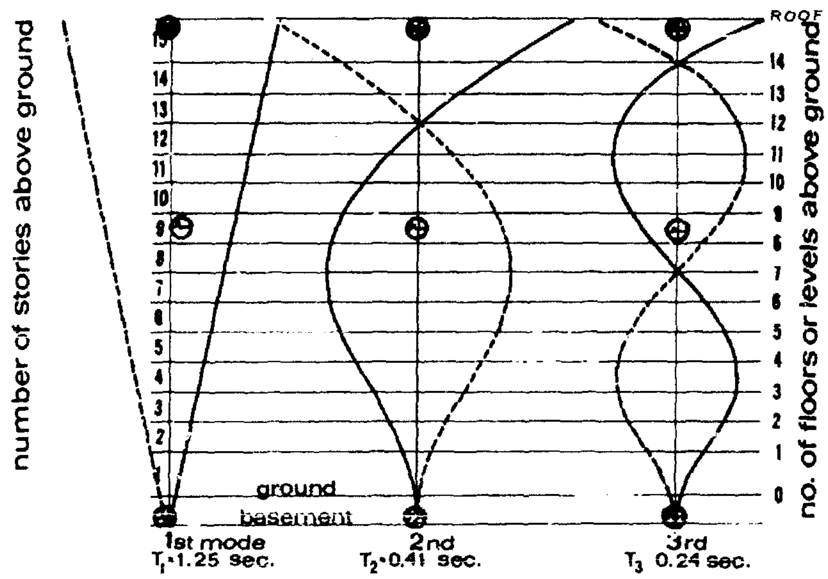


Figure 7.4. Mode Shapes of a 15-Story Building.

ground motion can induce different combinations of mode responses. The circular symbols indicate ideal positions for recording instruments to provide dynamic data on this building. The particular curves shown are for an actual San Francisco office building (Refs. 3, 4).

Figure 7.5 may be of interest to golfers, who know the great importance of the grip as the only connection of the player to the club that strikes the ball. If the grip is weak, or if it fails to transfer the energy of the body motion to the shaft and finally into the club head as the smooth swing of a compound pendulum, something goes very much wrong; the score rises, and perhaps some minor financial losses are incurred. The grip should be firm, but not completely rigid. So it is with a tall and slender building, such as the one shown. There is a peculiar interaction between structures and ground that not only changes the periods of vibration of the coupled system of structure and ground, but in many other ways complicates the life of a structural-dynamicist. Two identical buildings, one on hard rock and one on alluvium, will have considerably different dynamic response characteristics.

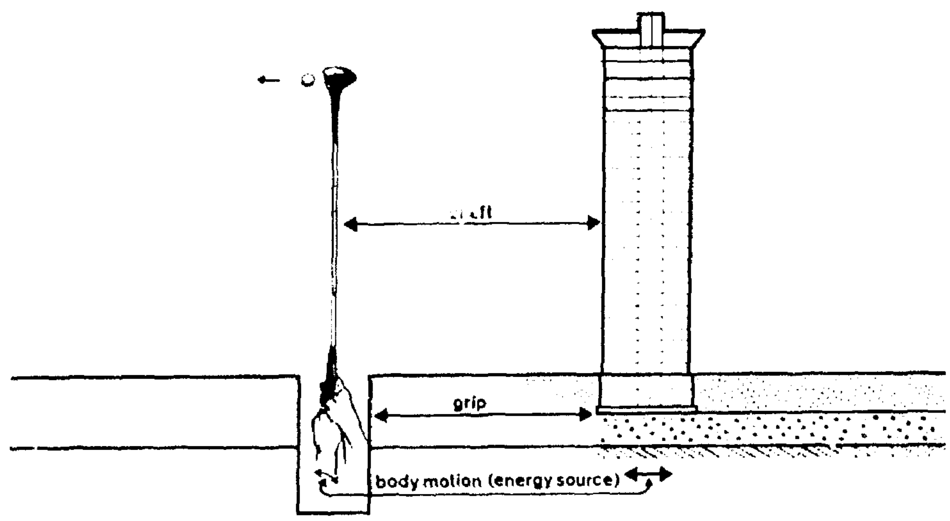


Figure 7.5. Grip for Structures Vital Too.

Energy has many forms, and it does work. The kinetic energy of ground motion resulting from released nuclear or chemical energy does work in a responding building. It causes vibration, distortion, and internal stress. It will also cause damage if the energy input is more than the structure can absorb in the nondamaging range of motion. Under certain conditions, about which not nearly enough is known, energy in some unknown degree is fed back into the ground as indicated in Figure 7.6. This can lessen the burden of energy absorption for the building and perhaps prevent damage. This is another phase of ground-structure interaction that will be explored and tested to help reach the ultimate objective of reliable prediction methods and data.

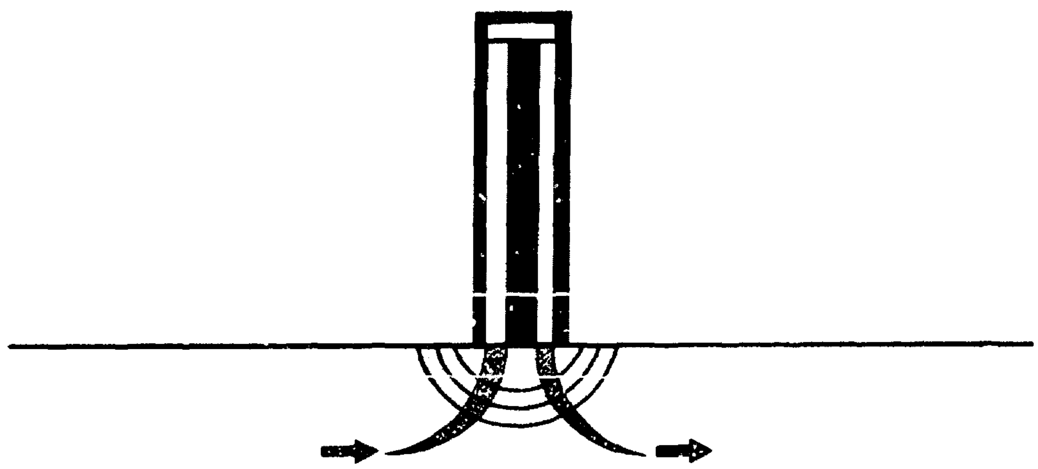


Figure 7.6. Energy Supply and Feedback.

Two separate parameters are combined in the schematic diagram shown by Figure 7.7. These are: (1) ground conditions (rock or alluvium), and (2) the distance from GZ, or the source of energy. Short period ground waves tend to dominate the complex spectrum of ground motion with (a) short epicentral distances (surface distance from the explosion point or earthquake fault), and (b) in rock. On the left, the low, rigid building with its short natural period of vibration would be excited into motion while its tall neighbor may not be affected. On the right, in another hypothetical case at greater distance from the detonation, and bearing on alluvium instead of rock, the tall building may respond vigorously while the small rigid structure is quiet. This phenomenon has occurred in several

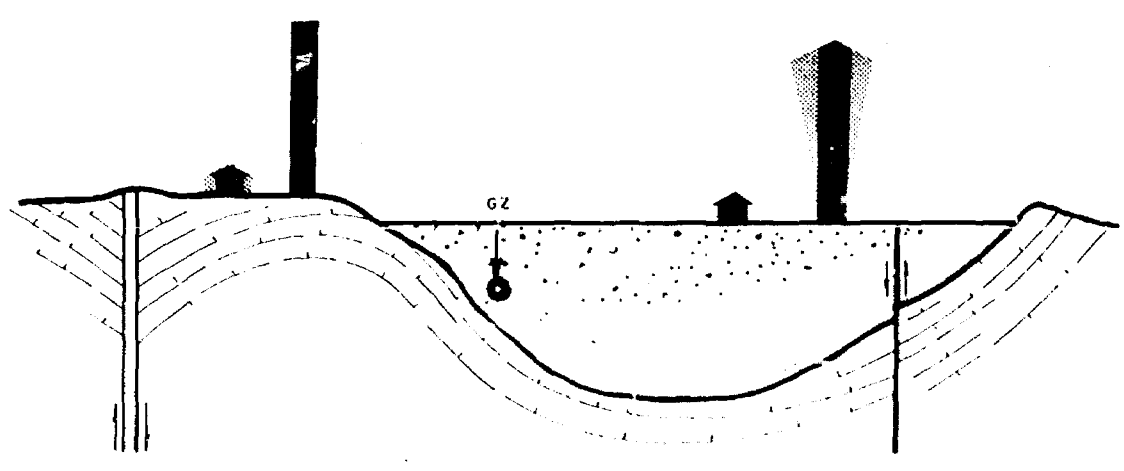


Figure 7.7. Distance and Foundation Conditions.

major earthquakes, and it can happen from nuclear explosive ground motion, as well. There are valid reasons why things happen or do not happen in structural dynamics, if one considers all the factors and the facts. The various anomalies and so-called supernatural events, which are common in earthquake history, can be demonstrated with mathematical procedures.

When a vibratory system is disturbed by an outside agency or source of energy, which can be called a *forcing function,* there is *forced vibration*. Depending upon the degree of tuning, or the ratio of the period of the structure to the period of the ground motion, the structure may respond from a little to a great deal as compared to the motion of the forcing function. In Figure 7.8, the response ratio represents the steady state magnification over that of the ground motion. If the tuning is close to 1.0, the response is materially increased; the amount of the increase depends upon the duration of ground motion and the damping or internal friction characteristics of the structure. Damping for actual structures is another item that needs more reliable numerical values.

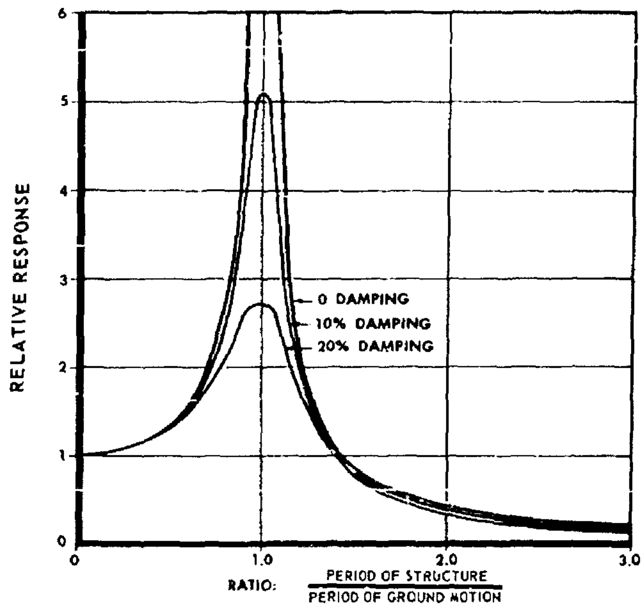


Figure 7.8. Response to Harmonic Motion.

Everyone has heard of the troop of marching soldiers breaking stride, or cadence, when crossing a bridge. The sergeant may not have studied dynamics, but for one reason or another he was ordering a random disturbance rather than a unified repeating rhythm that might have been close to a natural mode of vibration of the bridge, or close to the ratio of 1.0 in Figure 7.8. Another example would be the violinist breaking a glass situated across the room from where he was playing. In this case, the violinist deliberately sought the tuning ratio of 1.0, so that the air waves resulting from the violin string vibrations coincided with a natural vibration mode of the brittle glass.

Although perfect tuning, or a resonance ratio of 1.0 is not probable in structural response, there have been many examples to show that structures can and do respond according to Figure 7.8, and at times in a very few cycles of motion that are not necessarily closely tuned. This problem needs more reliable numerical values for structural response safety.

Figure 7.9 illustrates another parameter about which there is much more to be learned, the response characteristics of various building materials. There are two limits or boundaries as shown; *ductile*, represented on the left side of the figure; and *brittle*, on the right side. The ductile material tends to stretch like a rubber band and to absorb unwanted energy in the process. The brittle material breaks suddenly with a snap. Actually, there are all degrees between these two limits. The more work done (as represented by the area under the curves), the greater the ground motion that can be absorbed without collapse. Some tests need to be conducted in the more brittle materials, including the typical architectural finishes of buildings, in order to assess the response of finished buildings and to reliably predict damage thresholds. The 1952 Taft, California earthquake caused $10 million of nonstructural damage to tall buildings in the Los Angeles area, located from 75 to 100 miles away from the epicenter (Ref. 5).

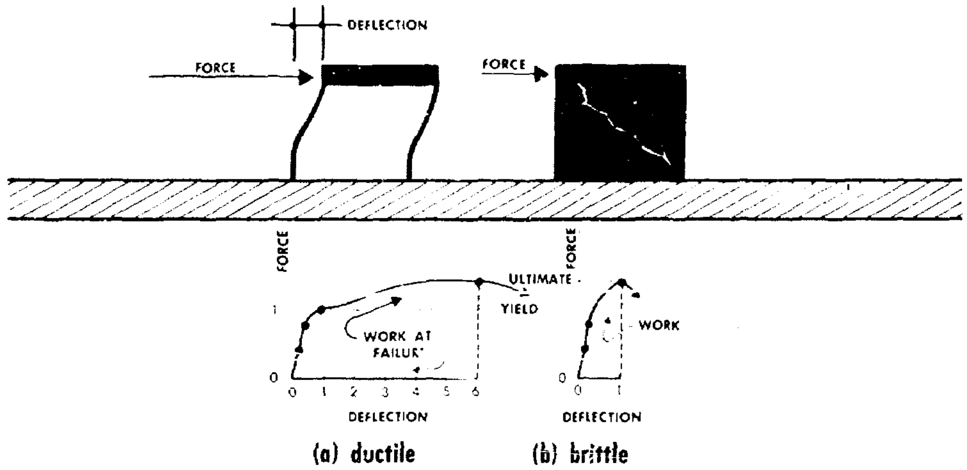


Figure 7.9. Building Material Characteristics.

Figure 7.10 is an elevation and soil profile for a forty-year old 15-story San Francisco building which may be termed the earthquake guinea pig of the world. Many research efforts have been conducted in or about this traditional-type structure (Refs. 3, 4, 6, 7, 8, 9, 10, 11). The building has a steel frame, brick walls, concrete floors, and its foundation is situated on alluvial material as shown.

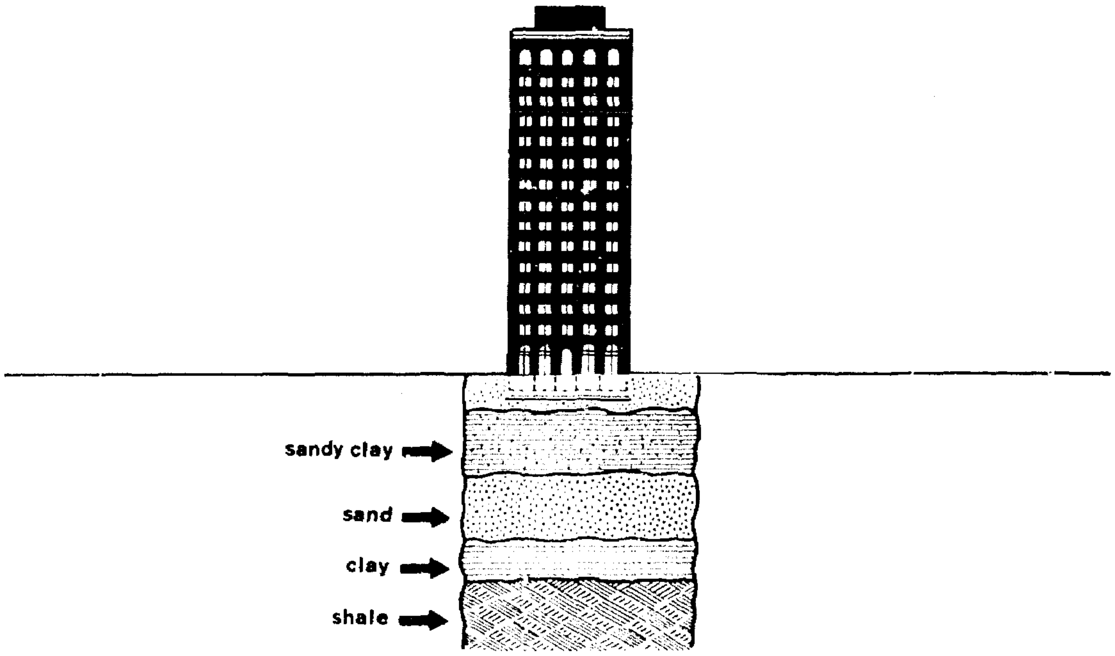


Figure 7.10 An Earthquake Guinea Pig.

In Figure 7.11, the guinea pig is responding to a minor earthquake (Refs. 3, 12). The acceleration is plotted against elapsed time. The response in the third natural mode of vibration (± 1/4 second) is obvious. Of course, other response is also indicated. The 10th story is plotted on the same side as the 15th (inverted) for convenience of viewing; actually, in this third mode, as the 15th story moves in one direction the 10th story moves in the opposite direction.

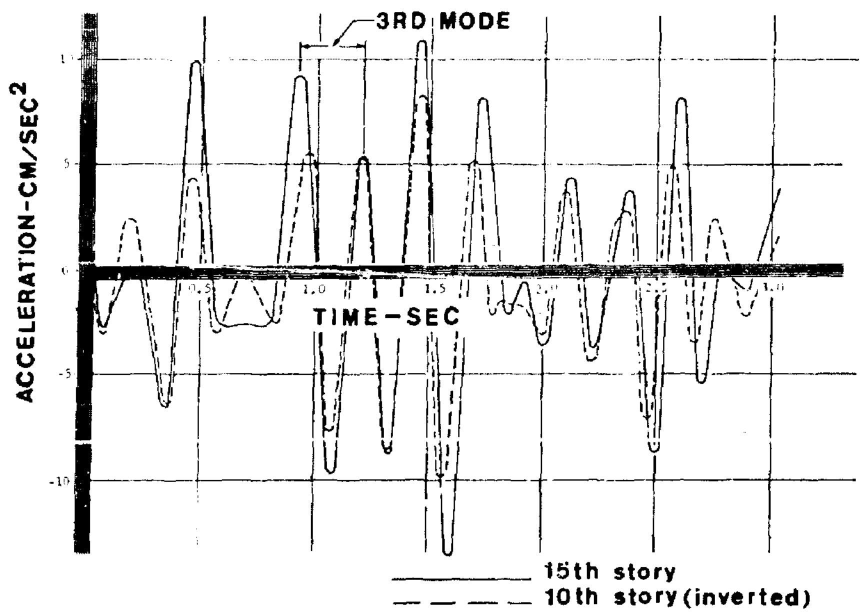


Figure 7.11. Response to Minor Earthquake in 1943.

In Figure 7.12, the natural modes of vibration are identified to show the response of the same San Francisco building by an artificial earthquake, or forced vibrations (Refs. 3,4). A machine was developed in 1934 for this purpose by Lydik S. Jacobsen, a member of the NVOO Panel of Consultants, and John A. Blume (Refs. 13, 14). It is planned to use modern machines with this same technique in certain tests and other buildings. The purpose will be to simulate mild ground motions to obtain numerical values of damping (Refs. 15, 16), and other characteristics of selected buildings as additional *guinea pigs* of a different type.

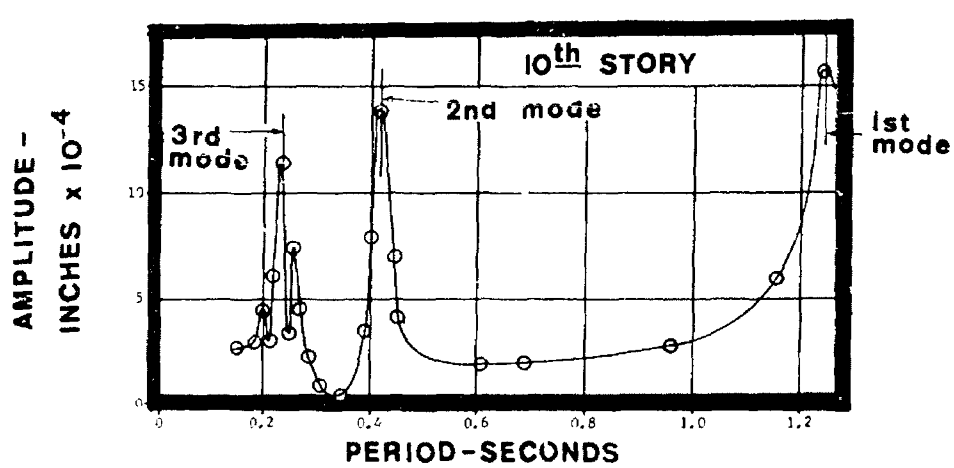


Figure 7.12. Forced Vibration Response.

Figure 7.13, also of the same San Francisco building, shows that the period of motion induced by the machine (by the forced vibration) is the same as that found under response to wind and earthquake motion (Refs. 3,4). The motion at the basement level also indicates some ground structure interaction. This artificial duplication of mild response to ground motion is a valuable research technique that does not depend upon costly events.

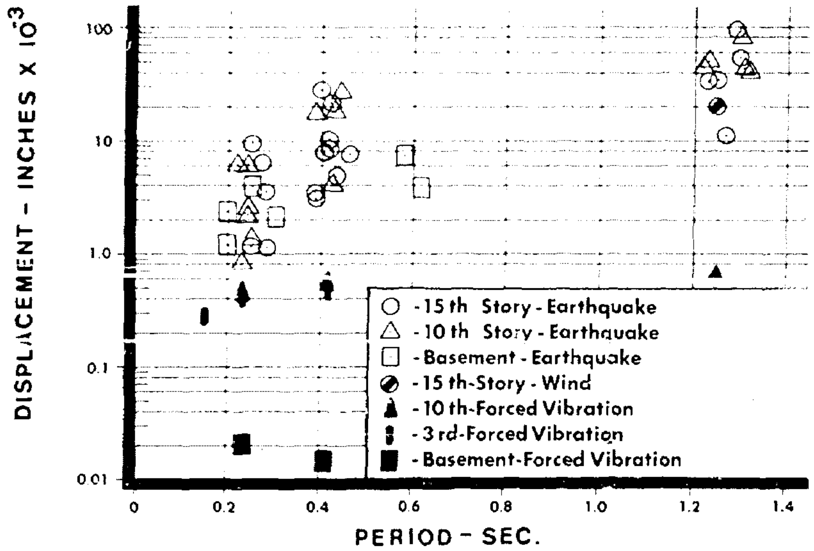


Figure 7.13. Comparison of Observed Vibrations.

Las Vegas High Rise Buildings

The Bilby event caused sufficient tall building response in Las Vegas to make many persons notice the motion and thereby create newspaper headlines. There was no reported damage. A basic question is, how much greater motion can be sustained in Las Vegas and other cities in the future without reaching the threshold of damage? A related question is, if the damage threshold is to be reached, what would be the type and extent of the damage, and what might be done, economically and practically, to prevent such damage and still release the desired level of energy? The structural response effort will address itself to these and to many other related questions for various types of structures and facilities.

Figure 7.14 shows the locations of the many high rise buildings in Las Vegas. Coverage of this area by permanent seismic instruments is planned as shown with the U. S. Coast & Geodetic Survey, plus special (temporary) instrumentation for Nevada Test Site events of significant magnitude. The accelerographs shown are accurate instruments with time recording drums, while the seismoscopes are inexpensive instruments of less reliability and no time scale. Attempts will be made to obtain the broadest possible coverage of future building motion in Las Vegas resulting from ground motion. The records obtained will be analyzed in detail, and will be correlated with building inspections where indicated and reports of motion perception in and about the buildings. In addition, the detailed drawings are being obtained and the buildings are being analyzed structurally, dynamically, and with special reference to the more *brittle* architectural materials and finishes. Models, mathematical and physical, will also be tested as indicated.

Plans have also been made to record and to document the response of certain tall buildings to severe wind storms and to earthquake motion. It is known that some persons have felt wind-induced motion in a severe Las Vegas storm. It seems important that this motion, resulting from nature's severe outbursts should be recorded as permanent

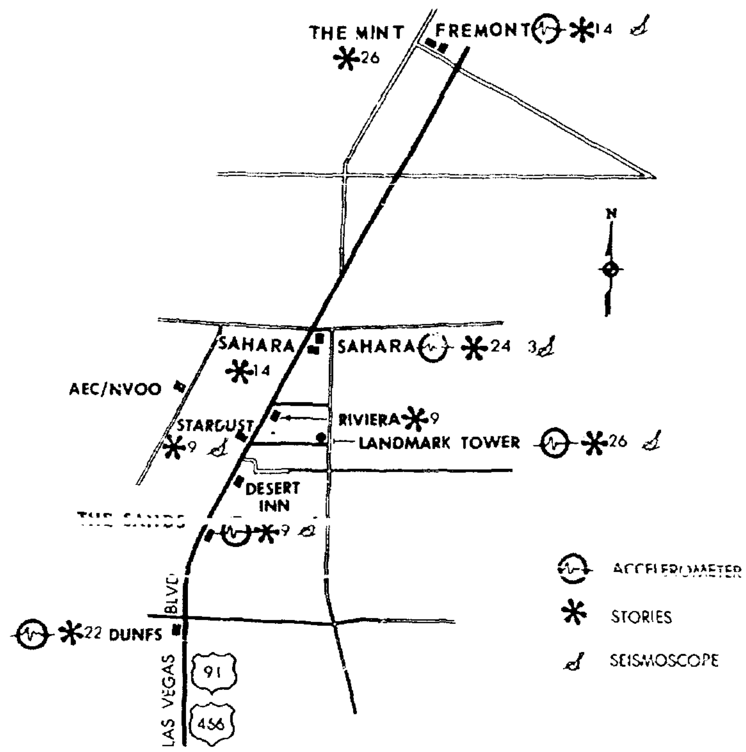


Figure 7.14. Locations of High Rise Buildings in Las Vegas.

records in connection with any problems or complaints resulting from future ground motion being induced by the Nevada Test Site. The building owners, managers, and architects have been most cooperative in this Las Vegas program; which is, of course, directed toward the prevention of damage, or the proper settlement of any damage that might be caused. It also provides valuable data for the structural response program in general.

Planned Experiments and Analyses

In addition to the already outlined problems and programs of high rise buildings in Las Vegas, various other tests and studies are planned to develop data for the overall long-range objectives of the structural response program. For example, other operations include:

(1) The preshot and postshot studies of all possible existing buildings and structures of all sizes and types, to be subjected to severe ground motion.

(2) The instrumentation of certain structures to be subjected to severe, and possibly damaging ground motion, together with special field tests, analyses, and documentation of these effects.

(3) The use of test structures and models of structures in the field at various distances from ground zero and on various types of soils.

(4) Studies and tests in both field and laboratory, of the interaction of structures and the ground.

(5) Forced vibration and other tests to develop reliable data on the various periods and damping values of buildings and other structures.

(6) Structural and dynamic laboratory tests of building elements and materials to provide data for existing gaps in knowledge or in reliable numerical values.

(7) Analysis of structures and of their response to a whole spectrum of actual and hypothetical ground motions.

(8) The continuing acquisition, study, and documentation of all applicable data.

The structural response program is planned to proceed simultaneously under several avenues of investigation. From time to time, there will be reconciliation of all these efforts and reevaluation as indicated. In time, as sufficient reliable data become available, modern statistical and probability procedures will be introduced to weigh the accuracy of the data and to make its application more meaningful.

It is very likely that information will be developed in the course of this program that will also be beneficial in the earthquake problem. With the AEC policy of prompt dissemination of unclassified data through the technical literature and by other means, such material will become available for utilization by the design professions and the building industry. It is to be noted that any enhancement of earthquake engineering data would be only a by-product of the basic Safety Program, and would occur at no extra expenditures than that necessary for the NVOO program.

Relationship with Other Organizations

Efforts in structural response will depend in no small measure upon information from, and services by, other agencies and contractors. Although there is no overlapping of responsibilities, there are certain interfaces of effort of two or more organizations. There is every reason to expect close collaboration and effective teamwork throughout the program. Support is expected in the following basic areas:

(1) Records are needed of event ground motion; processed to have the complete time history in terms of accurate acceleration, velocity, and displacement. The records are to be taken by the U. S. Coast & Geodetic Survey and to be processed by Roland F. Beers, Inc.

(2) Prediction of free-surface particle motion for coming events by Roland F. Beers, Inc.

(3) Accurate recording of the response of structures and adjoining ground with simultaneous time indications from various points, as needed. The disturbances to induce this response will include ground motion, vibration machinery, applied forces, wind, and other factors. Most of the instrumental work will be done by the U.S. Coast & Geodetic Survey, with the collaboration of John A. Blume & Associates as indicated.

(4) Geological information will be needed for the area in which structures are located as well as for the area of underground detonations. The United States Geological Survey will have this information.

(5) Information on the yield, depth, and certain other characteristics of the energy source by Plowshare, Defense, and Vela-Uniform agencies and through NVOO contractors.

(6) Construction and installation of test structures and models are necessary at the Nevada Test Site, and perhaps elsewhere. Contractors, such as Holmes & Narver and Reynolds Electrical & Engineering Company will participate in this work.

(7) Detailed drawings of existing structures, subjected to motion or to be otherwise tested as available, from operating agencies, public and private owners, architects, engineers, building officials, and others.

(8) Data and reports on all structural tests, or shaking of structures and facilities from various sources within the AEC program and from other areas in general.

(9) Overall direction and coordination by the AEC contract administrators at the Nevada Operations Office.

CONCLUSION

A great deal must be done in the next few years to fulfill the responsibilities of the structural response phase in the Safety Program. There is every confidence that with the continuity of effort and collaboration of the other organizations, the long-range objective of simple but reliable response prediction criteria and bracing procedures will be achieved; however, this does not underestimate the complexity or importance of the problem.

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CHAPTER VIII

SEISMIC MEASUREMENTS

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United States Coast and Geodetic Survey
Washington D. C.

INTRODUCTION

The Special Projects Field Party of the Seismology Division, U.S. Coast and Geodetic Survey has recorded over 8000 seismic data channels from nuclear detonations within the conterminous United States since September 15, 1961. Participation in seismic monitoring programs dates back to the CROSSROADS experiments in the Pacific in 1946.

This history of earth vibration has been collected at the request of the Atomic Energy Commission (AEC), Defense Atomic Support Agency (DASA), Air Force Technical Application Center (AFTAC), Lawrence Radiation Laboratory (LRL), Los Alamos Scientific Laboratory (LASL), National Aeronautics and Space Administration (NASA), and others to fulfill stringent data requirements with one objective of supplying vital information relative to the effects of large-scale detonations on life and property.

Possibly of passing interest is the physical range of seismic stations which have been occupied. Seismic data have been recorded from locations in the depths of Carlsbad Caverns to the heights of the Bren Tower, which represents the tallest structure made by man and serviced by an elevator.

BACKGROUND

During this Safety Program discussion, others have described the mechanics of a nuclear detonation and the processes involved in the conversion of the proportions of nuclear energy into seismic energy. There is the concomitant question of whether a sound is generated if there is no ear to hear the falling tree in the forest; the Special Projects Field Party provides this missing ear for earth vibrations. There are earth vibrations which do no damage, and there are those which result in the problems that should be avoided.

Predictions are only as good as the information upon which they are based. This applies to such diverse things as weather, horse racing, the world series, or earth vibrations.

It is common knowledge that earthquake effects are expressed in the change of state of portions of the earth's surface as it interests man or its effects on structures. One problem studied to various degrees of solution is the question of whether certain vibrations of the earth's surface are induced by the all encompassing elements of nature or whether they are man-made. Therein hinge unsolved political as well as scientific problems.

Much credit can be attributed to the pioneers who first studied our vibrating earth. They chose to define the parameters describing this vibration within three basic categories of displacement, velocity, and acceleration. For simplicity, the dimension of displacement can be assigned in inches of earth movement from some rest position.

Simple rationalization will place velocity as the time rate of change of displacement expressed in inches per second. Continuing along this same concept, acceleration can be logically defined as the time rate of change of velocity expressed as inches per second squared, or in parts of gravity. Periodic motion characteristics of vibration restrict these oversimplified definitions to recurring phenomena.

The effects of frequency of periodic motion cannot be over emphasized. Biophysicists have shown, with controlled tests, that vibration perception thresholds from 1.5 to 4 cps are approximately proportional to jerk or the time rate of change of acceleration; while from 4 to 30 cps the response is between particle velocity and displacement. Earthquake seismologists have long operated on the premise that 0.001 g is the threshold which is certainly reasonable for earth transmitted vibrations. Perception thresholds for vibrations at higher frequencies than earth transmitted are equally anomalous with 10 g being the threshold of perception for tangential vibrations at 1000 cps.

A normal seismic instrument measures with reservations jerk, acceleration, velocity, and displacement, but it prefers to look at one parameter better than any other; that is, its frequency response is flat to one of the parameters within a certain range.

The Alaskan earthquake was recorded at Cape Kennedy at a distance of about 3,700 miles. The horizontal earth motion was over 2 inches, peak-to-peak at a period of 21 seconds, or 1 cycle in 21 seconds. It was not felt nor were there reports of damage. In contrast to this, fingertip perception to tangential vibration at about 4 to 20 cps is 0.005 inch or equivalent to the thickness of 1-1/2 human hairs.

