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Fallout Forecasting—1945 Through 1962

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FOREWORD

FALLOUT FORECASTING was inspired by the continuing interest of two Los Alamos physicists:

Dr. Alvin Cushman Graves - (1909-1965)

Dr. Thomas Nash White - (1903-1955)

Both realized the extreme need for the knowledge as the Atmospheric Test Programs developed.

This is the history of the continuing development of the "dark art." Of course, the best answer has never been found. All methods depend on input forecast data being sound.

My thanks to all who worked with the Fallout Prediction Units (FOPUs), and to others who have helped me find the various reports, memoranda, etc. which were used in this compilation.

My special thanks to John Malik without whose continued support and constructive criticism this document could never have been completed.

FALLOUT FORECASTING - 1945 THROUGH 1962

by

William R. Kennedy, Jr.

ABSTRACT

The delayed hazards of fallout from the detonations of nuclear devices in the atmosphere have always been the concern of those involved in the Test Program.

Even before the Trinity Shot (TR-2) of July 16, 1945, many very competent, intelligent scientists and others from all fields of expertise tried their hand at the prediction problems.

This resume and collection of parts from reports, memoranda, references, etc., endeavor to chronologically outline prediction methods used operationally in the field during Test Operations of nuclear devices fired into the atmosphere.

TRINITY - Alamogordo - 1945

Choice of a site for the full-scale testing of a gadget was started in 1944. Considerations from a scientific standpoint, security standpoint, isolation and safety of ranches and settlements all entered into selection of a possible location. The description of factors involved is best summarized in "Trinity" by K. T. Bainbridge, and "Project Y" by David Hawkins.[1,2]

The final choice was made in September of 1944, and with the site settled, planning and study of the various effects, such as what later became known as "close-in fallout" could be considered. "Close-in fallout" is considered to be from a few miles to a radius of several hundreds of miles from Ground Zero (GZ).

On May 7, 1945, a rehearsal shot (TR-1) of 100 tons of high explosive (HE) was detonated on a 20 ft tower. A radioactive tracer, 900 to 1000 beta (β) Ci and 330-400 gamma (γ) Ci was placed inside the HE to simulate the radioactive materials to be released by the nuclear test TR-2.[3]

"Calculations based on a simple scaling up of the RaLa shots (^{140}La used at Los Alamos) would estimate 10% of the activity would remain in the soil within a 300 ft radius after the shot. Actually, only 2% was found in that radius, indicating as might be expected that simple scaling laws do not properly allow for the increase in updraft with increasing charge." (Ref. 1, page 11.) Meteorological studies and observations are described in References 4 and 5.

Other estimates and calculations were made for TR-2. They include consideration of thunderstorms, particle size of material acting as a scavenger, Stokes' Law for rate of fall of particulates, radiation intensity delivered to people in the "close-in" area downwind, and recommendations of soil stabilizations at GZ.[6] Reference 7 consists of calculations by Dr. Louis H. Hempelmann M.D., Leader of the Los Alamos Health Group. Those calculations refer to possible hazards from inhalation and ingestion of 49 (plutonium)* as well as fission products.

The RaLa method of implosion measurement used at Los Alamos: Radioactive Lanthanum (^{140}La) was separated from its parent, radioactive barium, and used as a very strong gamma source mounted at the center of an implosion HE assembly. Using special gamma detectors, the density history of the materials in the assembly as a function of time (microseconds) was measured during the

* 49; code name for plutonium, element No. 94, isotope atomic weight 239.

implosion. (Reference 2, pages 203 and 226.) The ^{140}La was mixed with the products of the HE implosion, was scattered at the crater, into the cloud, and was found in fallout down wind.

Estimates of expected cloud height varied from 12,000 ft to 15,000 ft. That observed for TR-1 was 14,000 to 15,000 ft. The cloud height reported for the Port Chicago, CA, disaster of July 17, 1944 was 15,000 ft (1600 t of HE).

TR-2 was fired on a 100 ft steel tower at 0530 hours on July 16, 1945. The yield was 19 kilotons (kt).[8] The main body of the cloud went to approximately 40,000 ft. The major part of the "sediment", as it was called, went approximately northeast and was detected on the ground several hundred miles from GZ. Discussions of time of fall, patterns of "Density of Sediment" and "Radiation Dosages" (2 weeks) are to be found in Ref. 6, pp. 19-24. The "Decay Law for Activity" (the so-called $t^{-1.2}$ Decay Law) is explained in the following quotation:

"Decay Law for Activity

In order to compare monitoring results taken at different times one must know the decay law for activity. Most of the monitoring was done by measuring γ activity. For pure fission products this would follow a t^{-1} law.

$$I = I_1 \frac{t_1}{t}$$

Here, I, I_1, are the intensities at the times t, t_1. Evidence as to the actual behavior has been obtained from two kinds of measurements.

1) Intensity readings have been made at contaminated places at various times. 2) Samples of contaminated earth have been measured in the laboratory. The first kind is subject to errors because the readings were made by different people with different instruments which had varying amounts of contamination; furthermore, the intensity varies as a function of the exact position, height above ground, etc. The activity is also continually redistributed by the wind and rain. The laboratory measurements are more consistent.

These measurements indicate that Eq. (1) is quite well followed, but the decay may be somewhat faster than t^{-1}, probably at first like $t^{-1.2}$."

(Reference 6, page 20.)

COMBAT SHOTS - Hiroshima & Nagasaki - 1945

Fallout was of little concern. Planning called for the fireball not to intersect the ground.[1] "Actual bomb deliveries are fused to explode at much greater heights than the July 16 shot and therefore a much larger fraction of the active material will condense out in the form of a fine smoke which will not drop down to the ground in any reasonable time."[6] "Close-in fallout" was very little. Some activity was found at considerable distance from GZ associated with "black rain". The "black" in the rain acted as a scavenger and was probably caused by the fire storm incendiary effects on the city.[9] A note occurs in part I-4 of the CROSSROADS Handbook[10]; "TRINITY 1% fiss. products within radius of 1000 ft, Nagasaki 0.025% fiss. products deposited within radius of 2000 ft."

The "Height of Burst" (HOB) of both as planned was to maximize the explosive force of the bomb.

CROSSROADS - Pacific Proving Ground (PPG) - Bikini - 1946

Operation CROSSROADS, conducted at Bikini Atoll in the Marshall Islands, consisted of two shots. ABLE was an air drop from an Army Air Corps B-29; BAKER was an underwater shot suspended from a ship in Bikini Lagoon. Details as to yield, locations, date/time, HOB, etc. are to be found in References 8 and 11.

Calculations were made by LA Group B-15 primarily to determine the safety of pilots who might fly near or through a cloud at early times and also to estimate contamination of ships in the target array. Ref. 10, part I-4, pp. 7-8.

Estimates were primarily made as to cloud height, wave height and length, and cloud activity.

Cloud height was estimated to go to the tropopause at 25,000 ft and push through to 60,000 to 70,000 ft. See Ref. 10, part I, p. 3.

Concern with pilots and drone samplers flying through the cloud was important, and estimates were made as to possible dosages of gamma radiation to such pilots. Discussion is to be found in part I-4, pp. 6-7, and the statement made is "no planes should knowingly fly through the cloud during the first day."

Much thought was given to residual and induced activity in water where diffusion of the material would take place as well as radioactive decay.

Neutron activation of sodium to ^{24}Na (15 h half life) and chlorine to ^{38}Cl (37 min half life) was also considered.[10] The conclusion was that for H + 1 through 48 h the fission-product radioactivity would always be about 10 times as large as the induced activity in seawater. Ref. 10, part I-4, p. 15.

The fate of the residual fission products is referred to as "the smoke column", or contamination of a ship by "water drops containing radioactive products falling on the ships".

W. G. Penney, in forecasting wave height and length, closes with the statement: "Much of this spray [caused by blast] will be swept into the cloud, become contaminated with fission products, and rain down on the ships downwind. This will leave a radioactive trail of some three or four miles long." Ref. 10, part IV, p. 3.

