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UNITED STATES GOVERNMENT

# *Memorandum*

TO : W. P. Gammill, Chief
Health Physics Branch

DATE: August 3, 1964

FROM : R. P. Bird, Health Physicist
Health Physics Branch

REPOSITORY INEL

COLLECTION SNAPTRAN
22305, FRC # 930 78 0073

SUBJECT: SNAPTRAN REPORT

BOX No. FILE: SNAPTRAN 1964

SYMBOL: HSHP:RPB

FOLDER SNAPTRAN REPORT

Enclosed with this memo is the majority of descriptive material, in first draft form, for a report on the Radiological Monitoring, SNAPTRAN 2/10A-3 Destructive Test. The outline followed for this material is also included. As you know, STEP people want to expand the scope of the report, primarily in analyzing the test direct radiation and by including a hazard evaluation of a postulated SNAP accident. Such an expanded scope means greater STEP participation in preparing the report. A new outline is also to be prepared. Preparation of the report is scheduled as follows:

September 1 - first draft for review and revision by the writers
September 15 - draft for review by supervisors
November 1 - published report

A tentative breakdown of writing responsibilities has been agreed to between G. Dinneen, R. Fielding, and myself. This breakdown will be based more definitely on the revised outline and will require considerable work on my part in the next few weeks. A copy of the material enclosed with this memo has also been sent to TAN.

This memo is intended to inform of the change in target dates for my work, to transmit the material I have prepared so far, and to indicate some concern with this new turn of events. I am in agreement that a single report of all test monitoring activities and results is desirable. In my opinion the report will be essentially the efforts of Dinneen, Fielding and myself but the recognition of these efforts will be difficult to ensure. I believe that, if the work progresses consistent with present indications, authorship of the report will belong to Dinneen, Fielding, and Bird. My concern is that an editor may be assigned, perhaps Ormand Cordes, and that major contributors will be recognized including half a dozen persons providing some analytical work. I propose that when an outline is agreed to and division of writing responsibilities is assigned authorship should be established in a definite manner.

Enclosures:
SNAPTRAN Report Draft

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## OUTLINE

I. Introduction

A. SNAPTRAN Program

B. Radiological Monitoring Program

C.

D. Scope of the Report

II. Preparations

A. Operational Plans

B. Instrumentation

1. General

2. Radiation Instruments

2.1 Monitors

2.2 Dosimeters

2.3 Neutron Detectors

3. Environmental Samplers

3.1 Water Samplers

3.2 Air Samplers

4. Meteorological Instruments

C. Meteorological Forecasting Program

III. Radiological and Meteorological Measurements

A. General

B. Radiation Measurements

C. Environment Samples

D. Meteorological Measurements

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IV. Analysis of Measurements

A. General

B. Radiation Hazards

C. Hazards from Airborne Material

D. Diffusion Analysis

E. Estimates of Fission Products Released into Air

V. Conclusions

A. Test Conclusions

B. SNAP Accident Hazards

C. Adequacy of Radiological Monitoring Program

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# I. INTRODUCTION

## A. SNAPTRAN Program

Several nuclear reactors are under development to supply auxiliary power for space vehicles. These SNAP reactors (Systems for Nuclear Auxiliary Power) cannot be provided with the usual engineered safeguards, even though the operations involved in assembling and launching these reactors pose unique nuclear safety problems. The Atomic Energy Commission has therefore established, as part of its overall nuclear safety effort, a program to simulate SNAP accidents and to evaluate the accident consequences. This program, conducted for the Commission by Phillips Petroleum Company at the National Reactor Testing Station (NRTS), is called the SNAPTRAN program.

The first reactor tested in the SNAPTRAN program is the SNAP 2/10A reactor for which two types of reactor accidents have been postulated: (1) accidental control drum movement during assembly or launch, and (2) accidental water immersion of the reactor core as a result of an aborted launching. For each accident type, a test series was designed to measure reactor properties necessary for predicting reactor behavior during an accident, for explaining the phenomena observed in the simulated accident, and for relating the knowledge gained to other reactors. The test series for the water immersion accident, designated as the SNAPTRAN 2/10A-3 test series, was culminated on April 1, 1964, by a simulated accident which resulted in self destruction of the reactor. The other accident type will soon be investigated in the SNAPTRAN 2/10A-1 test series.

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B. Radiological Monitoring Program

An extensive radiological monitoring program was carried out for the SNAPTRAN 2/10A-3 destructive test. Its primary purpose was the detailed evaluation of the test consequences. Monitoring was also accomplished for quick assessment of test hazards in order to ensure, if necessary, that no public hazard occurred. Some additional radiological and meteorological measurements were made for research aside from the test objective of evaluating the SNAP accident consequences. The monitoring program was the joint effort of the Health and Safety Branch of Phillips Petroleum Company (PPCo), of the Health and Safety Division of the AEC Idaho Operations Office (ID), and of the U. S. Weather Bureau Research Station at the NRTS.

Phillips Petroleum Company established a large monitoring grid with considerable instrumentation for evaluating the test consequences. Objectives were the measurement of radiations from the destructive test and the sampling of radioactive and other toxic materials released to the environment. These measurements were intended to be sufficient for application of test results to a postulated SNAP accident. The AEC-ID Health and Safety Division responsibility was to ensure the safety of the off-site population. Monitoring outside the test facility obstruction fence was correlated with that of PPco. Health and Safety branch so as to extend its monitoring grid. In addition, some research on film dosimetry, neutron dosimetry, and reactor water analysis was undertaken with this unique "accident" source to further the accident evaluation techniques of the Division. When preparations for the destructive test

were complete, the Weather Bureau issued weather forecasts so that the test could be conducted under proper weather conditions. The Weather Bureau also obtained meteorological data to establish the atmospheric conditions of the test and to estimate the diffusion of hazardous materials released into the air.

C. Destructive Test

The SNAPTRAN 2/A10-3 destructive test was conducted at the Test Area North (TAN) of the NRTS. Figure (  ) shows the location of TAN within the NRTS and indicates its location relative to the irrigated lands nearby. Also indicated in Figure (  ) are the prevailing daytime and nightime winds for the NRTS and its environs. The irrigated lands closest to TAN are in the direction of general daytime winds. However, the six mile distance from TAN to the NRTS boundary was sufficient safeguard, as determined in the radiological analysis of reference (  ) for the public.