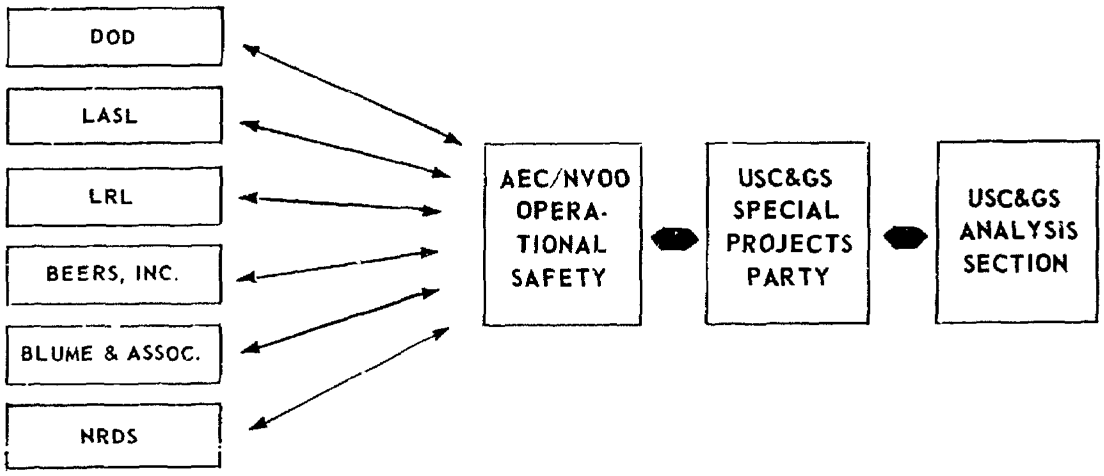
The universal seismograph would record the three main parameters of displacement, velocity, and acceleration over frequency ranges of less than 0.1 to over 20 cps. It would record earth motions as small as that recorded by the NGC-21 and as large as 3 feet. As yet, such an instrument has not been invented and it seems unlikely that it will be.

One can infer from this that not only are instruments needed to measure each of the three parameters, but several instruments are required of each category to cover the magnitude and frequency from large-scale detonations. Restricting the measurements to damage criteria alleviates the problem to a degree, but does not eliminate it.

An unqualified comparison between earthquakes and explosions in terms of damaging effects is not valid, but it is interesting to observe the effects of a small earthquake.

On April 4, 1961 at 1:32 a.m. an earth tremor caused a damaging slide at Terminal Island, Long Beach Harbor. It was felt as a slight earthquake in the area of Long Beach, San Pedro, and Wilmington. Long Beach reported an Intensity IV. The Modified Mercalli Intensity scale of 1931 defines Intensity IV as "during the day felt indoors by many, outdoors by few." Fire and burglar alarms were set off in downtown buildings of Long Beach. On Terminal Island, the subsurface damage to oil well pipes was estimated at approximately $4.5 million; more than 40 wells were damaged and out of production; and at least 3 wells, used for injecting water to halt subsidence in Long Beach Harbor, were damaged. An accelerograph in the Public Utilities Building in Long Beach recorded accelerations of 0.026 g at 5 cps and displacements of 0.03 cm. This earthquake was so small that it was not assigned a magnitude nor was it recorded at teleseismic distance.

A typical flow chart shows a representative sample of the agencies and organizations with seismic data requirements. One example shows Department of Defense (DOD) coordination through AEC/NVOO Operational Safety with the seismic program conducted by the USC&GS Special Projects Field Party. If a particular program has analytical requirements, the data are processed through the USC&GS Analysis Section and a report is prepared based upon the objectives of the seismic program. The flow chart is then reversed with the initiating agency receiving the needed information.



INSTRUMENTATION

A cutaway drawing of a 21V velocity transducer is shown with the dynamic elements of the instrument in Figure 8.1. The mass (solid black) is supported by a helical spring. Under ideal conditions, the mass is stationary with the case moving with the earth. A voltage is generated by the movement relative to the coil. Under certain conditions, this seismograph system is extremely sensitive and measures minute motions of the earth's surface.

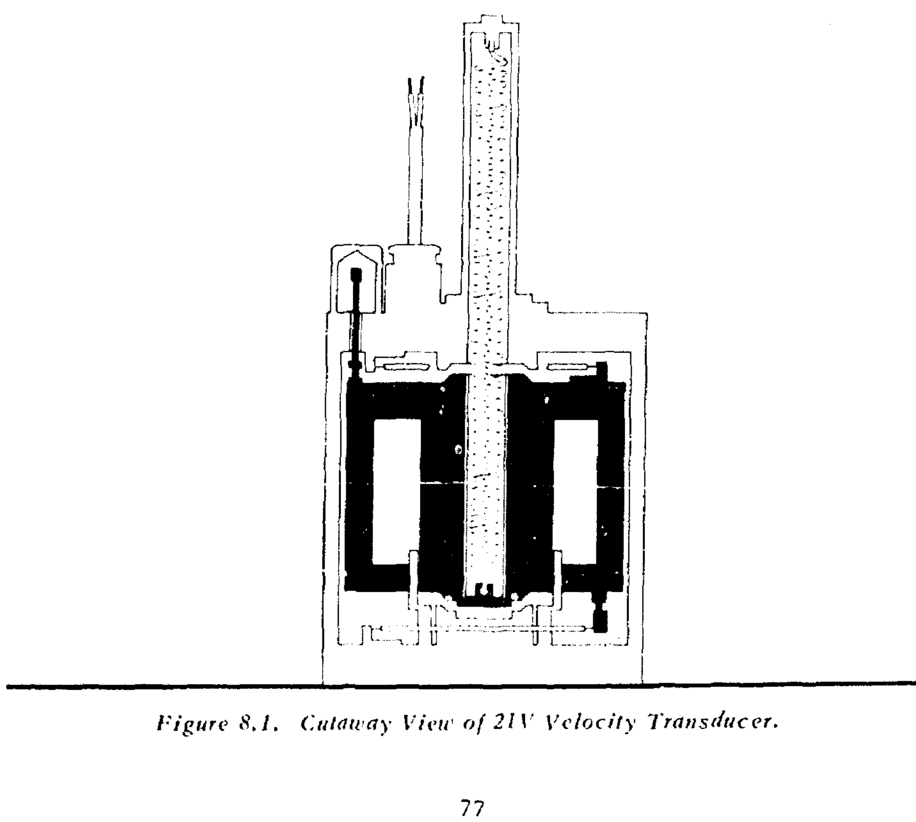


Figure 8.1. Cutaway View of 21V Velocity Transducer.

If a human hair could be split into 80,000 equal parts and the earth's surface were to move equivalent to one of these split hairs, this instrument would record this micro-motion. Under other special conditions, it can record as much as 1/2-inch peak-to-peak motion.

The system response is flat for particle velocities from about 1 to 100 cps.

A simplified diagram of the 21V seismograph system is shown in Figure 8.2. The seismometer or geophone senses the earth's vibration. The signal is amplified and converted to an analog signal through a sensitive galvanometer recording on photographic paper. Facilities are also available to record on magnetic tape.

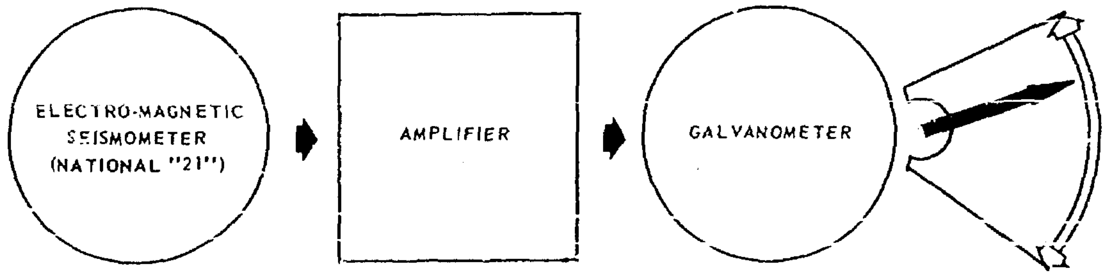


Figure 8.2. Simplified Diagram of 21V Seismograph System.

Figure 8.3 shows a typical USC&GS earthquake strong-motion seismograph system that normally measures three components (vertical, tangential, and radial) of earth vibration in terms of displacement and acceleration with recordings on photographic paper.

Over 100 of these instruments are standing by as earthquake sentinels in the active seismic areas along the land masses bordering on the Pacific from South America to Alaska. For earthquake applications, this instrument is passive until the very first motion of a seismic disturbance sends the instrument into operation.

This seismograph is used in the ranges of less than 1/2 to about 15 miles from the nuclear detonation ground zero at NTS.

The accelerometers can measure less than 0.1 to over 10 g in the frequency ranges of less than 1 to over 60 cps. The displacement meters can measure earth motions of 0.01 to over 10 cm at frequencies of 0.1 to 100 cps.

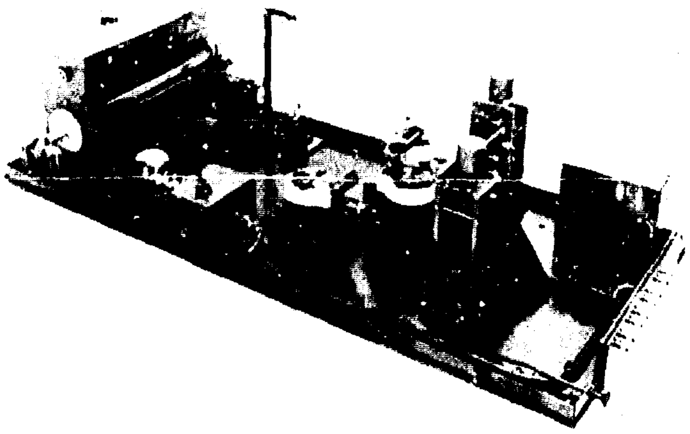


Figure 8.3. USC&GS Accelerograph.

Several accelerographs with pendulum starters have been put in operation in multi-story buildings in Las Vegas. If an earthquake should occur or if the building should move for any reason sufficient to actuate the starter, the motion will automatically be recorded. This should provide valuable data on building vibrations induced from natural causes, such as wind or earthquakes.

A 35 mm film recording seismograph system is shown in Figure 8.4. This is typical of the installations which have been in operation in Las Vegas, Beatty, Tonopah, Twin Springs, and Alamo, comprising a perimeter to the Nevada Test Site.

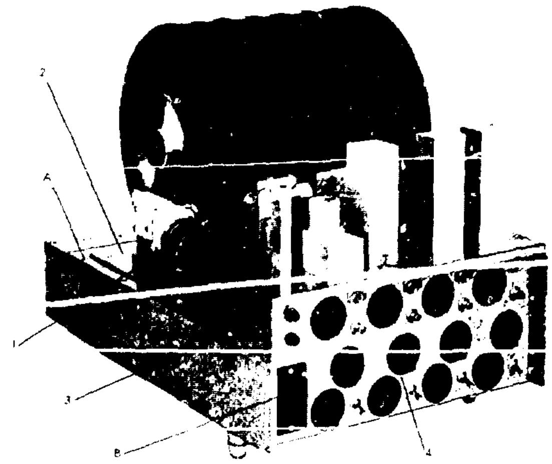


Figure 8.4. Model F Seismograph Recorder.

Two components of horizontal motion are recorded in a NS-EW direction or radial-tangential to a known source.

Figure 8.5 shows a Wood-Anderson torsional fiber seismometer. This so-called standard seismometer is identical to that used in developing the well-known Richter scale of earthquake magnitude. The seismograph recorder shown in Figure 8.4 has two of these instruments.

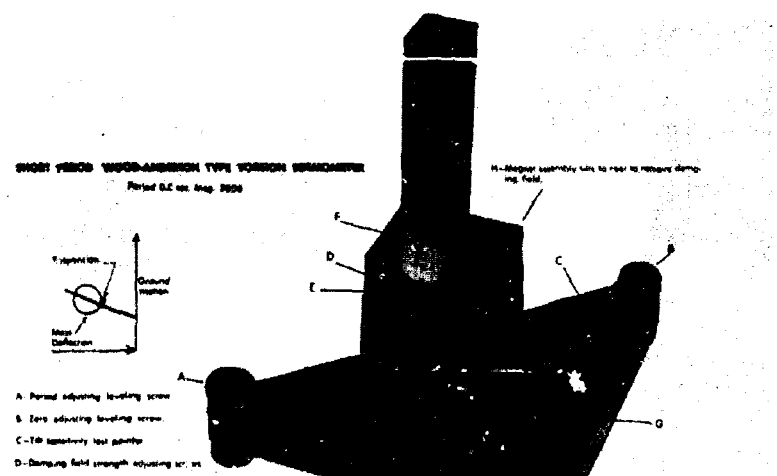


Figure 8.5. Wood-Anderson Torsional Fiber Seismometer.

A tungsten fiber, very slightly inclined from the vertical, has a small mass attached. Horizontal earth motions transmit torsional motion to the fiber which is rigidly attached at the top and bottom of the seismometer, whose overall height is about 10 inches. Recording is by a light beam through a system of optical levers on photographic paper or film.

Horizontal ground displacement of 0.0001 to 0.01 cm at frequencies of less than 1 to over 100 cps can be measured.

A strain gage type accelerometer is shown in Figure 8.6 with physical dimensions of about 3 x 4 inches and 1-1/2 inches high. Accelerations are sensed by this device and recorded on photographic paper or magnetic tape with electronic amplification.

Figure 8.6. Strain Gage Type Accelerometer.

The advantages of this small instrument are that it can be used in bore holes and in small spaces. Two basic types are currently in use, measuring as much as 1 to 5 g at frequencies up to 100 cps.

Several more instruments are used in addition to those shown in the previous figures. The EV-300 measures from 2×10^{-5} cm to 1 mm of displacement at periods of about 5 to 25 seconds.

A new long period strong-motion instrument is being studied for possible application. It measures from 0.002 to 2 cm at periods of 1/2 to 15 seconds.

SEISMIC PROGRAMS

A typical structural vibration response program is shown in Figure 8.7 as developed by John A. Blume & Associates Research Division. Seismographs are operated at the top of the structure, at the midpoint on floor 14, at the foot of the building, and on the ground near the structure. Additional instrumentation is operated on undisturbed ground at some distance from the building. It is proper here to point out that there are no earthquake-proof structures, but there are earthquake-resistant structures.

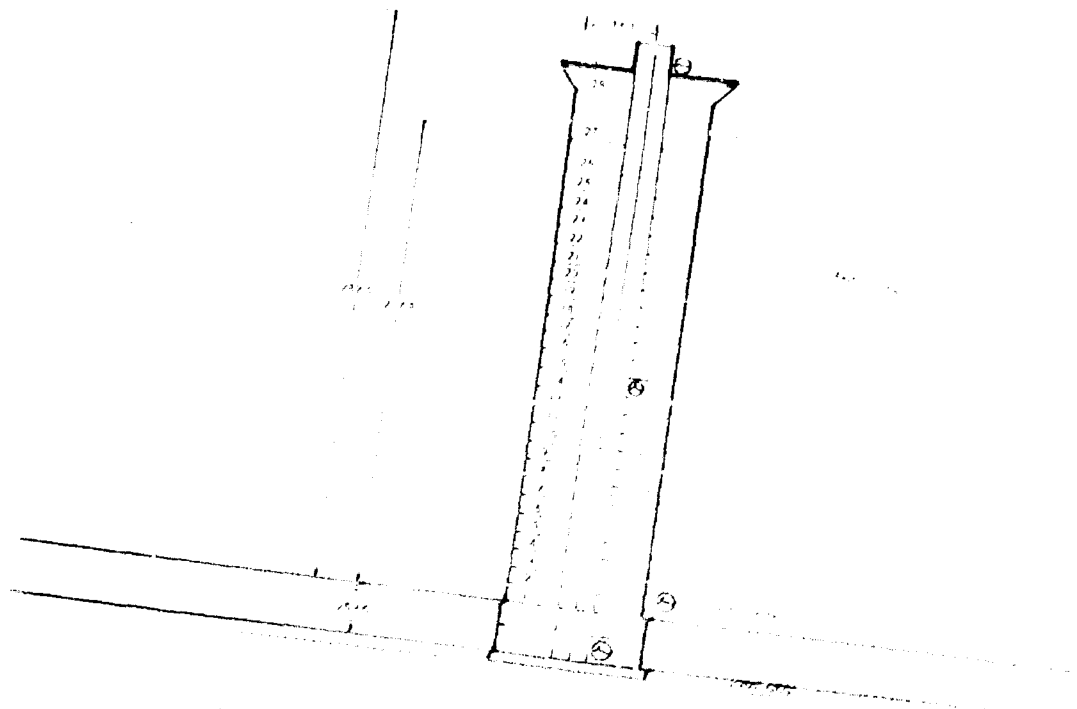


Figure 5.[illegible] Typical Structural Vibration Response Program.

A hypothetical seismic program is shown for an event at Pahute Mesa in Figure 5.10. The circles show anticipated earth motions in parts of gravity. The smallest circle is 1 g and the second circle is 0.1 g, outlining the zone of potential damage to low rise structures. The third circle is 0.01 g. For the range 0.01 to 0.001 g is the threshold of feeling. This would postulate that the detonation would not be felt by persons out-doors or in low level structures in Las Vegas.

The seismograph recording stations are shown for a typical program developed by Roland F. Beers, Inc., with stations in populated areas and along radial lines from the Nevada Test Site, to investigate seismic propagation characteristics and to refine earth motion prediction techniques.

CONCLUSION

Improved seismic instrumentation is being sought continuously for special application to vibration measurements. The complex problems of accurately recording seismic phenomena from vibrations induced by large-scale explosives are compounded by an increase in source yields. Conventional instruments developed in earthquake seismology are often restricted in dynamic range, and revisions must be made in existing instruments with consideration in development.

Benefits of the nuclear detonation [illegible] Plowshare application, but beneficial [illegible] decades of earthquake studies [illegible]

CHAPTER IX

WEATHER AND DETONATION SAFETY

By Philip W. Allen, Meteorologist in Charge
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Las Vegas, Nevada

INTRODUCTION

The interaction between detonations and the atmosphere is the topic under discussion for this part of the Safety Program. The geological areas already covered contribute information as to the probability and magnitude of venting. The science of meteorology attempts to describe the transport and behavior of radioactive material and of blast energy in the atmosphere.

To a large extent, the direct atmospheric effects of nuclear tests have been reduced by confining the debris underground, but it has turned out that these effects can neither be ignored nor relegated to relatively insignificant roles. Fortunately, radioactive fallout is now rarely a matter of real concern for the immediate safety of people, but with the reduction of such immediately hazardous effects, the public concern has broadened and increased in more than compensating intensity to include the long-term effects of accumulated small dosages of specific isotopes. Official concern now includes the possibility of violating the nuclear test treaty, which prohibits tests which cause radioactive debris to be present outside the territorial limits of the nation that is testing.

The Safety Program is directed toward the goal of vigorous underground testing with minimum risk to safety and of treaty violation. Fortunately, failures to achieve the design objective of containment have been rare. Since our knowledge of all of the factors affecting containment is not complete, preparations are necessary to deal effectively with the possibility of major venting with each proposed detonation. Venting involves the introduction of significant amounts of radioactive material to the atmosphere in either gaseous form or as a mixture of particles and gases. A wide range of particle sizes is possible, and a considerable variation is possible in the isotopes present on the particles and in the gas.

In addition to the possibility of venting from deep underground detonations, the proposed use of nuclear explosives in the Plowshare program to produce craters at shallower depths, and the testing of nuclear rocket and ramjet engines are known to inject significant amounts of radioactive material into the air.

By agreement with the AEC/NVOO, it is the responsibility of the U.S. Weather Bureau to study and to predict the transport and dispersion of airborne radioactive materials for the guidance of the AEC, its laboratories, contractors, the Department of Defense (DOD), United States Public Health Service (USPHS), and other agencies so they may take such actions as may be necessary to insure safety both inside and outside the test area.

ATMOSPHERE CONSIDERATIONS

The state of the atmosphere is also important in the transmission of blast waves. For those events in which blast is a potential safety problem, the Weather Bureau contributes measurements of the state of the atmosphere up to approximately 80 or 90 thousand feet, and Sandia Corporation makes similar measurements at higher altitudes. These are combined in a manner discussed in Chapter XII into evaluations of the degree of blast hazard.

Functions of the Atmosphere

The functions of the atmosphere in detonation safety can be summarized very simple and briefly in *Desirable* and *Undesirable* categories. First, the motion of the air very conveniently removes airborne debris from the working area immediately around an event so that reentry is somewhat simplified. The turbulence of the air dilutes the debris with air, thereby lowering radiation concentrations. And most combinations of temperature and wind structure will transmit blast waves upward into space where they are harmless.

ATMOSPHERIC FUNCTIONS IN NUCLEAR DETONATION SAFETY

Desirable	Undesirable
Removes debris from working area	Transports debris to other human activities
Can deflect blast upward	Deposits particles on ground surface
Dilutes the debris	Can focus blast

On the other hand, what is good for the test area may not be the best condition for other people or projects. Undesirably, the atmosphere transports the debris to downwind activities. When radioactive particles are present, the air allows them to be deposited on the ground where they remain and continue to emit radiation; the heavier ones failing first, and those of submicron size falling perhaps months or years later. Some combinations of temperature and wind can have the effect of deflecting blast back to the surface and focusing it into limited areas, sometimes with destructive force.

Effective Use of the Atmosphere

In order to assist in maximum utilization of the *Desirable* atmospheric functions, to warn of those conditions which may be *Undesirable*, it is necessary that meteorological support be provided in four general functions related to states of nuclear test activity.

STEPS IN EFFECTIVE USE OF ATMOSPHERE

Preshot

Study atmospheric behavior .... Planning

Predicting behavior for event .... Scheduling

Anticipating detonation effects .... Hazard Evaluation

Postshot

Documenting debris disposal .... Documentation and Study

Before a nuclear experiment, especially if it is in a new geographical area, such as Pahute Mesa or Tatum Dome, Mississippi, it is necessary to study the general atmospheric behavior in that area to assist in planning the event. Having learned as much as possible about existing flow patterns, the next step is to predict the specific atmospheric behavior for the particular event, in case the existence of unacceptable conditions at shot time may require changes in the scheduling of the experiment. Weather delays are still fairly common occurrences for events which are less certain to be contained, or are expected to release radiation. But, in order to assess the need for delay, predicted behavior of the atmosphere must be translated into detonation effects, such as the intensity of fallout resulting from maximum possible radiation release, exposure resulting from immersion in the cloud, or blast effects. These contribute to total hazard evaluation. Then, postevent, measurements of the motion and structure of the atmosphere are used, together with available radiological measurements, to document the actual disposal of debris. This information becomes the basis for official records and for study in relation to future events.

DATA ACQUISITION

Data acquisition is by far the most expensive portion of the weather program. The atmosphere is a tremendously large, complex, compressible fluid, having motions resulting from all sorts of influences: the rotational force of the earth and the heat of the sun down through deflection by mountains, differential heating over land and sea, over forest and desert, or over sunlit slopes and shadowed hills. Even the clouds in the sky can, and frequently do, create major changes in wind speed and direction over appreciable areas.

The ability to describe the behavior of the atmosphere at any one time, is directly related to the number and distribution of measurements at that time. These measurements are in turn limited by available resources in money, personnel, and time, and also by man's ability to handle and interpret large quantities of data.

Information Sources

The most common source of meteorological information is visual observation. Although it is now possible to record clouds, visibility, and precipitation forms by electronics, visual observation of these phenomena remains the cheapest and most thorough, in most circumstances. Instruments surpass man, however, in obtaining the information most directly usable in recording and predicting atmospheric turbulence, wind, and temperature distribution. These cannot be seen.

From left to right in Figure 9.1, information is received from surface based barometers, thermisters in little louvred boxes, and wind sensors on towers. The upper winds are tracked by optical theodolite from rising balloons, and by the more accurate automatic tracking radar at NTS. Data concerning upper winds, temperatures, and pressures are received from balloon-borne, radio-direction-tracked radiosonde instruments which reach, depending on balloon characteristics, to 90,000 feet or higher. Winds, when needed to those altitudes, may be obtained at higher levels by radar-tracked chaff released at around 200,000 feet by meteorological rockets. The chaff floats gradually down to about 100,000 feet, completing the measurement of wind through the full 200,000-foot layer of atmosphere.

A total of more than 19,500 data items are collected in the 12-hour period immediately prior to any forecast. Data used in the preparation of a single weather forecast are collected hourly from 180 surface stations in western U.S. alone, amounting to over 12,000 bits of information. Eight stations, operated for the AEC in and around NTS, produce at least 288 data bits in the same period. Thirty-nine national network and at least three NTS network wind sounding stations produce more than 3600 data bits at intervals of 1 to 6 hours. Thirty-three national and two NTS radiosonde stations produce some 3500 data bits at intervals of 6 to 12 hours. If needed, two national network and one Sandia Corporation rocket station yield over 130 data bits. All of the national network and much of the NTS network operates continuously, days, nights, and weekends.

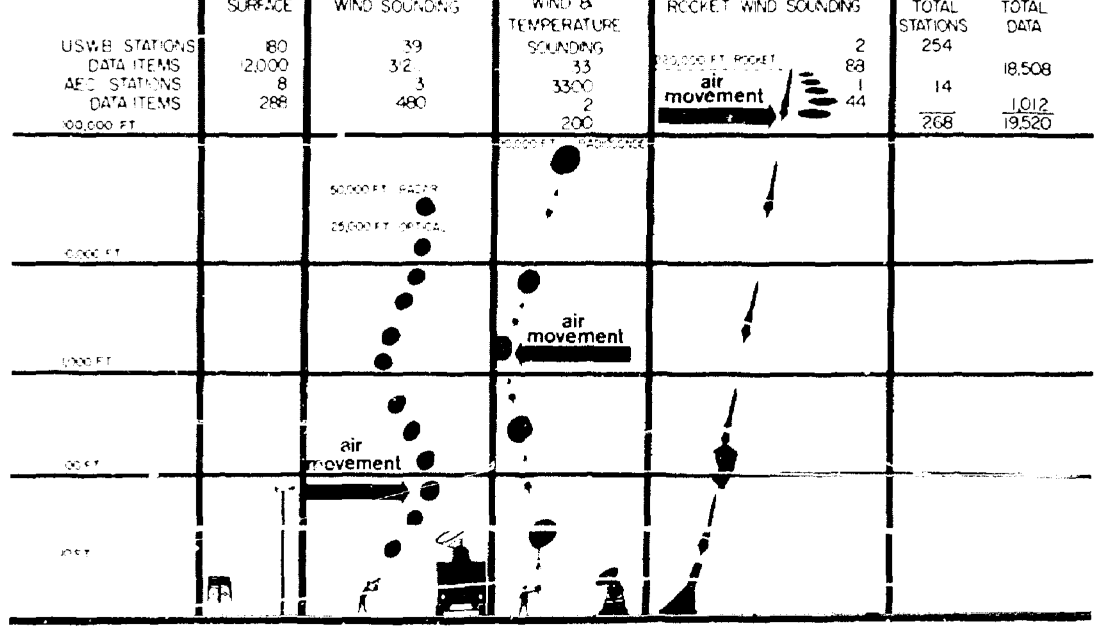
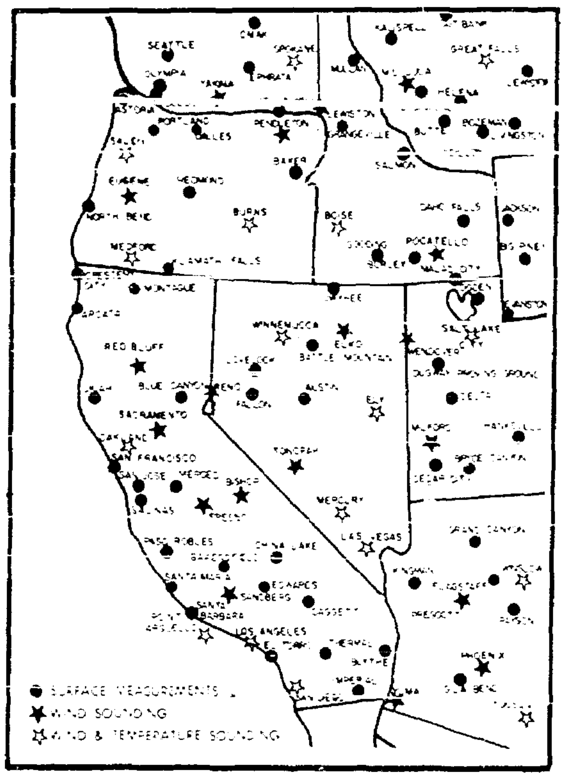


Figure 9.1. Available Weather Data from Western U. S. for Preparing One Weather Forecast.

Figure 9.2 shows the size and assembly of the two-stage JODY-DART wind sounding rocket used to obtain winds for the blast program by Sandia Corporation at Tonopah Test Range. Although expensive individually in comparison with balloon soundings, limited usage of these rockets produces the data for altitudes above that reached by balloons, and it is of great value in blast prediction.

Figure 9.2. Assembly of JODY-DART Wind Rocket.

Figure 9.3 shows the national weather network stations in western U.S. The scope of their data acquisition is indicated by the coded symbols. Each sounding station also takes surface data. Note the sparseness of stations in the immediate vicinity of NTS. To counter this weakness, Figure 9.4 shows that the USWB at NTS has set up an extensive network of surface stations and regularly operates at least three upper air sounding stations for underground tests. A capability is maintained to field up to 15 upper wind sounding stations for the more difficult reactor, cratering, or atmospheric tests with these temporary stations located in southern Nevada and adjacent areas, out to distances of 150 miles or more. The spacing between sounding stations is determined principally by the scale of atmospheric eddy motion which must be known in order to predict and interpret the trajectory of the radioactive cloud, secondarily by the degree or probability of hazard, and the cost.



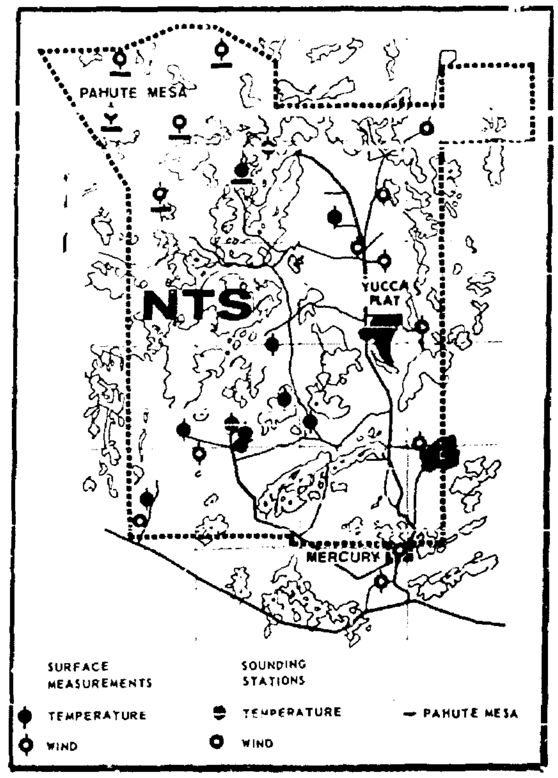


Figure 9.3 National Weather Network Around NTS. *Figure 9.4 Nevada Test Site Weather Network.*

Data Processing

The flow of weather data processing is shown by Figure 9.5. Nearly all northern hemisphere weather information is fed by teletype, radio, and other means into the National Meteorological Center at Suitland, Maryland, where it is processed initially in two somewhat independent series of activities. First, using traditional manual techniques, it is charted and subjected to searching air mass analysis, with tentative forecasts being prepared by subjective methods. Second, but at the same time, these same reports are received directly from the teletype lines by high speed computer, checked for internal consistency, analyzed in terms of the air momentum, shear, vorticity, thermal, and major terrain effects. These motions are projected out to many hours in the future by numerical extrapolation of their interrelationships. The end products of the numerical flow predictions are modified somewhat by the information developed subjectively, and the resulting forecasts clearly are superior to the purely subjective forecasts.

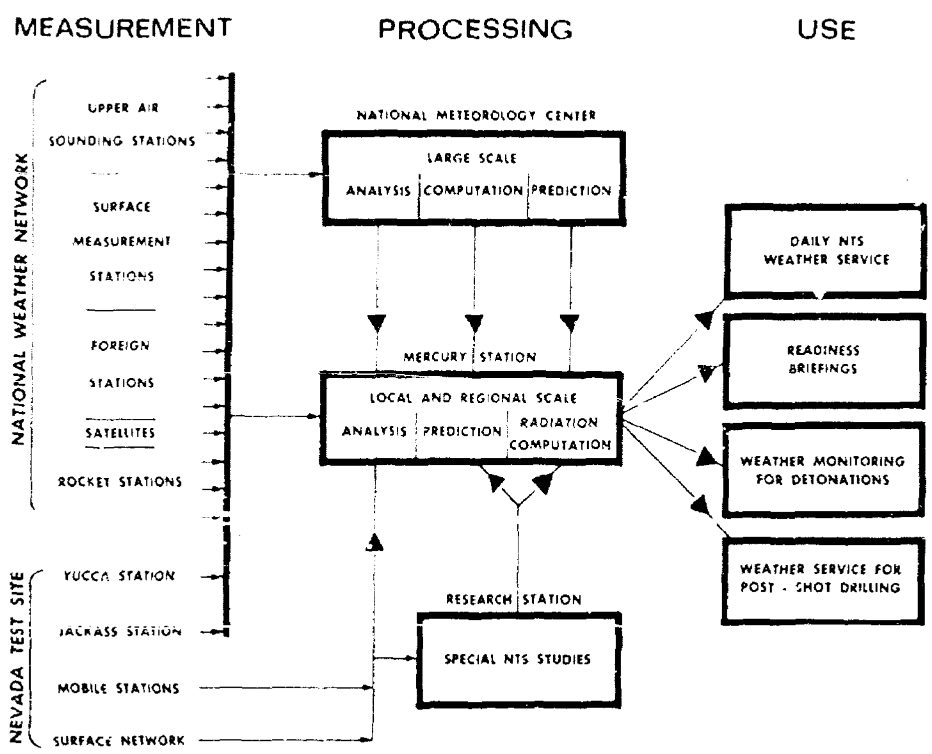


Figure 9.5. Flow of Weather Data.