Note that the term "fallout" as a noun has not appeared in the vocabulary in any of the literature written prior to the CROSSROADS shots.

SANDSTONE - PPG - Eniwetok* - 1948

As in the case of TRINITY and CROSSROADS, the fallout forecast was part of the duty of the Task Force Meteorologist. However, a Radiological Safety Officer entered the picture. Meetings were held on D-3 for the long-range forecast, then if plans were to go forward, again on D-1 at 1100, continuing at 1800. At 1800 the latest weather forecast was given by the Meteorologist and a RADEX (Radioactive Exclusion area) or forecast of travel of the radioactive cloud was given by the Radiological Safety Officer. A RADEX consisted of a vector diagram, all vectors originating at Ground Zero, based upon the winds aloft forecast and cloud height forecast as a function of lapse rates in the atmosphere. The various altitude vectors subtended an arc which was considered as the forbidden zone. (Ref. 12, pp. 14-17.)

The prime requirement of the Radiological Safety Officer was that there be no northerly components in the RADEX winds. Informal meetings might be held, but the final decision to shoot or not was made at H-1 hours when possible changes in weather forecast and RADEX changes were considered.

"By chance, the winds on the dates originally selected for XRAY and ZEBRA days were operationally suitable. However, prior to 30 April, the day originally scheduled for YOKE DAY, there was a high frequency of northwesterly winds in the anti-trades at levels between 20,000 and 30,000 ft. In fact, prior to

* The then current names of locations and units are used throughout.

the actual YOKE DAY, there were fourteen impossible firing days because of wind conditions." (Ref. 12, p. 14.)

The term "fallout" is used as a noun to designate the radioactive material falling from the cloud. (Ref. 12, pp. 38, 43, 71, 72.)

RANGER - Nevada Test Site (NTS) - 1951

Following SANDSTONE in 1948, the Joint Chiefs of Staff and the Military Liaison Committee of the Atomic Energy Commission (AEC) supported the establishment of a test site within the Continental United States. To mount a test series at the PPG was very expensive for logistic reasons, very time consuming, and a potential security problem.

Several possible sites for a Continental Test Site were considered, and the location of the NTS was chosen. President Truman announced his approval on December 18, 1950. A discussion as to where, when and why this choice was made is to be found in References 13 and 14.

RANGER was the first Test Operation to be conducted at NTS. Under the direction of C. L. Tyler, General Manager of the Santa Fe Operations Office (SFOO) of the AEC, a Test Organization was formed with A. C. Graves (LASL) as Test Group Chief. Radiation Safety (RAD-SAFE) was delegated to T. L. Shipman, MD, and T. N. White of LASL Health Division. Meteorology support was delegated to the Air Weather Service (AWS) of the U.S. Air Force. The unit was commanded by Maj. D. H. Russell.

The AEC made a public release regarding the tests and the Las Vegas Project Office notified those in the area of the tests by handbill dated January 11, 1951. The first event occurred on January 27. The Operation consisted of five events--all air drops. The final shot of the series was on February 6. See NVO-209 for names, dates, descriptions and yields.[8]

The concerns of the RAD-SAFE Group were many. On site there was the possible radiation to on-site test personnel at shot time and also during recovery of scientific data post-shot.

The concern for off-site effects included:

1. Flash blindness--the result of being startled and momentarily unable to see, which might happen to persons glimpsing the burst. People driving automobiles on highways, airplane pilots (commercial, private and military) might be affected. Protection was provided by road blocks on highways in direct line of sight with the burst at the proper time.[14]

2. Airways--taken care of through the Civil Aeronautics Administration (CAA) for closure of air space and NOTAMS to pilots (Notices to Airmen). Cloud passage--again was covered through coordination with the CAA for airway closure and NOTAMS.[14,15]
3. Winds aloft--prediction was part of the duties of the AWS unit. Times considered were H-hour, H+6 and H+24 for trajectories downwind. On D-1, a formal briefing was held at 1300. The weather forecast was presented by the weather briefing officer. Details of the procedure are to be found in Reference 14.
4. Fallout--the H-1 Weather Section of the Health Division at LASL had been established following recommendations of White to the Director, Norris E. Bradbury, in December 1949. Local problems included fallout from the RaLa shots at Bayo Canyon Site.[2] The first USAF Detachment Commander was Capt. Robert E. Heft, USAF. Some experience in fallout prediction had been acquired by Heft during the year before RANGER, working with the RaLa program. In addition to the above AWS Unit procedure, fallout forecasts were provided by Capt. Heft to the RAD-SAFE Group for operational use in locating fallout by mobile teams with radiation survey instruments. Details are given in WT-204, Appendix F, pp. 95-102, along with shot time wind vector diagrams and fallout detected by mobil monitoring teams after each shot.[15]
5. Air shock--the air shock from some of the first RANGER shots focused to cause considerable damage in Las Vegas (66 miles away) and Indian Springs (24 miles away). The problem was assigned to E. F. Cox of Sandia Corp. A system of pre-nuclear detonation shots of high explosive with microbarograph readings at populated points surrounding the Test Site was developed to enable blast forecasts to be made. See Sandia Corporation--Blast and Fallout Prediction Section, page 21 of this report.

For the first time, a hodograph of forecast winds aloft was used in forecasting the location on the ground of fallout particulates after they were carried to height by the bomb detonation. The procedure is described in Ref. 15, pp. 96-97.

The method used by Heft was later modified and improved by Heft and Lt. Col. Clifford A. Spohn, USAF, during Operation BUSTER-JANGLE.

The Fallout Forecast does not include forecast of radiation rate intensity and "infinite dose". Directions, locations and time of arrival were forecast.

GREENHOUSE - PPG - Eniwetok Proving Ground* (EPG) - 1951

Planning for Operation GREENHOUSE followed the SANDSTONE series. "J-Division" was organized at LASL, with Dr. Alvin C. Graves as Division Leader.[16] The Division was created to provide a permanent test unit to supervise experimental work on weapons.

The Operation was organized with Lt. Gen. Elwood R. Quesada, USAF, in command of Joint Task Force Three.[16] Meteorology was supplied by a unit composed of USN and AWS meteorologists under the command of Col. George F. Taylor, USAF and his deputy, Cdr. Elbert W. Pate, USN. Cdr. Russell H. Maynard, USN, was designated Task Force Radiological Safety Officer.[17] Meteorological data are found in WT-49.[18] The "state of the art" of fallout prediction is well explained in Appendix "C", pp. 59-67 of WT-46.[17]

Radiological safety was the responsibility of Task Unit 3.1.5 (TU-3.1.5) under the command of Brig. Gen. James P. Cooney (MC, USA).

Operation GREENHOUSE consisted of four tower shots. The first was April 7; the last, May 24, 1951. Details are given in NVO-209.[8]

Plans for the operation were discussed by Col. B. G. Holzman, Lt. Col. Delmar Crowson and other meteorologists who had been associated with Operations TRINITY, CROSSROADS and SANDSTONE, as well as with Dr. C. E. Palmer of the University of California at Los Angeles (UCLA).

In April of 1950, plans were made for the training of JTF-3 weather forecasting personnel in the latest techniques of tropical weather analysis and forecasting at UCLA with Dr. Palmer.[17] "Streamline analysis" was introduced as well as the normal types of analyses and forecasting.[17]

Concepts as to "close-in fallout" were considerably altered by events following the first shot, DOG (a tower shot with fireball intersection of the ground). Approximately two hours after zero time, fallout did occur on Parry Island.[17,19] Some of the radioactive particles were picked out, physically measured, and identified as to height of origin in the cloud by application of

* For GREENHOUSE only, the test site was known as the Eniwetok Proving Ground.

Stokes' Law, to match arrival time on the ground.[17,19,20] The uses made of the wind vector diagrams and Stokes' Law fall rate are described.[17]

Discussion of particle size and possible internal hazards to personnel are to be found.[19] The conclusion was: "Therefore, it is assumed that no internal hazards were present."[19] "There was nothing in these [later] observations to alter the earlier conclusions."[19]

Intensity at arrival time and "infinite dose" have not yet been included in fallout forecast calculations.