The test facility was designed for remote operation of a reactor and for removal of the reactor to a hot shop for maintenance or disassembly. This facility designated as the IET (Initial Engineering Test) facility, consists of a test pad that allows remote operation from an earth-shielded control building, a weather protection building that can be withdrawn from the test pad, and a four rail track connecting the test pad to the large hot shop and maintenance facilities at TAN. The test facility is separated by at least one mile from all other NRTS facilities.

Figure (  ) shows a double-flatcar dolly on the test pad connected to the coupling station. The weather building has been withdrawn from the

test pad by the large shielded locomotive in the left foreground. In the right foreground is the earth-covered control building. The 150 foot stack shown in the picture was not used in the test. In the background, the flat, sagebrush covered plain of the NRTS can be seen.

Figure (  ) is a drawing of the reactor test package. The reactor vessel, mounted on a pedestal on the four rail dolly, is surrounded by water within a steel and concrete environmental tank. The calorimeter tank shown in the drawing was used for reactor physics measurements but was removed for the destructive test. A binal sleeve encloses the reactor vessel. This sleeve provided neutron absorption to keep the reactor in a sub-critical condition, similar to that for a rocket launching, when the reactor was in the tank water. Rapid removal of the binal sleeve by a pyrotechnic actuator simulated the accident situation of an aborted launching that drops the reactor core into water.

The SNAP 2/10A reactor is described in detail elsewhere (for instance, see reference (  ) which also described the program.) Briefly, the stainless-steel vessel, approximately nine inches in diameter by twelve inches long, contains a core of thirty-seven rods of fully enriched uranium in a zirconium-hydride matrix. A fixed beryllium reflector surrounds the vessel. Four beryllium drums are rotated to control the reactor by varying the neutron leakage from the core. A NAK system provides reactor coolant.

For the SNAPTRAN 2/10A-3 tests the fixed beryllium reflector surrounding the reactor vessel was removed. Tests of the reactor components showed that the reflector would probably separate from the reactor vessel upon

impact with the water (reference ), although the reactor core would remain intact. However, the reactor excursion and a NAK-water reaction were expected to provide enough energy to disassemble the reactor core and disperse excursion-produced fission products and control drum beryllium into the tank water and into the air. Thus, the hazards expected from a SNAP accident are radiations from the reactor excursion and its fission products, and the beryllium and fission product contaminants released to the environment.

D. Scope of the Report

This report is an account of the SNAPTRAN 2/10A-3 radiological monitoring program. ~~As an account,~~ It is intended to be complete for the reader's understanding of the monitoring program objectives, the instrumentation used, and the results of the various measurements and analyses. Emphasis is placed on the monitoring directly concerned with the destructive test objective of evaluating the test consequences. The results obtained from additional research with this "accident" source are reported but the descriptions of methods and instruments are brief when more extensive descriptions are available in other reports. The results of the radiological measurements are reported as test results but they have also been compared in the report with analytical models developed to describe the test consequences. A prime objective of the test analyses has also been to extend the analytical models to evaluate the hazards of a SNAP accident. To this end, a hazard evaluation of a water immersion SNAP accident is incorporated in the report.

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Reports covering other aspects of the SNAPTRAN program, for instance the reactor physics studies and fuel metallurgical analyses, will be published separately.

Terminology throughout this report, particularly the use of specific units of measure, assumes some familiarity with each of the disciplines involved in the monitoring program. Physics, reactor, radiation, and weather terms and units are used with minimum, if any, explanation.

Section II, Preparations, primarily provides a description of the various instruments and sampling methods used with relation to the specific information to be obtained. Some description is also given of the functions and programs of the monitoring organizations. The section is divided into a brief account of meteorological restrictions required for the test and of some procedures and activities established for the test countdown; detailed descriptions of the instrumentation for radiation measurements, environmental sampling, and meteorological measurements; and an account of the Weather Bureau meteorological forecasting program. The description of instruments is divided according to function, as indicated above. Radiation measurements include gamma, beta, and neutron radiation measurements of the reactor excursion, gamma and beta radiation measurements from the residual fission products, gamma radiation from radioactivity released into the air, and gamma radiation from the radioactivity deposited on the ground downwind of the reactor. The environmental samplingincludes sampling of fission product and beryllium air concentrations, sampling of water ejected from the open tank around the reactor, and sampling of the downwind

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deposition. The meteorological measurements include vertical temperature measurements, wind speed and direction measurements, wind turbulence measurements, and measurements for estimating the trajectory of airborne fission products.

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Section III, Destructive Test, is a brief account of the test day weather conditions, organization activities, and of the test phenomena. The test phenomena that are reported include observations external to the reactor and a brief account of the reactor phenomena.

Section IV, Monitoring Results, reports the results of the monitoring program. The section is an account of the general test results, specifically describing the lack of significant hazard beyond the test facility. The measurement and sampling results are given according to the division by function indicated above, that is, according to radiation measurements, environmental sampling, and meteorological measurements. Analyses of the data are limited in this section to a qualitative discussion. The results of research efforts in accident evaluation are also given.

Section V, Conclusions, provides a brief summary of the monitoring program and results. An evaluation of the program adequacy is discussed with specific recommendations for the SNAPTRAN 2/10A-1 destructive test monitoring program.

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## II. Preparations

### A. Operational Plans

The potential hazards of the destructive test, particularly the release of fission products and beryllium to the atmosphere, demanded that the test be restricted to good atmospheric diffusion conditions. In addition, the wind direction for the test was limited to a 60° sector so that the size of the monitoring grid and the amount of instrumentation needed were reduced. The 60° sector was the minimum size that would permit high confidence in forecasting a wind direction. The sector direction was chosen according to the prevailing wind direction for good diffusion. Accordingly, the destructive test was restricted to the following meteorological conditions:

1. lapse (unstable) conditions, to persist three hours from test time, in order to ensure adequate diffusion conditions,
2. mean wind direction in the sector between 180° and 240° with allowance of an additional 20° on each side of the sector for short term wind fluctuations,
3. wind speed between 10 and 30 miles per hour, the lower limit to ensure reliability for forecasting a persistent wind direction and the upper limit to assure safe aerial monitoring, and
4. no precipitation in the area, in order to maintain good sampling conditions and to prevent localized washout of radioactive material.

In addition, adequate lighting conditions for the high speed movie photography of the test was desirable.