The National Center transmits its results to the local and regional forecast offices all over the country in the form of national or hemisphere scale charts for both current and predicted weather patterns along with a written explanation.

The NTS weather station receives all of this information that it can conceivably use, which is several times as much as can be used in any one weather situation. The rest of it may be of value on other days or for other test problems. Therefore, all of this information must be continuously available. In addition, the local station receives, charts, and analyzes upper wind information coming directly from the western states and northern Mexico, adding in the special soundings taken locally in Nevada. It adapts or reinterprets the predictions received from the National Center, making them applicable to the local terrain, local and more recent measurements, local statistical guides, and the nuclear problems at hand.

Numerous statistical aids and models have been developed by the Research Station over the 8 years the Weather Bureau has been studying the Nevada Test Site weather. These are the result of accumulating large volumes of weather data, but are also an outgrowth of studying the effects of forecasts on nuclear operations, and relating actual radiation patterns with known atmospheric behavior.

The Mercury Weather Station uses all of the information at its disposal to produce the four categories of assistance to the NTS user organizations. These are:

(1) Routine daily forecasts for construction activities and miscellaneous safety problems, such as strong winds, thunderstorms, and perhaps severe temperatures.

(2) Preshot readiness briefings, discussed in further detail below.

(3) Weather monitoring, during the arming, final countdown, firing and period of waiting to make sure venting will not occur. During this period weather advice is available in case venting does occur to the test manager, scientific advisor, cloud tracking aircraft, USPHS, onsite radiological safety organizations, and numerous other concerned project leaders.

(4) Weather monitoring and predictions are provided for the use of the test manager and his safety organization in case the drillback for radiological samples releases radioactive gas.

A typical readiness briefing weather forecast, based on consideration of all these data studies, is illustrated in Figure 9.6 which shows the weather elements which bear on the safety and long-range detectability of an underground nuclear detonation. Many of these items are reviewed, revised, or expanded as time progresses and they are needed.

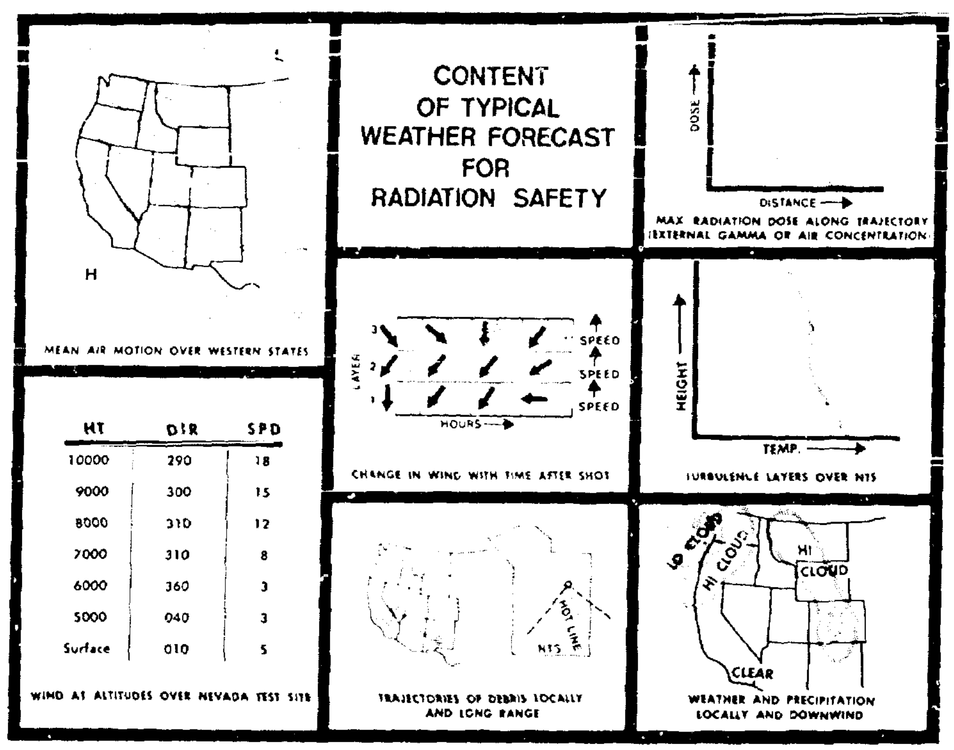


Figure 9.6. Typical Readiness Briefing Weather Forecast.

(1) For background information, the predicted mean airflow is shown over the western U.S.

(2) For the Nevada Test Site, the flow is broken down by altitude, giving the forecast wind for every thousand feet up to the maximum cloud height.

(3) Of course, the wind would not remain constant with time, so these wind changes are charted for several heights.

(4) The height to be reached by a vented cloud would depend on many factors, most important of which would be the depth of the turbulent layer of air near the surface. Thus, the temperature is predicted in relation to height, which will determine the height reached by the cloud.

(5) Trajectories are of primary importance, both on NTS where other test activities might be affected, and also downstream where milksheds, cities, ranches, and air lanes may be located.

(6) Precipitation along the trajectory might accelerate deposition, and clouds hamper cloud tracking aircraft, so clouds and weather are predicted for the entire area of concern.

(7) Finally, but far from least, all of the wind information is combined with an evaluation of the maximum conceivable venting to create a series of predicted maximum dose-distance curves. These may be simple dose rates due to immersion in the cloud, total infinity dose from deposited debris, or air concentrations of specific isotopes, depending on the nature of the experiment, the direction of the trajectory, and other factors.

PROBLEM AREAS

The main meteorological problem area is really the scope of the problem. There are too many variables, too few measurements, too little knowledge of the atmosphere, too high a cost, and all of these combined tend to argue against a full scale attack on the problem. However, there are portions in which progress is possible, and is in fact being made. A few are described below:

Limited Measurements

The scale of any specific measurement network is determined by the scale of that particular problem. To describe the motion of clouds of radioactive debris, atmospheric soundings are needed at least as close together in time and space as the changes in motion which are likely to affect the cloud. Studies have been made showing the occasional need for far more stations than exist at present.

If winds are steady for many hours or days, the national network schedule of two soundings per day at stations hundreds of miles apart, adequately describes the motion. This schedule is adequate to provide information about the large weather systems which are tracked nationally. In other cases, soundings at 15-minute intervals on a 2-mile station grid would not catch all of the significant changes. This is frequently true on the local scale within Yucca Flat in the hours right after sunrise. It sometimes takes more time to receive and interpret the meaning of large numbers of frequent soundings, and to predict future changes than for the changes to occur.

Slow Communications

The average time now used to receive information from the upper atmosphere, to interpret instrument dials and printouts, and to transmit this information nationally by teletype and facsimile to all stations requiring it, approaches 2 hours. Information obtained from instruments located within, or near, the Nevada Test Site can be processed locally much more rapidly, the time in some cases varying from instantaneous readout to a matter of 5 to 10 minutes in others. The measurment of upper level data takes longer, but this is only to wait for the balloon to ascend. At present, the area over which there is ability to obtain data so rapidly is far too small, usually extending only to tens of miles. A portion of the long-range development program of the Weather Bureau at NTS is to design, procure, and install appropriate instrumentation to extend the area over which there is rapid measurement and communications. By using radar to acquire winds by tracking balloons above the surface, there has been developed the capability of transforming upper wind information into a fallout plot within a minute or two of the time the rising balloon responds to the air motion up to the desired altitude. Design is progressing on facilities to display the upper wind information remotely and currently, wherever it is needed.

Data Processing and Computation

Current Methods — Present methods of data processing at the Nevada Test Site and subsidiary project sites include subjective analysis of data from all sources, application of statistical computations and information, and the use and modification of electronically computed analyses from the National Meteorological Center.

The analytical processes include subjective interpretation and correlation of raw data, both local and from distant sources, in order that the meteorologist can form a mental picture of what the atmosphere is doing. He then identifies which of these processes may be considered to be trends toward future motions. There are a number of extrapolation techniques that may be used for dynamic processes to project these motions into future hours. The resulting set of future motions must fit acceptable descriptive models in order to constitute a consistent forecast.

Having a tentative forecast, the meteorologist then checks it against climatology as there is no point in forecasting something which rarely happens, without very good reason. He also applies the appropriate correlations between weather variables which have been worked out for the Nevada Test Site over a long period of time.

The local forecast is always compared with that produced numerically at the National Meteorological Center. Since the latter is a calculation of equations of motion, based on data grid points about 300 miles apart over the entire northern hemisphere, it can give no consideration to small local phenomena. Therefore, this comparison covers only broad scale consistency. An exception is made in the use of the trajectories produced by these computations. Because of their extended range, long trajectories come more nearly within the grid scale of the numerical computation. Computer programming for the extraction of long-range trajectories originating at NTS has been completed recently, and the trajectory forecasts by numerical computer are being transmitted routinely to NTS twice daily.

Studies for Improving Methods — The interpretation of incoming weather data can be considerably accelerated and improved by the complete description or modeling of the large numbers of circulations affecting the southern Nevada area. The Weather Bureau has a group working continuously to improve these models.

Now that some 8 years of data exist for portions of NTS, it has been possible to develop some sets of correlations that are useful in forecasting specific situations. Many more of these are being computer programmed now for future testing. The large quantity and variety of meteorological information has always intrigued computer people, and this is one area of progress in developing new, faster, and more effective computer techniques.

Much publicity has been given to the use of computers to solve the equations of motion of the atmosphere on a hemispheric scale. Needed right now, but there is not yet an adequate practical set of equations for describing the smaller scales of motion needed to interpret early nuclear cloud motion. Such equations when appropriately modified will probably require as input:

(1) Boundary conditions from computations of larger scale motions, such as may be obtained from the National Meteorological Center.

(2) Numerous soundings from a relatively small but dense grid, covering Nevada and portions of surrounding states.

(3) Mathematical models of local terrain features. Since each new set of data may introduce changes, the equations must be recomputed frequently, perhaps as often as every 2 or 3 hours.

To prepare for these computations, many studies will be required to develop dynamic models of local air circulation. The eventual system will be costly and achieved gradually over many years. The courses to be taken are not clear cut, and those efforts being expended in that direction are currently rather small.

Air Transport Processes

The transport of any radioactive debris from nuclear tests influences the activities of large numbers of workers at and near the test site, but there exist relationships between the amount or distribution of debris and restrictions placed on activities. Therefore, the Weather Bureau attempts to predict the intensity of fallout; or more accurately, the intensity of radiation, since it does not all fall to the surface. A few of the factors involved in atmospheric transport are:

Formation of Initial Cloud — Injection of material into the atmosphere creates a cloud, which can be referred to as a nuclear cloud as opposed to the moisture cloud. What happens to the material in the nuclear cloud depends on several initial characteristics discussed in further detail below.

Movement (Trajectory) — Once a cloud has formed and no longer has buoyancy or vertical momentum, it is considered stabilized. It then moves with the ambient wind and becomes subject to changes in the wind as it moves downstream. The resulting motion becomes its trajectory.

Diffusion (Turbulence) — One of the characteristics of the atmosphere is its tendency to be turbulent and mix, with eddies tending to spread or diffuse horizontally and vertically, and along or behind the cloud, not always at the same rates or in the same direction.

Settling of Particles (Fallout) — Since many clouds contain particles of varying sizes and densities, these clouds produce fallout, which is simply the settling of the heavier particles down to the surface in relatively short periods of time.

Precipitation Scavenging — The atmosphere contains areas which include rain or snow showers, and sometimes broad areas of precipitation. Falling moisture drops tend either to gather the radioactive particles or to entrain them in their downward motion, or in the case of some gases to absorb the gases and carry them down to the surface.

Deposition (Surface Effects) — Fallout brought to, or near, the surface by one or more of these meteorological phenomena, the radioactive material then has available a variety of methods for deposition or attaching itself to the surface. Among them are settling, impingement, and adsorption. These methods depend on the nature of the material, the nature of the meteorological processes at work near the surface, and the nature of the underlying surface.

Let's now examine some of the difficulties of determining the structure of the initial radioactive cloud. Each underground venting case may be different, as discussed by Chapter V and Chapter XIII in the evaluation of containment. When material is injected violently upward through a fissure into the atmosphere under high temperature and pressure, the cloud may go thousands of feet high and carry with it large quantities of heavy particles of soil, which become heavy fallout particles. When venting has occurred through cased shafts, the upward momentum has been great but the solid particulate size was much smaller and sometimes even absent. In some cases, venting occurs as slow seepage of gases through a porous medium and arrives at the surface with no buoyancy, little pressure, and contains mostly long-lived gases. Cratering experiments sometimes even include small mushroom clouds at the top of the column of debris. The Weather Bureau is cooperating with the laboratories and others to learn as much as possible about the distribution of particles and activities in each of the possible venting situations; and is also engaged in long-range studies to determine methods for predicting the cloud heights and activity distributions in the effluent from nuclear rocket and ramjet engines, whether fired vertically, horizontally, or at some intermediate angle. Consideration has been given towards initiating studies to determine the feasibility of using infrared and laser radar techniques to learn more about airborne radioactive clouds.

Improvement of Fallout Computations

Figure 9.7 illustrates only a few of the major items of information useful in radiation prediction. Several acceptable procedures exist for converting a known vertical distribution of particles into a fallout pattern through a known distribution of wind and temperature. In the absence of known initial particle distributions, empirical distributions for atmospheric events have been arrived at by detailed comparisons between the measured fallout fields on the ground and the winds producing them, to infer what the initial vertical cloud must have been. For underground tests, also, each fallout pattern and wind field case is carefully analyzed for its contribution to fallout computation technology.

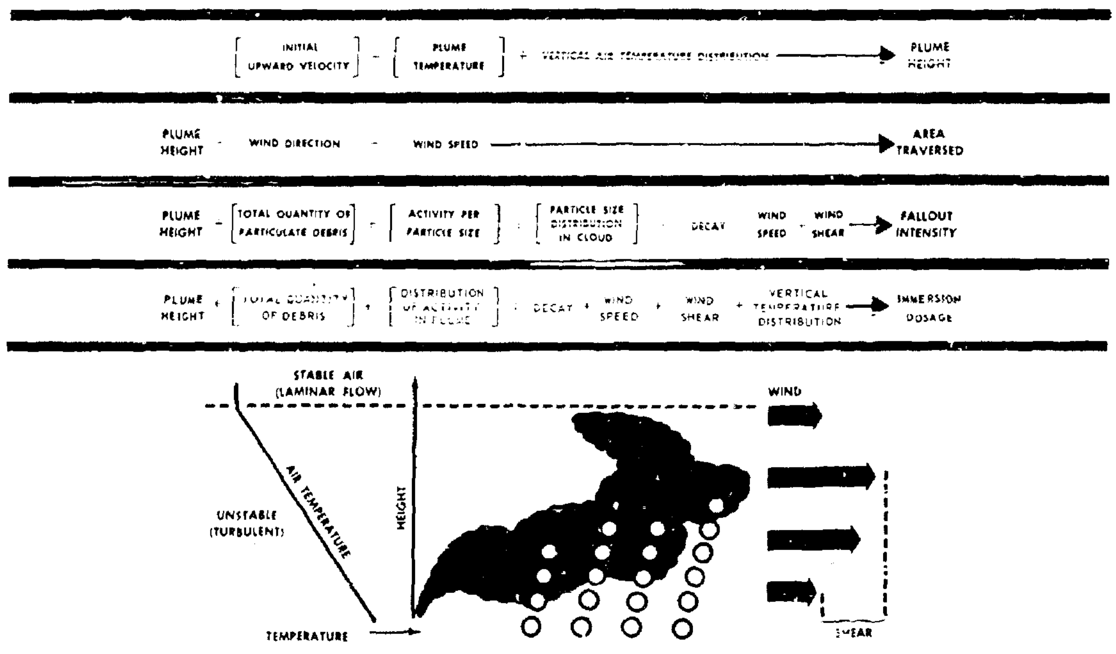


Figure 9.7. Input to Radiation Prediction.

The top line in Figure 9.7 shows that the initial upward velocity, plume temperature, and the vertical air temperature distribution are major parameters which determine plume height. This is illustrated at the bottom where a vented radioactive plume is shown rising through the unstable air near the surface and being distorted by wind shear. The first two parameters in the top line are entered in brackets because they are rarely known prior to the event or even until long after the radiation prediction has been made and has served its purpose. It is up to the radiation predictor to make a preliminary judgment on the basis of his experience as to what these two quantities will do to the prediction. The second line shows that plume height, together with the predicted wind direction and wind speed, determine the downwind area that will be covered by the cloud at some time during its travel. All of these can be estimated with useful accuracy. The third line indicates that the plume height combined with the total quantity of particulate debris, the activity on each particle size, and the distribution of these sizes through the cloud, the rate of radiological decay, the wind speed, and the wind shear all contribute to the prediction of fallout intensity on the ground. Again the bracketed parameters are rarely known prior to an underground event and are sometimes only approximated for even the best planned nuclear rocket engine test. In the case of nuclear rocket engines, LASL and other contractors are approaching these quantities both experimentally and theoretically. Much more information is needed to accurately fill these brackets. In the fourth line with the exception of large particle contributions, the same quantities plus the vertical temperature distribution contribute to the dose acquired by a man standing immersed in a passing radioactive cloud.

The rough indication coming from these radiation estimates gives the test management of AEC, REECo, and USPHS information on which to work, in case venting occurs, to place into effect countermeasures in the form of evacuating onsite workers, install or augment networks for the purpose of checking radiation and isotope levels, and if necessary even in extreme cases to divert milk supplies or other food distribution processes.

Documentation of the path and intensity of debris after the event, whether by actual measurement as accomplished by the USPHS, or by meteorological analysis as performed by the Weather Bureau, provides protection to the government from unjustified claims of radiation effects, and in the more scientific vein it provides information of value to the entire nuclear explosives industry in applying this form of energy to peaceful activities. Improvement in radiation prediction will come through careful documentation and study of all aspects of radiation release and transport for each nuclear event.

Precipitation Scavenging

Much has been written in the literature on various aspects of removing particles and gases from the atmosphere through precipitation of rain and snow. Nearly all of these experiments have been conducted either in the laboratory where water drop sizes were accurately measured and particle sizes occurred in limited ranges, or in very small portions of the atmosphere under well controlled conditions, or occurred in the larger atmosphere where the only measurement was made at the surface with no knowledge of the manner in which foreign particles and moisture drops came in contact, their initial concentration, or the vertical changes in rain intensity. As a result, there exists no information that can be applied directly to predicting quantitatively, the effect of precipitation scavening. Add to this the general inability of meteorologists to predict the timing, intensity, duration, and areal extent of precipitation, and it is apparent that precipitation scavenging is likely to remain for many years a large variable in radiation hazard evaluation.

Deposition

A problem in trying to interpret radiation measurements has been the micrometeorological conditions which influence the deposition and collection of debris. This was true even when levels were relatively high, during atmospheric tests. Now that concern exists even with the low levels of exposure, and with measurement technique being improved, it is becoming more important to establish the meteorological and terrain conditions which affect the delivery of radioactive material to the sampler. Fluctuations in radiation levels with time have in some instances appeared to be related to the diurnal fluctuation of thermal stability—with higher readings being obtained at night when the cloud came under a capping thermal inversion, or lower readings if the cloud was above the inversion.

Fallout intensities have been measured on all sides of variable terrain. The results have not always been consistent with meteorological theory, but it generally is believed, that with strong winds, fallout occurs a little more readily in the relatively quiet but somewhat turbulent air on the lee side of large obstructions than on the upwind side. If atmospheric testing is ever resumed, this should be one of the fallout studies to be pursued. In the meantime, a larger problem exists in understanding the deposition of radioactive iodine from both underground tests and nuclear rocket engine tests. The USPHS, with assistance of the Weather Bureau, is engaged in an extensive program of field measurement to study the uptake of radioiodine released from NTS and NRDS. This work is expected to be mostly with very low concentrations of iodine 131. The program is in three parts. First, routine measurements will be taken downwind of all underground tests, even though the possibility of iodine release is very small. Second, sampling programs using animals and instruments are planned in connection with reactor tests and cratering tests. Third, there will be experiments involving one or more irrigated farms.

Meteorological experience with exposure of sampling equipment in the paths of pesticide releases over vegetation in general desert surroundings has shown a multitude of effects, reflecting on the representativeness of samples. The exposure of radiological instruments and samplers in the atmosphere relative to the vegetation, to the surrounding hills, to the height of the cloud, and to irrigation methods can affect the sampler results by orders of magnitude, depending on local winds and on vertical temperature distributions which can change air concentration or prolong or shorten exposures of the instruments to the clouds of debris. Figure 9.8 illustrates one such relatively frequent effect. The continuous lines are isotherms, lines of equal temperature. The thin dashed lines are of equal iodine concentration. Note that the irrigated vegetation patch on the surface has evaporated enough moisture to cool the air overhead well below that of the temperature of the surrounding desert. An effective thermal barrier has formed over the vegetation from the resulting temperature increase with height. The top of the thermal barrier is shown by the heavy dashed line through which the radioiodine has difficulty penetrating. Therefore, measurements taken of radioiodine in that particular vegetation patch will show lower concentrations during the daytime than it should have. If the cloud had passed at night when exactly the reverse thermal condition would have applied, the cloud would have mixed downward more readily into the vegetation and would have received more deposition than the surrounding desert.

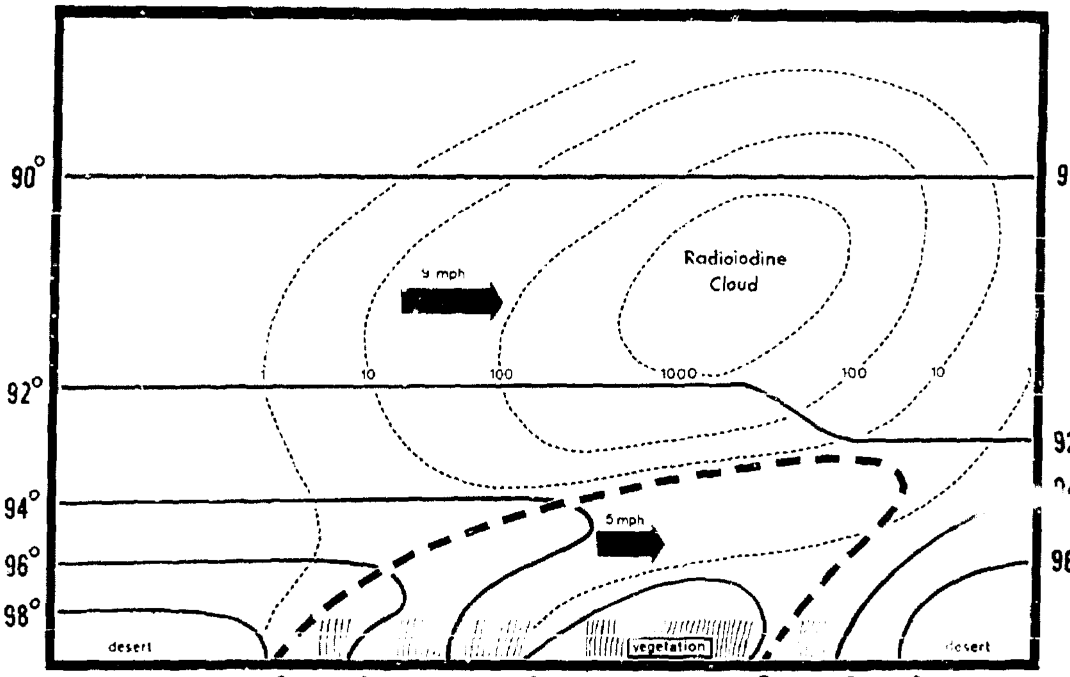


Figure 9.8. Vertical Wind and Temperature Gradients Affect Deposition.

The Weather Bureau is cooperating with the USPHS in their field studies by instrumenting each remote radioiodine sampling instrument and each farm patch enough to identify these peculiar meteorological phenomena, yet to be economical, with the hope of being able to assist in the interpretation of radioiodine results.

Long-Range Trajectory Prediction

One of the most interesting problems facing the radiological safety program at the present time, is that of predicting long-range trajectories of diffuse nuclear clouds. Air trajectories are of interest for their value in locating the areas downwind in which released radiation might impose safety problems. Cloud trajectories have been predicted for each atmospheric, cratering, and reactor event, and for all underground tests at Nevada Test Site. Venting from underground tests presents a particularly difficult problem in trajectory prediction. (See Figure 9.9.) The cloud, being introduced at the surface with little buoyancy, remains near the surface and early in its trajectory becomes subjected to the multitude of terrain-induced circulations in the mountainous western states. During the daytime, each cloud diffuses upward to the top of the mixing layer, which may be as shallow as 1,000 or 2,000 feet in winter or as deep as 10,000 or 15,000 feet in summer. Aircraft trackers who encounter the upward-diffused portion of the cloud (shown as the right trajectory in this case) may follow it and miss the lower altitude, possibly more intense, portion on the left. While still in the small, difficult-to-find stage, the cloud may also encounter directional or speed shear, or eddies which separate the upper from the lower part or the left from the right portion, such as is shown in central Nevada, creating multiple patches of cloud with each having a different trajectory. This has occurred on occasion, leading to confusion in the interpretation of aircraft and surface sampling results, because the aircraft located cloud wisps at points where nothing was detected on the surface and vice versa.

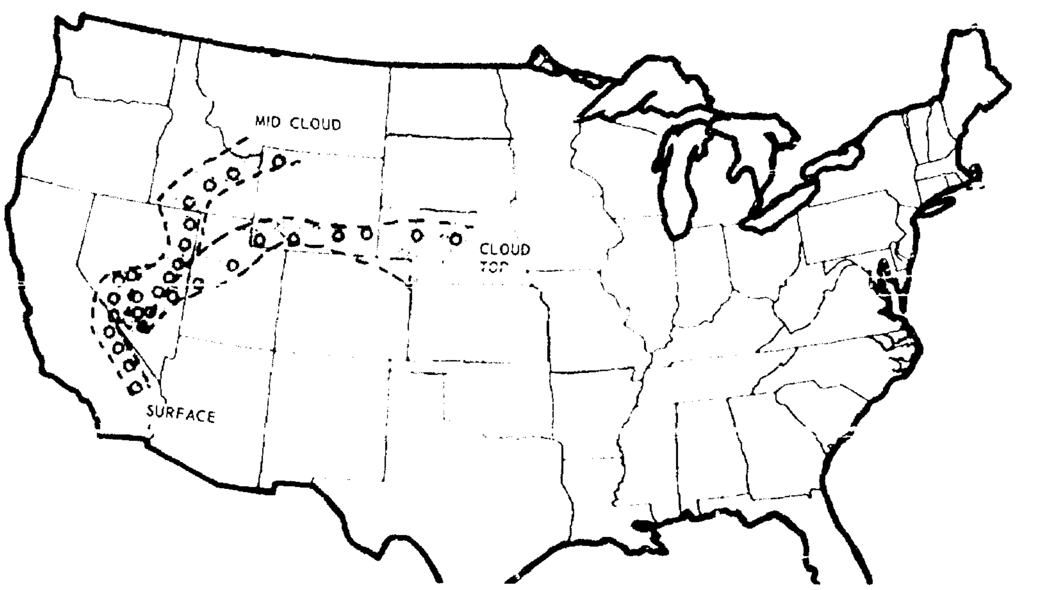


Figure 9.9. Trajectories of Diffuse Nuclear Clouds.

The Air Research Field office, ESSA, has established capability for floating plastic balloons, called tetroons, at preselected altitudes, for the purposes of marking the air for easier long-range tracking. Imagine the advantage of having each cloud mass tagged as shown by the circles in Figure 9.9, which represent balloons in the illustration. These balloons can be skin tracked by NTS based radar out to about 20 or 30 miles and to hundreds of miles by FAA and USAF radar, but the balloon-borne electronic beacons and receivers to be used in this system are still being tested and the system is not expected to be operational for some months. An airborne system for balloon positioning is also being developed. A crude model was tested in May, 1964 by the Weather Bureau Research Flight Facility in Miami, and a more comprehensive test was run in mid-June, 1964. Balloons released from the NTS were tracked across up to 300 miles of mountain area and covering 2 days of travel. The airborne system will probably not be available for several months in the miniature form required for the light aircraft used at NTS in routine cloud tracking. A major contribution of these balloons will be to evaluate trajectory prediction on a routine basis, thereby assisting in developing better prediction methods. Routine use of tetroons by many Weather Bureau stations is soon to contribute much valuable scientific information.

SUMMARY

The meteorological problems relating to nuclear detonation safety extend most of the way across the spectrum of weather interpretation and prediction. The effort expended in the field of meteorology has been relatively small due to cost and measurement difficulties. The Weather Bureau and other federal agencies, engaged in studying the improvement of weather prediction, have expended hundreds of millions of dollars over many years developing equipment for useful measurements, for data processing, for developing statistical approaches, and more recently have developed mathematical and computer approaches to many of the very same problems which affect the weather support of nuclear testing. The Weather Bureau Research Station, in operating the AEC supported meteorological service at NTS, has tried to avoid duplicating work that is being effectively pursued elsewhere. Instead, results of other investigations are used as much as possible with concentrated effort being given to the solution of weather prediction problems which are peculiar to NTS and to those transport problems which are more applicable to nuclear detonation safety, or are not being attacked adequately elsewhere.

CHAPTER X

ONSITE RADIOLOGICAL SAFETY

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INTRODUCTION

The Radiological Sciences Department of the Reynolds Electrical & Engineering Co. (REECo), holds an enviable position in the nation's nuclear program. REECo contractually represents the AEC/NVOO and participates in many interesting and varied nuclear test programs. The range of activities is quite broad, and includes support for many scientific programs undertaken by the testing laboratories and agencies at the Nevada Test Site and at other selected locations. For example, these services include direct support of the scientific laboratories in technical programs associated with weapons and reactor tests, support in handling kilocurie radiation sources, and routine radiological maintenance of the Nevada Test Site complex.

The function of the Radiological Sciences Department is to provide complete, integrated health physics and technical support to users and contractors at the Nevada Test Site. Specifically, the following requirements are identified in the Nevada Test Site operating procedures:

(1) Provide a pool of certified radiation monitors, radiological instruments, and equipment to the testing laboratories, user organizations, and contractors.

(2) Maintain an active onsite environmental surveillance program and distribute information to concerned agencies.

(3) Provide radiological engineering assistance and training.

(4) Control and document radiation exposures to people.

(5) Prepare final reports with accumulated radiological data from significant tests or test series.

(6) Continually upgrade technical competence to meet the challenges of new complexities and demands in the testing program.

BACKGROUND

Before considering how the overall radiological safety program is carried out, it may be appropriate to examine the scope of this program. Accordingly, a review of a few of the developments that have influenced the department's efforts over the years is warranted.

Since the inception of the Radiological Sciences Department in 1956, the organization of the program, its equipment, facilities, and capabilities have undergone revolutionary change — especially during the last 3 years.

Although potentially acute, the radiological health problems were simple and straightforward during the days of atmospheric testing. The hazard limits of an area were quickly defined and easily controlled. Reentry personnel were simply excluded from areas until the atmosphere had cleared. Radiation hazards were limited largely to external exposure, and therefore, were easily monitored and controlled.

New problems appeared, primarily in tunnels, during the development of underground test techniques. Most of the radioactive debris was effectively confined at the point of detonation. But reentry into the tunnels was complicated by both air-borne radioactive contamination and toxic materials. Occasionally, failure of the stemming barrier in a tunnel complex introduced widespread contamination problems and necessitated stringent control procedures.

The approaches to underground testing changed again when vertical shafts were used for tests. Occasionally, at zero time, there was pressurized venting which released radioactive gases into the atmosphere. Samples were recovered through postshot drilling and gradually the time between detonation and ground zero penetration was reduced from weeks to hours. With this narrowing of time, the magnitude of problems increases manyfold. On drillback, toxic gases and explosive mixtures were encountered, along with some leakage of the radioactive gases.

Monitoring and area access control at the work sites extended far beyond the problems associated with short-term health controls. The craftsmen — drillers, miners, and radiation monitors — required for reentry worked under the standard control limits for occupational exposure. (This procedure was significantly different from those of the testing operations during the 1950's when special dose provisions were sometimes granted for a short-term series.) These specialized people developed skills peculiar to reentry operations. It was essential, then, that radiation dose allotments be precisely defined, thus giving to the exposure-control problem an importance greater than that of the health factor.

During the past year, considerations relating to the dispersal of radioiodine contamination and the test ban treaty have brought to bear new pressures. Consequently, the radiological ground rules have been changed again.

Radiological safety to workers remains a prime factor. But all procedures, especially those dealing with documentation of data, must be continually scrutinized to ensure that international political commitments are upheld. Thus, the accumulation of voluminous and detailed data (both negative and positive) has become vital to the nation's nuclear testing program. All radioactive material transported or escaping by any means from the point of production must be accounted for and fully documented. The sampling methods and the subsequent analysis needed to produce these data are challenging to say the least.

SCOPE OF OPERATIONS

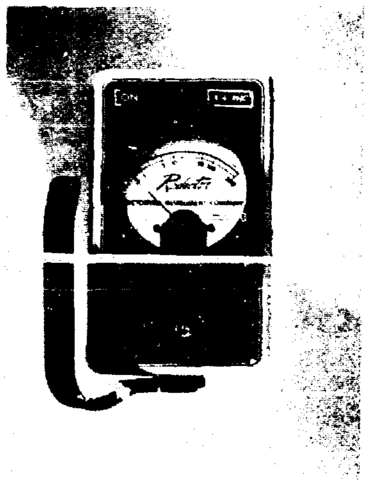
An understanding of the current radiological safety program is now appropriate. It can be obtained best through a consideration of the support activities provided during and after a typical test.