FALLOUT PREDICTION - MID 1951

As of the summer of 1951, there had been very little information after the fact on "close-in fallout." The TRINITY shot of July 16, 1945 had given the most information.[6]

Both combat shots were air bursts (no fireball intersection). The same was true of the five RANGER shots. CROSSROADS and SANDSTONE had been concerned primarily with zero to 25 miles in radius--keep fallout away. During GREENHOUSE, meteorologists and RAD-SAFE personnel had experienced some problems with fallout on the DOG shot.[17] Fallout did occur on Parry Island. Slight fallout occurred on Eniwetok from EASY, and again on Parry from ITEM. GEORGE, shot on May 5, scooped up the tower, some buildings and part of the island creating a crater in the lagoon. See Reference 16, p. 542.

Efforts of the meteorologists and the "streamline analysis" paid off on GEORGE. Deliberate use of Typhoon "JOAN" provided ideal radiological safety conditions, and no "close-in" fallout.[17] A description of "JOAN" and her prognosis and progress is to be found in WT-46.[17]

So far, the "hodograph" (wind vector diagram) had been developed by Heft, and carried on by Pate and Taylor.[15,17] Large (over 100 microns [μ] in diameter) fallout particles had been measured physically and for radioactivity, and had been identified by using Stokes' Law as to height of origin in the cloud. Time of arrival on the surface could then be forecast.

PRE-JANGLE - 1951

The JANGLE Feasibility Committee meetings, May 21-22 and July 13, 1951, were to consider the Radiological Safety of surface and underground shots (see References 21a and 21b). Considerable discussion was held on the subject of possible particle size and the hazards of inhalation and/or ingestion of material from the cloud following an explosion.[22] A list of "Criteria" was prepared that considered Geology, Meteorology, Radiological Safety, and Radiological Test Data to be obtained.[21a]

Among those present and taking part was Gaelen L. Felt of J-Division, LASL. Felt developed a theoretical fall-out model, he called C (section C of Ref. 23) wherein he considered the TRINITY hot spot and the GREENHOUSE experience. Felt's model, as he states, is theoretical. He uses Stokes' Law for size versus rate of fall purposes, and finishes with tables of Total (Infinite) Dose versus distance, prepared from curves considering particle size, rates of fall, average wind velocity, and radioactive decay using the $t^{-1.2}$ law.

The JANGLE Operation concept had originally consisted of three shots: Deep underground, Cratering, and Surface. Felt's analysis recommended the Surface shot as "...the best one to start with."[23] The Deep Underground shot was removed from the Operation.[21b]

So now for the first time we have a prediction (theoretical) of maximum radiation dose versus distance. The "where" and "when" are left to the hodograph people.

BUSTER-JANGLE - NPG - 1951

The BUSTER part of the series consisted of one tower shot and four air drops. JANGLE followed with one surface and one underground shot. The first BUSTER shot was October 22. The last JANGLE shot was November 29. Descriptions, dates and yields are to be found in NVO-209.[8] Operational procedures of the Test Manager and his staff were conducted pretty much as they were during RANGER.

On the day preceding a planned shot, a formal briefing was held at 1300 hours. Members of the Consulting Committee, later known as the Advisory Panel, were present under the direction of the Scientific Director/Advisor or his deputy. Other key staff members and representatives of participating organizations attended. Technical matters, such as whether the shot could go, were settled first. Then a forecast of the weather situation, the forecast of possible fallout, possible blast effects, plans for security matters, etc. were brought up. If the consensus of opinion of all was to continue, the next meeting was held at 2000. Again the decision must be to continue, or plans must be made to delay. The final formal briefing was held at 0300 on D-day, and then conditions were closely watched by those concerned with technical matters and possible changes in weather until zero time. Meteorological services, including shot time wind forecasts were provided by AWS.[24,25]

Fallout forecasts and plots postshot were provided by the Weather Section of Group H-1, LASL, under the command of Lt. Col. Clifford A. Spohn, USAF. Services as provided during Operation RANGER were continued. Additional responsibilities included bomb cloud height forecasts and postshot observations plus airway closure and clearance problems with the CAA.[26] The mechanics of constructing a wind vector diagram (hodograph), fall time and particle size forecasts are described in the Appendix of Ref. 26.

Off-site fallout detection and measurement were part of the responsibilities of the Radiological Safety Group. Results are documented in Ref. 27, Appendix D, "Mobile Monitoring for Fall-Out" (pp. 31-40), and Appendix E, "Fall-Out Project" (pp. 41-60).

TUMBLER-SNAPPER - NPG - 1952

The Operation consisted of four air drops followed by four tower shots. The first shot was April 1, and the last was June 5, 1952. Details with dates and yields are listed in NVO-209.[8] Meteorological service was supplied as in BUSTER-JANGLE by the AWS.[28]

Fallout prediction, fallout plots, cloud height forecasts, CAA airspace control and related services were provided by the H-6 (previously H-1) Weather Section of the Health Division, LASL, commanded by Lt. Col. C. A. Spohn, AWS. In addition to similar services provided in BUSTER-JANGLE, twenty-four-hour postshot analyses were provided for long-range trajectories of the various elements of the shot-time clouds.[26] Details and discussion are to be found in Reference 29. Briefings for the Test Manager, his staff, the Advisory Panel, et al., were conducted in the same way as in previous operations (see BUSTER-JANGLE).

Cloud-height forecasts were made as described in Section 3.1 of Ref. 29. The small yield regression equation is described in a memo (H-6-48).[30]

A detailed study of early time (H+1 minute to H+10 to 15 min.) cloud rise as measured by theodolite was included in Section 3.2 of Ref. 29.

FALLOUT PREDICTION - MID 1952

During TUMBLER-SNAPPER, the Radiological Safety Group, under the command of Lt. Col. Philip S. Gwynn, USAF, had as a subdivision the "Off-Sité Operations Department" with Maj. N. M. Lulejian, USAF, as Chief. This Department included Ground Survey, Aerial Survey, Fallout Measurement, the Weather Section, and the RAD-SAFE Information Center.

Following the Operation, Lulejian became interested in the problem of fallout prediction and had contacted Felt. Felt in turn wrote to Lulejian describing his C Model as he had used it for JANGLE feasibility-discussion purposes and during TUMBLER-SNAPPER.[31] His comment at the end of his letter to Lulejian states: "The validity of the results depends upon two main points, the correspondence of forecast wind conditions with the assumptions on average wind velocity and degree of shear which are included in the model and the degree of luck one has in choosing the appropriate numerical values for the free variables." This letter was written after both BUSTER-JANGLE and TUMBLER-SNAPPER. Some changes have been made in Felt's model. In paragraph 4, p. 2 of his letter, he mentions a double distribution of particle sizes. On p. 3, and paragraph 5 of p. 4 he refers to the "mixing fraction". As to cloud height, he was rather empirical based on past experience. However, he mentions Spohn's work.[30]

Felt had also done some planning work using "memo SD-9441" for the upcoming IVY-MIKE thermonuclear shot in the Pacific.[23] His rough notes were given to William E. Ogle, February 25, 1952.[32]

IVY - Pacific Proving Ground - EPG - 1952

On September 9, 1952, the AEC and the Department of Defense (DoD) made a joint press release, "that in the autumn months Joint Task Force 132, under the Command of Maj. Gen. P. W. Clarkson, USA, would hold atomic tests in the Pacific."[16]

The Task Force was organized with Dr. Alvin C. Graves as Scientific Test Director. Meteorology and Radiological Safety at Task Force level were supplied as in GREENHOUSE and by some of the same personnel. Cdr. Elbert W. Pate, USN, was JTF Staff Weather Officer. Capt. Russell H. Maynard, USN, was JTF Staff RAD-SAFE Officer.