The monitoring grid established downwind of the test pad was a series of concentric arcs at distances from 10 meters to about 6100 meters

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from the reactor. These arcs were primarily 60° arcs based on the required wind direction sector, although the arcs closest to the reactor were extended as much as to encompass the test pad. The grid layout is diagrammed in figures (  ) on pages _____. PPCo Health and Safety instrumented the monitoring grid within the IET obstruction fence, which is about one mile downwind of the facility. In addition, telemetry stations were placed on the closest arc outside the fence. Power for operating the grid instruments was supplied by three sources. The telemetry units were supplied with power from the 2.5 kilowatt generators contained within each unit. Power for all the arcs out to and including the 300 meter arc was supplied from the IET facility. Thirty 3.5 kilowatt generators supplied power for instruments on arcs beyond the 300 meter arc.

The three arcs outside the obstruction fence were instrumented by the ID Health and Safety Division. The air sampling equipment and recording dose rate instruments were supplied with power from 3.5 kilowatt generators at each station requiring it. Telemetry units, part of the ID Health and Safety environmental monitoring network, were located beyond the NRTS boundary and were powered from rural power lines. An aerial monitoring unit, three mobile monitoring units, and some research equipment and neutron detection systems located near the reactor also were the responsibility of ID Health and Safety.

A thirty-five foot trailer was modified for use as a PPCo mobile control facility for dispatching, installing, and recovering sampling media on the outer PPCo arcs immediately preceeding and following the destructive test. Equipment in the trailer included a radio, portable survey

instruments, scalers, an air monitor, clothing, hot and cold change areas, and shower and lavatory facilities. The trailer was made completely mobile by using a 5 kilowatt trailer-mounted generator for power and a 250 gallon tank for its water supply. It was located near the IET obstruction fence about a thousand feet west of the 60° arcs. After the test, samples were brought by recovery teams to the trailer where they were monitored, placed in containers, and given to sample transfer taxis for delivery to the TAN Health and Safety building for analysis.

Similarly, an ID grid control center for dispatching samples, for coordinating grid crews, and for transferring samples for analysis was centrally located at the west edge of the three exterior 60° arcs. This center had two twenty-foot trailers with a radio, equipment storage space, portable survey instruments, and clothing. A 5 kilowatt trailer mounted generator supplied power for the grid control center. Samples recovered from the grid were brought to the grid control center, marked, and packaged for quick transfer to the Central Facilities Area (CFA) at the southern end of the NRTS (see figure ). The samples were analyzed at the ID Health and Safety Division laboratories in CFA.

A second control center, called AEC control, was located in a trailer one mile west of and overlooking the IET and the monitoring grid. This trailer was equipped with radio and telephone for communicating with IET test personnel, Weather Bureau stations, grid control center, and individual monitoring units.

The meteorological restrictions for the test required an extensive Weather Bureau forecasting program. The forecasting was particularly

important because of the four hour lead time required by the test countdown procedure. It was also important for getting off the test with minimum delay due to improper weather conditions. Some delay was expected since the test was scheduled for late winter or early spring, a time that is climatologically poor for meeting the test requirements. To demonstrate the poor climatology, three years of TAN meteorological records for the months of November through March show that the percentage number of days with acceptable wind conditions are 27, 3, 6, 14, and 35 percent by month, respectively. For the entire period an average of 17%, or approximately five days per month for the fifteen months considered, were acceptable. When precipitation is also considered, the number of acceptable days may be reduced by half.

Normally, two weather briefings to ID Headquarters, ID Health Physics Branch, and PPCo test directors were issued at 0930 and 1530 each day. In these briefings, a synopsis of the current synoptic pattern was given along with any expected changes in the pattern. A qualitative forecast of the meteorological variables specified in the test restrictions was given for the current and succeeding days in the morning briefing and for the next two days in the afternoon briefing. For periods up to five days beyond the specific forecasts, trends and general weather conditions, based on National Meteorological Center prognostic charts, were discussed. In addition to the above forecasts and outlooks, a probability rating of acceptable test conditions was also given for each day. The rating was of necessity a combination of the individual meteorological variables expected and an expression of confidence in the total forecast. The test directors then decided whether

or not the countdown procedure would be started the following morning, or in the case of a morning decision that same morning.

In addition to forecasting the meteorological conditions, the Weather Bureau measured the meteorological variables necessary to define the existing conditions. Measurements for describing the atmospheric diffusion conditions were made in order to estimate the amount of hazardous material released into the air from the test. Two field units and remote recording instruments were established for this meteorological measurement program.

As indicated in the preceding paragraphs, each of the three monitoring organizations had field groups carrying out various tasks during the countdown procedure and immediately after the test. Definite lines of communication with the field groups, as well as between organizations, were necessary. Figure (  ) is a diagram of the IET communication network showing communication lines with the Weather Bureau and showing that radio communication was primarily used between the various Phillips Petroleum Company groups. Figure (  ) similarly diagrams the communication lines between ID Health and Safety groups and with the Weather Bureau. The two diagrams obviously overlap at the IET control building and the Weather Bureau office at CPA.

Communication for the test was actually accomplished at two levels. The status of the test, particularly concerning the meteorological conditions, was discussed between Weather Bureau persons at CPA, test directors at IET, and ID Health and Safety persons at the AEC control center. These discussions

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occurred by telephone conference call during the countdown procedure and particularly at times when a "hold" could be placed on the countdown, if necessary. The status of the countdown procedure, particularly the progress of test system preparations and checkouts, of grid preparations, and of Weather Bureau field operations, was discussed within organizations by the means indicated in the communication diagrams and then interrelated by organization persons stationed in the IET control building.

The destructive test was initiated remotely from the earth-shielded IET control building. The shielding and filtered air supply were adequate safeguards for the personnel in the building. During the countdown procedure, personnel were involved in tasks around the reactor and test pad, such as arming the actuator for initiating the test, locating sampling devices, and checking equipment. However, the test facility was cleared of personnel, except for those in the control building, at the time the environmental tank was filled with water. That is, all outdoor activities within the area fence were necessarily completed at the time of the tank filling, about one hour before the scheduled test time. At one-half hour before test time, the aerial monitoring unit flew over the IET and downwind of the facility to visually ascertain that the grid was clear of personnel. This flight was extended to the NRTS boundary to ensure that unauthorized personnel were not downwind of the test.

After the test, the shielded locomotive was used to remove the E G & G photography dolly from the test pad and to replace the weather building over the reactor. The environmental tank water was drained to ensure that

the reactor was in a safe condition. Re-entry teams, with portable radiation instruments and protective clothing, then advanced to the test pad and to the monitoring grid to measure the radiation field and to recover samples. After sufficient decay time, the reactor dolly was transferred by the shielded locomotive to the TAN hot shops for disassembly and detailed investigation of the environmental tank and the reactor components.