The services of the Radiological Sciences Department include radiation monitoring and decontamination, external and internal dosimetry, radiochemistry and low level counting, radiological engineering for health physics procedures and equipment, instrument maintenance and calibration, radioactive waste management, and source control. These services are adapted for normal site maintenance, for specific tests, and for the recovery of radioactive samples by postshot mining and drilling.

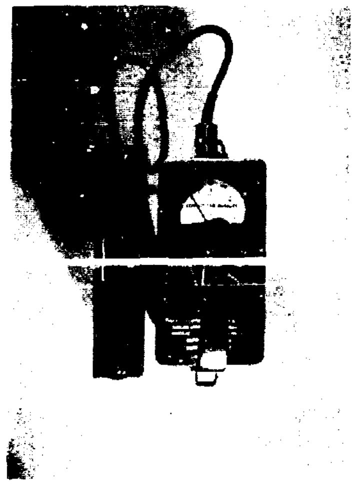
The test director of the laboratory in charge of a particular test is responsible for the safety of people in test areas during tests and until scientific data are recovered.

Radiological support is provided to the test groups during these periods, and the requirements are stipulated by the test group before an event. When test areas revert to the control of the AEC test manager, support continues for radiation area control, for environmental surveillance, and for nontest oriented programs by users and contractors.

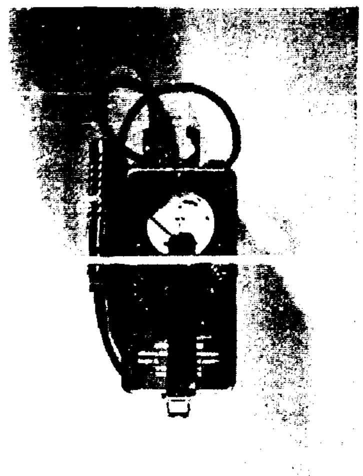
Extensive radiological data for each test are obtained by radiation monitors and health physics technicians. They use a variety of radiation detection and sampling instruments as shown in Figures 10.1 and 10.2. This monitoring and sampling effort is supplemented by a network of remote monitoring stations and by a mobile, site-wide air monitoring program.



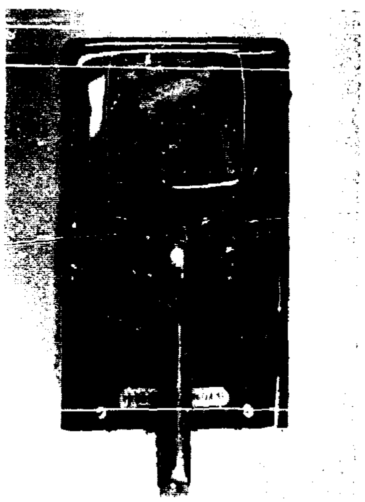
BETA, GAMMA HIGH AND LOW RANGE SURVEY METER



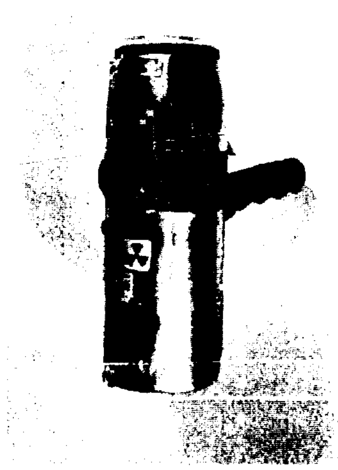
ALPHA SURVEY METER



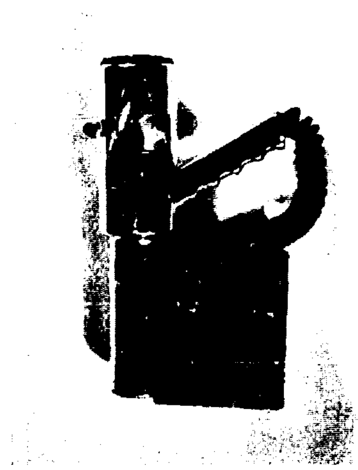
BETA, GAMMA GM-COUNTER ION-CHAMBER INTERMEDIATE RANGE



ALPHA, BETA GAMMA HIGH AND LOW RANGE SURVEY METER



BETA, GAMMA HIGH AND LOW RANGE SURVEY METER



GAMMA LOW RANGE SURVEY METER

Figure 10.1. Portable Radiation Survey Instruments.

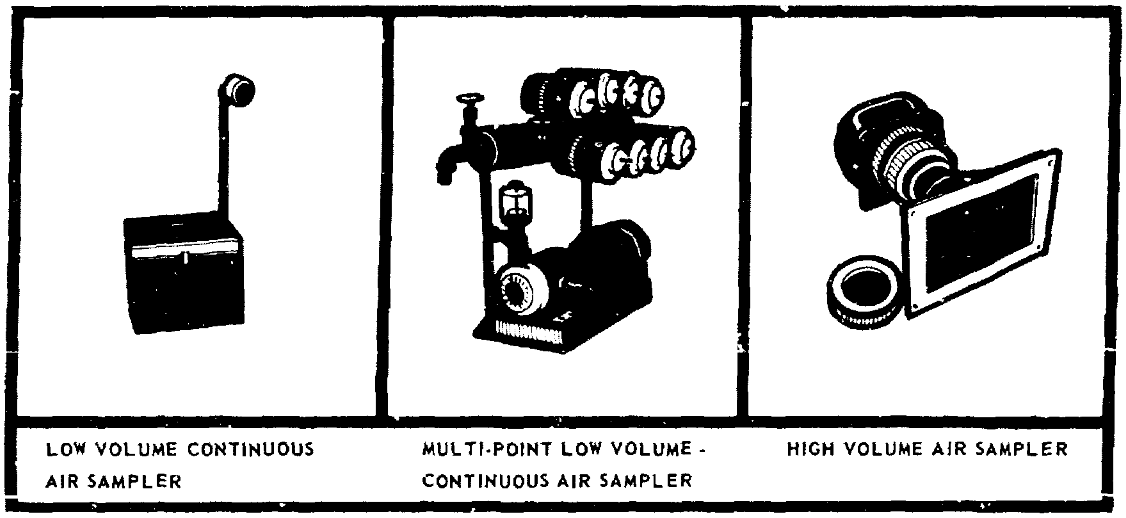


Figure 10.2. Portable Air Samplers.

Members of the department staff participate with the AEC and the test groups in planning for tests and in the readiness briefings before detonations, and with the advisory panel during postshot drilling.

Staff members are thoroughly trained and experienced in the application of field procedures, and in the actual use of associated equipment. Under emergency conditions, or during unusually demanding test conditions, the staff participates both in carrying out and supervising field operations.

Before each test, radiation monitors are on duty at road blocks on the perimeter of the test area, and at manned stations within the controlled area. The monitors continuously survey the local region during and immediately after the tests for an assay of conditions before personnel are permitted to enter the area. Other monitors make surveys for radiological evaluation of test areas immediately following detonation. A team of monitors is assigned to cover reentry parties.

Two mobile teams, equipped with a full range of radiation detection and air sampling devices, are within the forward test area at zero time. The movement of these teams is directed from the control point as they measure radiation levels and collect samples in downwind locations if radioactive debris is released. These data are used by the U.S. Weather Bureau in development of models for fallout prediction, as well as for other documentary purposes.

The field supervisor maintains communications with members of the management staff who are located with the test manager's advisory panel. Contact is also maintained with the U.S. Weather Bureau, the U.S. Public Health Service, and the test group director.

A van-type truck containing safety equipment, radiation detection instruments, air sampling equipment, and personnel dosimeters is positioned at the main security barricade near the actual test area. As soon as radiological conditions are assessed after a test, the van is moved to a more convenient location for service to people in the immediate test area.

One hundred and forty-eight small mobile air sampling trailers are used to assist the test groups in source evaluation, to measure and document released radioactivity, and to augment normal environmental surveillance. (See Figure 10.3.)

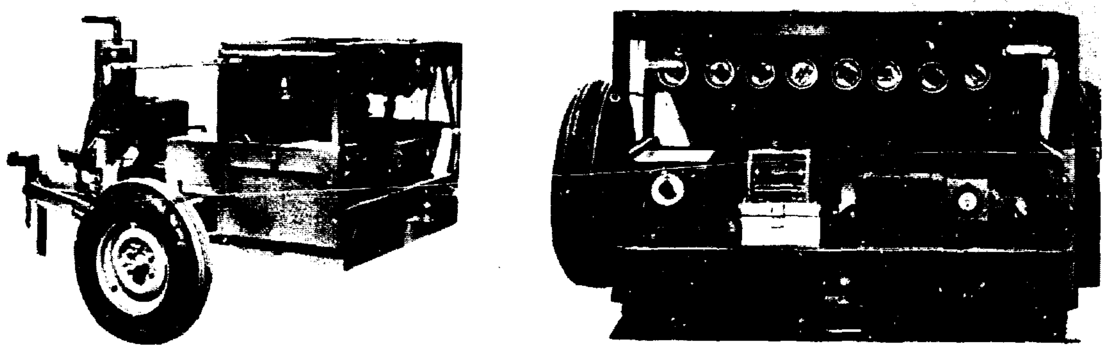


Figure 10.3. Mobile Air Sampler.

At least 18 of the units, and as many as 45, may be requested by the test group for a particular event. Each unit has eight sampling heads capable of continuous or sequential air sampling in addition to a gamma detector and recorder. The samplers are placed at intervals around the test area before each test. The equipment remains in use through the conclusion of drilling operations and is not removed until the area is secured.

Adhesive surfaced trays for collecting samples of airborne dust are positioned at quarter-mile intervals on roads surrounding the test area. If there is an escape of radioactive debris during the operation, the collectors are retrieved and analyzed by the laboratory, and the data documented.

Two hundred remote radiation detector channels are available to continuously evaluate radiological conditions and assess exposure hazards before the test area is entered after detonation. (See Figure 10.4.) Approximately 30 of these units are positioned in each test area before an event. The detectors are placed in circular arrays, at appropriate distances from surface ground zero. The distance of the detectors relative to surface ground zero varies with the device yield and the predicted wind direction. An additional 45 permanently established remote radiation detector stations operate continuously throughout the Nevada Test Site.

Radiological data obtained by remote monitors are carefully evaluated. When it is determined that the general test area is radiologically safe, survey teams are sent to monitor the area personally. Each team of two monitors, equipped with survey instruments, enters the area by a specified route. A detailed radiological survey of the area is made; readings are transmitted by radio to the control point, evaluated, and recorded.

Upon completion of the initial survey, a mobile radiological control station is set up near the surface zero site. All persons entering or leaving the radiation area must pass through this facility. Those entering the area are dressed in the necessary protective clothing, outfitted with respiratory equipment if appropriate, and issued self-read pencil dosimeters. Personnel and equipment leaving the area are carefully monitored, and decontaminated, if necessary. Film badges are exchanged, dosimeters are retrieved and read, and a composite dose record is made, reflecting the personnel dosimeter readings which are added to previous exposure records. Film badges are forwarded to the dosimetry laboratory for evaluation and official documentation.

Radiological services during the recovery of scientific samples include all aspects of the department's capabilities. Gamma radiation detectors are placed at all sensitive locations. The detectors are linked by hard wire to recorders and meters in the area control facility. This instrumentation is augmented by the array of continuously operated air sampling trailers surrounding the work area. Samples may be screened and gross counted in a nearby mobile laboratory as shown in Figure 10.5, and then completely analyzed in the main laboratory for final documentation.

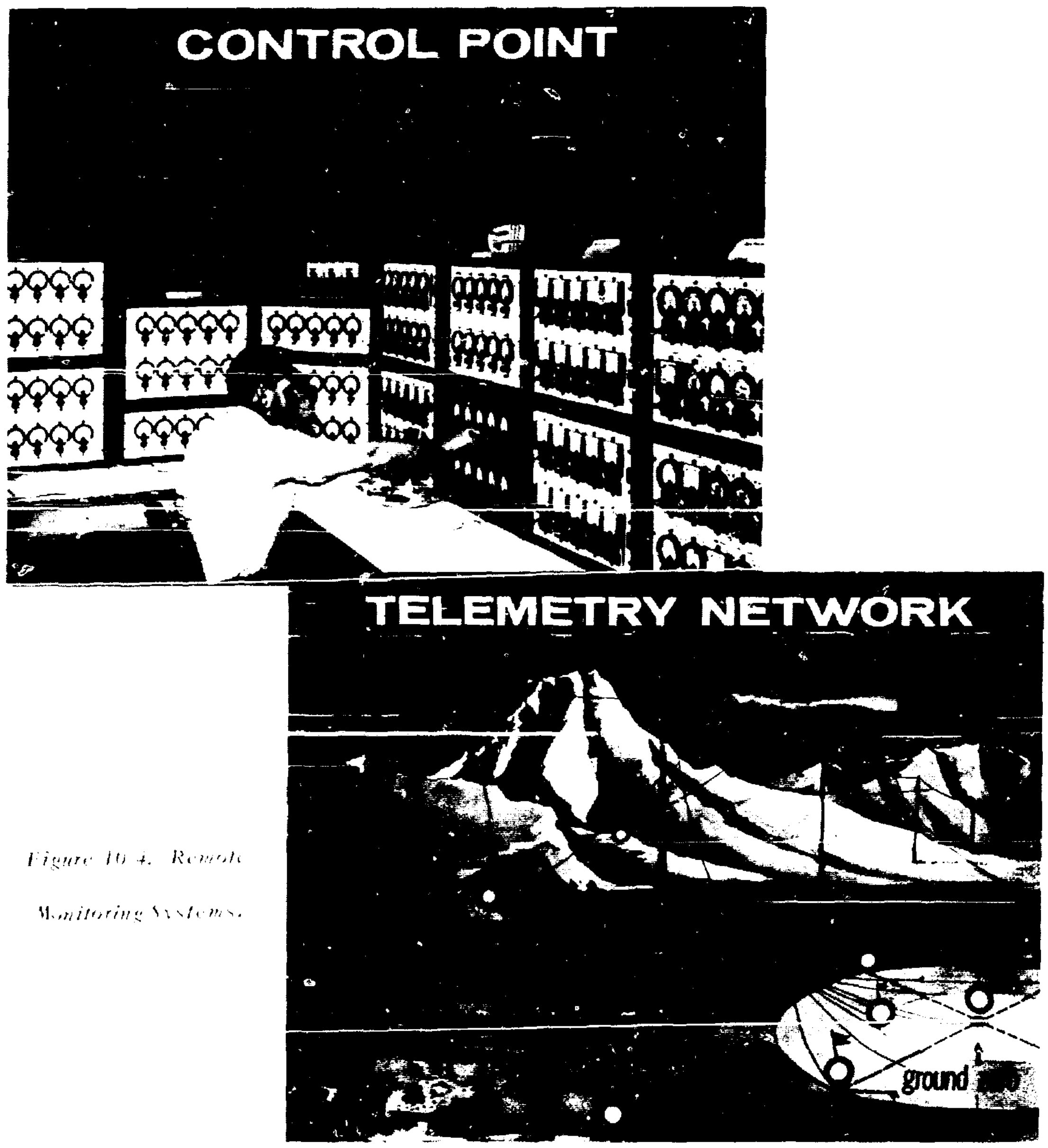


Figure 10.4. Remote Monitoring Systems.

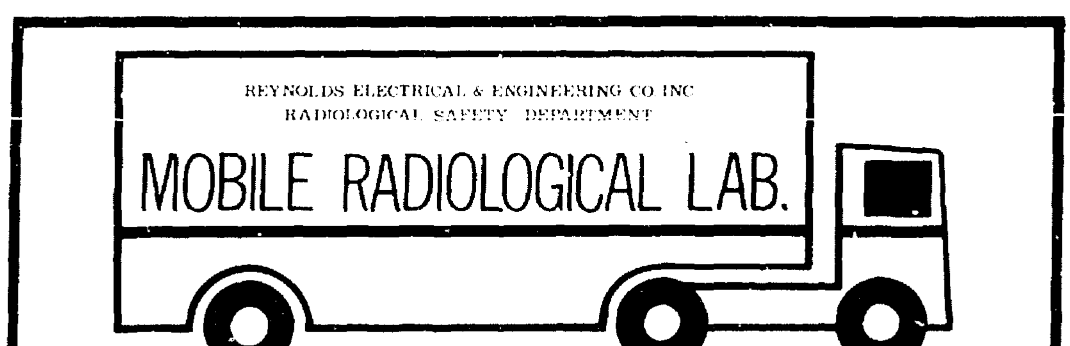


Figure 10.5. Mobile Laboratory.

A team of monitors is assigned to each shift during postshot drilling operations. Typically, personnel are used in the following ways:

(1) Monitors at the area control facility ensure compliance with all area entry and exit requirements. They document personnel exposures and maintain a continual and complete log of activities in the controlled area. One or more monitors are continuously in the work area to survey work activities, to gather and evaluate special samples, to ensure that protective equipment is properly used, and to inspect all personnel dosimeters periodically.

(2) During the retrieval of radioactive debris from the detonation point, monitors survey and extract the core samples. Using tongs, lead gloves, aprons, and other necessary protective equipment, they place the radioactive core samples in shielded containers and arrange for shipment in compliance with regulations. At the completion of recovery operations, monitors decontaminate all equipment and vehicles, and finally secure the area by use of barricades and warning signs.

The 227 people, who stage this program at every test location in the 1,200 square miles of the Nevada Test Site, travel more than a million miles a year in providing services. The dosimetry laboratory processes and records the data on approximately 200,000 personnel film dosimeters annually. Field support is provided for more than 20,000 actual entries into radiologically controlled areas in a typical year.

Two categories of reported data are prepared. These consist of site maintenance reports and test oriented reports. The site maintenance reports are not related to test activities, and are prepared on the following basis:

Exposure and Dose Report	Daily
Activities Report	Monthly
Dose Summary	Monthly
Source Locator Report	Bimonthly
Dose Summary	Quarterly
Environmental Surveillance Report	Semiannually
Radioactive Waste Disposal Report	Semiannually
Dose Summary	Annually

Test oriented reports are prepared as a primary requirement for the AEC or test group, or both, as follows:

Event Support Plan	AEC and test group
Postshot Drilling Procedures	Test group; copy AEC
Zero Time to H + 6	AEC and test group
H + 6 to Start of Drilling	AEC and test group
Postshot Drilling "Button-Up"	Test group; copy AEC
H + 30 Preliminary	AEC and test group
D + 3 Weeks Final	AEC; copy test group
Series Final	AEC and test group

FUTURE IMPROVEMENTS

Plans for the future are directed toward increased sophistication of capabilities and economy of operation. Investigation of procedures, techniques, and equipment is stressed. Shortly, the sample analysis program will be automated by electronic data processing equipment (See Figure 10.6.)

Selective recruiting has been rewarding. There is evidence of substantial strengthening of professional capabilities in health physics and radiological engineering.

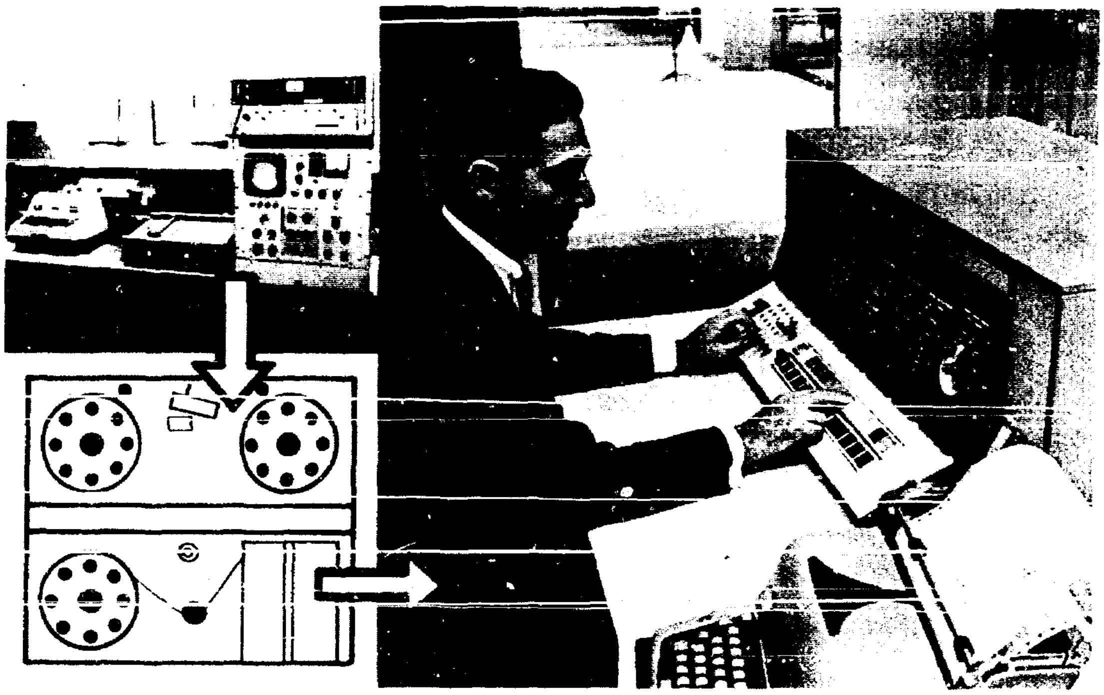


Figure 10.6. Electronic Data Processing Equipment.

New applications of remote monitoring and automated work area air surveillance are now in the testing stages. These developments show prospects, not only of improved safety surveillance, but of increased economy as well.

Comprehensive audit programs for calibration, radiochemical procedures, low level counting, and health physics procedures are being developed.

CONCLUSION

In summary, ons. . radiological safety services at NTS are characterized by their dynamic nature. Support is provided to a number of users, such as the Los Alamos Scientific Laboratory, Lawrence Radiation Laboratory, Sandia Corporation, and the Department of Defense, each of which requires significantly different services. The primary objective of the Radiological Sciences Department is to sustain a technical service which reflects state-of-the-art capability.

CHAPTER XI

OFFSITE RADIOLOGICAL SAFETY

United States Public Health Service
Las Vegas, Nevada

SCOPE OF OPERATIONS
By John R. McBride; Assistant Officer in Charge

INSTRUMENTATION AND ANALYSIS
By Allan E. Smith; Chief, Physics and Data Analysis Service

RADIOIODINE FIELD INVESTIGATION PROGRAM
By Delbert S. Barth; Chief, Bioenvironmental Research Program

SCOPE OF OPERATIONS

The general objectives of the Public Health Service programs for the AEC are attained by providing a Radiological Safety Program in designated offsite areas adjacent to the Nevada Test Site and other testing locations as requested. The purpose of these programs is to document the radiological situation through comprehensive environmental sampling and radiation monitoring in support of the nuclear testing activities. As required, a public contact and information program provides assurance to the public that all reasonable safeguards are being employed for protection of public health and property from radiation. The Public Health Service performs special field investigations to determine biological effects, and necessary investigations of incidents which might be attributed to radioactivity that possibly could result in damage claims or create unfavorable public opinion.

In 1958, the first permanent staff introduced an environmental sampling program within the designated offsite area. This continuous sampling program, taken at specific intervals, includes air, water, milk, vegetation, and sometimes soil. In 1959, the Public Health Service established the Southwestern Radiological Health Laboratory in Las Vegas.

Several types of portable monitoring equipment are used, depending on the type of testing. Normally there are 10 to 20 monitors available downwind, who are dispatched in trucks equipped as shown in Figure 11.1 with two-way radios, monitoring instruments, background recorders, portable air samplers, and portable generators.

In Figure 11.2, a whole body counter is shown mounted on a railroad car with a loaned passenger-type U.S. Army hospital car. This unit is located at Nellis Air Force Base in Las Vegas. The equipment is completely calibrated and available to contractors at the test site or anyone else who might need the facility at such times as may be necessary.

Sampling aircraft as shown in Figure 11.3 is one of the recent acquisitions. An air sampling program, utilizing two C-45 aircraft, began about 3 years ago. Two addi-

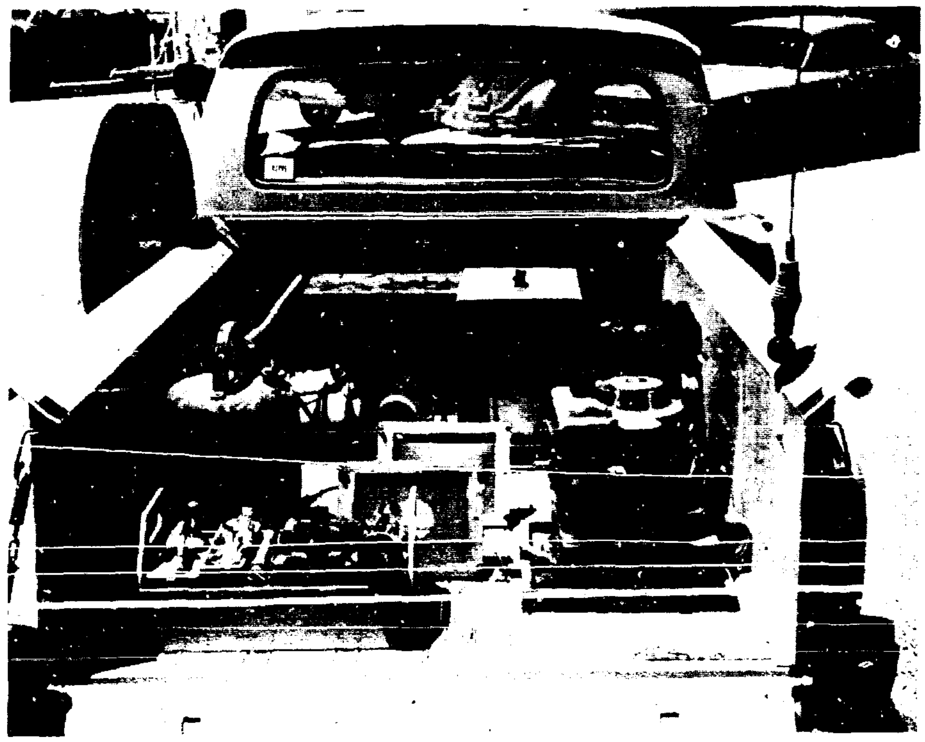


Figure 11.1. Mobile Ground Monitoring Equipment.

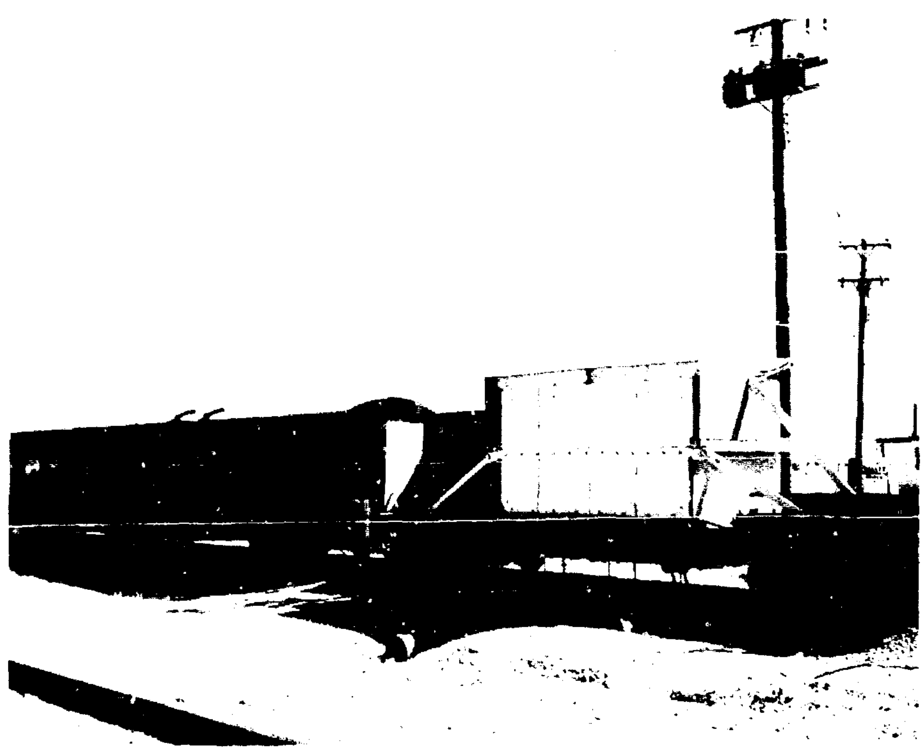


Figure 11.2. Mobile Whole Body Counting Facility.

tional C-45 aircraft have been acquired and have undergone considerable modification to increase aircraft safety. As final checkout and instrument calibration is completed on the two modified aircraft, the original C-45 aircraft will be phased out. The C-45 aircraft are primarily used on shot day, and orbit near ground zero at shot time. The sampling aircraft can take both a gas sample by using a cryogenic collector and particulate sample by utilizing an electrostatic precipitator collector. These aircraft also serve to give the monitors an idea of where the cloud is, its intensity, and its rate of movement and direction.

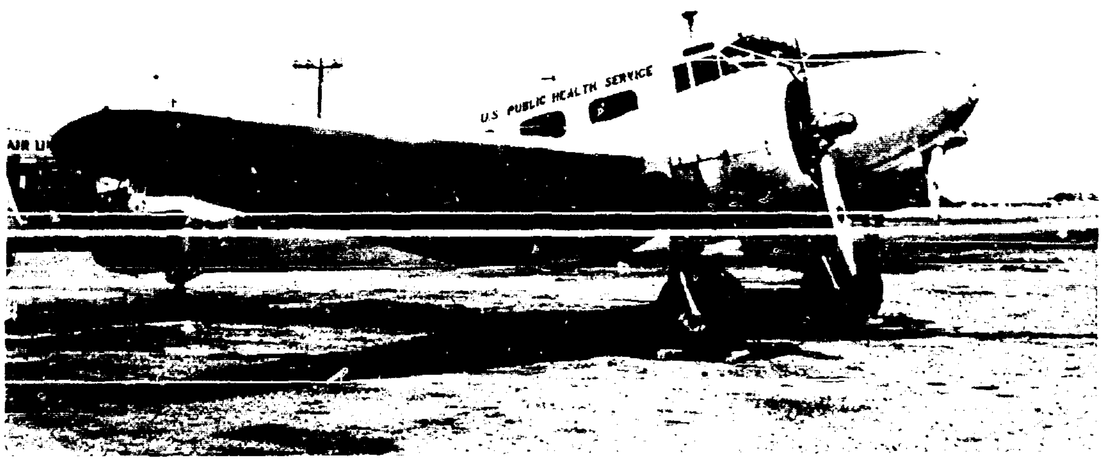


Figure 11.3. Sampling Aircraft.

The nose probe used on the aircraft is shown by Figure 11.4, and the retractable belly probe is shown by Figure 11.5.

Figure 11.4. Aircraft Nose Probe.

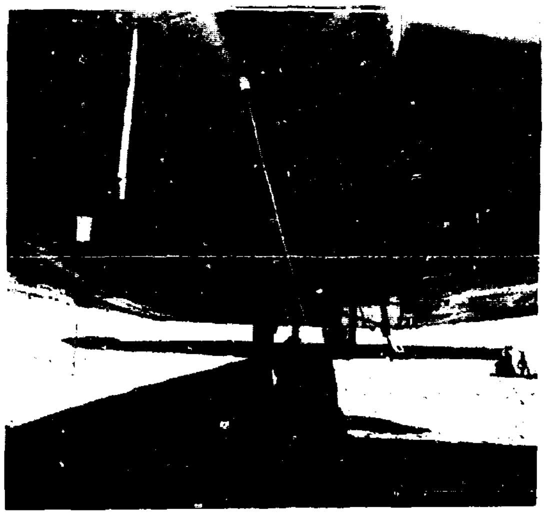


Figure 11.5. Aircraft Retractable Probe.

Figure 11.6 shows the locations around the test site of the air sampling stations which are in constant operation. If it appears the cloud might traverse a gap in the network, the field monitors may be directed to set up additional stations with equipment carried on the trucks. All samples are returned for analysis to the laboratory on the campus of the Nevada Southern University at Las Vegas. The currently operational air sampling stations outside Nevada are shown in Figure 11.7. All permanent sampling stations are operated by people in the area, with the filters being returned by air mail on a daily basis. Figures 11.8 and 11.9 show milk and water sampling stations, respectively. Figure 11.10 shows dose rate recorder locations.