Weather service and forecasts were supplied primarily by the AWS, USAF.[33] "At peak strength Weather Central was manned by nine Air Force officer forecasters, one airman forecaster, seven airman observers, four Navy officer forecasters, and ten Navy enlisted observers. These personnel were in addition to the permanent Air Force Upper Air Weather Detachment at Eniwetok."[34] Radiological Safety (RAD-SAFE) was the responsibility of Task Unit-7 (TU-7) under the command of Maj. John D. Servis, USA.[35]

IVY consisted of two shots, one surface and one air burst, at Eniwetok Atoll.[8]

The first was a "thermonuclear device--christened MIKE--which would be detonated in the Pacific on November 1, 1952 [October 31, Greenwich Civil Time (GCT)], as part of the IVY series," (Reference 16, p. 590). "The detonation--later measured to be 10.4 megatons--had erased from Pacific charts the island of Elugelab," (Reference 16, p. 592).

"MIKE was detonated on the date scheduled several months earlier and this date was, providentially, the only day during a period of approximately one month when acceptable conditions prevailed. Unacceptable conditions had existed for fourteen days preceding and nine days after 1 November, and the KING detonation was no less complicated due to the added condition for a visual drop" (see Ref. 34, p. 107). As before in Pacific operations, a RADEX was forecast and used.[34] The RADEX subtended an arc, azimuth 258° true through 320° true out to 100 nautical miles. A special fallout forecast was made for Project 5.a (see Ref. 36, pp. 51-52).

Fallout was found and measured inside the lagoon (see Ref. 36, p. 38 and Ref. 34, p. 183). In addition, fallout was experienced by the ship MV HORIZON, located approximately 100 nautical miles NNE of Zero. The ship turned south and, after steaming approximately 28 miles, moved out of the fallout field, using its washdown system.

The KING shot was an air burst. For the forecast and RADEX used, see Ref. 34, p. 201. Fallout was not a problem.

Fallout prediction for operation IVY was still only qualitative. Hodographs and fall rates were forecast, but not infinite dose and dose rates.

Meteorology and radiological safety at Task Force level were supplied as in GREENHOUSE and by some of the same personnel.

UPSHOT-KNOTHOLE - NPG* - 1953

The Operation consisted of seven tower shots, three air drops, and one airburst (gun shot). The first shot was March 17 and the last was June 4, 1953. Details with dates and yields are listed in NVO-209.[8] Locations and HOBs are given in Ref. 37, pp. 13-14.

The Test Manager was Carroll L. Tyler for the AEC. Alvin C. Graves was Scientific Test Director, with John C. Clark as his deputy. Clark also served as Chairman of the Advisory Panel. Radiological safety was the responsibility of the RAD-SAFE Unit, under the command of Lt. Col. Tom D. Collison, USA.

Meteorological service was supplied by the AWS as in the BUSTER-JANGLE and TUMBLER-SNAPPER operations.[38]

Fallout prediction, cloud height and cloud trajectory forecasts were provided by the Weather Section, Group H-6, Health Division of LASL, Lt. Col. C. A. Spohn, USAF Commander, (later Maj. George J. Newgarden III, USAF). Details and forecasts, both from forecast winds and post shot soundings are to be found in Ref. 39.

Prior to each shot, a series of Advisory Panel meetings were held. Data and forecasts on meteorology, fall-out, and blast place-time were presented. Fallout information from previous shots as found and measured by the RAD-SAFE Unit, Off Site Operations section under the direction of William S. Johnson, was presented. On occasion, Gaelen Felt presented his theoretical estimates of maximum fallout intensities--Total Dose.[31] Where information was available from Civil Effects Program 27, this was also presented by Kermit H. Larson.[40]

As in TUMBLER-SNAPPER, the RAD-SAFE Control Section, under Major N. M. Lulejian, was making aerial surveys downstream of the shot for fallout activity on the ground. Lulejian served as Control Officer for part of the UPSHOT-KNOTHOLE operation. When he left, he submitted a draft report, "Forecast Fallout Plot".[41]

A very intensive series of fallout detection, measurement, and evaluation programs were set up for Operation UPSHOT-KNOTHOLE. See References 40, 42, 43, 44, and 45.

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* The Nevada Test Site (NTS) had originally been so named. Then prior to BUSTER/JANGLE, the name changed to Nevada Proving Ground. However, confusion of NPG with "Naval Proving Ground" caused reversion to NTS. NTS it again became after UPSHOT-KNOTHOLE.

FALLOUT PREDICTION - Fall of 1953

During UPSHOT-KNOTHOLE a tremendous amount of data on fallout was generated by the RAD-SAFE Unit. Another source of information on some shots was the Civil Effects Group, Project 27, under Kermit Larson. This information was available in part, as it developed, to all those concerned with "close-in fallout". Following the operation, the various programs each wrote their reports, and the data have been used by all.

Felt wrote two memos to Graves on the subject, Ref. 46 and 47. Then Felt and Graves wrote "CRITERIA FOR FUTURE CONTINENTAL TESTS".[48]

The Weather Bureau Project described below was under way.

Lulejian continued with what he had started during TUMBLER-SNAPPER and had left his "Forecast Fallout Plot" with the RAD-SAFE Unit.[41] Then he wrote "Radioactive Fallout From Atomic Bombs".[49]

In References 46, 47 and 48, Felt and Graves considered fall-out from 300 foot tower shots, and refer to Lulejian's work following TUMBLER-SNAPPER on the subject.[41] Attempts were made to use the same approach on the UPSHOT-KNOTHOLE tower shots, with varying success. Spohn's work on cloud height was used. See References 29, 30, and 39.

WEATHER BUREAU PROJECT

By invitation from the AEC, the Weather Bureau (WB) sent a representative to the Nevada Test Site during UPSHOT-KNOTHOLE to consider work the WB might do for the AEC. Lester Machta of the Special Projects Section was the WB representative. The possibilities were discussed with Mr. Ruben Cole, AEC, SFOO, and others, and a proposal of a study of "Close-In Fall-Out From Continental Atomic Tests" was offered by F. W. Reichelderfer, Chief of the WB, in his letter of July 20, 1953 to Cole.[50]

The objectives were outlined. An estimate of personnel (two full-time meteorologists plus backups of administrative, secretarial help, travel, etc.); cost ($12,750) and time (completed within 12 months) were included.

The proposal was accepted by Carroll L. Tyler, Manager, SFOO, AEC, by letter of August 12, 1953.[51] A "Memorandum of Understanding" was prepared and signed by representatives of both agencies with minor changes (travel was increased by $500.00) with the Director of LASL as supervisor of performance.[52] Acceptance of the proposal was made by Tyler for the AEC on September 29, 1953; acceptance by WB on November 4, 1953.[52]

Progress reports were sent to Graves by Machta.[53] The final report on the project (as originally conceived[54,55]) was made in 1955.

Actually, the contract was continued and the same people, with additions, continued to work in Washington and in the field on each Test Operation, both at PPG and NTS.

CASTLE - Pacific Proving Ground, PPG - 1954

Work on the thermonuclear device had been carried forward since 1950 as described in Ref. 16. GREENHOUSE had been a "test of thermonuclear principles" (p. 542), followed by IVY-MIKE (p. 592). "If this trend continued, the Super might be tested in the spring of 1954." (p. 543).

CASTLE was planned to continue development. The Operation consisted of six shots, the first February 28, the last May 13. Dates, locations and yields are listed in NVO-209.[8]

Up to and through CASTLE, the forecasting of fallout direction and intensity was somewhat divided between the meteorologists (winds) and Radiation Safety people (intensity, dose). Everyone was welcome to try a hand at the business.

This had been true since before Trinity. Reference 6 is a collection of working memoranda, proceeding chronologically, of thoughts starting in April 1945 which J. O. Hirchfelder put together. Discussions were held with F. G. Cottrell, Bernard Welch, G. I. Taylor, C. S. Smith, W. G. Penney, and Victor Weisskopf. Others invited for comment were H. Bethe and E. Fermi.

The meteorologists were responsible for wind and weather forecasts up to shot time; for a period of 3, 4-6, or over 12 hours later; and for a history of these same parameters downstream for periods of possibly a day or more. Post-shot air particle trajectory forecasts are also necessary. For the few surface shots detonated prior to CASTLE, only limited amounts of data were available---and all were dealing with kiloton-size yields only.