B. Instrumentation

1. General

The bulk of the instruments used in the monitoring program was located on the twelve concentric arcs downwind of the test pad. The instruments and their locations are indicated in figures (  ) which show the inner and outer PPCo Health and Safety grids, and the ID Health and Safety grid, respectively. The inner grid accs at distances of 10, 25, 50, 100, 200 and 300 meters were extended beyond the 60° wind sector to encompass the test pad. Instruments placed on the arc extensions provieed background airsamples and radiation measurements exclusive of effluent puff radiation. Some of the outer grid arcs, which are at distances of 500, 900, and 1500 meters, were also extended slightly beyond 60° to provide additional air sampling for borderline wind direction. Figure (  ) indicates that some instruments were also placed beyond the ID Health and Safety arcs at 2515, 3960, and 6100 meters. For instance, radiotelemetry stations for radiological and meteorological measurements were located as far as seven miles from the IET.

Samplers and other instruments were located on and around the environmental tank. Figure (  ) shows the locations of these instruments, primarily for radiation measurements and water samples, with respect to the reactor. Instruments were also strung vertically on a 150 foot radiological tower about 20 meters northeast of the reactor and on the IET stack about 75 meters north of the reactor. These elevated instruments were to measure the height of the radioactive puff as if left the reactor area. A clothesline type of device, with pulleys allowing sample recovery from a 200 foot distance, was constructed to avoid excessive personnel exposure during the early recovery of priority samples located near the reactor. One pulley attachment was tied to the reactor superstructure approximately twelve feet above the reactor core and a second pulley was achored 200 feet east of the test pad. This clothesline system placed radiation instruments in near proximity to the reactor and in line-of-site exposure to the reactor core.

In addition to the instruments in fixed locations, mobile monitoring and aerial monitoring units were used to estimate the intensity, travel, and dispersion of the radioactive puff. Descriptions of the many instruments and their purposes are given in the remainder of this section.

2. Radiation Instruments

The fixed location instruments used to determine radiation hazards consequent to the destructive test included recording dose rate and integrated dose monitors, high range dosimeters and film packet dosimeters, and neutron activation systems. Some instruments observed multiple radiation sources

so that measurements to sort out the contribution from each source were required.

## 2.1 Monitors

Twelve direct radiation monitors, commonly known as remote area monitors, were used in the test. These remote units (Figure ) had detector units housed in weather proof containers and connected by cables to a central recording and control panel located in the IET control building. The gamma dose rates observed at the remote stations were indicated on the rate meters at the central control panel and also on conintuous strip-chart recorders. These detectors recorded primarily gamma radiation since beta radiation is for the most part shielded out by the detector housing assembly. Detectors capable of measuring 1000 r/hr were positioned on the lip of the environmental tank, at the 75 foot level of the radiological tower, and at grid locations as follows (See figure ): A-4 and A-10 on the 25 meter arc, B-4 on the 50 meter arc, C-8 on the 10 meter arc, D-8 on the 200 meter arc, and E-17 on the 300 meter arc. Remote detectors with a range up to 100 r/hr were placed on the east and west sides of the test pad, and on the grid at locations B-10 on the 50 meter arc and F-19 on the 500 meter arc. The detectors located at A-10, B-10, and east and west of the reactor were expected to measure the gamma radiation dose rates from the reactor excursion and from the fission products formed in the excursion. The other detectors, placed on the centerline of the downwind $60^{\circ}$ arcs, were expected to measure the dose rates from the excursion and fission products and also from the radioactive puff.

Nine dose rate measuring and recording instruments were located on the ID Health and Safety grid outside the IET obstruction fence. These instruments were GM tubes connected to continuous strip-chart recorders. The GM tubes were expected to measure the puff gamma and beta dose rate. Four instruments were evenly spaced across the 3960 meter arc and five were evenly spaced across the 6100 meter arc, as indicated in figure (  )
(  ).

A telemetry radiation monitoring network of twenty-five remote stations (Figure  ) and a master readout control panel were used by PPCo. Health and Safety. The network, with thirteen units on the 1500 meter arc and twelve on the 2515 meter arc, was designed to measure and report the puff gamma dose and the relative amount of beta and gamma radiation from the puff particulate material. Each unit contained both a high level and low level ion chamber for measuring the puff gamma dose and an air particulate monitor for filtering and measuring airborne particulate activity. Each unit also contained a motor-generator set and a voltage converter to convert the voltage induced on a memory unit, by the radiation exposure, into an audible tone. The tone was then broadcast to the central unit where the information was printed out on a typewriter and a punched tape.

Six units of the ID Health & Safety radio-telemetry, radiation monitoring network were stationed downwind of the IET and beyond the NRTS boundary. Four of the units were left in their routine locations and two additional units were moved into the area for increased coverage. Each unit (Figure  ) had an ion chamber and an air sampling system with a

GM tube measuring particulate activity collected on a filter and with a scintillation detector measuring gaseous activity collected in a charcoal trap. Each radiation sensor output was converted into digital data and transmitted to a master station at CFA where it was processed and programmed into a typewriter. Normally, the data from each station and each sensor is recorded hourly. However, at the time of the destructive test, the master station was switched to continuously record data.

## 2.2 Dosimeters

Since high dose rates from the reactor transient were expected in the immediate vicinity of the test cell, several types of high range dosimeters were installed. The commercially available chemical and glass dosimeters were supplied by Edgerton, Germeshausen, and Grier Company. Two thermoluminescent dosimeters were acquired from the Control for Radiation, Inc.

Silver phosphate and cobalt glass dosimeters (Figure ) were used. The silver phosphate dosimeter consists of five glass rods contained in a one-half inch diameter by one-half inch high energy discriminatory shield. This dosimeter measures gamma doses in the range from 25r to $10^4$r. The cobalt glass dosimeter consists of three cobalt glass wafers contained in a one-half inch diameter by three-quarters inch high energy discriminatory shield and measures the $10^4$r to $2x10^6$r gamma dose range. Chemical dosimeters, also shown in figure ( ), were of the type used in the commercial model of the ORNL nuclear accident dosimeter, with five ampoule packets housed in a three and one-quarter inch by four and one-eighth inch lithium can. The range of gamma doses measured by the chemical dosimeters is from 25r to $10^5$r.

The thermoluminescent dosimeter, which is based on the thermoluminescence of a lithium flouride phosher, contains the phosphor in a hermetically sealed container one-half inch in diameter and one and one-half inches high. The dose range for this dosimeter is 10mr to $10^5$r. These high range dosimeters were positioned around the top of the environmental tank, on the reactor dolly, on the EG & G dolly, on the clothesline and on the ten meter arc (see figure ) to provide additional monitoring of the reactor excursion and fission product gamma radiation.