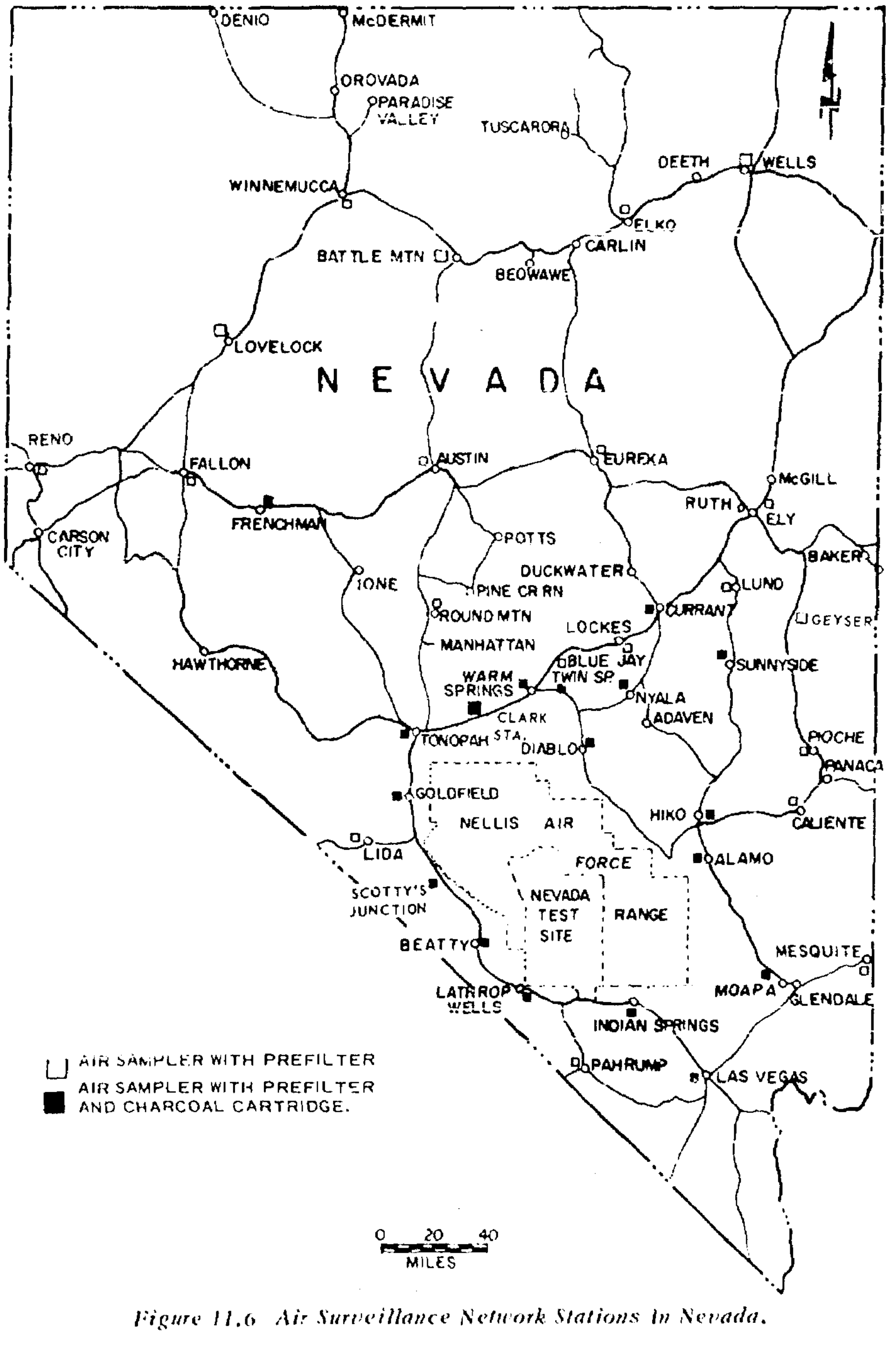


Figure 11.6 Air Surveillance Network Stations In Nevada.

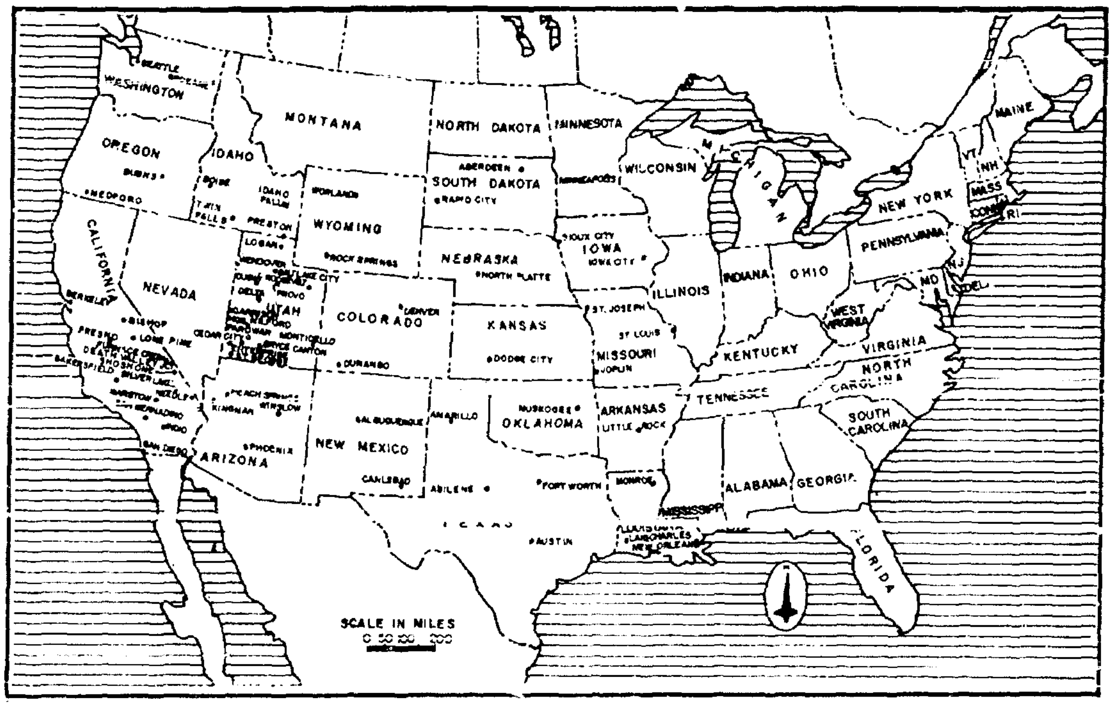


Figure 11.7 Air Surveillance Network Stations Outside Nevada.

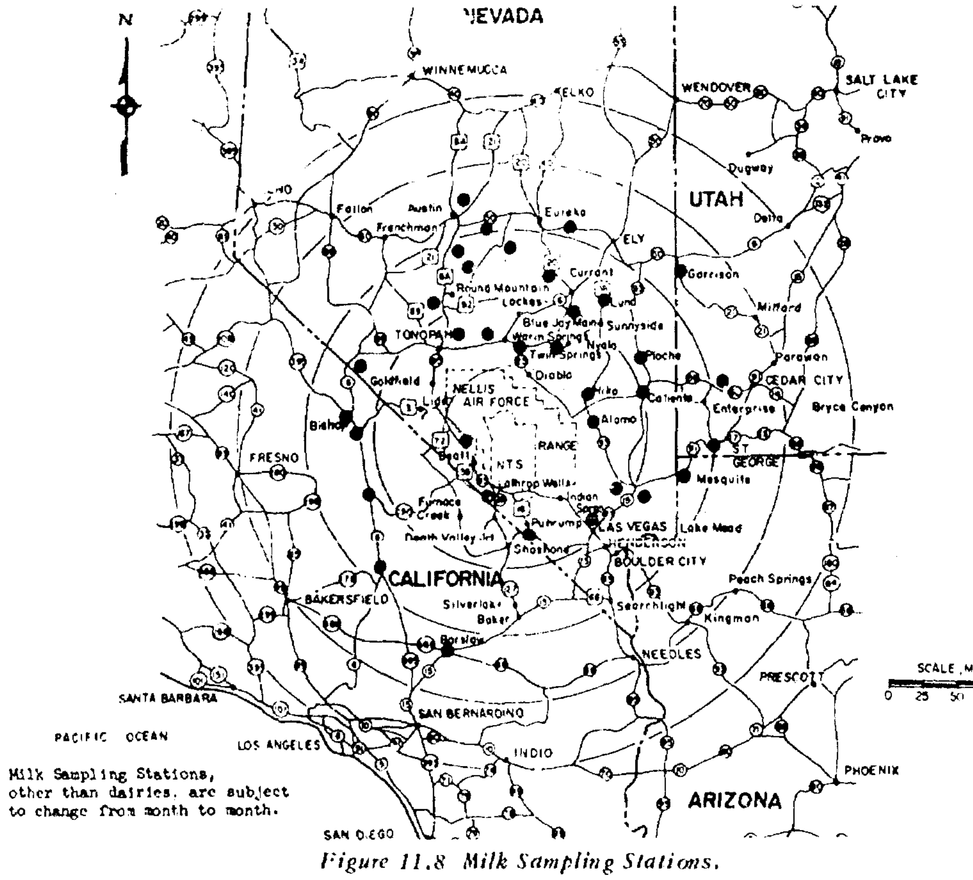


Figure 11.8 Milk Sampling Stations.

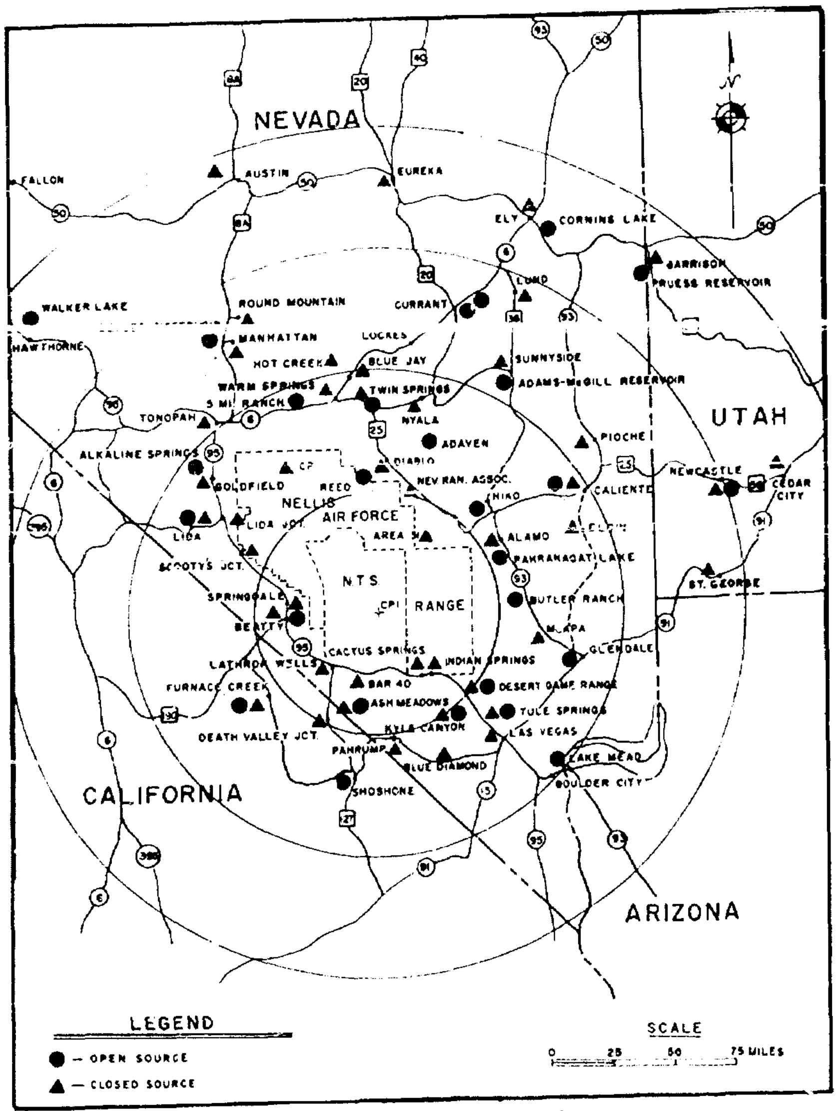


Figure 11.9 Water Sampling Stations.

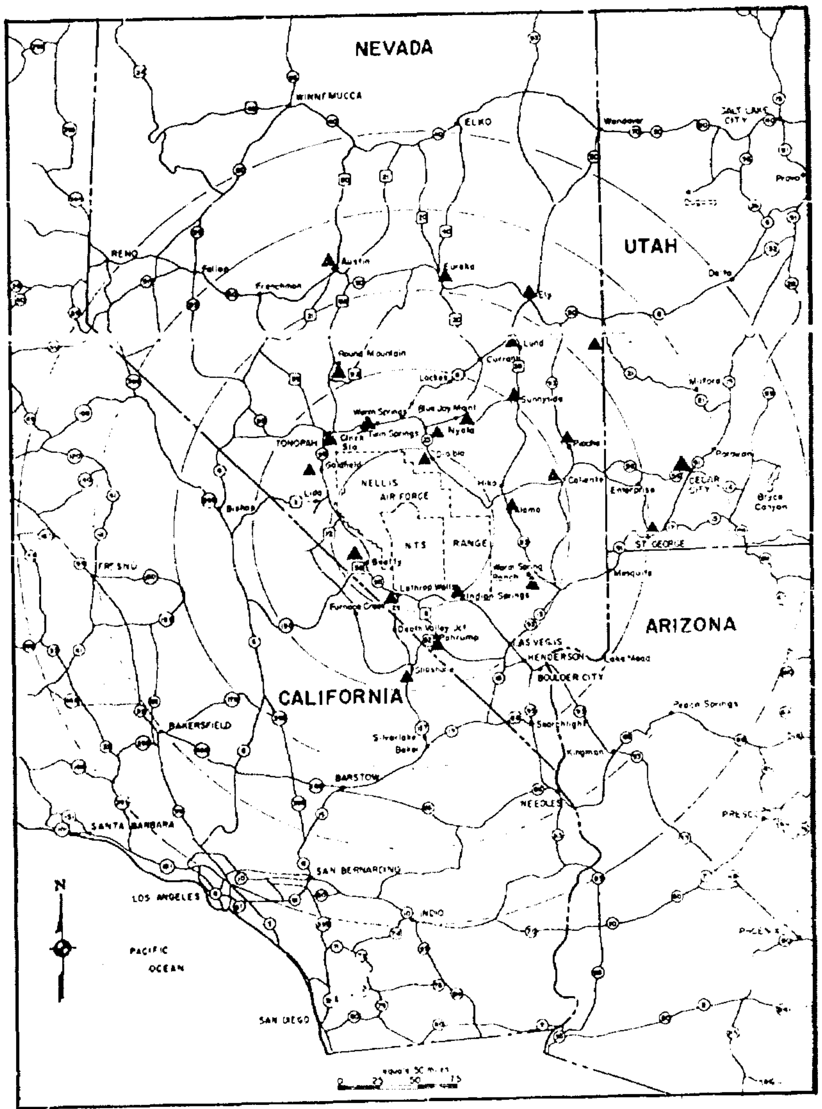


Figure 11.10 Dose Rate Recorder Locations.

Some other accomplishments during the past 10 years include a film badge program which was established in 1954. Originally, film badges were issued to all of the people that could be found to wear them, without any statistical significance. Since that time, a valid sample is obtained of the population exposure by determining the number of people living in each given area and distributing a statistically representative number of film badges.

An up-to-date census is maintained of the offsite area as to the number of people in each community, individual ranches scattered in the desert, dairy cattle, wells, and water supplies, both potable and domestic. If any activity is released, then this census helps to determine where to go, what is there, and what it means in terms of health hazard.

A standby milk surveillance network has been established by cooperative arrangements with each adjacent state. This merely identifies the milk sources within the state so that if a venting should occur, the Public Health Service telephones to have designated milk samples shipped by air mail for analysis. Such samples may be scheduled to be taken daily or weekly. This method is inexpensive, and it is helpful in determining the situation early in each state.

Responsibility for veterinarian activities was assumed on June 1, 1961. A herd of about 40 beef cattle is kept on a ranch at the Nevada Test Site. The herd has been reduced, but it remains valuable in establishing what amount of radioactivity these animals absorb by being on the test site. The veterinarian also participates in offsite activities, where he will talk to ranchers, meet other veterinarians, and be available if domestic animals are reported injured after an event.

The Public Health Service collects samples in the field for study and analysis in the laboratory. These data are correlated, evaluated, and eventually become a comprehensive report. However, the most important part of the effort remains, in the prompt and honest dissemination of the data to the public. Neither the AEC or Public Health Service can afford to be accused of withholding data from the public. This operation is in a public area, and that must be remembered. All kinds of people can make measurements with relatively cheap radiation detection equipment or a gamma spectrometer. The best interests of all can be served by telling what happened factually and honestly, rather than have others tell about it, based on hearsay or conjecture.

INSTRUMENTATION AND ANALYSIS

The concept of change is significant as applied to the Safety Program at the Nevada Test Site, and it is equally as important when considering the analytical laboratory operations of the Public Health Service which serve in support of the Offsite Radiological Safety Program.

Much of this change results from improvements in instrumentation and technique, while this in turn has been spurred by an increased awareness of the public health problems, both actual and possible, resulting from nuclear testing. The present concern about radioactive iodine in the human food chain might serve to illustrate this point as applied to the Offsite Radiological Safety Program. The development and general availability of pulse height analyzers made possible the identification and quantitation of the various components of fallout, and led to a change in emphasis from the gross to the specific. As this change came about, it was realized that the biological availability of each isotope, and its uptake by man would be the dominant factor in considering any potential hazards. The advent of underground testing meant a high probability that any radioactive material released to the atmosphere would be in a gaseous rather than particulate form, and this in turn increased the importance of the gaseous fission products (which of course included the isotopes of iodine). In order to best evaluate gaseous releases, it was felt that a method of sampling for the inert gases, krypton and xenon, should be developed.

Figure 11.11 is a schematic diagram of the cryogenic air sampling system which is mounted in an aircraft. Air is taken from outside of the aircraft, and the particulate materials are removed by a high efficiency prefilter. The reactive gases are removed by an activated charcoal cartridge, and only the inert gases will pass through to the cold trap. It is here that the kryptons and xenons are removed at very low temperatures. The remainder of the gas passes through a dry gas meter to permit calculation of the volume sampled. In addition to this sampling, the aircraft will attempt to define the limits of the cloud height, width, and length. At the appropriate moment the sample is taken, and subsequently returned to the laboratory for analysis. All of this information permits an estimate of the total content, in curies, of the cloud.

Although the content is presented in terms of curies, the most basic problem is that of measuring extremely low levels of activity. Thus, the importance of refined laboratory instrumentation techniques is obvious.

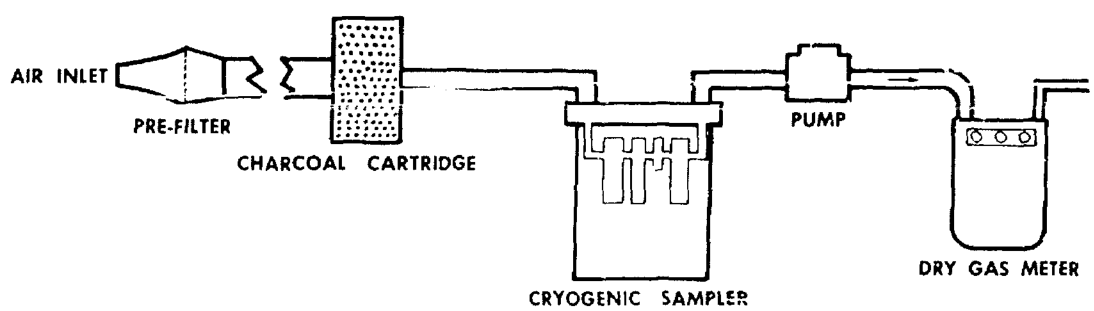


Figure 11.11. Cryogenic Air Sampling System.

Figure 11.12 is a schematic diagram of a precipitator air sampling system which is installed in an aircraft to provide additional sampling capability within any cloud of radioactive material. In this system particulate material is deposited on the walls of the precipatator tube by electrostatic action. Particles which are too large to be deposited are removed by an 8- by 10-inch filter. The remaining gas is used to inflate a grab bag type apparatus which is returned to the laboratory for inert gas analysis. In the laboratory, the precipitator tube is washed with several solvents in an attempt to characterize the chemical form of the various isotopes through a knowledge of their differential solubilities. Some work may also be done on particle sizes.

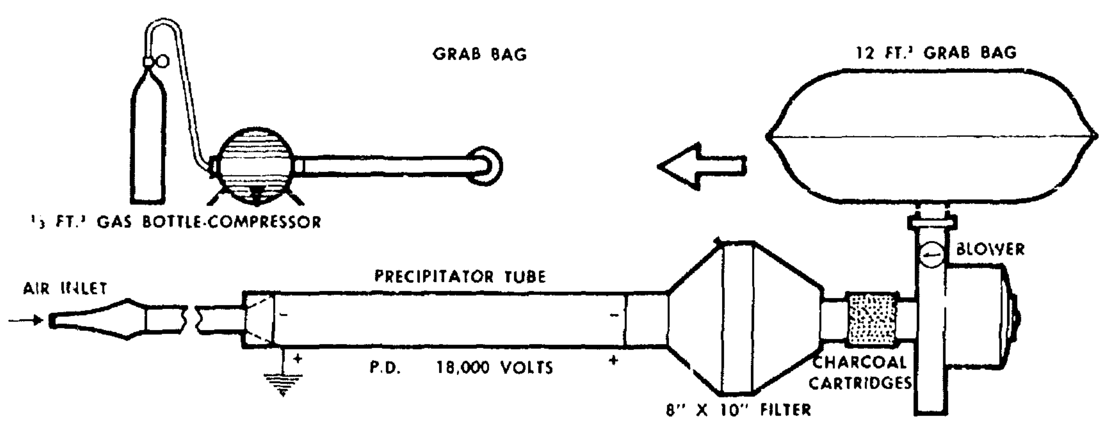


Figure 11.12. Precipitator Air Sampling System.

These two sampling systems are utilized only after a nuclear detonation and particularly in the event of a release of activity to the atmosphere. However, there are many continuing programs which are maintained on a routine basis, and merely intensified following a detonation. Included among these would be the air surveillance system.

The present operational air surveillance system utilizes a low flow rate, positive displacement pump with an induction motor expected to provide several thousand days of continuous operation, a Whatman filter, and charcoal cartridges, where indicated. The laboratory counting equipment has been improved with a low background beta system, having an automatic sample changer and card punch output.

Routine programs for the collection of milk and water samples from the offsite area permit a continuing evaluation of environmental contamination. While this program concentrates on individual farms and dairies, the Public Health Service operates surveillance programs designed to evaluate the concentrations of activity available to large population areas by examining processed milk samples. The laboratory makes no distinction as to the source of the sample, and the data from each source serves to supplement the other. As an example of the interaction of these various programs, the detection might be considered of high levels of I^{131} in pasteurized milk from Utah in 1962, following the Sedan event. This detection permitted more intensive investigation of individual dairy farms and a more precise definition of the activity as a function of area.

The general laboratory policy is to use pulse height analyses for all isotopes emitting gamma rays. Chemical separations are avoided, except where absolutely necessary as for isotopes, such as Sr^{89} and Sr^{90} which emit no gammas. The gamma spectrometer system is shown in Figure 11.13. It consists of a dual shield holding two 4- by 4-inch NaI(Ti) crystals. The output from each detector is fed to one-half of a 400 channel analyzer, each half examining the range 0 to 2 million electron volts. The data is presented as both typewritten copy and on punched paper tape. The paper tape serves as the input to an IBM 1620 computer which performs the mathematical analysis. This is an extremely rapid process for all long-lived isotopes. Certain problems still exist with the analysis of spectra containing many short-lived isotopes for which no standards are available. It is hoped that a method to simulate the spectra of these isotopes may soon be developed.

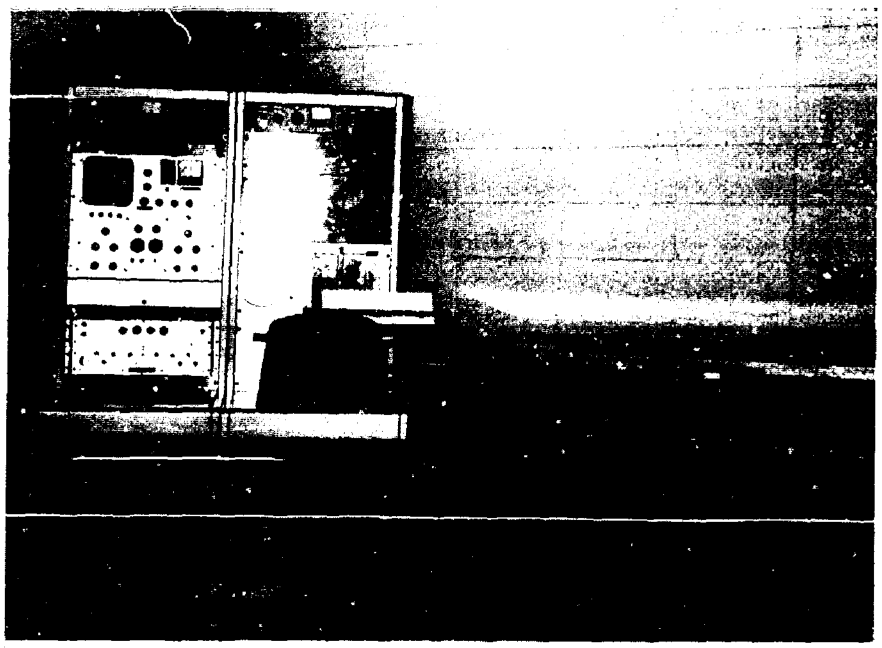


Figure 11.13. Gamma Pulse Height Analyzer System.

Although the number of chemical separations is kept to a minimum, a laboratory capacity does exist for handling several hundred such determinations per week. In addition to the radioactive isotopes, certain stable elements, such as calcium and phosphorous are of interest due to similarity of their behavior to that of strontium. These are routinely determined. The automated low background beta counting system is shown in Figure 11.14.

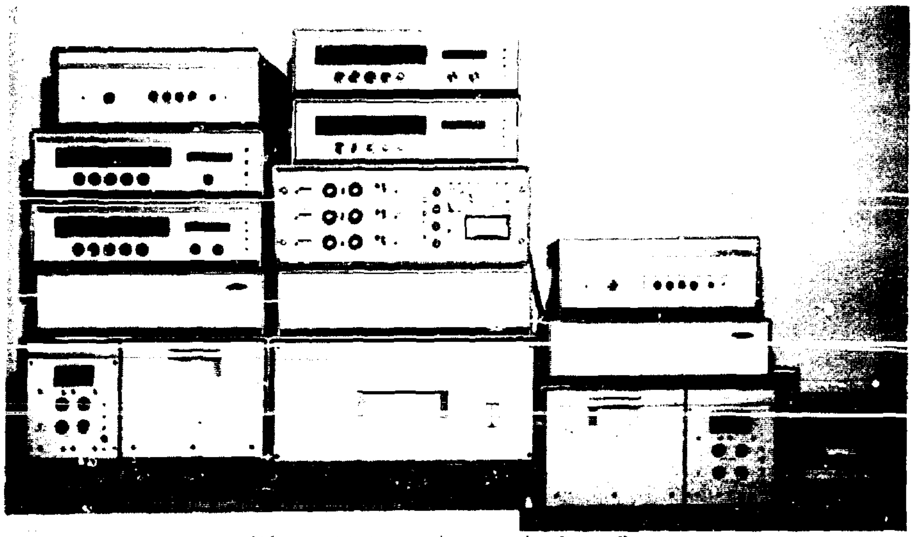


Figure 11.14. Automatic Beta Counter.

Certain specialized equipment is available for development projects related to the overall programs of the station. Included among these is a pulsed neutron generator, having a nominal output of two or three times ten to the tenth fast neutrons per second. Most recently, this has been used to help develop a sampling system specific for radioactive iodine. It is hoped that this sampler will help to define the chemical and physical form of the iodine in any radioactive cloud. Although this is still in the development stage, some success has already been noted. The most recent additions include equipment to be used in particle sizing of radioactive particulates. Particle sizing and counting devices and an electron microscope will increase the knowledge of the biological availability of any activity released from the Nevada Test Site.

Figure 11.15 shows the IBM 1620 computer system, having punched tape and card input and output. This unit is installed in the laboratory, and offers speed of analysis as its primary advantage. This permits evaluation of any potential health problems within a very short period of time after sample collection (usually less than 24 hours). This system also serves as a storage and retrieval system for all data associated with any activities at the Nevada Test Site. The importance of high speed retrieval of information is becoming increasingly apparent.

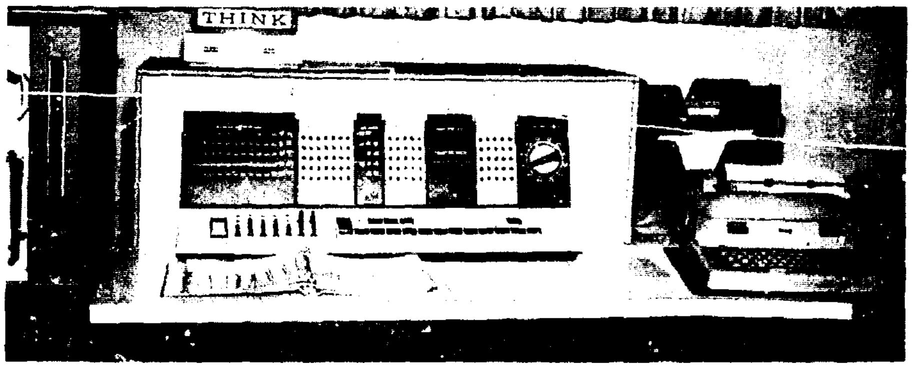


Figure 11.15. IBM 1620 Computer Console.

RADIOIODINE FIELD INVESTIGATION PROGRAM

In the spring of 1963, a committee met to make specific recommendations as to what additional information was needed to better define the possible radioiodine hazard that might result from venting of underground detonations, reactor testing, or from any other type of radioiodine source. This committee was divided as four subcommittees to consider sources, monitoring, transport phenomena, and biological studies. Specific recommendations were made by each of the subcommittees and, in order to partially implement these recommendations, the Radioiodine Field Investigation Program was formed.

In general, the program is not primarily concerned with source term definitions other than from the standpoint of taking samples and attempting to relate these samples to the probable sources. It is considered to be the province of the individual laboratory conducting the test to define the probable radiation sources. Principal experimental efforts of the Public Health Service are in the monitoring and biological fields. In addition, there is a combined program with the Weather Bureau in the area of transport phenomena.

The general purpose of this study is to collect data to estimate the probable average and the maximum value of radioiodine levels in raw milk consumed by farm families in the offsite population and to estimate total human dosages in this population from ingestion exposure plus any inhalation exposure.

The first objective is to relate levels of radioactivity in the air to levels of radioiodine in the thyroids of selected humans breathing that air. Similarly, attempts shall be made to relate air levels of radioactivity to levels of radioiodine in raw milk collected from individual farms at the same locations.

The Public Health Service shall do its best to establish these relationships, but it must be recognized that there may not be any consistent relationships to be found. In other words, there may be certain parameters which will alter the relationships for specific cases to such an extent that it will be necessary finally to conclude that there are no consistent relationships which can be established.

The second objective is to seek to relate external gamma and/or beta plus gamma measurements obtained with portable survey instruments and film badges to levels of radioiodine in the thyroids of selected humans and to levels of radioiodine in raw milk produced at the same location.

The third objective is to seek to relate levels of radioactivity deposited on the ground and on forage as dry fallout or as rainout to the levels of radioiodine in raw milk at the same locations.

The fourth objective, in cooperation with the Weather Bureau, is to assess the significance of local meteorological variables, such as wind velocity, temperature, precipitation, humidity, and dew on the deposition of I^{131} on vegetation.

The fifth objective is more long-range in nature and will be to estimate dose distributions to human tissues, organs, and organ systems resulting from various combinations of ingestion and inhalation exposures to radioiodine.

In general, the approach to achieve these objectives will be to identify specific parameters which seem to affect these relationships significantly, and particularly to seek the variances which might be expected under different conditions. The Public Health Service will never be content to obtain, for example, a grand average relationship which will relate external gamma taken with portable survey instruments to radioiodine levels to be expected in milk. In each case, a plus and minus variance will be sought to attach on the end of any relationships obtained. This will necessitate the taking of large amounts of data under many different conditions. Emphasis will be put on field investigations as the final definitive data must be taken in the field. Thus, the laboratory will be used only for the minimum amount of time necessary to achieve whatever equipment calibration is needed to interpret and evaluate the data collected in the field.

These objectives are being attacked on a rather broad front in terms of the scientific disciplines involved. In particular, the program is organized as the Biomedical Section, Physical Sciences Section, and Agricultural and Soil Sciences Section. It is believed that a team of biologists, agronomists, soil scientists, chemists, physicists, and engineers is needed to solve the many and varied problems.

The objectives may be broken down into both short- and long-range objectives. Short-range objectives are related to field investigations for specific events. It is appropriate to point out the relationship of the Radioiodine Program to the Offsite Program. After an event occurs, the offsite organization determines how much activity went where, and must necessarily operate over relatively large distances to plot where the cloud went and to give some quantitative information over large geographical areas. Many various kinds of samples are collected during this period, but a specific location is not usually sampled in depth. The task is more properly a function of the Radioiodine Program.

Following the Pike event for example, arrangements were made to mount studies at two local dairy farms after the offsite organization indicated that radioactivity had passed over the city of Las Vegas. This study of the Latter Day Saints Welfare Farm and the Habbart Farm was set up in some depth in that daily samples of soil, water, air, milk, hay, and vegetation were taken at both of these farms. A distribution study was done in one of the fields to determine whether or not the deposited activity was homogenous. A brief summary of some of the results obtained at that particular study is presented later.

To accomplish the long-range objectives, it will be necessary to have controlled releases of radioactive aerosols at the Nevada Test Site. An experimental farm has been established for this purpose as shown by the arrow marked UE-15D in Figure 11.16.