The CASTLE Operation was conducted by Joint Task Force Seven, under the Command of Maj. Gen. P. W. Clarkson, USA. Alvin C. Graves was JTF-7 Scientific Director. The Task Force (JTF-132) from Operation IVY had held on to some of the same people and Armed Forces Units.

The first shot, BRAVO, was fired at Bikini Atoll, off Namu Island, at 0645 Mike time, March 1, 1954. Significantly exceeding its expected yield, BRAVO released large quantities of radioactive materials into the atmosphere, which were caught up in winds that spread the particles over a much larger area than anticipated.[56] Fallout did occur on some inhabited atolls of the Northern Marshall Islands, and radiation intensities were high enough to justify evacuation of certain such islands.[57]

Prior to BRAVO, experience from overseas operations had included that from CROSSROADS, SANDSTONE, GREENHOUSE and IVY. GREENHOUSE-GEORGE had been fired using the Typhoon JOAN as a buffer, and the fallout had been quickly distributed over a very wide area--little "close-in fallout". IVY-MIKE (10.4 Mt) had been the only megaton shot, and very little after-the-fact fallout had been found.

Failure of the fallout forecast to predict the BRAVO incident was the result of compounding of three factors:

1. Lack of fallout information on previous high-yield shots.

2. The unexpected high yield, which put a large part of the fallout material into the stratosphere.*

3. A change in postshot winds from those forecast of approximately 10° in an unfavorable direction.[57]

A narrative and discussion of fallout prediction as it started and developed during CASTLE are to be found in Ref. 56, pp. 109-112.

The Operation was started using the hodograph and RADEX as used in previous overseas operations and as described above.

The elliptical approximation method was tentatively used for BRAVO fallout forecast intensities. For the description and development of the elliptical method by Lt. Col. N. M. Lulejian, see Ref. 49.

After BRAVO, and using data acquired during BRAVO fallout, new fallout forecasting techniques were developed. These are described in Ref. 58 and 59.

Using these methods in addition to what had been used for BRAVO, the remaining shots were detonated without further fallout incident.

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* The high yield and the unexpected "fission product" production have been explained by John M. Fowler.[60] "In short, the weapon builders had found a way to use the neutrons that would otherwise have gone to waste; they had made a fission-fusion-fission bomb in which common Uranium-238 was added to the fuel." So the yield was unexpectedly high, and the fallout carried an unexpected amount of fission products.

FALLOUT PREDICTION - POST CASTLE - PRE TEAPOT - 1954-1955

The era of the "big machines" had started in 1953. The first IBM-701, called the "Defense Calculator," was delivered to Los Alamos in April 1953. By August, six 701s had been delivered nationwide. The first run of 701s used vacuum tubes (hundreds of them). The memory used Williams cathode ray tubes (CRTs) (electrostatic storage) and generated a tremendous amount of heat requiring complete forced draft air conditioning. The system needed a lot of maintenance. (IBM company engineers required several hours a day to run check programs and tweek the machine up.) The user/programer had to think and write in binary octal ("machine" language), run the machine, and probably had to punch or modify his own cards and do his own debugging.[61]

Everyone with an interest in fallout considered using the "machine" for forecasting; for modeling, for effects--long term as well as short term. At LASL, White, Kennedy and Israel, of the Health Division, Group H-6, started to use the IBM-701 as a tool for the many iterative calculations necessary; and for the integration-summation of such for fallout patterns.

Because of the events following the CASTLE-BRAVO detonation, the Armed Forces Special Weapons Project (AFSWP) invited those concerned with the close-in fallout problem to a Fallout Symposium in Washington, D.C. in January, 1955. The papers presented included two from LASL. (1) Gaelen L. Felt's "Forecasting of the 10R Isodose Line,"[58] and (2) Thomas N. White's "A Method of Estimating Radioactive Fall-Out".[62] In a letter to Lt. Col. Rankin[63], White describes use of the IBM-701 on the problem in paragraph 6, continuing in paragraph 7.

White refers to A. Vay Shelton, LRL, Livermore, CA as also starting work using the IBM-701 in Livermore. His closing sentence in paragraph 7 was: "We have merely a mechanism of calculation, the value of which has not yet been proven as far as BRAVO is concerned."

Another paper presented by K. M. Nagler of the U. S. Weather Bureau was essentially like Ref. 55. No machine data were used.

TEAPOT - NTS - Spring 1955

The Operation consisted of fourteen shots: three air drops, one crater (surface/underground), and ten tower shots. The first shot was February 18, the last on May 15, 1955. Details with dates and yields are listed in NVO-209[8]. Times, area locations, and height of burst (HOB) are to be found in Ref. 64.

The Test Manager of the Joint Test Operation (JTO) was James E. Reeves of the Santa Fe Operations Office, AEC. Alvin C. Graves, LASL, was Scientific Advisor.

In February of 1954, a "Committee to Study the Nevada Proving Grounds" submitted a recommendation that planning consider the capability of having more than one device ready to go at the same time. And that "shots will be scheduled with more elasticity, so that non-critical shots may be fired when conditions are not right for more critical or marginal shots".[65] Operation TEAPOT was organized to have the "dual" capability. In other words, the plan was to have more than one shot ready to go as a shot date approached. Then as the weather situation developed and changed, the "more hazardous" of those ready might be postponed while the "less hazardous" might be shot.

Accordingly, the Test Manager and his Scientific Advisor had assigned a "hazard factor", based on expected difficulty from the off-site fallout point of view, to each of the proposed shots. The "H" factor is described in Ref. 48.

The plan did indeed work out. The schedule called for TURK to be ready February 15. However, it could not be fired until March 7. In the meantime, WASP, MOTH and TESLA (all "less hazardous") were fired on Feb. 18, Feb. 22 and March 1. A similar situation developed with APPLE-1. When planned for March 10, APPLE was delayed. While delays on APPLE continued, HORNET, BEE, ESS and HADR all were being carried through. Finally getting good weather, APPLE-1 and WASP PRIME were detonated on the same day, March 29.

As the TEAPOT Joint Test Operation was set up, the Test Manager had a Technical Staff Operations Group (TSOG) under the technical direction of the Scientific Advisor. The TSOG consisted of the following:

1. Weather Prediction (AWS) under Lt. Col. C. A. Spohn, USAF, and Maj. R. E. McKown, USAF.

2. Fallout Prediction under T. N. White, LASL.

3. Blast Prediction under E. F. Cox (SC). (See Sandia Corporation - Blast & Fallout Prediction, page 21.)

The Weather Prediction Unit information, together with yield information from the Scientific Advisor, was used by both F.O. and Blast Prediction units to provide forecasts for the Test Manager, his Advisory Panel, and other elements of the Joint Test Organization.

FALLOUT PREDICTION UNIT (FOPU)

The Fallout Prediction Unit was composed of personnel from LASL, UCRL and the U.S. Weather Bureau. Normal strength during the operation was six persons.

The method of forecasting cloud height was the same as used during Operation UPSHOT-KNOTHOLE. The wind forecast, needed for the fallout forecast, was also used by the Radiological Safety Coordinator in recommending an airways-closure pattern. The methods of forecasting fallout are outlined below. One of the objectives of Operation TEAPOT was to provide information concerning the joint effect of yield and tower height on radioactive fallout within a distance of about 200 miles. Previous tests had shown the importance of contact between the fireball and the ground but had provided little data for conditions of marginal contact. TEAPOT was designed to provide such conditions for several important shots. Hence, another important but rather uncertain item of input data was:

"c" The "scaling factor" (the fraction of the yield that should be assigned to the fallout pattern).