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Film dosimeters on the grid were mounted three feet above the ground on stakes located as shown in figures _____. On the 60° arcs out to and including arc E, a small "well" was dug and fitted with a metal can about four inches deep. Film dosimeters placed in these cans were shielded from direct radiation from the reactor and fallout. In this shielded position, the "well" dosimeters monitored only the radioactive puff. Subtracting the puff dose from the dose measured three feet above the ground provided a dose value for the excursion and fallout radiation.

The fixed-location monitors and dosimeters provided definitive measurements for analyzing the test radiological consequences. For a quick assessment of the magnitude of the consequences, aerial and mobile monitoring of the puff as it passed across the monitoring grid and across the NRTS boundary provided a measure not only of radiation intensity but of dispersion and radioactive decay of the puff as well.

The ID Health and Safety Division was responsible for these early assessments. An airplane was equipped with a scintillation detector and other monitoring instruments and with a radio for communication with the AEC control and IET control centers. After tracking the puff as far as possible, the airplane flew back over the IET for a visual and radiological check of the reactor condition. Three vehicles with four-wheel drive were also equipped with radios and with monitoring instruments for mobile monitoring of the puff. The ground vehicles were directed into the path of the puff by Weather Bureau reports of the wind direction and speed.

Film dosimeters were placed on phantoms (figure ) located near the reactor. These phantoms, which were the responsibility of ID Health and Safety, were large polyethylene bottles that approximated a man's torso. They were filled with a solution which was tissue-equivalent for gamma radiation attenuation. Fifteen film dosimeters were placed at each phantom station: twelve on a belt surrounding the phantom, two hanging in free air below the phantom, and one hanging inside the phantom. The phantom dosimeters provided not only a measure of radiation doses at the phantom stations but also a determination of the effect that personnel film badge orientation may have on accident dose measurements (reference _____). Eighteen phantoms were located around the reactor tank downwind as far as 40 meters, as indicated in figure ( ).

Two types of film dosimeters were used in the test. Both types contained Dupont film packets with sensitive and insensitive film for measuring high and low range exposure. One type had the film packet hermetically sealed in special red plastic designed to reduce the effect of long exposure to sunlight (reference _____). This type was used at stations not readily accessible on the day of the test. The other type of film dosimeter had the Dupont film packets in the film badge monitor worn by nearly all NRTS personnel. These dosimeters have been used for a longer time and therefore provide greater accuracy in measuring radiation fields. These badges were located on the film-badge-drop stations, on the phantoms, on the clothesline, on the edge of the environmental tank, and on water catch cans at the 10 meter arc. The sealed film dosimeters were placed on the grid, on the radiological tower, and on the rope elevator reaching to the top of the ETR stack.

## 2.3 Neutron Detectors

Several neutron activation systems were used to measure the neutron spectrum and the neutron dose due to the reactor excursion. Six nuclear accident dosimeters (NADs) of the ORNL Hurst type were placed around the reactor (see figures ) where they could be recovered as soon as possible after the test. Two Nads were on the clothesline in line-of-sight with the reactor, one NAD was on the E G & G dolly, and NAD was located at each of the 25 meter, 50 meter, and 100 meter arcs along the railroad track. An arm on the E G & G dolly recovered the NADs from along the track as the dolly was pulled from the test pad after the test. In addition to the two NADs on the clothesline, two NRTS film badges, a sample of human hair, an activation foil box, and a copper wire were attached to the clothesline. Tow samples of blood, about two liters per sample, were placed on the edge of the environmental tank and on the test dolly.

The NAD systems (reference _____) contain bare gold, cadmium-covered gold, three fission foils and sulfur in a fireproofed can. This combination allows an approximate measure of the neutron spectrum, which must be known before a neutron dose can be determined. The induced activity of the gold and cadmium-covered gold gives a measure of the thermal neutron flux. The plutonium 239 fission foil gives the neutron flux with energy greater than 1 Mev. The Neptunium 237 foil gives the flux with energy greater than 0.75 mev. The uranium 238 foil gives the flux with energy greater than 1.5 mev. The Sulfur 32 bar gives the neutron flux with energy greater than 2.5 mev.

The two clothesline film badges contained the NRTS-ID personnel neutron threshold detector (reference _____) incorporating sulphur, indium, gold foil and cadmium-encased gold foil. These detectors measure neutron fluxes in the thermal and fast energy ranges. The sample of human hair was used to study the application of neutron activation of sulphur in hair as a measure of accidental neutron exposures. Similarly, the blood samples were to be analyzed for activation of sodium in blood as a measure of neutron exposures. The copper wire was placed over the reactor for experience in applying copper activation as an indicator of an accident magnitude. The NADs film badge neutron detectors, hair and blood samples, and copper wire were analyzed by the ID Health and Safety Division.

The activation foil box on the clothesline and another on the edge of the environmental tank were used to investigate activation materials that might improve the NAD systems. One set of materials was located on the outside of the box and a second set was in the center of the paraffin filled box. Bare and cadmium-covered samples of indium, gold, manganese, copper and cobalt, as well as nickel, iron, and titanium samples, were used.

3. Environmental Samplers

3.1 Water Samplers

Three types of water samples were set up to obtain data concerning fission and neutron activation products retained in water. These samplers included long compartmented trays, water catch cans with three inch diameter tops and sample bombs in the environmental tank drain.

Compartmented trays (figure _____) were set on each corner of the reactor dolly to catch water and debris that might be expelled from the environmental tank immediately following the reactor excursion. Supplementing the trays, a series of water-catch-cans (figure _____) were located on the edge of the environmental tank and on the ten, twenty, twenty-five, fifty and one-hundred meter arcs. Catch-cans on the environmental tank and on the ten meter arc completely surrounded the reactor while those on the other arcs were limited to the 60° downwind sector. Each can contained a Schierhart and Schman 576 filter which screened the water sample before it was collected in a reservoir at the bottom of the can. Sample bombs were set up to draw off water samples from the water remaining in the environmental tank following the test but prior to the draining of environmental tank water the liquid waste tank.

Air samples

3.2 A variety of air samplers were used on the monitoring grid to measure concentrations of beryllium and fission products in the air and to analyze the particle sized of the airborne contaminants. High volume air samplers, fission gas samplers, three types of particle sizing samplers, and sequential air samplers were all used for specific measurements.