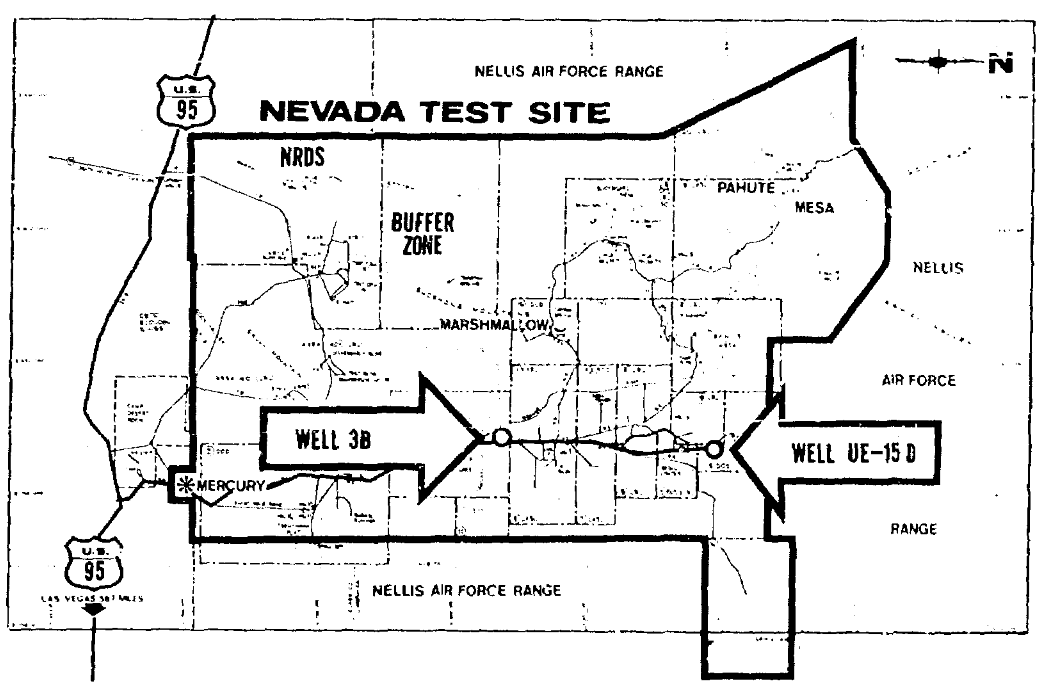


Figure 11.16. Experimental Farm Location.

At the present time, 26 dairy cattle are temporarily located in the vicinity of Well 3B. Only the lactating cows are moved to the UE-15D site. In addition, there is an area of approximately 20 acres of irrigated farm land where alfalfa and other forage crops common to dairy farms in southern Nevada and southern Utah will be grown.

Figure 11.17 shows a photo of the experimental farm building. Figure 11.18 shows the interior of the barn near Well 3B with three of the experimental dairy animals.

Figure 11.17. Experimental Farm Site in Area 15.

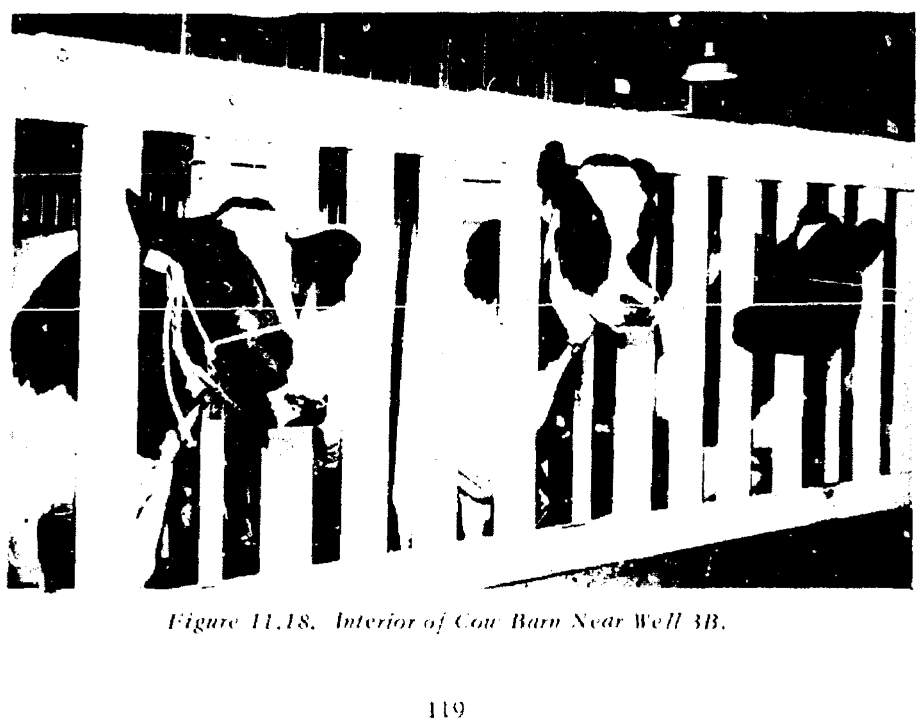


Figure 11.18. Interior of Cow Barn Near Well 3B.

The general approach in this investigation can best be described as a systems approach. For input there is a given level of I^{131} in man's environment; this is then operated on by some kind of transfer function in the system, man's food chain plus man, with the output being a certain dosage of I^{131} to humans. The Public Healt 'ervice will begin with the total large system and proceed to the small subsystems. This is in contrast to most basic research programs, where usually the effort involves building from the small subsystems to the large total system. The plan is to seek the overall effective transfer function in the field, first; and then to break down this transfer function into its constituent transfer functions at a later date.

One of the more extensive studies conducted by the program followed the Pike event and took place at two Las Vegas dairy farms. Figure 11.19 shows the location of the Latter Day Saints Welfare Farm and the Habbart Farm. These farms are approximately 5 miles apart with no major topographical features, such as mountains, valleys, or streams between the two farms. At each farm, arrangements were made with the farm managers to separate three cows from the herd, placing them on green feed together with the normal supplement of grain and hay which dairy farmers usually feed in this particular part of the country. The rest of the herd was to be kept away from all green feed and allowed to eat only dry feed.

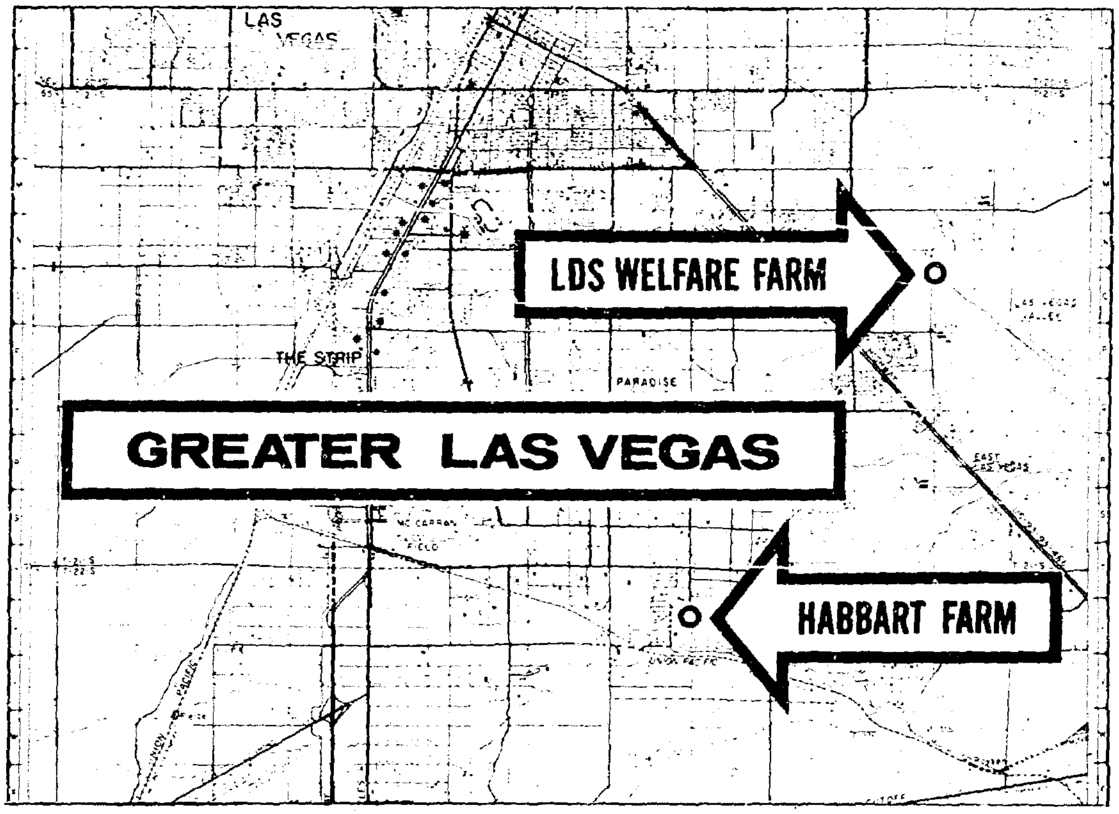


Figure 11.19. Dairy Farm Locations.

The highest level of I^{131} found in raw milk from cows on green feed was 420 picocuries per liter. This level was observed to decay with an effective half-life of approximately 3-1/2 days.

For cows on dry feed, a maximum of 70 picocuries per liter I^{131} was observed in raw milk with an effective decay half-life of about 6-1/2 days. These half-lives are probably correct to plus or minus one day.

There are three findings which the Public Health Service believes might be significant. Higher than expected I^{131} levels were found for cows on dry feed only. There was a significant difference in I^{131} levels between the Latter Day Saints Farm and the Habbart Farm samples. For different samples, the Habbart Farm was higher by a factor ranging from two to five. The highest level of I^{131} observed in the raw milk of cows on green feed at the Latter Day Saints Farm was 70 picocuries per liter compared to 420 picocuries per liter for the comparable sample at the Habbart Farm. Calculated ratios of the I^{131} deposition on vegetation to the I131 levels in milk at the Habbart Farm gave apparent general agreement with similar factors calculated following the Windscale Reactor accident in England. This last finding was not expected, and it should be recognized that it could possibly be due to fortuitous combinations of circumstances.

In conclusion it should be noted that this particular program has been coordinated with many different laboratories doing related investigations, such as the group at the National Reactor Test Station, Idaho Falls, Idaho; the Lovelace Foundation, Albuquerque, New Mexico; and the Los Alamos Scientific Laboratory, Los Alamos, New Mexico. Copies of program documents have been transmitted, and several liaison visits made, to the Biomedical Division of the Lawrence Radiation Laboratory. There has been general agreement in every case that the field approach with radiation sources at the Nevada Test Site will complement other studies rather than result in unnecessary and wasteful duplication.

CHAPTER XII

SANDIA CORPORATION

AIR BLAST PREDICTIONS

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INTRODUCTION

Need for offsite blast prediction for Nevada tests became known with the first operation, Ranger, in January and February 1951. There were no significant adverse reactions to the first three shots, but a fourth test of 8 kilotons was shot on February 2 which sent a strong blast wave into Las Vegas, breaking windows and shaking dishes from shelves. Four days later, a 22-kiloton test went practically unnoticed.

It was established that atmospheric conditions caused this so-called anomalous blast propagation, and that weather was often more important than yield in determining distant blast effects. For example, only a barely audible compression was detected at 40 miles from a multimegaton burst at Christmas Island in 1962. In the opposite extreme, an irate mother once claimed that her baby was knocked from bed by a 100-pound high-explosive blast, 7 miles away at Sandia Base. Normalized for yield and distance differences, these two events demonstrate a factor of at least 150 difference in atmospheric blast transmissions.

Blast predictions have been evolved and used at the Nevada Test Site so that, except for one instance, there have been only a few widely scattered and inexpensive damages from subsequent test operations. The exception, Buster-Jangle Dog 21-kiloton shot in November 1951, broke several large windows in downtown Las Vegas. Operational pressures on that date had prevented further test delay in spite of a pessimistic blast prediction, and late weather changes made things even worse. Since that time prediction techniques and confidence levels have been considerably improved, so that it seems quite unlikely that serious accidents or incidents from air blast should recur.

PREDICTION TECHNIQUES

Atmospheric refraction causes nonuniform blast pressure patterns to be propagated great distances. A simplified illustration of this is shown in Figure 12.1. In a real atmosphere temperature changes with altitude, as shown by the left curve, so that sound speed is also different at different altitudes. Wind changes with height added to temperature-determined sound speeds give a sound velocity versus height structure, as shown by the dashed curve. A vertical plane wave, as shown on the right, would be propagated through this atmosphere at different velocities at different altitudes and become increasingly distorted with passage of time. Sound rays, perpendicular to the wave front, are curved upward from the ground in layers where sound velocity decreases with height. These sound rays are curved toward the ground in layers where velocity increases with height.

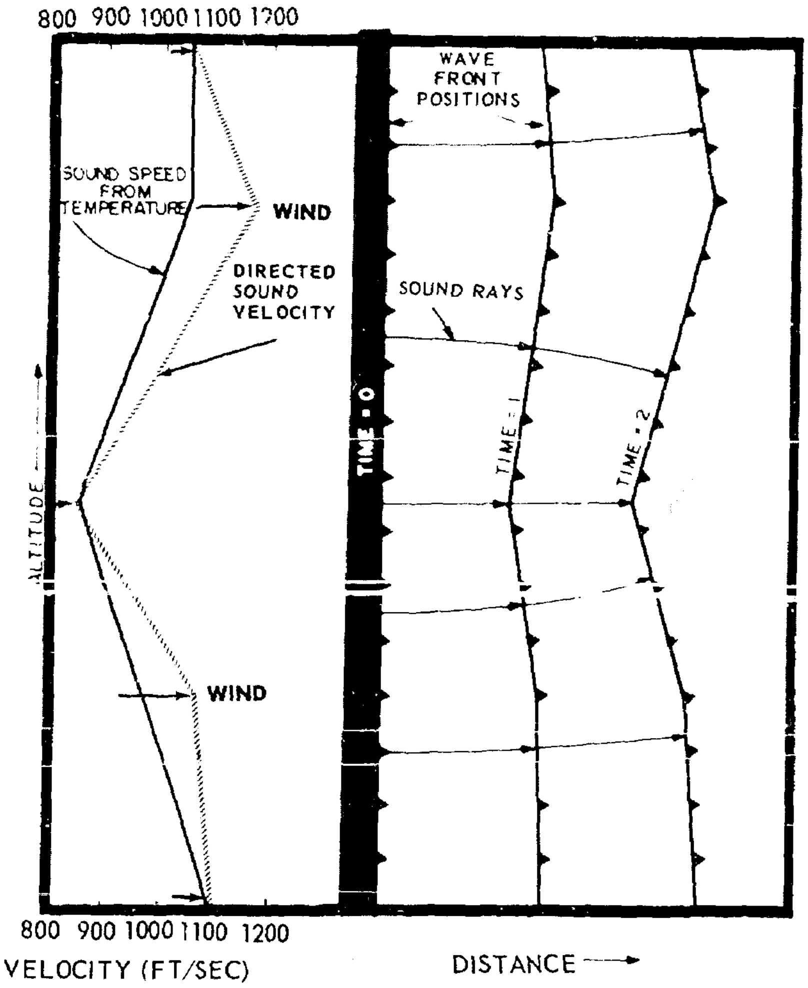

Figure 12.1. Shock Wave Distortion by Layered Atmospheric Temperature and Wind Structure.

This same bending affects rays from a point source or explosion, as shown in Figure 12.2. A most important sound velocity versus height structure for explosions is where sound velocity decreases, then increases with height above ground. Various rays emanating from a burst curve upward, then are turned over by velocities aloft and return to ground in a band some distance away.

Relative blast intensities may be predicted from the density of ray arrivals. There may be varying degrees of focusing of blast waves in these sound rings. This is usually the sound velocity versus altitude profile which causes exceptional disturbances, sometimes called caustics, at long ranges.

There are three layered regions of the atmosphere which may give strong sound or blast propagation. The lowest, a surface inversion layer, does not often give significant focusing but instead causes wave energy to diverge cylindrically rather than spherically, and thus causes abnormally high blast pressures. This surface sound duct, as shown in Figure 12.3, may be generated by a surface temperature inversion, where temperature increases with height above ground in a shallow layer which is seldom more than 1000 feet thick. Inversions develop at night when the ground cools by radiation and, then in turn, it cools the boundary air layers by conduction.

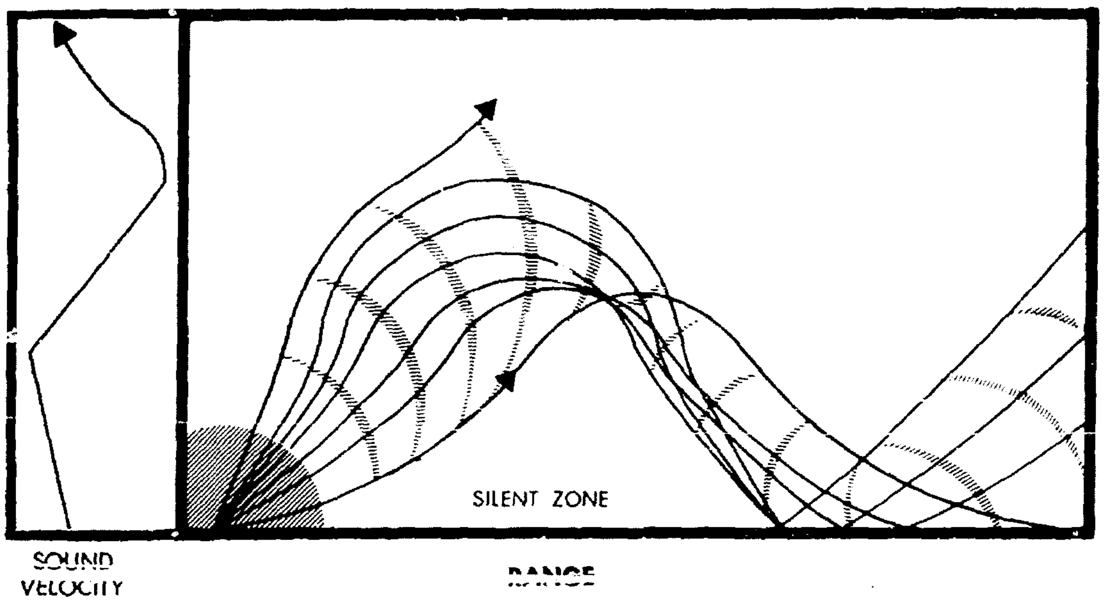

Figure 12.2. Typical Explosion Ray Paths.

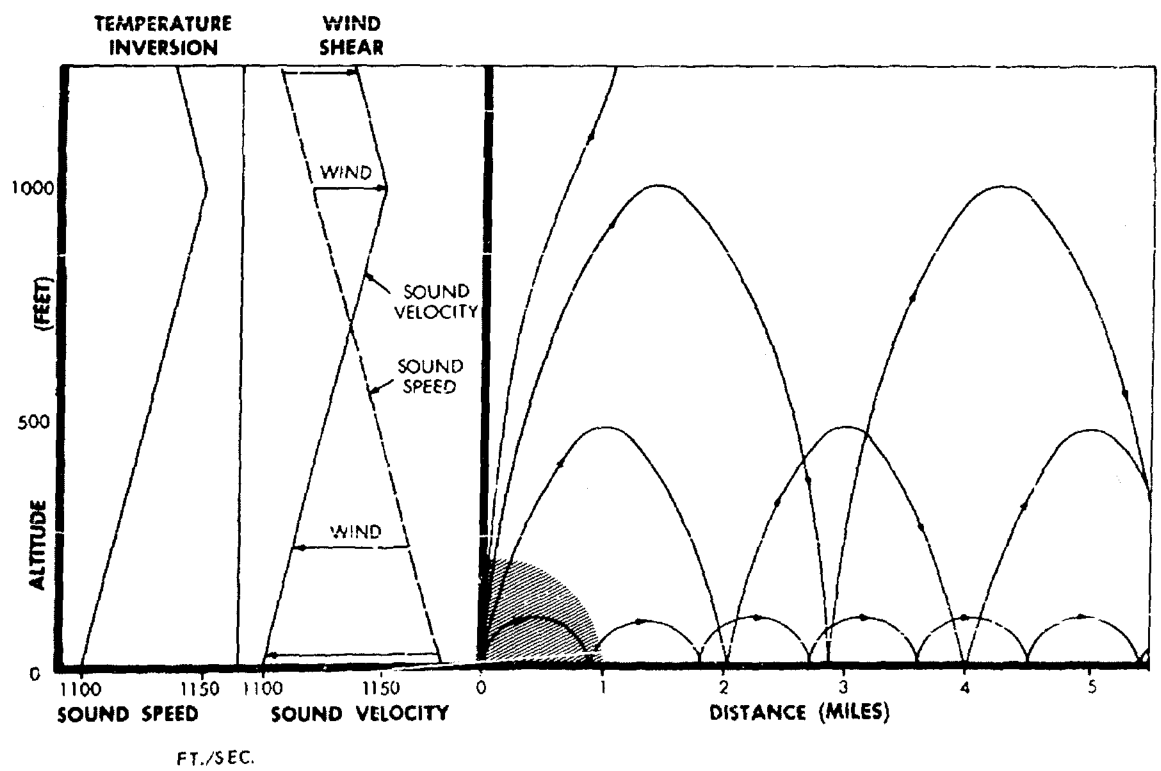

Figure 12.3. Surface Inversion Sound Ducting.

With temperature decreasing with height, as is normal in daytime when the ground is heated by the sun, wind direction or speed may change with height to cause a sound velocity inversion. In either case, sound rays are ducted to first strike at ranges of less than a couple miles. These sound rays are almost perfectly reflected by the ground (at least for frequencies and wave lengths given by most explosions) and repeat their cyclic path many times as illustrated. Even small ground reflection losses become significant after being compounded dozens of times, so this atmospheric duct is only of concern in blast prediction to a few tens of miles. In Nevada this duct is generally blocked by mountains at less than 20 miles range.

Weather conditions responsible for extensive blast damages in Las Vegas are shown in Figure 12.4. Jet-stream winds, which usually blow from the west direction quadrant, may have speeds as high as 250 knots. Very low temperatures and sound speeds at 25,000 to 40,000 feet are counteracted by these high wind speeds to give some higher downwind sound velocities near tropopause altitudes than at ground level. The tropopause is the level where temperature stops decreasing with altitude. A resulting sound ring, with possible strong focusing, may land at 30 to 100 mile downwind ranges, depending on height and strength of ducting jet-stream winds.

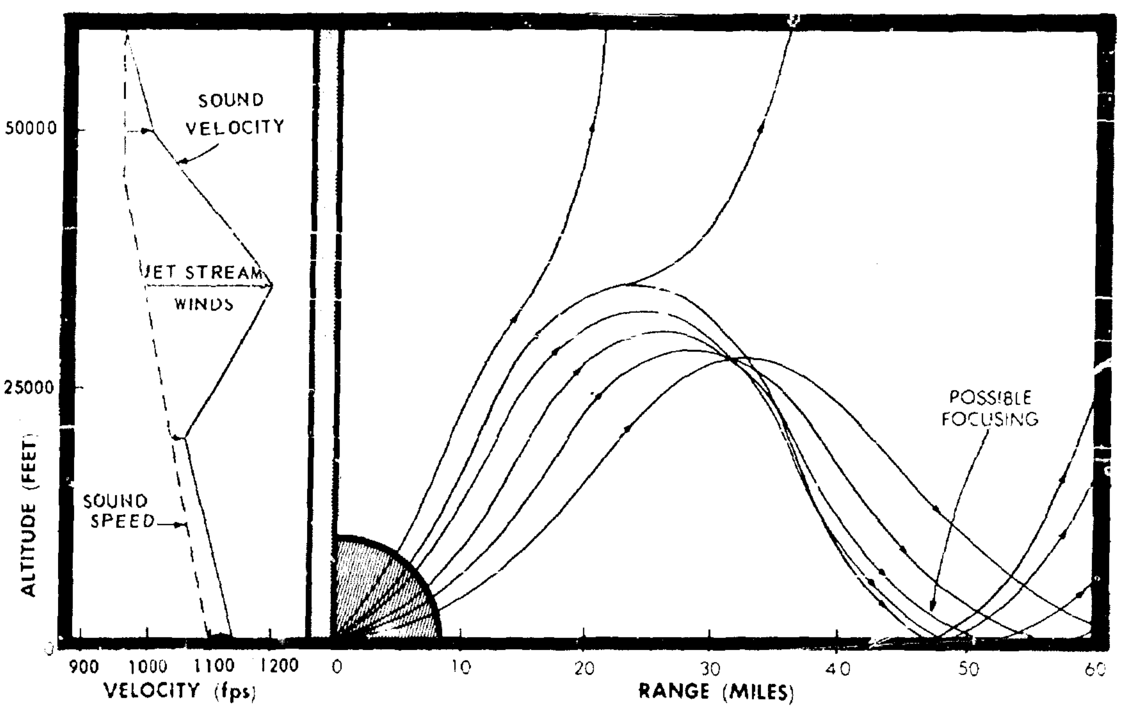

Figure 12.4. Jet-Stream Sound Ducting.

At higher altitudes, in the ozonosphere, there is a warm layer centered near 150,000 feet, where temperatures and sound speeds are nearly as high as at ground level. This is shown by Figure 12.5. Fairly steady, strong winds to 150 knots blow with seasonal directions at these high altitudes, from west in winter and from east in summer. This creates sound ducting toward downwind directions which gives a sound ring at ranges from about 70 to 150 miles. In most cases nominal yields, typical of past Nevada atmospheric tests, do not give damaging pressures at these long ranges but there have been several scattered incidents of windows broken by waves which traveled this route. Rocket weather observations at these high altitudes, which are used to calculate ray and blast predictions for ozonosphere propagations, have been made only since 1958. Upwind, blast waves are refracted away from the ground and only minor waves are diffracted into the silent zone, while stronger blast waves pass far overhead. These diffracted waves have measurable but usually inaudible intensity, and about 2 percent of the downwind pressure amplitude.

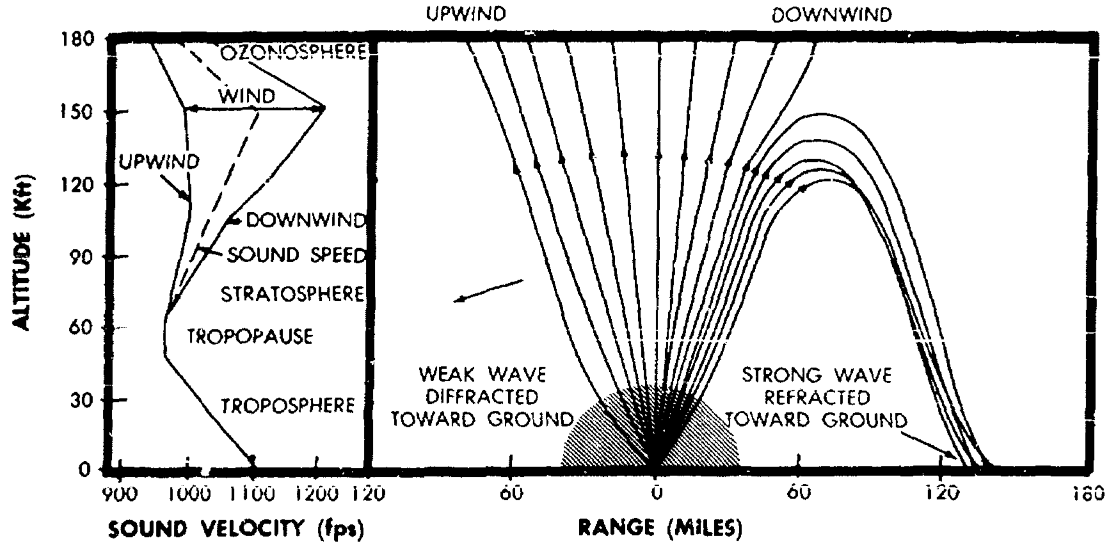

Figure 12.5. Ozonosphere Wind Effect on Sound Ducting.

Even higher, in the ionosphere above 300,000 feet, very high temperatures also duct waves to strike the ground at over 100 mile distances. These are usually carried to directions opposite from downwind ozonosphere propagation. At such high altitudes, low air densities cause most blast wave energy to be absorbed, so no structural damages have been reported from this wave route. However, high frequency pops and rattles result when ionosphere waves do reach the ground, which can cause stampedes on California turkey farms.

As stated previously, sound ray density gives a relative measure for blast amplitude prediction. Actual amplitudes depend also on explosive yield and burst environment conditions. A set of curves in Figure 12.6 shows how source strength depends on height or depth of burst. In the center curve, a 1-kiloton nuclear burst in free air at 2500 feet above ground surface is shown to give the same distant blast pressures as other yields at other burst elevations. For a burst at lower heights above ground, the incident and ground-reflected shocks fuse in a Mach stem with relatively large pressures. As illustrated, only 190 tons yield burst near 500 feet above ground gives the same overpressures at fixed distances as a 1-kiloton free air burst.

Bursts at high altitude, as shown by the upper curve, are less efficient blast wave sources. Note the changed altitude scale. At high altitude air density is very low, mean free paths of radiations are large, and a larger fraction of total yield is lost as radiation before a shock wave is formed. It turns out that apparent blast yield decreases about in proportion to the fourth root of ambient air pressure at burst altitude. Thus, it takes just over 3-kiloton yield at 100,000 feet altitude to give the same pressure at the same ground level range as given by a 1-kiloton free air burst at 2500 feet elevation.

Underground bursts are muffled by material surrounding the explosion. At shallow depths used in cratering and excavation, for example, blast amplitudes at long range (greater than 10 miles) are 10 to 35 percent as large as expected from a free air burst of the same yield. As burst depth is increased, the yield required to give constant overpressures is increased in double logarithm coordinates as shown in the lower curve.

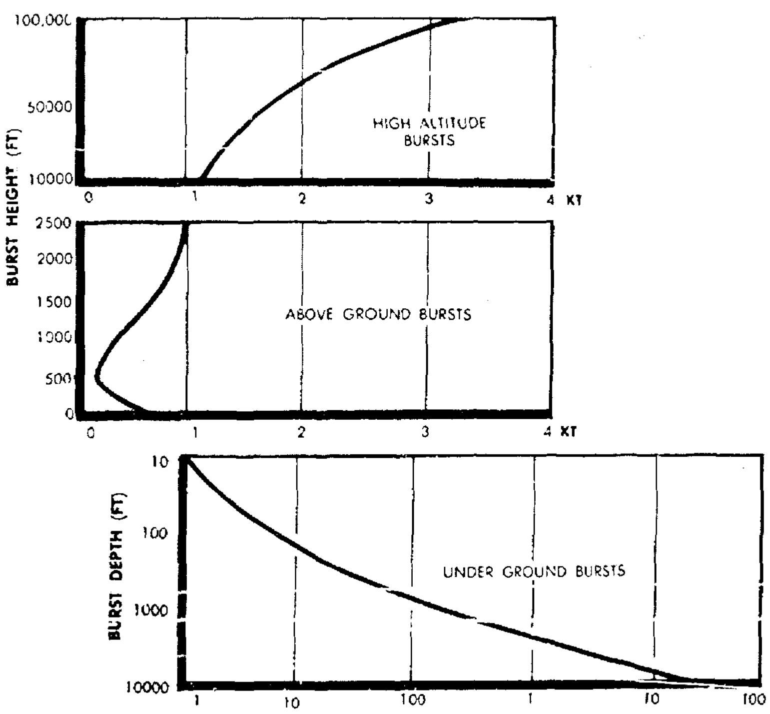

Figure 12.6. Yields Which Give Same Overpressures at Fixed Distance for Various Burst Heights.

This curve may be misleading for bursts larger than 100 kilotons because attenuation of air blast seems to decrease with increased yields, other conditions being similar. In fact, extrapolation of observations from a shot of 100-kiloton yield and another shot of approximately 200-kiloton yield shows that contained shots of a few megatons yield would give air blast amplitudes about like air bursts. This seems absurd, but proof awaits more measurements from gradually increased test yields to determine the true state of affairs.

Furthermore, data from shots in Rainier Mesa tuff show strong coupling into air waves at least in some directions. So far, it cannot be resolved whether this results from tuff material near shot zero or from the irregular ground surface and shape of Rainier Mesa. In fact, an event of approximately 20-kiloton in Rainier Mesa could have been heard by a careful observer in Las Vegas, while 100-kiloton shots under alluvium and gravel in Yucca Flat are barely detectable by using sensitive offsite microbarographs. It is not known how these terrain and yield parameters will affect plans for still larger tests in Pahute Mesa. Observations will be made when that new test area opens to find what yield limits are needed. An uncertainty in yield effect on blast from buried explosives is also extremely important to safety planning for much larger devices involved in nuclear excavation of a new Isthmian sea-level canal.

Now for a brief review of explosives blast overpressure versus distance curves and yield scaling laws. This may be familiar as these are shown in The Effects of Nuclear Weapons, and many other handbooks and publications.

The basic blast overpressure-distance curve is shown in Figure 12.7 for a 1-kiloton nuclear explosion in free air at 1000-millibar sea-level pressure. It is adapted from a theoretical calculation made at Los Alamos and called IBM Problem M. It varies only slightly from other calculations, observations, and handbook values. This calculation was carried out to 9000 feet range. From there the curve has been extended by empirical data from high altitude bursts which were little affected by atmospheric refraction. This curve slopes with overpressure decreasing in proportion to the 1.2 power of distance. Acoustic expansion would gi e a -1.0 slope, but this will be discussed later.

Scaling laws as illustrated show that a given shock strength, or overpressure-ambient pressure ratio $\Delta p/p$, will reach to distances, R, which are proportional to the cube root of yield, W, and inversely proportional to the cube root of ambient air pressure, p. Subscripted M refers to IBM Problem M. This scaling has been applied to two examples. First, for a 1-megaton free air burst at sea level, given blast pressures reach ten times their range from 1-kiloton. The other example, 1-kiloton burst at 50,000 feet altitude, would give a blast overpressure curve displaced to the right for distance scaling; then reduced, as shown, for horizontal propagation to conserve shock strength or overpressure-ambient pressure ratio. Propagation from one pressure altitude to another is done similarly, but ambient air pressure at gage height is used.