PREDICTION METHODS

The formulae used for predicting fallout were based almost entirely on past experience with moderate to heavy fallout, and TEAPOT predictions were not made for situations in which light fallout was assured. Further, none of the methods was designed for predicting on-site fallout; in general, TEAPOT predictions were for distances greater than 20 miles. At pre-shot briefings, a conservative compromise between the predictions of several methods was presented. Most reliance was placed on the following methods:

a. "Weather Bureau Method"

This was an operational version of a method developed by the Special Projects Section, Scientific Services Division, U.S. Weather Bureau, while working on a contract with SFOO for the study of NTS fallout. (See Weather Bureau Project, page 15.) A description of the basic work is contained in Ref. 55, but the details were modified by the time of TEAPOT.

b. "Machine Method"

This method uses IBM-type 701 Electronic Data Processing Machines at Los Alamos and/or Livermore and telephone communication. The theory of the method is described in Ref. 62 and 63. Wind data, cloud height, a coded shot identification, scaling factor, and instructions concerning the desired area of calculation were telephoned to a FOPU representative at Livermore or Los Alamos. He punched the input data on cards, started the machine, and obtained from it a printed listing of radiation doses at the desired distances and directions, which he telephoned back to NTS.

From these data, a plot of the forecast isodose contours was prepared. Early in the test series, the radioactivity versus particle size results of the Weather Bureau study were incorporated into the machine calculation. By the middle of the series, there had been developed a simplified hand-calculation version of the machine calculation. This gave the main features of a fallout pattern in less time than it took to get results from the machine. This method came to be relied upon for final forecasts during early morning hours when the machine was not readily available. This method is described in Ref. 66a and 66b.

The scaling factor problem was closely investigated after MOTH, where the fireball did not touch the ground, but considerably more than expected yield appeared in the fallout pattern. After MOTH, an increased scaling factor adding weight of material from tower and cab was used. Discussion of the scaling factor can be found in References 67 and 68.

A comparison between the preshot prediction and the observed fallout pattern for each shot with significant off-site fallout is to be found in References 69 and 70.

SANDIA CORPORATION - BLAST AND FALLOUT PREDICTION

During Operation RANGER in 1951 (Ref. 14, pp. 25, 27, 28 and Ref. 1), air shock waves from the test shots caused considerable damage in Las Vegas (66 miles away) and Indian Springs (24 miles away). The Sandia Corporation (SC) Weapons Effects Department, under the direction of Everett F. Cox, was assigned to provide forecasts of long-distance blast effects prior to each shot. For subsequent operations this program was carried on and developed throughout the atmospheric test operations.

Input for the blast effects program required wind forecasts just as did fallout prediction. Accordingly, the people involved in each program found themselves working together, and there was considerable cross talk and help.

In addition to Cox, others involved in the blast forecast program were: Melvin L. Merritt, Maynard Cowan, and Capt. Jack W. Reed, USAF. All later became involved in the fallout prediction work. For the history, methodology, and progress of blast forecast work, see the References 71, 72, 73, 74 and 75.

In 1954 Sandia personnel developed an analog computer, RAYPAC,[75] which considerably cut the time and man-effort necessary to the blast-forecast problem.[74]

RAYPAC generated interest in the possible creation of an analog computer for fallout prediction. Correspondence between T. N. White of LASL and T. S. Church of Sandia led to the development of "Dropsey", which was then one of the forecast tools used by FOPU in future operations.[76] "Dropsey" design was based on Tom White's "TEAPOT-Gaussian Hand Calculation Method for Fallout Prediction".[66]

Another product of the Sandia people was "A Slide-Rule Fallout Calculator" from Maynard (Bill) Cowan.[77] The method is used as a "one point" forecast. The best short description is to be found in Ref. 78, pp. 11-12.

REDWING - PPG - Summer, 1956

The Operation consisted of seventeen shots: two air drops, three surface (on land) shots, six barge shots, and six on towers. The first was May 4, the last July 21, 1956. Details with dates and yields are listed in NVO-209.[8]

The Operation was conducted by Joint Task Force Seven (JTF-7), which had been "established as a permanent organization in 1953 to conduct nuclear weapon testing in the Pacific."[79] Both atolls were used (Eniwetok and Bikini) and the principle of "dual capability" developed at NTS for TEAPOT was continued, for the PPG.

The concept of a Fallout Prediction Unit (FOPU) was also continued. The Prediction Methods used were:

1. Weather Bureau Hand Method--a continuation of the work started after UPSHOT-KNOTHOLE. See Weather Bureau Project.
2. The TEAPOT Hand Calculation Method.[66]
3. The SHERMAN Hand Calculation Method.[80]
4. Analogue computers.
   a. Felt Optical Analogue.

      The machine designed by Gaelen Felt was used. The fallout pattern was traced on a photographic plate for each calculation. After processing, the plate could be displayed on a projector. The method required service of a photographic technician + facilities. Also, calibration against a known standard pattern was required.[81]

b. NBS Analogue.

The National Bureau of Standards, at the request of the AEC, did design a high-speed electronic computer that would display a fallout pattern on a cathode ray tube (CRT). Two of the machines were delivered. The equipment was complicated and required an electronics technician to maintain it. Further, after measurement of relative light intensity at various spots on the CRT, using a hand held light meter, comparison must be made with a similar standard pattern for calibration.[82]

c. "Dropsey" - the Sandia Corp. Analogue.

The computer was developed at Sandia Corp. following TEAPOT. (See Sandia Corporation - Blast and Fallout Prediction, p. 21 of this report.) The machine was based on Tom White's hand Gaussian calculations method.[66] Computation of each of eight layers of the cloud falling on a traverse at a chosen radius was made. Results were expressed on an X-Y recorder and the dose rates (or infinite dose) were summed manually at a point or points on the radius. Using a series of radii, the operator could then see the maxima at various distances and construct the "hot line" on a bearing. Interpolation between traverse radii could then be used to construct forecast dose contours.[76]

The procedures for preshot briefings of the Commander, Joint Task Force, are outlined in Ref. 79, p. 101-103. At the main briefing for the Commander of JTF and others, the best-estimate compromise of all methods was presented by a member of FOPU.

RADEX and predicted fallout areas, with notes on levels found after the fact are to be found, shot by shot, in Ref. 79, pages 177 through 252.

POST TEAPOT - PRE PLUMBBOB - NTS

As mentioned in TEAPOT-FOPU, "scaling", the problem of scavenging material entering the fireball and cloud was being considered. Certainly for tower shots, the cab and contents (gadget, instrumentation, shielding) were all vaporized or nearly so in the fireball. Various amounts of tower, metal, cables, etc. were also a part of the scavenging material available. Material on the ground, to some degree depending on fireball size or blast-thermal effect to raise dust, was also a possible contribution. There could be elements activated by neutrons to radioactive isotopes. The pulverized material and the vaporized residual isotopes of elements plated out on the particles, all served to give "close-in fallout."

Much thought had been given to ways of eliminating or limiting such material.[83]

1. One was to use a sky hook (tethered balloon) to support the device and related material, and to eliminate the tower. In November of 1955, the AEC had requested Sandia Corporation to investigate this idea. Design and tests of such were conducted at Albuquerque, and later at NTS, and the result approved.[84] Accordingly, plans for PLUMBBOB included the construction and use of three balloon sites.

2. The composition of the tower, if towers must be used, was also discussed. Aluminum was mentioned again, and the statement was made: "The use of aluminum in towers instead of steel will probably not reduce fallout, and might even increase it." This comment was due to past experience with UPSHOT/KNOTHOLE-9-HARRY. For HARRY, because of a shortage of steel during lead time (strikes?), an aluminum tower was shipped from PPG and used for the upper section. Fallout from the shot had been surprisingly higher than the fallout-forecast people had predicted.

3. Methods to be used by FOPU during PLUMBBOB were also discussed. Leon Sherman (LASL/J-DO) wrote an outline of modifications to his hand method of forecasting using streamline analyses.[80]

PLUMBBOB - NTS - 1957

The Operation consisted of thirty detonations; four underground, three on the surface, nine on towers, thirteen suspended on balloons, one air burst. The first occurred April 24 (Project 57 is included), the last October 7. Names, dates and yields and type shot are given in NVO-209.[8] The same information is given in Ref. 85 (pp. 41-42) plus time, location by area, and type and height of burst.

The Test Manager was James E. Reeves of the AEC-Albuquerque Operations Office (ALO). The Nevada Test Organization (NTO) operated under the Test Manager to organize and manage the many activities associated with the operation.