The Staplex model high volume air sampler is designed to draw large volumes of air through a four inch diameter aerosol filter. This sampler (figure _____) was modified so that a carbon cartridge could be inserted behind the filter as a backup collector. To ensure that the air was being pulled through the filter and the carbon cartridge,

an additional "O" ring seal was installed behind the cartridge. With this arrangement, the flow rate of the samplers ranged from fifteen to twenty-five cubic feet of air per minute. The high volume air samplers placed on the PPCo outer grid arcs were modified (figure _____) to increase the air flow to approximately forty cubic feet per minute by enlarging the size of the inlet. The distribution of the high volume samplers on the gird is shown in figures (  ). Additional samplers were located on the 150 foot radiological tower.

The aerosol filter selected for use in this test was a spun polystyrene mat with a low flow resistence and high collection efficiency. The filters are rated 99% efficient for one-quarter micron particles at face velocities ranging from four to seven hundred feet per minute. They have been used at this laboratory to measure noble fission gases with an efficiency greater than 95%. In addition, they contain no beryllium so that they are useful for beryllium analysis. The majority of the filter samples were analyzed first by gamma ray spectroscopy after which they were analyzed on a mass spectrometer for beryllium.

In addition to beryllium analysis of high volume air samples, two sequential samplers (Figure _____) with twelve sampling stages and four stationary air monitoring samplers were used specifically for beryllium monitoring. These samplers were located in the immediate reactor vicinity and in the test pad coupling station.

The radioactive noble gas concentration in the puff near ground level was measured by drawing an air sample through a high efficiency filter and then into a n air tight balloon (figures _____). Eleven of

these samplers were used on the 60° wind sector out to and including arc E. The air sampler was started at the instant the destructive test was initiated and was allowed to run for four minutes during which time the puff passed by. The entrapped noble gases were then allowed to decay until recovery teams made re-entry to the grid and deflated the balloon through a second high efficiency filter. The radioactive daughters from the gases were trapped on the second filter and on the inside of the balloon. The balloon and filters were analyzed on a multi-channel analyzer to determine quantitative amounts of the daughters deposited.

The particle size distribution of an airborne particulate must be known before the potential hazard associated with its inhalation can be adequately evaluated. The reason is that particulate deposition in the lungs is a function of particle size and differential deposition occurs within the respiratory tract. Selective samplers were therefore placed on the grid in an attempt to distinguish between particle sizes. The three types of particle sizing samplers used were the cyclone sampler (reference ), the Unico cascade impactor (reference _____) and the Anderson Sampler (reference _____). These samplers were positioned in the 60° downwind sector of the grid at the stations indicated in figures ( ).

The cyclone sampler is a two stage collector consisting of a cyclone sampling device in series with a high efficiency filter. The cyclone stage captures the larger particles, that is, those greater than ten microns in diameter. The smaller particles are captured by the filter. The flow rate of this instrument is eight and one-half cubic feet per minute which is approximately mans' breathing rate at restful times.

The Unico sampler is a cascade impactor with four deposition stages and a backup filter. Mass median sizes from twenty microns down to one-half micron in diameter can be measured with this sampler. Air was drawn through the Unico sampler at the rate of one cubic foot per minute.

The Anderson sampler consists of six stages through which air is drawn at the rate of one cubic foot per minute. Each stage contains a sieve plate perforated with four hundred holes and backed by a stainless steel plate coated with a particle-retention silicone medium. The size of the holes is constant for each stage, but is smaller in each succeeding stage; consequently, the jet velocity is uniform in each stage but increases in each succeeding stage. When the velocity imparted in a particle is sufficiently great, its inertia overcomes the aerodynamic drag and the particles leaves the turning stream of air and is impinged on the surface of the silicone coating. At the sampling rate of one cubic foot per minute the sampler is designed so that any airborne particle of one micron or larger will be collected on one of the stages.

3.3 Fallout Samplers

Fallout plates (figure ) were used to obtain the fallout distribution, concentration, and isotopic identification of the fission products deposited on the monitoring grid. Those plates with sufficient activity were also analyzed for beryllium. Sticky type fallout paper similar to transparent office tape was used to retain the fallout particles. Two sizes of fallout plates, twelve by fifteen inches or four by nine inches, were used. The larger plates were used close to the reactor in the 60° downwind sector to assure that sensitive measurements were obtained. The smaller plates were used on the outer PPCo arcs where a large number of samplers were desired. On the ID arcs, the larger plates were again used.

Sticky paper was mounted on metal frames which were in turn mounted on four foot high stands at each grid position (see figures _____). In addition, fallout plates were located on the radiological tower, on the IET stack, and at several locations near the reactor.

Those plates not located in the $60^{\circ}$ downwind sector were set out prior to the test in order to reduce the time required to prepare the radiological grid on the test day. The upwind plates gave an upper limit to the background fallout from sources other that the destructive test.

4. Meteorological Instruments

Operations at TAN had not required meteorological restrictions and forcasting programs for some time prior to the destructive test. Considerable instrumentation had to be installed to supplement the 200 foot meteorological IET tower used for routine, continuous measurements of wind and temperature at TAN. The additional instruments were required for both the operational functions of forcasting and of measuring the test restriction parameters and the research function of measuring variables for diffusion calculations and of correlating the calculated puff diffusion and trajectory with the measured puff behavior.

The IET tower had aerovanes at the 20 foot level and 150 foot level for measuring wind direction and speed. It also had temperature measuring devices at the 5 foot, 75 foot, and 150 foot levels. This information is telemetered to a Weather Bureau office at CFA. In order to ascertain whether or not the meteorological restrictions were met on a given day, more knowledge of the winds over the monitoring grid and downwind of IET was required than the single IET tower could provide. Data from the tower alone was not adequate because of the complex wind patterns that can exist at TAN. In particular, a wind shear line occasionally exists such that the wind directions at two locations, separated by only a few hundred feet, are in general opposition. Therefore, two stations for measuring wind speed and direction were positioned downwind of the

1185853

monitoring grid. These stations, part of the ID Health and Safety Division's radio-telemetry network for environmental monitoring, were placed near the centerline of the 60° wind sector. The information from these two stations was telemetered to the Weather Bureau office in CFA. Figure (____) shows the station locations, one at Monteview and the other a milepost 179 on Idaho Highway 28. With data from these two stations and the IET tower, a picture of the wind field over the monitoring grid and downwind of the NRTS boundary was available. This data was also useful in placing the mobile monitoring units in the path of the effluent puff, for assisting the aerial tracking of the puff, and for determining the more important grid samples for quick recovery and analysis.