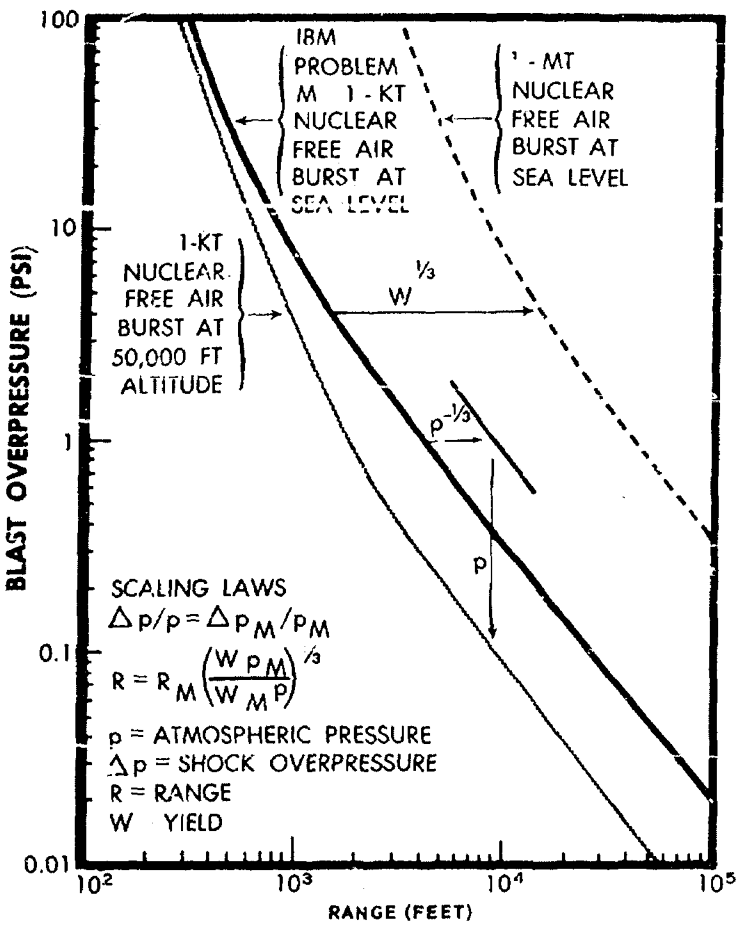

Figure 12.7. Standard Explosive Overpressure-Distance Curves.

Similarly, a standard curve can be generated for any known burst environment or yield. True yield must be adjusted to an apparent yield for special burst heights, as shown in Figure 12.6, before scaling distances. For underground bursts an attenuation factor is used to decrease overpressure, depending on other previously mentioned conditions. The resultant overpressure-distance curve is then what should be expected — if our atmosphere were calm, homogeneous, and not the refracting sound lens that it truly is.

Atmospheric ducting and focusing, as shown in Figures 12.2 through 12.5, cause ray concentrations which may considerably modify standard pressure predictions, as shown by Figure 12.8. For three distance ranges, 20, 50, and 125 miles from an assumed 120-kiloton free air burst, standard spherical propagations are shown to give various millibar overpressures. Propagation under an inversion, however, may give 2 to 3X amplitude magnifications to somewhat beyond 30 miles. On the other hand, much smaller amplitudes would reach this range from a shot on a calm sunny afternoon or a shot downwind from an observer. Most blast energy would then be refracted upward into the high atmosphere.

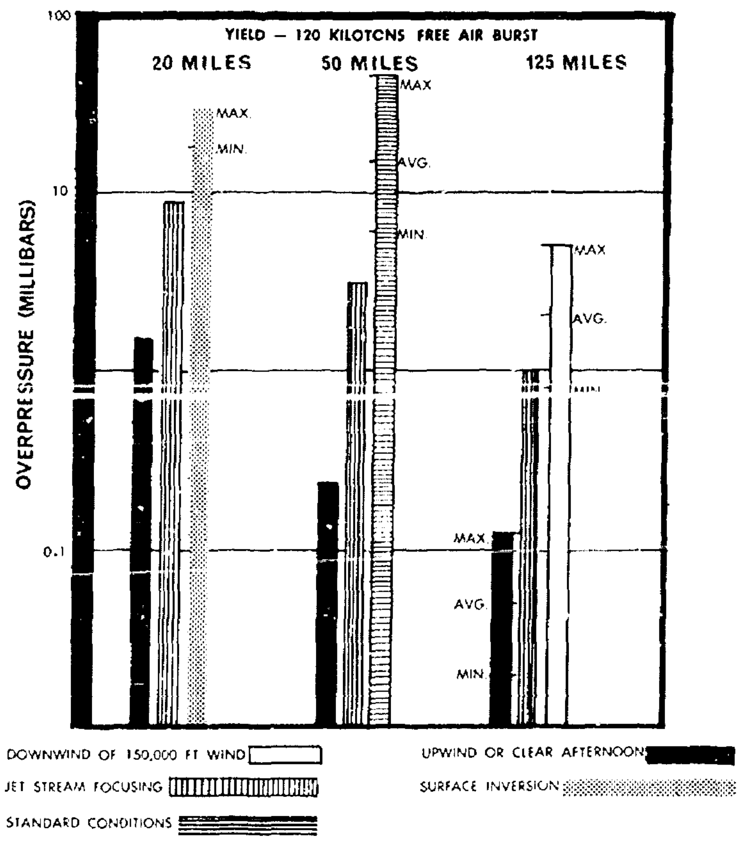

Figure 12.8. Atmospheric Effect on Overpressure.

At 50 miles range, where jet-stream ducting may cause focusing, as much as 15X amplifications have been observed from high-explosives tests at NTS; even higher values may be possible in narrow regions missed by the finite numbers of microbarograph recorders. Again, propagation upwind or on afternoons is much reduced.

At 125 miles downwind, near the midpoint of typical ozonosphere-ducted sound rings, 5X magnifications have been recorded from nuclear tests, and 2X amplification is about average for all past tests. Some higher magnification has been observed from high-explosives shots and a real safety limit may be near 10X magnification. Upwind from ozonosphere circulations, amplitudes are usually only one-fortieth as large as at the same distance downwind, so that only extremely large bursts could cause any distant ozonosphere-ducted disturbance in the upwind directions.

All these factors are assembled to make a blast safety prediction for a specified event. A prediction for planning purposes might look like the set of areas delineated in Figure 12.9. An operational prediction, for preshot briefings would have pressure-distance curves calculated and drawn from weather observations and forecasts. Of course, prediction lines must be drawn with a broad brush to allow for atmospheric

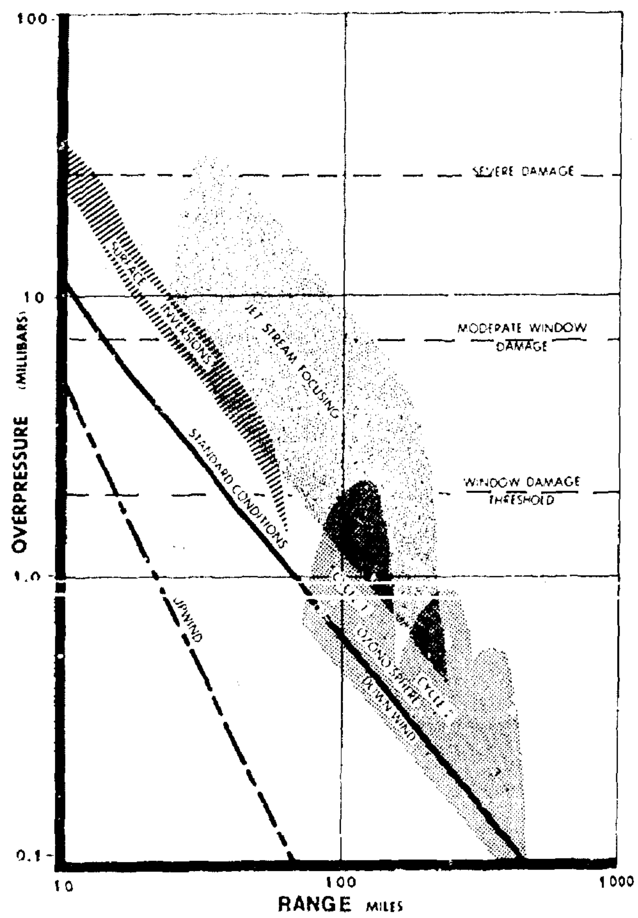

Figure 12.9. Blast Prediction for 1-Megaton Excavation.

turbulence, wind variability, and other possible sources of error. Usually a factor of two error in pressure, up and down, will encompass the actual results.

Here, however, in an example of planning and feasibility studies, ranges of likely results are delineated and compared with their damage potentials. A standard overpressure-distance curve is shown for 1-megaton burst at a depth for maximum cratering. Upwind there is little likelihood of any damage beyond 15 miles range. For a burst under an early morning inversion, or with wind direction changing with height, windows could be broken out to 50 miles if this sound channel were not blocked by mountains. Jet-stream focusing could cause severe damages to 40 miles and is independent of terrain, because this ducting takes place at 25,000 to 40,000 feet altitudes. This would mean most windows smashed, doors broken off, etc. With reflected cycling, this wave duct could break windows to nearly 200 miles. Since strong jet-stream winds usually curve as they cross a weather map, a blast wave would not likely encounter many further repetitions of the same weather conditions needed to maintain sharp focusing through many ground-reflected cycles. There are no direct observations of this defocusing after several reflected cycles from nuclear tests. Waves from small high-explosives are too weak to record accurately at hundreds of mile ranges. Also, shorter wavelengths and higher frequencies from small bursts are more absorbed enroute. Scaled experiments do not therefore, appear to be very helpful in determining just how far jet-stream focusing can carry from low frequency nuclear test waves. On the bright side, a day or two shot delay will usually bring changed weather and lighter wind speeds and no focusing.

Ozonosphere propagation is comparatively more steady. If there is a possibility of distant damage, as shown in Figure 12.9 near 120 miles, a delay for relative minima in upper wind speeds and total refracted propagation may be required. If yields larger than 1-megaton are planned or somewhat worse blast pressures than this are forecast to land on a significant community, the solution is to wait 6 months when wind directions will be reversed. If this threatens another city in an opposite direction, firing could be attempted during spring or autumn transition periods, when ozonosphere winds become nearly calm for about 2 weeks. In these periods propagation amplitudes usually fall below the standard curve in all directions.

An envelope for successive reflections of ozonosphere cycling extends almost indefinitely because of the relative uniformity of high altitude winds. This seems to be born out by observations of multimegaton test waves which have circled the earth two or three times.

Damage level threshold is based on two incidents of large, single-strength, aged glass panes breaking from 2-millibar overpressures, one case in Las Vegas and another in St. George, Utah. At 7-millibar overpressure, quite a few moderate size panes were broken in Johnston Island barracks by Orange shot. At the Nevada Test Site, 25-millibar overpressure is the maximum observed at CP-1.

Nevada tests are often preceded or accompanied by 1-ton, high-explosive shots. On atmospheric nuclear tests, these are shot 1 to 3 hours before full-scale zero hour and the blast waves are recorded offsite by a network of microbarograph stations. Depending on shot yield, season, and current weather, from 6 to 12 of the stations shown in Figure 12.10 record a given shot. These stations make recordings from the pretest high-explosive shots and report them to the Blast Prediction Unit at Yucca Pass Control Point. Results are compared with predictions calculated from weather reports. Amplitudes are scaled to expected full-scale test yields and reported in final briefings.

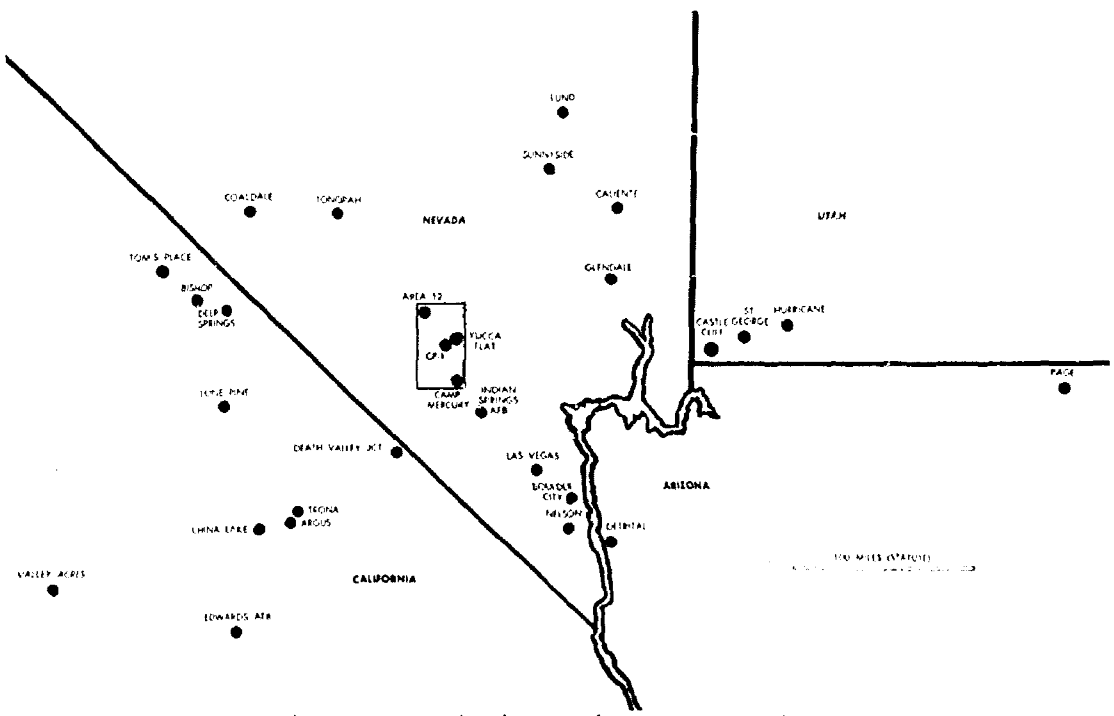

Figure 12.10. Microbarograph Measurement Sites.

At underground or cratering test events, similar high-explosive charges are fired only a few minutes from full-scale zero time. Scaling from microbarograph results shows that would be expected from full-scale yield, but free air burst. Comparison with actual full-scale shot wave amplitudes gives the muffling or attenuation factor caused by shot burial.

Some of the microbarographs are mounted in trucks, complete with power generators and radios, so they are mobile and may be quickly dispatched in attempts to observe predicted focusing. A final function of microbarograph measurements is to document wave arrivals for use in assessing the validity of damage claims.

Blast predictions are thus begun with burst yield and environment data as furnished by LASL, LRL, or DASA (for effects tests), and an approximate date or season and time of day. Weather data — rawinsonde observations of upper temperature and winds and forecasts — are obtained from a U.S. Weather Bureau Research Station attached to AEC/NVOO. Weather reports from above 100,000 feet are obtained from rocket firings by Sandia Corporation at Tonopah Test Range, about 90 miles north-northwest from Yucca Flat. Onsite propagation in the lower layers is calculated from detailed micrometeorological observation by wind and temperature systems which are mounted on towers.

LONG-RANGE IMPROVEMENT PROGRAM

Several uncertainties in blast prediction were stated previously in the prediction techniques. Mostly, detailed explanations of certain peculiarities are needed, so that confident extrapolations can be made to very large yields which, so far, have not been tested at the Nevada Test Site.

Currently, the major effort is to determine the attenuation of air blast from buried shots, the relations to yield, environment material, scaled burst depth, ground-to-air interface effects, and for model studies, high-explosive nuclear-explosive air blast generating efficiency.

Reasonable predictions for air blast are able to be made from single charge cratering shots, but there is little information on blast from multiple charges in a row. One documented experiment with eleven 8-pound charges, buried for maximum ditching, gave a blast pressure pattern as shown in Figure 12.11. Waves from the several charges

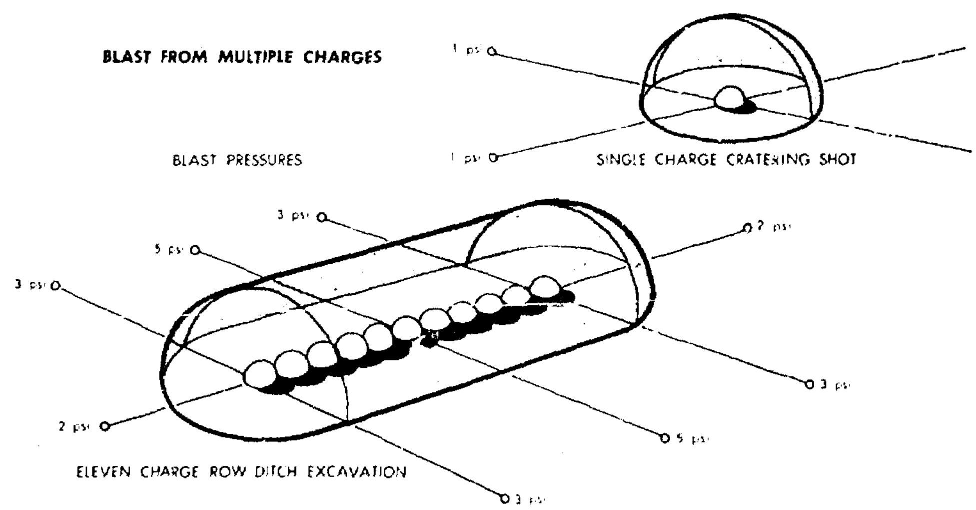

Figure 12.11. Blast from Multiple Charges.

merged or fused into a cylindrical source, in a manner similar to the formation of a Mach stem wave by ground reflection from blast-optimized burst height. Stronger blasts were recorded normal or perpendicular to the row than at the same distance off the ends of the row. Even off the ends of the row, pressures were double the values expected for single charges. Interpreted in terms of yields being considered for Panama Canal excavation, this means that a row of eleven 1-megaton shots would give the same blast amplitudes in perpendicular directions as 56 megatons buried over three times as deep. Such gross extrapolation from pounds to megatons is not easily defensible, so measurements will be made of almost every Plowshare cratering event in hopes of refining the empirical approach and aiding theoretical explanation.

Figure 12.12 describes another element of prediction that is not thoroughly understood — blast attenuation caused by air. This attenuation is so small on a laboratory scale as to be difficult to measure, but when compounded over hundreds of miles it may well be significant, even for very long wavelengths and seconds per cycle frequencies from large explosives. As previously shown by standard overpressure-distance curves in Figure 12.7, the empirical -1.2 slope indicated nonacoustic energy losses.

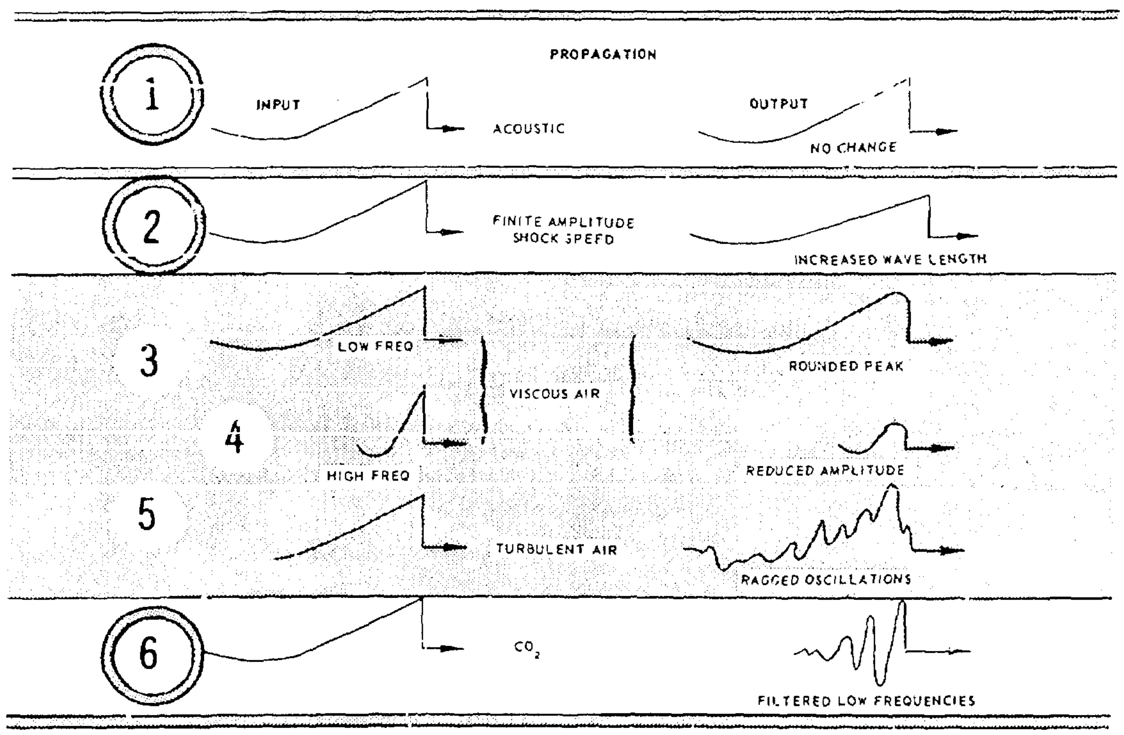

Figure 12.12. Atmospheric Effects on Shock Wave Form.

An acoustic assumption, that there is no energy or wave form change, is valid in air only for infinitesimal compression waves. Even with weak but measurable shock waves, the shock front travels slightly faster than the rest of the wave, so wavelength is eventually increased. If energy is conserved, then overpressure must drop. This condition may be calculated and appears to explain the -1.2 law for the particular high-altitude burst experiments where it was observed. However, this finite-amplitude effect depends on the history of ambient air pressures and temperatures passed by the wave and requires extensive computation for every long-range ray path, especially for ducting at very high altitudes. This should be investigated further, and simplified with a computer program in the near future.

Nearly 50 years ago, the viscous sound attenuation coefficient for air was determined, and that it was proportional to sound frequency squared and inversely proportional to air density. A few years ago it was found that this coefficient was about 30 percent too small, but still almost insignificant for frequencies involved in nuclear blast prediction. From calculation, it turns out that low frequency shock waves at long ranges from 1-kiloton air bursts are only slightly rounded off, as shown by the third line of Figure 12.12. Megaton waves are not detectably affected. Waves from 1-ton high-explosive reference shots, as shown in line four, are damped by a factor of about two in travel through the ozonosphere and to 125 miles range.

Another mechanism for pressure reduction, as shown in line five, is the energy scattering effect of air turbulence. Recent Russian studies and texts have been applied by sonic boom researchers at the Boeing Aircraft Company with some success in explaining anomalies observed in recent Oklahoma City trials. This too is a complex calculation and may or may not be a significant and effective wave modifier for low frequency explosion waves. Air turbulence power spectra are needed for this calculation and, so far, there are no very good ideas on how to acquire these data at altitudes above tower heights.

A recent study at the Denver Research Institute has shown that even minute quantities of carbon dioxide in air may effectively absorb cycle per second low frequencies, and give wave forms as shown in line six. This possibility needs further study and calculation for application to long-range propagations.

Many other categories of problems need study as shown in the following list, which includes some of the more interesting applications.

SANDIA LONG-RANGE STUDIES

PROBLEM	INTEREST
(1) Underground Burst Blast Attenuation	Large Underground Tests, Plowshare, and Detection
(2) Cratering Blast Attenuation	Plowshare and Military
(3) Multiple Charge Effects	Plowshare
(4) Atmospheric Attenuation	All Explosives, Sonic Booms, Detection, and Rocket Engine Tests
(5) Ozonosphere Observation	All Distant Propagations
(6) Ozonosphere Climatology	Site Selection, Test Planning, and Plowshare
(7) Inversion Propagation	Onsite Safety and Military
(8) Structural Response	Site Selection, Plowshare, Claims Adjustment, Sonic Booms, and Rocket Engine Tests
(9) High Altitude Bursts	Vunerability and Military
(10) Underwater Bursts	Plowshare and Military

Underground burst attenuation problems concern underground testing, clandestine test detection, and some Plowshare programs. Crater burst attenuation factors concern Plowshare excavation designs and military effects. Multiple charge effects seem to only concern Plowshare. Atmospheric attenuation problems affect any long-range blast wave propagations, whether from explosives, supersonic aircraft, or large booster rocket engines.

Refined methods and systems are being pressed forward for ozonosphere wind and temperature measurement. To date, Sandia has been unsuccessful with rocket-borne temperature observation because of various equipment failures. However, some agencies have had much better luck. Rocket wind observations are satisfactory, but there should be further cost reductions. Recent price quotations for $425 per round are considerably improved over $3,500 per round paid 5 years ago. A goal of $200 per round seems reasonable.

With lower rocket prices it will be possible to make more observations and collect climatic data about diurnal (day-to-night) changes, day-to-day variations, and seasonal weather cycles over larger areas of the earth and not be restricted to a few measurements, made mostly in the United States. This will aid in safe site selection for test and Plowshare planning, and affect time schedules designed for Plowshare excavations.

Also, Sandia has supported some development of balloon systems to rise to 150,000 and eventually 180,000 feet altitudes. Hopefully, these would be cheaper than rockets for many of the ozonosphere observation requirements, but so far progress has been very slow. The Air Force Cambridge Research Laboratory and the U. S. Weather Bureau seem to be pushing this development about as fast as can be effective.

Some new inversion propagation studies and experiments are expected with instruments on the 1500-foot Bren Tower at the Nevada Test Site. Detailed weather data and high-explosive tests will allow checks on predictions from some new special solutions to wave equations derived by the theoreticians. This research should help improve safe design of onsite installations and manned facilities, and provide useful data about weapon effects on light military targets, such as helicopters, blimps, etc.

Very little is really known about structural response to weak blast waves. That windows may break at 2-millibar overpressure is surprising, since in the laboratory it has been impossible to break a window pane with less than 10-millibar overpressure. Glass condition, age, and prestressing are all very important, and the mixed conditions of a real city cannot easily be duplicated by design. Also, only very small breakage probabilities are enough to cause considerable public response. This was demonstrated in the explosion at Medina Base, Texas; where only thousands of window panes were claimed broken from the millions of exposed window panes in San Antonio. This incident is being studied from a blast prediction standpoint, as it was largely intensified by wind shear ducting and possible focusing. Results from this study will affect Plowshare plans, nuclear test site selection, claims adjustment procedures, supersonic transport designs, interpretation of current sonic boom tests at Oklahoma City, and test facility locations designs for large rocket booster engines.

Although not directly pertinent to Nevada test safety, Sandia has studied and observed blasts from high altitude tests in the Pacific and underwater explosions. Results from high altitude tests concern the weapon vulnerability programs, and are of interest to the military. Data from underwater bursts, besides being of military interest, also concern Plowshare programs for excavations under shallow water or in saturated ground.

[illegible]

[illegible]

[illegible] WT-[illegible]

Cox, E. F., "[illegible]" Tumbler-Snapper Report WT-[illegible] (SRD)

Cox, E. F., and J. W. Reed, "[illegible] Measurements, and Upper Atmosphere [illegible] Knothole, Castle, and Teapot," General Report on Weapons Tests WT-[illegible] (SRD)

Cox, E. F., H. J. Plagge, and J. W. Reed, "Damaging Air [illegible] from Explosions," Operation [illegible] Report WT-[illegible] April [illegible] (U)

Reed, J. W., "Long Range Air Blast Measurements and Interpretations," [illegible] Report POR/WT-[illegible] Aug. [illegible]

Reed, J. W., and H. W. Church, "Blast Predictions [illegible] Island," Operation Dominic Report WT-[illegible] Oct. [illegible] (SRD)

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Vortman, L. J., and J. D. Shreve, Jr., "The Effect of Height of Explosion on Blast Parameters," Sandia Corporation Report SC-[illegible](TR), 30 June 1956 (U)

CHAPTER XIII

STEMMING DESIGN AND SEISMIC NET OPERATION

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STEMMING DESIGN

A difficult problem in the past and for the future has to do with the stemming of tunnel shots. The first successful stemming of a tunnel shot was done by the Lawrence Radiation Laboratory. Successful stemming is a matter of great practical importance from the standpoints of reentry and reuse of tunnels. The release of radioactive iodine has come to prominence as a potential hazard; thus, successful stemming is also very important with respect to public safety.

The involvement of Sandia in stemming design is in connection with underground nuclear detonations sponsored by the Department of Defense. This discussion concerns the stemming used on Marshmallow, a tunnel shot in tuff, because a reentry program was carried out to try to find what features of the stemming plan were most effective.

The stemming used on Marshmallow is shown in Figure 13.1, where the dotted areas show sand fill plugs. Sand fill is used to slow down shock progress down the tunnel, so that at some point the shock in the rock gets far enough ahead so that inward

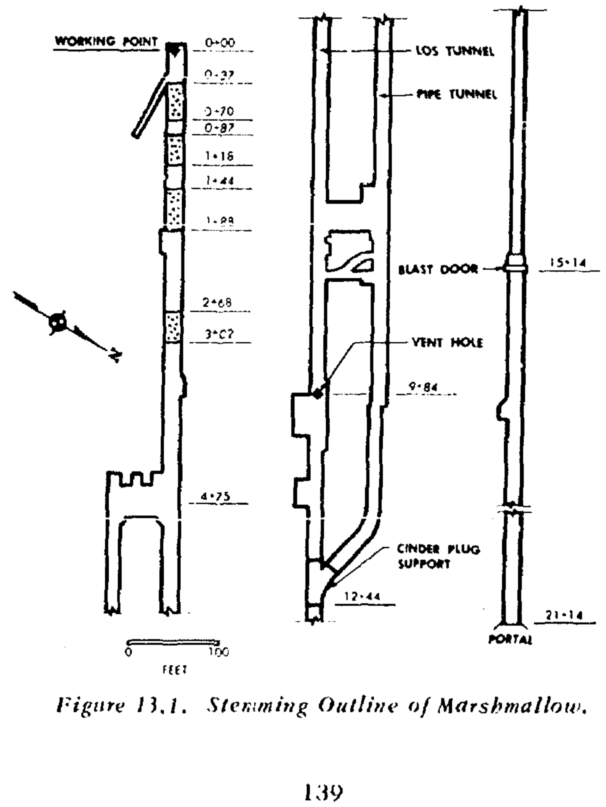


Figure 13.1. Stemming Outline of Marshmallow.

motion closes the tunnel walls. This was expected to take place before the fourth sand plug. Two very large pipes were in this tunnel. A special design, not shown here, was used to close the pipe near the source. The short drift, leading off at an angle 37 feet from the working point, was designed to aid tunnel closure. Tunnel collapse was hoped not to occur beyond about 400 feet, as the station at 475 feet contained specimens to be recovered. Additional recovery was needed at 800 feet. A venthole was placed at 984 feet to allow venting if large pressures appeared in the tunnel. The blast door at 1514 feet was designed to contain tunnel air pressures up to 75 psi. The combination of venthole and blast door was to prevent contamination at the portal. In the future, an unfiltered vent pipe would be disallowed because of the Test Ban Treaty.

Six months after the event was fired, reentry was made to determine how the stemming plan worked. Figure 13.2 shows the reentry exploration. The dotted ellipse is the border of the collapsed area as judged from radioactivity probes. The nose down the tunnel is an area in which the tunnel was not completely closed so that voids and radioactivity were present. Material from that general region was found jammed up against the fourth sand plug with the large vacuum pipes completely crushed. Although the angle drift perhaps contributed to the ellipticity of the collapsed area, it is not clear whether it in fact aided tunnel closure. The tunnel was not collapsed at 475 feet, and was only slightly radioactive so that sample recovery operations were started 4 days after the shot. No appreciable pressure buildup occurred behind the blast door.

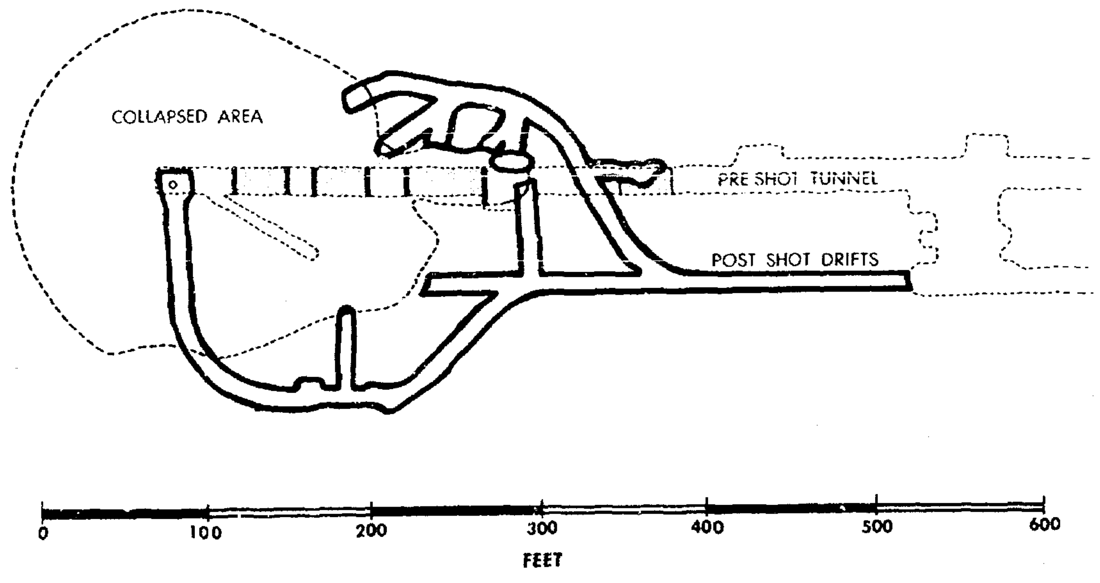


Figure 13.2. Reentry Study of Marshmallow Stemming.

Each event in a tunnel is unique in some respect, and so requires detailed attention to the stemming plan. Stemming adequate to assure the operational integrity of the test site appears not to be difficult. Stemming adequate to assure easy data retrieval and reuse of a tunnel complex appears to be difficult, but was achieved in the instance of Marshmallow.

