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NATIONAL REACTOR TESTING STATION

IDAHO OPERATIONS OFFICE
U. S. ATOMIC ENERGY COMMISSION

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SPERT I DESTRUCTIVE TEST SERIES
ENVIRONMENTAL MONITORING AND RESEARCH STUDIES

by
D. F. Bunch

Idaho Operations Office
U. S. ATOMIC ENERGY COMMISSION

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ABSTRACT

The Spert I Destructive Test Program consists of several test series, each of which is terminated by a short-period excursion in which some limited melting or core damage is obtained. One of the major objectives of the series is to investigate the consequences of reactor accidents. The radiological hazards research efforts involved in these tests were a joint effort of Phillips Petroleum Company, the U. S. Weather Bureau, and the U. S. Atomic Energy Commission's Health and Safety Division (Idaho Operations Office).

Fission Products Released to the Atmosphere. The first test of the Destructive Test Series at the Spert I facility (using a highly enriched, uranium-aluminum plate core) had a nuclear energy release of 31 MW-sec with a period of 3.2 msec. Gross damage occurred to the core, and water was expelled some 25 meters above the vessel. Only daughters of noble gases (Sr-91, Y-91, Sr-92, Y-92, and Ba-139) were detected on downwind air samples by gamma spectrometry. An estimated 3.6×10^4 curies of noble gases were released to the atmosphere as a result of this excursion. This amount represents about 7.2 percent of the noble gases which were produced from the excursion and about 0.7 percent of the total fission product inventory.

The second test (using a low enrichment UO_2 "pin" type core) had a nuclear energy release of 155 MW-sec with a 2.2-msec period. Only slight damage occurred with two fuel pins being ruptured. The release to the atmosphere was about 540 curies, a release fraction of 350 times less than from the first test. Again only daughters of noble gases were detected. This release was about 0.02 percent of the noble gases and 0.002 percent of the total fission product inventory.

The third test (using essentially the same core as the second test) had an energy release of 165 MW-sec with a 1.55-msec period. About 1900 curies of noble gases were released, about 0.06 percent of that produced and 0.006 percent of the total fission product inventory.

Based on minimum detection limits of sampling methods, a maximum of 0.01 percent of the iodines produced from each of these tests could have been released to the atmosphere. The fission products that were released from these tests did not create any hazard to personnel or the environment on or off the National Reactor Testing Station.

Field Studies. Data from an extensive film dosimeter system indicated maximum doses of about 15 R gamma and 250 rad beta, 3 meters from the reactor vessel in the first test. At the same locations, doses were 0.6 R gamma and 1.6 rad beta from the second test and 1.2 R gamma and 1.3 rad beta from the third test.

Studies were conducted with grass samples as well as fallout plates. The average deposition velocities for the first, second, and third test, respectively, were: grass -- 0.025, 0.033, and 0.042 m/sec; gummed paper fallouts -- 0.003, 0.005, and 0.004 m/sec.

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SPERT I DESTRUCTIVE TEST SERIES
ENVIRONMENTAL MONITORING AND RESEARCH STUDIES

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I. TEST ONE

1. INTRODUCTION

1.1 General Objectives

This report deals with the radiological aspects of the Spert I Destructive Test Series. The reactor technological objectives of the series are outlined in the following quotation:

> The inherent capability of reactors, in general, to experience rapid increases in power has been recognized from the first as offering serious potential hazard to personnel and property. Although the probability of an accident and its consequences have been largely unknown, cognizance that such hazards were possible has given rise to a necessary technological conservatism, in order to provide protection against the hazards implicit in a maximum credible accident. This conservatism arises in almost all phases of reactor technology, from the original reactor design, involving isolation of the plant by containment and distance, to the final detailed procedures adopted for operation of the reactor.
>
> In recognition of the need to obtain an understanding of the physical phenomena involved in reactor excursions and the implications in regard to reactor accidents and consequences, Phillips Petroleum Company was asked by the U. S. Atomic Energy Commission in 1954 to undertake a long-range reactor safety program. Instructions at the inception of the Spert program included not only basic nondestructive studies of the importance of various parameters in reactor kinetic behavior but also planned integral-core destructive tests to investigate the consequences of reactor accidents [1].