In order to measuring the atmospheric diffusion conditions during the test, special meteorological measurements were required. Highly-sensitive wind speed and direction instruments, cup anemometers and bivanes (reference _____), were installed aththe 20 foot and 200 foot levels of the IET tower. These instruments measured the wind speed fluctuations and the two-directional wind fluctuations necessary to correlate measured diffusion of the puff to calculated diffusion. The data obtained were recorded by the Weather Bureau high speed data acquisition system that was installed at the IET control building for the test. A detailed vertical temperature profile was measured by releasing a balloon with a T-sonde, a temperature transmitting device (reference _____), to heights greater than the IET tower. The vertical temperature measurment defined the

1185854

temperature lapse conditions, that is, the stability conditions of the atmosphere.

In addition to measurements of diffusion variables, a determination of the puff trajectory was desirable for comparison with the grid measurements. The Weather Bureau M-33 radar was located at Circular Butte three miles east of and overlooking IET. It was used to track a tetroon-transponder unit (figure _____) that was to be released upwind of the IET just prior to the test. The tetroon (reference _____) is a plastic, tetrahedron balloon designed to float at a constant air density level and therefore to approximate the trajectory of a puff of effluent. The transponder (reference _____) is a device that is triggered by a radar signal, transmits a stronger signal at a different frequency, and therefore permits tracking for a greater distance than would be possible by tracking just the aluminized tetroon. The radar was also used to track the T-sonde so as to provide an upper air wind sounding.

Tracking the tetroon-transponder with the M-33 radar provided data for comparing the turbulence statistics of a Lagrangian sysstem (the coordinate system moving with the tetroon or puff) with the turbulence statistics of an Eulerian system (the bivane coordinate system fixed with respect to the ground). Such a comparison study is useful for checking puff diffusion theories using fixed bivanes.

C. Forecasting Program

The Weather Bureau forecasting program was an essential part of the destructive test since the test was restricted to specific meteorological conditions. A practice forecast program was initiated in mid-November, 1963, to obtain a statistical basis for forecast accuracy and to give forecasters practice in forecasting specific meteorological variables at TAN under various synoptic regimes. The specific variables that were forecast were wind direction and speed, stability, and precipitation. This practice program was completed with the last scheduled dry run of the SNAPTRAN tests. For the dry run, on March 2nd, a forecast was issued and, although the expected winds were 180° from the test conditions, Weather Bureau operations were conducted as scheduled for the destructive test. All Weather Bureau systems and procedures were proven to be operational and ready for the actual test.

The practice forecast program provided a total of 96 morning forecasts and 94 afternoon forecasts. Each forecast was given either a YES or NO rating considering all the desired meteorological conditions. For this practice period, four YES ratings were forecast in the afternoons, covering a twenty-six hour period. The observed conditions during this period, also rated YES or NO considering all the necessary test conditions, verified YES only once. The forecast score therefore showed correct morning forecasts 93 out of 96 times and correct afternoon forecasts 90 out of 94 times.

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The period covered by the practice forecasts was somewhat anomalous in that the number of days of acceptable test conditions was noticeably lower than the average number of days that could be expected from climatological records.

The earliest date for which the destructive test was scheduled was March 5th. Starting on the day before, a continuous forecast service was set up with two daily weather briefings. In addition to forecasts and outlooks of synoptic patterns, a qualitative forecast of the meteorological variables specified for the test were issued along with a probability rating of acceptable test conditions. The rating was a combination of the individual meteorological variables and an expression of confidence in the overall forecast. The probability figures were rated as indicated in Table I.

Table I
Probability rating of SNAPTRAN forecasts

| Probability Range (%) | Degree of condfidence for achieving test conditions |
|---|---|
| 20 - 40 | Poor |
| 40 - 50 | Slight |
| 50 - 70 | Fair |
| 70 - 80 | Good |

The first test attempt was made on the 11th of March. A probability of less than 50%, due to a forecast of precipitation, was given for achieving test conditions. Even though satisfactory wind and stability conditions were realized, the test was cancelled due to extensive snow showers over the NRTS.

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The second attempt was made on the 18th of March. A special rawindsonde was requested of the Weather Bureau Airport Station at Medford, Oregon, to aid in judging the movement of a low pressure trough in the air flow at high altitudes. Unfortunately, this sounding at 1100 MST yielded no specific information on the timing of the trough movement. A 40% chance of obtaining test conditions was given on the afternoon of March 17. The countdown procedure was set for 0900 hours on the 18th. However, the winds in the TAN area switched to strong northwesterly sinds at about 0630 hours. The trough had sped up and passed the NRTS earlier than expected, so that the favorable wind conditions occurred during the early morning hours when stability conditions were unfavorable. The test was therefore cancelled due to unfavorable winds.

The third test attempt occurred on March 20th. The vertical wind profile measured in the morning showed a shallow layer of southwesterly winds of adequate speed. However, a 45 to 50% probability of obtaining satisfactory conditions was given since the high altitude wind flow was too westerly and northwesterly to be favorable. The proper stability and precipitation conditions were realized but the test was cancelled due to lack of adequate winds.

The fourth attempt was conducted on the 26th of March. In order to obtain the desired test conditions, favorable wind conditions at the upper levels were again necessary. A rawindsonde at 1100 MST was again requested from Medford, Oregon, to aid in judging the movement of an upper air trough. The morning wind profile at the NRTS showed an even shallower layer of favorable winds than on the 20th. The upper air flow was again only bordering a favorable situation, so a 50% chance for acceptable test conditions was issued. Again, satisfactory stability and

1185858

precipitation conditions were realized, as had been forcast, but the test was cancelled due to a lack of favorable winds. This siuation nearly produced acceptable conditions. Favorable winds developed over the southern end of the NRTS in the morning and progressed across the site. The shear line between favorable southwest winds and northeast winds reached within a mile of the IET and its sampling grid.

On Sunday, March 29th, the major synoptic features were relatively unchanged from the pattern that had persisted most of March, that is, high pressure and northwesterly air flow over the Intermountain area and a deep low pressure area off the West Coast. The first forecast probability over 50% was issued, for March 31st, based on National Meteorological center prognostic charts. The favorable forecast was issued because a short wave trough and associated surface front was expected to move out of the low off the Pacific Coast which would allow southwesterly upper air winds to move into southeast Idaho.

By Monday afternoon on the 30th, the chances for the test conditions on the 31st were dropped to 45 to 50%, but chances for April 1st were taised to 55 to 60%. These changes resulted from a change in the trough movement out of the Pacific low. The new rating was maintained through the afternoon of the 31st. At that time, the test directors decided to hold their final decision on whether to test and to base it on the April 1st forecast to be issued at 0810 hours.