Among units of the NTO were:

1. The Advisory Panel, Chairman Alvin C. Graves, LASL, who was also the Scientific Advisor to the Test Manager.

2. The Weather Prediction Unit (USAF, AWS) under the direction of Major R. E. McKown, USAF.

3. The Blast Prediction Unit (Sandia) under the direction of Jack W. Reed (Sandia).
4. The Fallout Prediction Unit under the direction of A. Vay Shelton (UCRL).

The duties and operation of these units were similar to those conducted during TEAPOT. The dual capability started during TEAPOT was continued. The preshot briefings with forecasts of weather, blast, and fallout were given on a format in a similar manner by members of each unit.

A new method of supporting the device, captive balloon, was used at three different Areas.[84]

FOPU, as in past operations, was composed of personnel from LASL, UCRL, Sandia, and USWB. Most FOPU members had performed the same functions in previous operations.

The fallout prediction methods used were:

1. Gaussian Hand Method.[66]
2. Weather Bureau Hand Method.[86]
3. Shelton Hand Method.[87]
4. Sandia Analogue Computer.[76]
5. U.S. Bureau of Standards Analogue Computer.[82]

A description of principle and use of each of these methods is to be found in Ref. 78.

A resume of the activities of FOPU and the results after the shots as found by the RAD-SAFE Off-Site Unit are in Ref. 88.

<u>HARDTACK I - PPG - Spring & Summer, 1958</u>

HARDTACK I consisted of thirty-five shots: thirty shots were on the surface of land or water, three at high altitude and two below the ocean surface. The first shot was April 28, the last August 18. Details with dates, locations and, in some cases, yields are given in NVO-209[8] and Reference 89.

The Operation was conducted by Joint Task Force Seven (JTF-7), Maj. Gen. Alvin R. Luedecke, USAF, Commander. Both atolls were used (Eniwetok and Bikini) and the two high-altitude rocket shots were over Johnston Island.

The duties of various parts of the Joint Task Force are delineated in Reference 90 (with Annexes). Meteorology with wind and weather forecasting was provided by USAF-AWS as in previous Operations (see Ref. 90, Annex J). Radiological safety, including FOPU, is addressed in Annex K (see Refs. 90 and 91). Dual capability at both Eniwetok and Bikini Atolls is defined on page 2 of Ref. 90. (Note: Rocket-launched events planned for Bikini were later moved to Johnston Island.)

FALLOUT PREDICTION UNIT (FOPU)

FOPU was composed of personnel from LASL, LRL, Sandia (SC), and the U.S. Weather Bureau (WB). All of the people had served in a similar capacity in previous operations. Methods used were:

1. Shelton Hand Method.[87]
2. Weather Bureau Hand Method.[86]
3. Sandia "Dropsey" Analogue Computer.[76]

At the briefings for the Commander of JTF-7, a member of FOPU presented the best estimate compromise of the various methods.

Forecast RADEX (both air and surface), FOPU fallout and cloud trajectories are to be found in References 89, 92 and 93.

HARDTACK II - NTS - September-October, 1958

The Operation consisted of thirty-seven events. Eleven were balloon shots; ten were on towers; three were in surface structures. The remaining thirteen were in shafts or tunnels underground. The first event was on September 12, the last on October 30. "HARDTACK II was the last series before the United States adopted a nuclear test moratorium, which had been originally intended to last one year but continued until 1961."[94] Details as to dates, locations, yields, type of shot, times and related information are to be found in NVO-209[8] and Reference 94. The Operation was conducted by the Nevada Test Site Organization (NTSO) with James E. Reeves as Test Manager. Working for/with the Test Manager was an Advisory Panel. Providing information for the Advisory Panel was the Prediction Group.

Three units make up the Group:

1. Weather Prediction Unit--staffed primarily by personnel from the U.S. Weather Bureau.

2. Fallout Prediction Unit--again Weather Bureau personnel. These people were from the Special Projects Section of the U.S. Weather Bureau in Washington, D.C. Many had served in previous operations as part of FOPUs.

3. Blast Prediction Unit--staffed by personnel from Sandia Corporation.

"The Fallout Prediction Unit estimated the extent and path of fallout by comparing expected weather conditions, expected yield, and topographical conditions with actual fallout patterns from earlier shots." (Ref. 94, p. 55.)

One of the purposes of the Operation was to improve containment techniques for underground detonations. So patterns with possible broaching of fallout material were expected to be in a new area of prediction methods.

Patterns used in the analogue comparison were from previous operations.[95] Further, as the series progressed, the patterns of previous shots were used in the comparison.[96]

NOUGAT - NTS - 1961-62

"The United States began a series of underground tests in Nevada on 15 September 1961, and U.S. atmospheric tests were resumed on 25 April 1962 in the Pacific."[97] A listing of events, chronologically, is to be found in NVO-209.[8] However, as shown, there is an overlap. The first shot of DOMINIC I was April 25 in the Pacific while the NTS program continued.

Thirty events were shot at NTS between September 15, 1961 and April 21, 1962. Most were in shafts, some were in tunnels, and one (DANNY BOY) was a crater shot. The chronological listing of both NOUGAT and DOMINIC I appears in Reference 8.

The techniques of containment of radioactive materials were constantly changing. The aim was to find more effective methods of total containment of material at shot time, during subsidence underground, and at drillback to procure representative samples of radioactive materials.

The Operation was under the direction of James E. Reeves, Test Manager for the Nevada Test Site Organization, Albuquerque Operations Office, AEC. The usual procedures were followed with Scientific Advisors and technical staffs (weather, fallout, blast and an Advisory Panel). Both weather and fallout prediction groups were made up of U.S. Weather Bureau personnel.

The FOPU operated as in HARDTACK II, using primarily an analogue approach. Sources used in the comparison can be found in References 95 and 96.

Fallout patterns, where they were of measurable consequence, are to be found in Reference 97. Patterns, with descriptions of each shot, are listed in Reference 95.

DOMINIC I - PPG - 1962

The Operation consisted of thirty-six shots: twenty-nine air drops, five high-altitude bursts rocket launched, one detonated underwater, and one air burst launched from a submerged Polaris submarine. The first was April 25, the last November 3, 1962. Details with names, dates, type of shot, locations and yield range are given in NVO-209[8] and "Operation DOMINIC I - 1962".[98] Further comments and information are to be found in DASA 1251-2-EX.[93]

The Operation was conducted by Joint Task Force Eight (JTF-8), Maj. Gen. Alfred D. Starbird, USA, Commander. Points at sea near Christmas Island, Johnston Island, and other Pacific locations were used.

The Christmas Island portion consisted of 24 air drops, with detonations over the ocean. Targets were moored rafts equipped with radar reflectors and lights, placed at various points 10 to 20 miles south of the southeast tip of the Island. Also, there was one underwater burst, and one rocket burst launched from a Polaris submarine.

The Johnston Island phase of the Operation consisted of five air drops and five high-altitude burst rocket shots launched from Johnston Island.

Organization of the Task Force was somewhat different for this, the last atmospheric test series in the Pacific. A line diagram is on page 46 of Ref. 98. The Weather Branch, the Radiological Safety Branch and the Hazards Control Center are each a part of JTF, J-3, Operations and Planning. The responsibilities of the Weather Branch are described on page 83 of Ref. 98. A line chart of the organization is on page 84 and a short description of Weather Branch activities is given on pages 83-85.

The responsibilities of the Radiological Safety Branch, its Hazards Evaluation Branch, and the Hazards Control Center are given in Appendix 1, Annex J to Op., Plan 2-62, page 384 of Ref. 98.

The Hazards Evaluation Branch (HEB) predicted possible fallout and the effects of thermal, blast, and water-wave damage to populated areas within 1,500 miles of the detonation. The personnel were from Los Alamos Scientific Laboratory (LASL), Lawrence Radiation Laboratory (LRL), Sandia Corporation (SC), U.S. Weather Bureau, Scripps Institution of Oceanography, and the Navy Hydrographic Office.