Sandia also designed the stemming of the Shoal event in granite near Fallon, Nevada. In the case of Shoal, drilling for a radiological-chemical sample was delayed a month, because of extreme concern about measurable release of iodine and possible detection of radioactivity in violation of the Test Ban Treaty. Shoal stemming was successful, and differed from Marshmallow, in that a button hook arrangement was possible, and was employed.

Stemming of Hardhat, on the test site and also in granite, was like stemming a hole shot rather than a tunnel shot. The problem on Hardhat had to do with possible opening into the test drift. This did not produce a public safety problem.

Several tunnel stemming tasks now confront Sandia — all in connection with Department of Defense events. Problems with these events have more to do with reentry safety and the Test Ban Treaty than with public safety.

SEISMIC NET OPERATION

Another activity of Sandia that bears some relation to public safety is the Sandia seismic net shown in Figure 13.3. This net has been operated long enough (since 1961) that some of the test site areas are calibrated for seismic signal versus yield. This allows a prompt estimate of yield shortly after an event. The net has gathered information which shows that the seismic signal is very much dependent on the type of ground in which the explosion takes place, and on the direction from the shot. Data from the net have been used, along with data from other sources, to predict motions from larger yields.

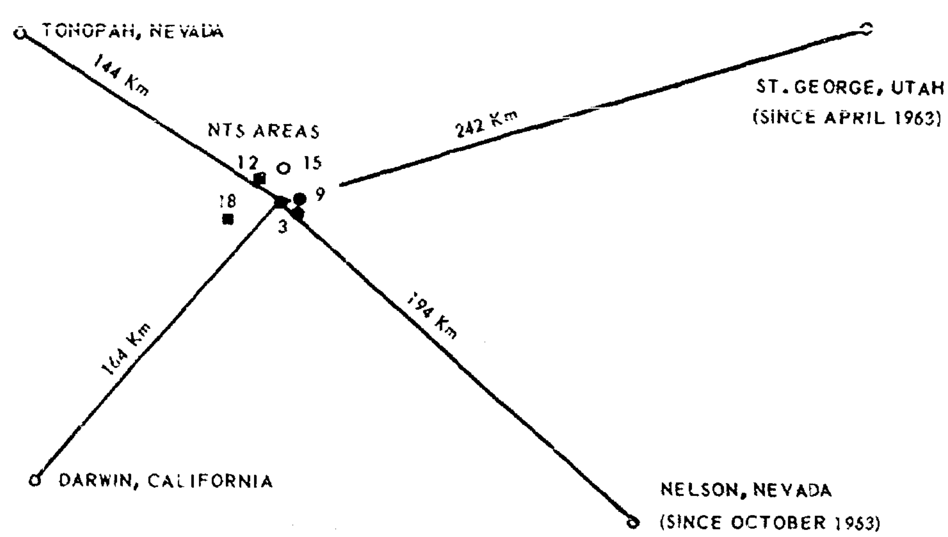


Figure 13.3. Sandia Seismic Net.

CONTINUING ACTIVITIES

In summary, the activities at Sandia that relate to safety in detonating nuclear devices are:

(1) Long-Range Program on Distant Blast Damage

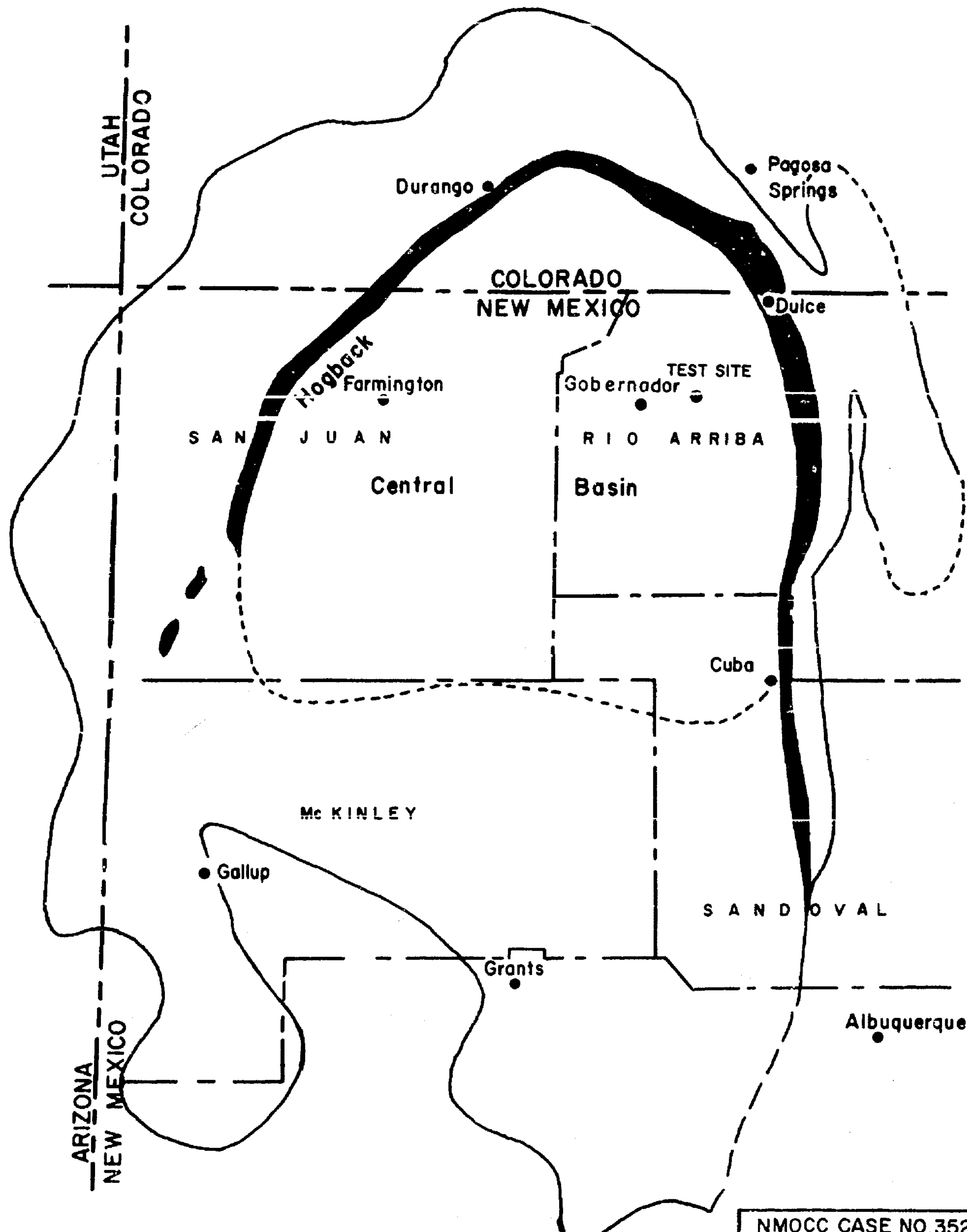
(2) Stemming Design on Many Department of Defense Effects Shots

(3) Seismic Net Operation

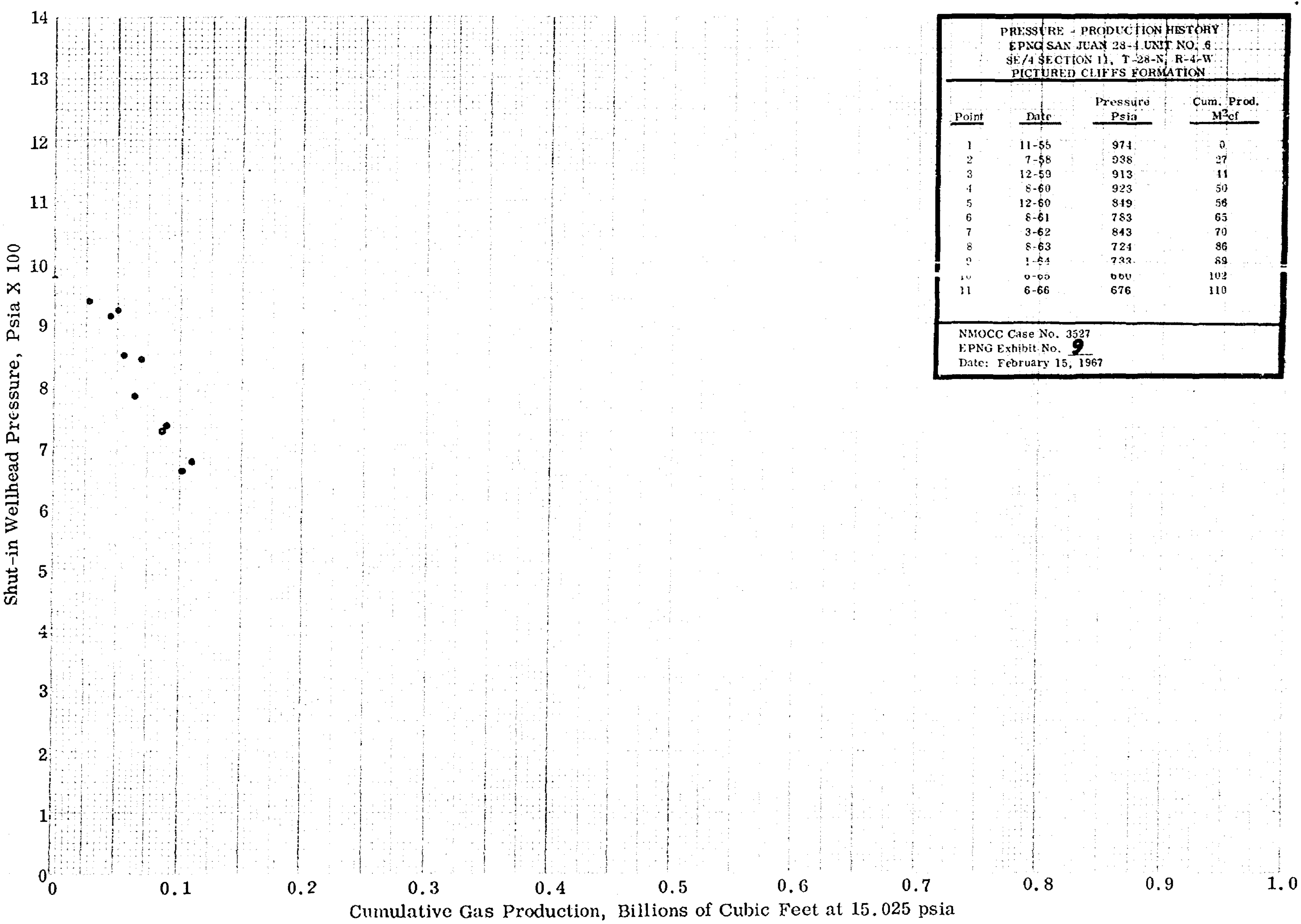
(4) Participation on AEC NVOO Safety Committees:

- Test Managers Advisory Panel
- Site Selection Committee (Effects Evaluation Group)
- Radioactive Effluent Subcommittee
- Ground Shock Evaluation Subcommittee
- Test Evaluation Panel

SAN JUAN BASIN AREA



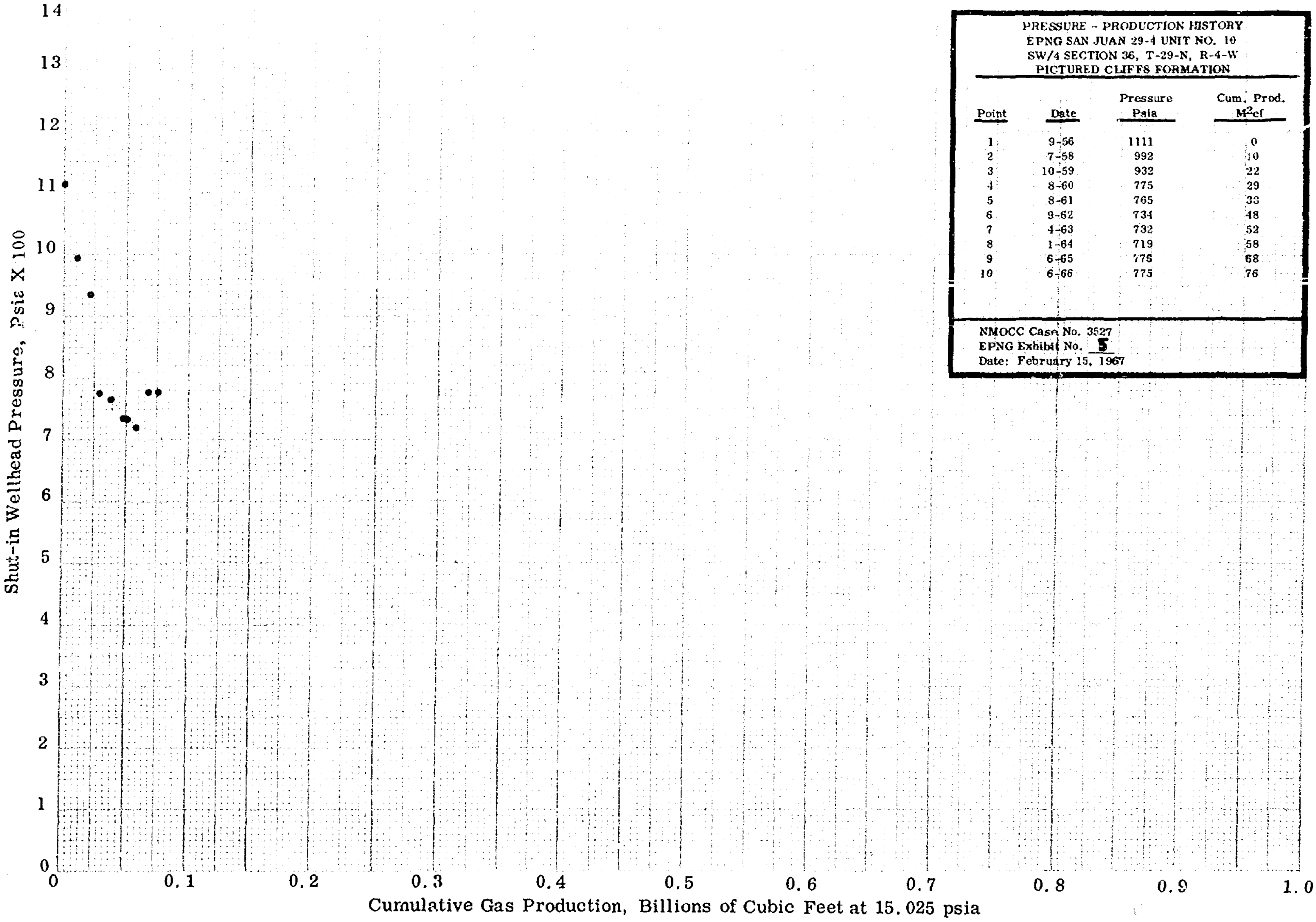
NMOCC CASE NO. 3527
E.P.N.G. EXHIBIT NO. 1
FEBRUARY 15, 1967



PRESSURE - PRODUCTION HISTORY
EPNG SAN JUAN 28-4 UNIT NO. 6
SE/4 SECTION 11, T-28-N, R-4-W
PICTURED CLIFFS FORMATION

Point	Date	Pressure Psia	Cum. Prod. M²cf
1	11-55	974	0
2	7-58	938	27
3	12-59	913	41
4	8-60	923	50
5	12-60	849	56
6	8-61	783	65
7	3-62	843	70
8	8-63	724	86
9	1-64	733	89
[illegible]	6-65	660	102
11	6-66	676	110

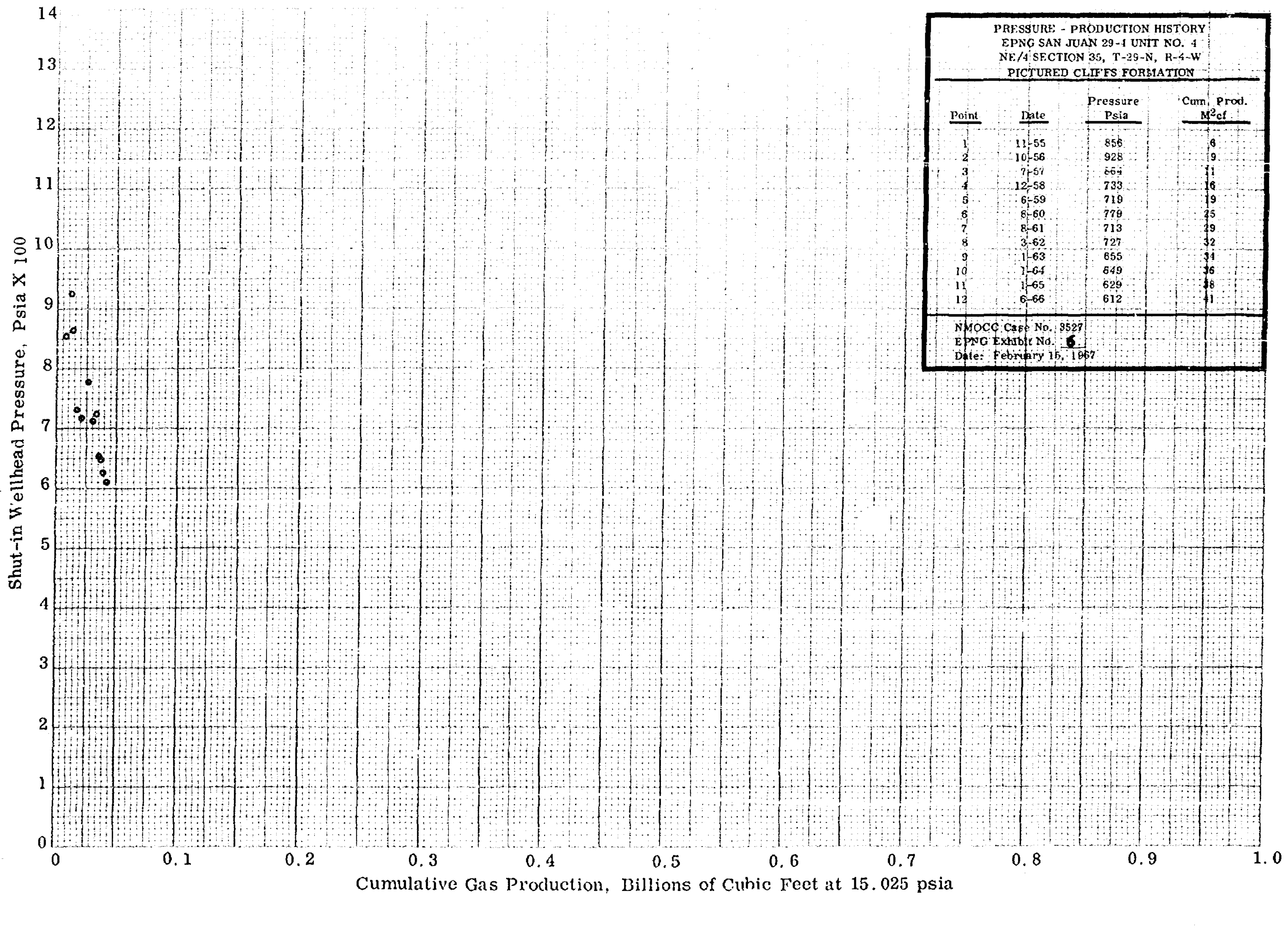
NMOCC Case No. 3527
EPNG Exhibit No. 9
Date: February 15, 1967



PRESSURE - PRODUCTION HISTORY
EPNG SAN JUAN 29-4 UNIT NO. 10
SW/4 SECTION 36, T-29-N, R-4-W
PICTURED CLIFFS FORMATION

Point	Date	Pressure Psia	Cum. Prod. M^2cf
1	9-56	1111	0
2	7-58	992	10
3	10-59	932	22
4	8-60	775	29
5	8-61	765	33
6	9-62	734	48
7	4-63	732	52
8	1-64	719	58
9	6-65	776	68
10	6-66	775	76

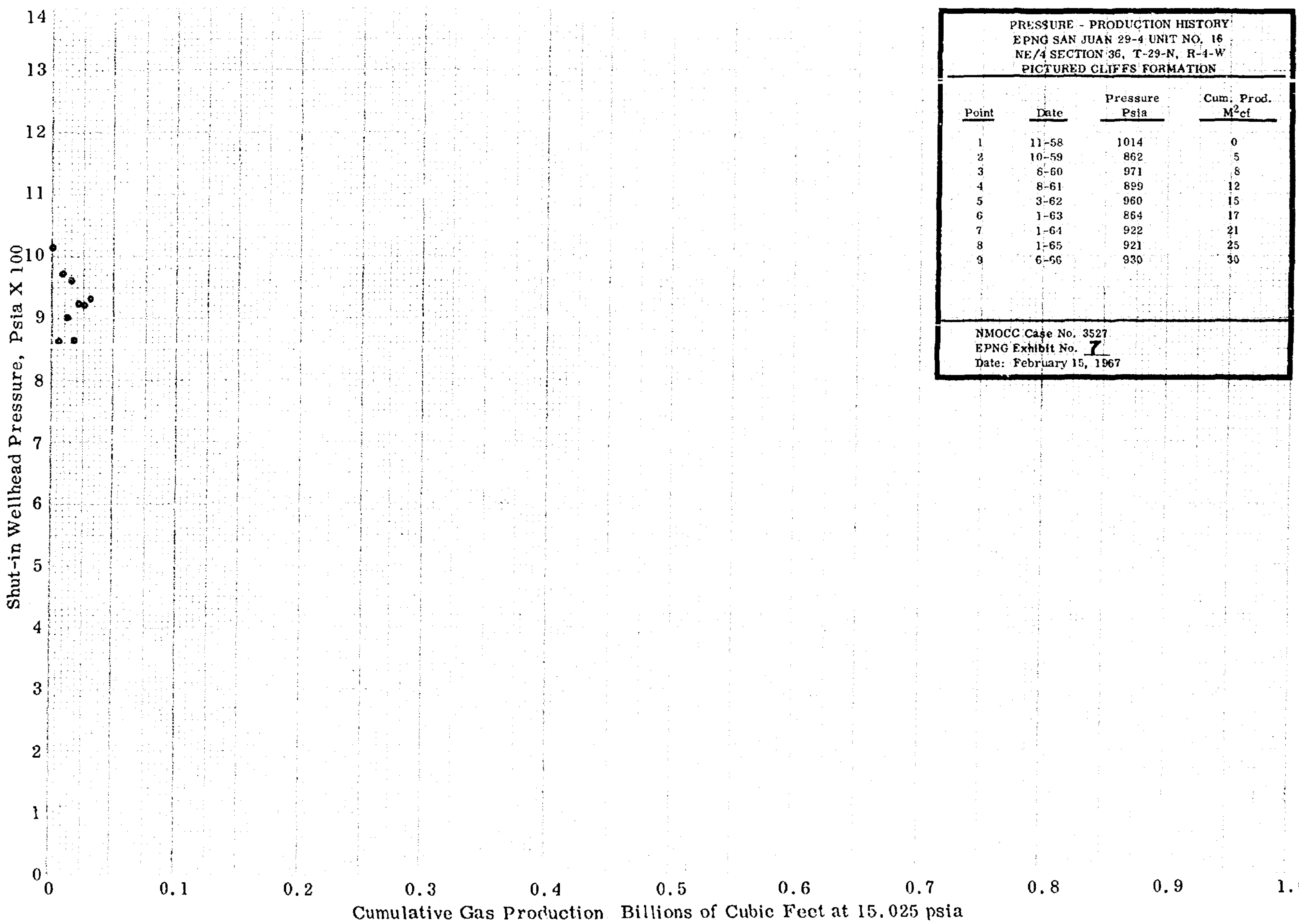
NMOCC Case No. 3527
EPNG Exhibit No. 5
Date: February 15, 1967



PRESSURE - PRODUCTION HISTORY
EPNG SAN JUAN 29-4 UNIT NO. 4
NE/4 SECTION 35, T-29-N, R-4-W
PICTURED CLIFFS FORMATION

Point	Date	Pressure Psia	Cum. Prod. M^2cf
1	11-55	856	6
2	10-56	928	9
3	7-57	864	11
4	12-58	733	16
5	6-59	719	19
6	8-60	779	25
7	8-61	713	29
8	3-62	727	32
9	1-63	655	34
10	1-64	649	36
11	1-65	629	38
12	6-66	612	41

NMOCC Case No. 3527
EPNG Exhibit No. 6
Date: February 15, 1967



PRESSURE - PRODUCTION HISTORY
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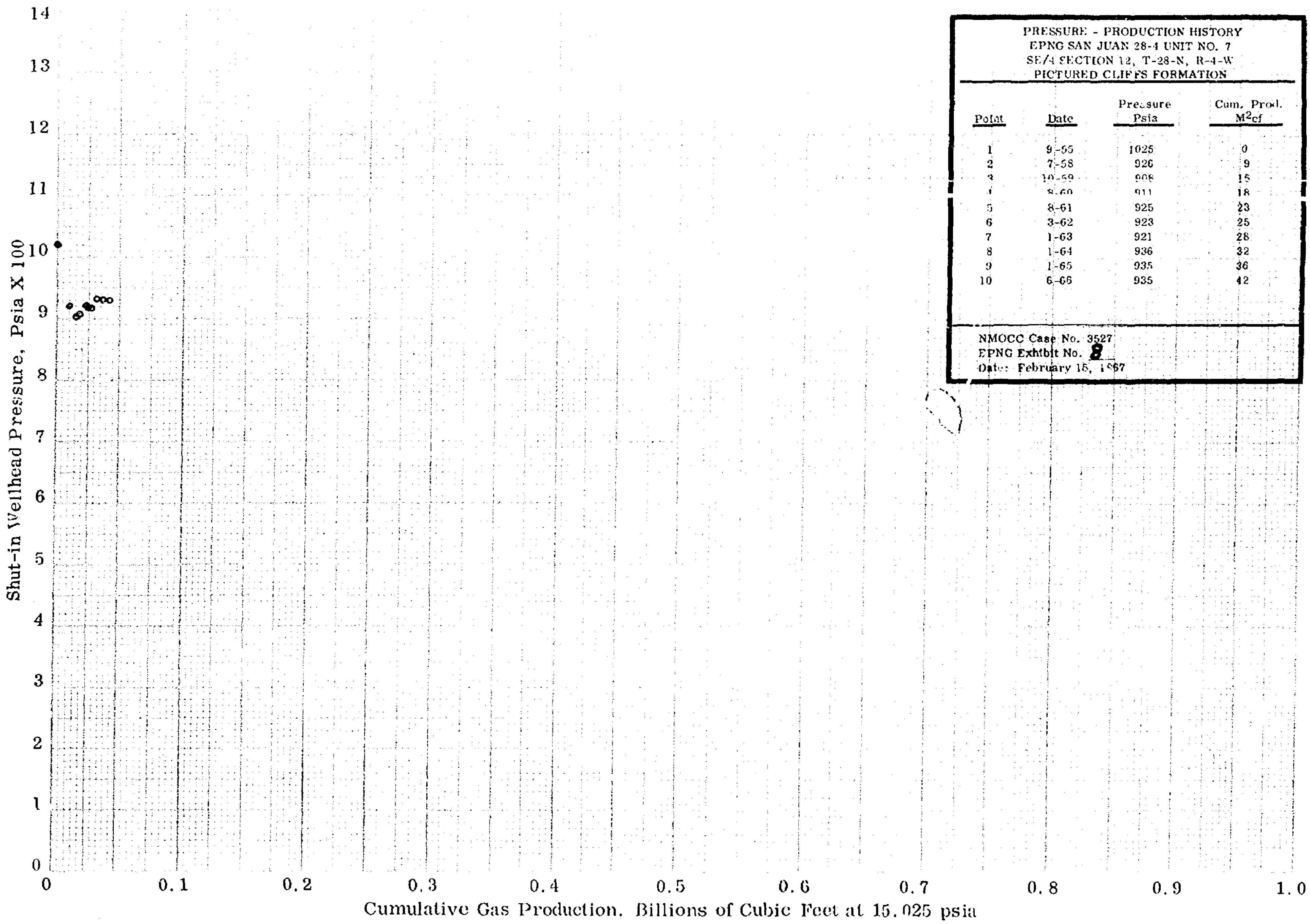
NE/4 SECTION 36, T-29-N, R-4-W
PICTURED CLIFFS FORMATION

Point	Date	Pressure Psia	Cum. Prod. M^2cf
1	11-58	1014	0
2	10-59	862	5
3	6-60	971	8
4	8-61	899	12
5	3-62	960	15
6	1-63	864	17
7	1-64	922	21
8	1-65	921	25
9	6-66	930	30

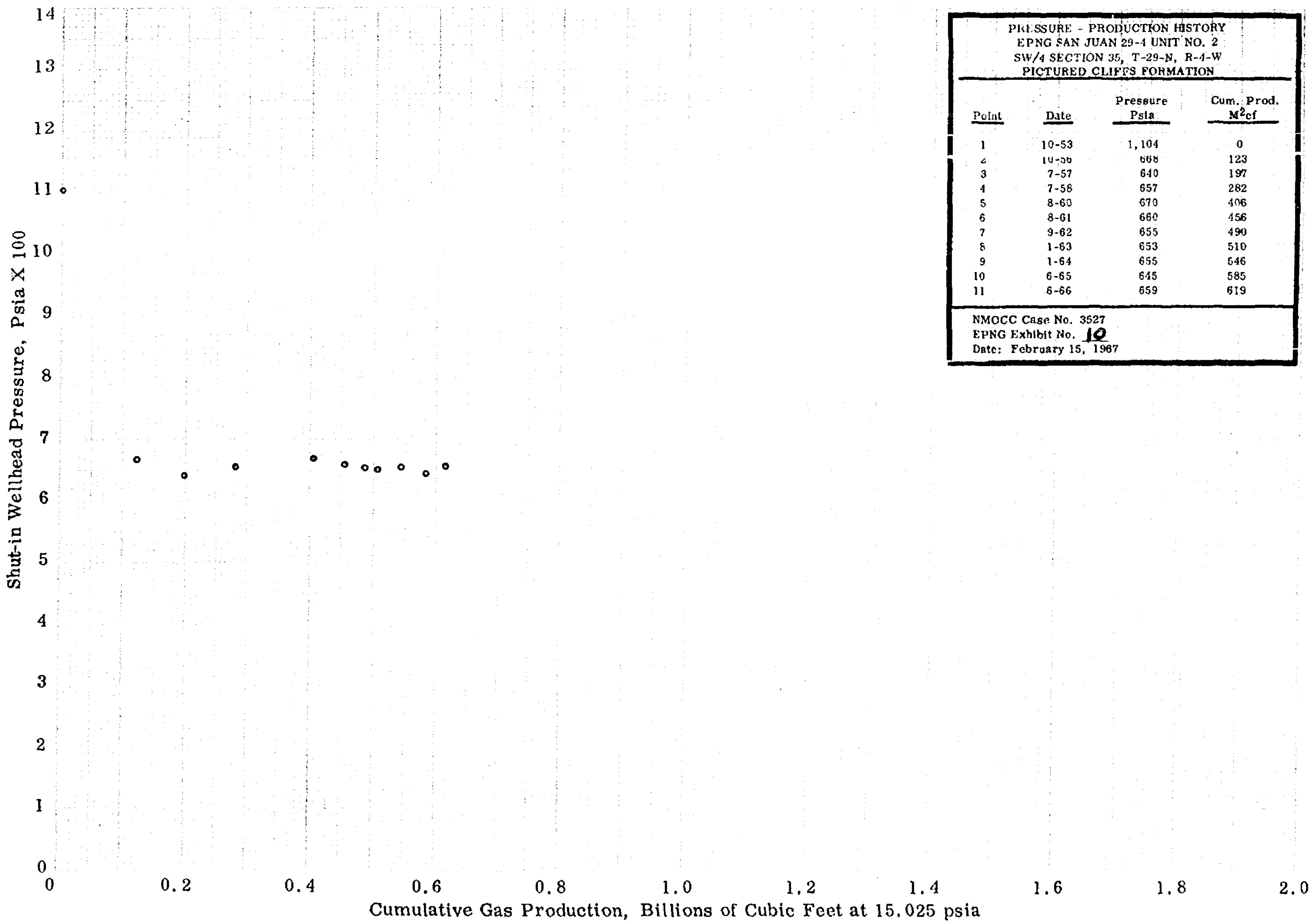
NMOCC Case No. 3527
EPNG Exhibit No. 7
Date: February 15, 1967



PRESSURE - PRODUCTION HISTORY
EPNG SAN JUAN 28-4 UNIT NO. 7
SE/4 SECTION 12, T-28-N, R-4-W
PICTURED CLIFFS FORMATION

Point	Date	Pressure Psia	Cum. Prod. M^2cf
1	9-55	1025	0
2	7-58	926	9
3	10-59	908	15
4	8-60	911	18
5	8-61	925	23
6	3-62	923	25
7	1-63	921	28
8	1-64	936	32
9	1-65	935	36
10	6-66	935	42

NMOCC Case No. 3527
EPNG Exhibit No. 8
Date: February 15, 1967



PRESSURE - PRODUCTION HISTORY
EPNG SAN JUAN 29-4 UNIT NO. 2
SW/4 SECTION 35, T-29-N, R-4-W
PICTURED CLIFFS FORMATION

Point	Date	Pressure Psia	Cum. Prod. M^2cf
1	10-53	1,104	0
2	10-56	668	123
3	7-57	640	197
4	7-58	657	282
5	8-60	670	406
6	8-61	660	456
7	9-62	655	490
8	1-63	653	510
9	1-64	655	546
10	6-65	645	585
11	6-66	659	619

NMOCC Case No. 3527
EPNG Exhibit No. 10
Date: February 15, 1967