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By 0500 hours on the 1st, surface features had changed rapidly to the situation shown in figure (_____). The frontal system off the West Coast and the high over the Rocky Mountain area moved rather rapidly eastward leaving the large low pressure area covering the Western states. The secondary cold front that formed in the Utah-Arizona area was of little significance to the NRTS area, the main concern being the area of low clouds and general precipitation preceeding the main front in western Idaho. At 0500 hours, precipitation was occurring in all of western Idaho as well as most of the extreme southern part of the state. With the movement of both the upper air trough and the surface front, precipitation in the form of showers was expected to begin in southeastern Idaho in the early afternoon.

In the morning of April 1st, balloon wind sounding was taken and the synoptic data summarized above were gathered and analyzed. The wind sounding showed the direction and speed shear in the stable air layer near the surface (figure _____). Above this layer, moderate southwesterlies were present which would work their way to the surface as the stable layer was dissipated by shear from above and by surface heating. The wind soudning and general weather conditions showed that favorable southwest winds could be established over the test area by noon. The only problem of attaining test conditions was whether the precipitation associated with the frontal system would reach the test area too soon.

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Figure (_____) illustrates the upper air flow over the western United States at 0500 hours on the 31st. The isolines are the height of the 700 millibar pressure level in meters above sea level. Flow is generally along the isolines with a speed proportional to the horizontal spacing. As seen in Figure (_____), southeastern Idaho was under the center of a high pressure ridge extending from Washington southeastward to New Mexico. A light southwesterly flow prevailed over the NRTS. At this time the high pressure ridge was expected to move eastward in advance of this low. Such a movement would allow the southwesterly flow to increase over the NRTS giving sufficient speeds at this level (approximately 10,000 feet mean sea level) to initiate and maintain surface winds favorable for the test.

Figure (_____) illustrates the 700 millibar chart at 0500 hours on April 1st. As seen in this figure the low off the West Coast had opened into a trough as it moved inland, while the high pressure ridge moved east of the Rockies. The total effect of these changes was to produce a moderate southwesterly flow over southeastern Idaho.

Figures (_____) illustrate the surface patterns of interest at the time of the test. The general surface features shown in figure (_____) are quite similar to the upper air pattern at the same time (shown in figure _____). The main features which could affect the test were the front off the West Coast associated with the upper air trough and the large area of precipitation preceeding and and accompanying the frontal system.

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From the available data, the Weather Bureau gave the following forecast, at 0815 hours on the 1st of April, to the Phillips Petroleum Company test directors, to ID Headquarters, and to the ID Health and Safety Division:

> "Winds will be southwesterly, 15 to 20 miles per hour by 1100. A large area of precipitation covering the southwestern part of the state extending from Boise to Gooding will move eastward and probably arrive at the NRTS about 1300 hours."

The test directors decided that the countdown procedure could be shortened enough to allow testing before the occurrence of any precipitation. The test was scheduled for that day.

## III. Results of Radiological and Meteorological Measurements

### A. General

After four attempts to conduct the destructive test were unsuccessful because of improper meteorological conditions, a change of improper meteorological conditions, a change in the month-long weather pattern over the western United States permitted a forecast for April 1st with greater than 50% probability rating for achieving test conditions. The time alloted for the countdown procedure was shortened in order to initiate the test before precipitation arrived at the test area. A few sprinkles were observed at CFA in the test day morning and general shower activity occurred in eastern Idaho. At TAN, favorable wind and stability conditions were estcblished over the test grid by 1015 MST. Cloud cover varied from broken to overcast and was forecast to stay that way and to thicken and lower. At 1145 MST on the 1st of April, the destructive test was successfully initiated. The cloud cover at TAN was broken, the atmospheric condition was unstable allowing good diffusion, and the wind, measured instantaneously at the 150 foot level at IET, had a direction of 205° and a speed of 25 miles per hour. The wind measurements over the test grid and downwind of the IET are summarized in Table_____.

Table_____

Lapse rate ($T_{150'} - T_{5'}$) = - 2.5° F (strong lapse)

Mean Directions and Speeds During the test

| Instrument | Direction (Degrees) | Speed (MPH) |
|---|---|---|
| IET 20' | 203 | 22.2 |
| IET 200' | 208 | 25.5 |
| Station 179 | 209 | 17.7 |
| station Monteview | 197 | 18.6 |
| Tetroon | 209 | 27.9 |

The streamline flow pattern is shown in figure_____.

The meteorological conditions for the destructive test adequately met the test requirements for radiological measurements and for the safety of the public.

Within milliseconds following the initiation of the reactor power excursion, steam and water were ejected from the environmental tank in a mushroom shaped cloud. The cloud maintinsed its symmetrical mushroom shape for a short time unitl the majority of the water collapsed back into the environmental tank. Following this collapse a visible vapor-filled cloud was blown down over the instrumented grid. High speed movies taken of the test indicate that there may have been three distinct releases of airborne effluent from the test, one during the initial water burst which did not collapse with the

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mushroom cloud, a second that blew downwind with the vapor filled cloud, and a third that came from the environmental tank following the collapse of the mushroom cloud. The third release seemed to merge with the vapor-filled cloud by the time they reached the radiological tower. The period of effluent release was on the order of ten seconds, which is a short term release commonly described as a puff release.

The aerial monitoring unit intercepted the puff at one mile from the test site and followed it for twenty-one miles before diffusion and radioactive decay reduced the radiation levels to background. Eleven miles from the test site, the airplane measured a peak dose rate of 0.1 mr/hr while flying at 1,200 feet. Sampling media, mobile monitoring and the aerial monitor gave indication of the puff size at distances greater than one mile (table_____).

Table_____

Approximate Puff Dimensions

| Distance | Puff Width | Passage Time | Puff Length |
|---|---|---|---|
| 1.5 miles | 2000 feet | 30-45 seconds | 1400 feet |
| 2.5 miles | 3000 feet | 90 seconds | 3300 feet |
| 5.5 miles | Unknown | 3 minutes | 6600 feet |
| 11 miles | 2 miles | Unknown | Unknown |

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The constituents of the puff, sampled across the monitoring grid, were found to be daughters of short-lived noble gases produced in the power excursion. The particular isotopes observed were members of decay chains 91, 92, 138, 139 and 140. No other fission products, particularly no radioiodines, were detected by any of the air samplers.

In addition, essentially no beryllium was observed. The air samples indicated a lower percentage release of fission products than was expected. The detailed results of the various radiological and meteorological measurements are given in the following sections.

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