The FOPU part of HEB was manned by people from LASL, LRL, SC and USWB. Most had been with FOPU in previous operations in the Pacific and in Nevada. The methods used were:

1. Shelton Hand Method.[87]
2. Weather Bureau Hand Method.[86]
3. Sandia "Dropsey" Analogue Computer.[76]
   (Note: The number of cloud levels used was increased to 12.)

All but one of the shots were air bursts with the height of detonation well above the fireball radius to prevent inclusion of surface material in the cloud. Nevertheless, forecasts were made for ocean-surface bursts based on the winds forecast by the Weather Branch. These forecasts were presented to the briefing of the JTF Commander and his Staff.

"For the Christmas Island air-drop events, JTF-8 established a Safety Committee to evaluate weather and other aspects of each shot. This Committee then would recommend 'go' or 'postpone' to the task force commander." See page 83 of Reference 98.

Fallout, particularly "close-in fallout", was never a problem. However, between July 11 and October 2 there were no nuclear shots detonated. There had been an abort (BLUEGILL Prime) plus a fire on the launch pad on Johnston Island on July 25. The Operation was on hold until October during clean-up of the launch-pad area. See pages 232-233 of Reference 98.

The Fallout Plotting Center (FOPC), which was a part of the Hazards Control Center (Branch), kept an up-to-date plotting of danger areas, RADEX areas, and the actual air and surface radioactivity. These are to be found in Reference 98. The underwater detonation (SWORDFISH) is described on pages 196-217. The changes in the radioactivity in the GZ pool as a function of time and diffusion are to be found on page 322 of Reference 93.

DOMINIC II - NTS - July 1962

The Operation was carried out concurrently with the DOMINIC I operation in the Pacific. There were four low-yield events, the first on July 7, the last on July 17, 1962. Three were near the ground surface, one on a small tower (10 ft.). Dates, locations, type of shot, and in some cases yields, are given in NVO-209[8] and Operation DOMINIC II.[99]

The Operation was conducted by the Nevada Operations Office (NVOO), U.S. AEC, James E. Reeves, Test Manager. Weather Predictions and Fallout Predictions were provided by the Weather Bureau Research Station (WBRS), Las Vegas, Nevada. (This organization had been set up, became a permanent part of the Nevada Test Organization, and was a continuation of the original agreement between the AEC and the Weather Bureau created in 1953. See Weather Bureau Project, page 15 of this report.)

Fallout prediction was carried out in a manner similar to that used during HARDTACK II. A catalog of analogs was being developed from previous similar shots. See References 95, 96 and 97.

Fallout patterns and hodographs are to be found in Reference 95.

POSTSCRIPT

During the period from pre-TRINITY, 1944-1945, through HARDTACK I, 1958, people from many different fields tried their skills at the problem of "close-in fallout" from an atomic blast. The meteorologists, of course, were among the first; and with dependence upon the proof of their forecasts in a four dimensional frame of reference as the basic start of any method or model, the "dark art" certainly should be considered as an extension of their field of science. The first Operation on which meteorologists alone operated both the Weather Prediction and the Fallout Prediction was HARDTACK II.

During the Test Moratorium, the Weather Bureau Special Projects Section continued to amass and compare fallout data from all the previous operations. A later hand method came out of this work, done by Jerome L. Heffter, who had been a member of FOPU during DOMINIC I. See Reference 100. The method was used in a computerized evaluation of a sea level canal project across the Isthmus of Panama. See Reference 101.

After DOMINIC II, a.k.a. SUNBEAM, the Weather Bureau Research Station, Las Vegas, evolved into what is known as the National Oceanic and Atmospheric Administration (NOAA), Weather Service Nuclear Support Office (WSNSO), Las Vegas, Nevada. Testing of nuclear weapons has continued underground at NTS, and occasional releases (usually confined to the Test Site) do occur. Weather forecasting and fallout forecasting are provided by WSNSO. Fallout forecasting depends primarily on a catalogue of analogs of fallout patterns built up over the years, starting with those used for HARDTACK II and DOMINIC II/SUNBEAM, and subsequent operations. For "worst possible" occurrences, the method/model used is known as the Cluff-Palmer "cratering" fallout scaling model upon which the "PIKE Model" is based using data from the PIKE event, March 13, 1964.[8] While the method and model have not been written up as a formal report, information may be found in Reference 102.

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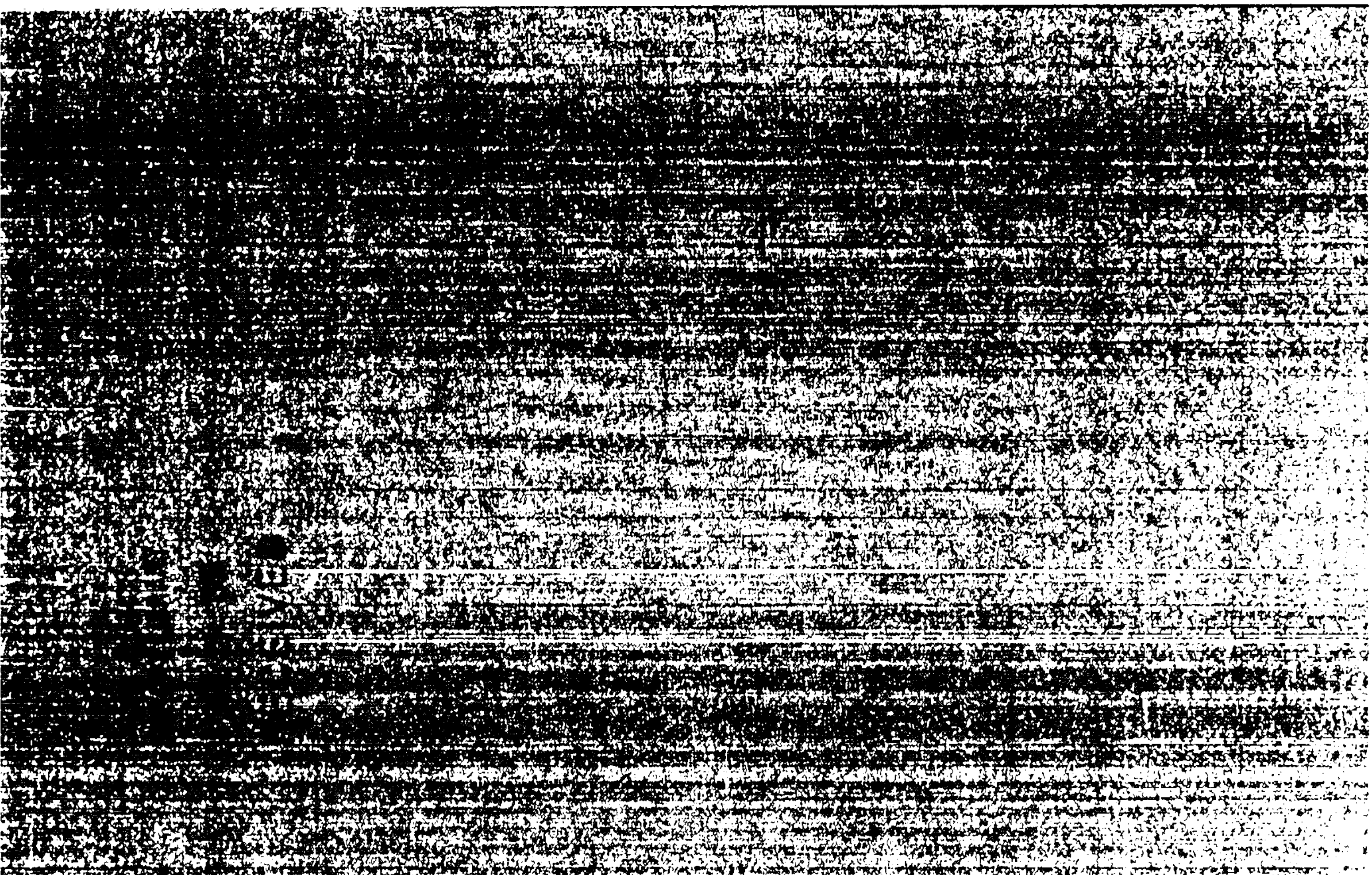

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