The Spert Destructive Test Program consists of several test series, each of which is terminated by a short-period excursion in which some limited melting or core damage is obtained. It is necessary to approach this with a series of transients, in which the period is successively shortened, in order to increase the information to be obtained in the "Destructive Tests"; that is, to verify the extrapolation of longer period data and, in particular, to obtain information on the possible existence of a period dependent threshold [2]. Periods of about 5 msec were thought to be near the threshold of such limited damage.

From the inception of the Spert project, it had been planned that at an appropriate time in the program, tests would be performed of similar magnitude to the first BORAX I excursion (with a period of approximately 2.6 msec and excess reactivity of about 5$) in which the reactor core was violently disassembled by a 135 MW-sec excursion [3]. Such tests would allow the application of longer period data into the severe accident region, thus checking the extrapolability of the nondestructive test data. They would also provide data of direct interest to problems of containment and fission product release.

The primary responsibility of the AEC Health and Safety Division has been to ensure that the tests were conducted in such a manner as to preclude the

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possibility of undue radiological hazards, both on and off the NRTS. In addition to these radiological safety responsibilities, the Division has undertaken several research studies. The major objective of these studies has been to gain information useful in making future calculations of the hazards resulting from such a test or a similar type of accident. Estimation of radiation exposure and fission product release to the atmosphere, by several methods, was considered an integral part of the objectives of the test series.

Among other research objectives, the foremost have been studies of materials which could be used to calculate neutron dosages and to estimate the magnitude of the excursion. To this end, copper wire and nuclear accident dosimeters were placed proximate to the reactor vessel.

1.2 The Reactor Area

The reactor building is an uninsulated galvanized iron structure, 7.2 x 5.4 meters, which houses the reactor and associated equipment. Operating experience has shown that this type structure is the minimum required to afford protection for personnel and equipment from dust conditions and winter weather existing in this area.

A cylindrical tank, 3 meters in diameter and 5 meters deep, embedded in the building floor, contains the reactor core. The tank is equipped with a drain and sump pump for automatic removal of waste water to a leaching pond outside the building. Adjacent to the northeast side of the reactor pit, and also embedded in the building floor, are eighteen 15-cm-diameter, 42-meter-long tubes for the temporary storage of fuel or other radioactive material. The storage tubes contain a common drain to the building sump, and are equipped with a 10-cm-thick lead plug. On the south side of the reactor are four similar tubes to accommodate neutron sensing devices. All reactor operations are controlled remotely at the Control Center Building, 800 meters away [4].

A pictorial view of the reactor installation is shown in Figure 1. The mechanisms for driving the control rods are supported in a bridge structure spanning the pit. The top of the reactor vessel is open to the atmosphere. The inside surface of the vessel is painted to reduce corrosion, and deionized water is used exclusively. Furthermore, the water is drained and the vessel refilled as required to maintain water quality. The drain and fill valves are operated from the Control Center Building.

The first core used in the Destructive Test Program was composed of plate-type fuel assemblies whose plates were fabricated of 93.5 percent enriched uranium-aluminum alloy clad with aluminum. The reactor was controlled by means of blade-type poison rods operating in slots through the core. In addition to four outer rods which serve for operational control of the reactor, a central rod was utilized to initiate power excursions at ambient temperatures by step-insertions of reactivity [5, 6].

1.3 Description of the First Test Series

Once the core was assembled, static tests and experiments were conducted to obtain information about flux shape, void coefficient, temperature coefficient, control-rod worth, and prompt-neutron lifetime [7]. A series of self-limiting, nondestructive, step-transient tests was then conducted, beginning with a period of 943 msec and ending with a 4.6-msec period.

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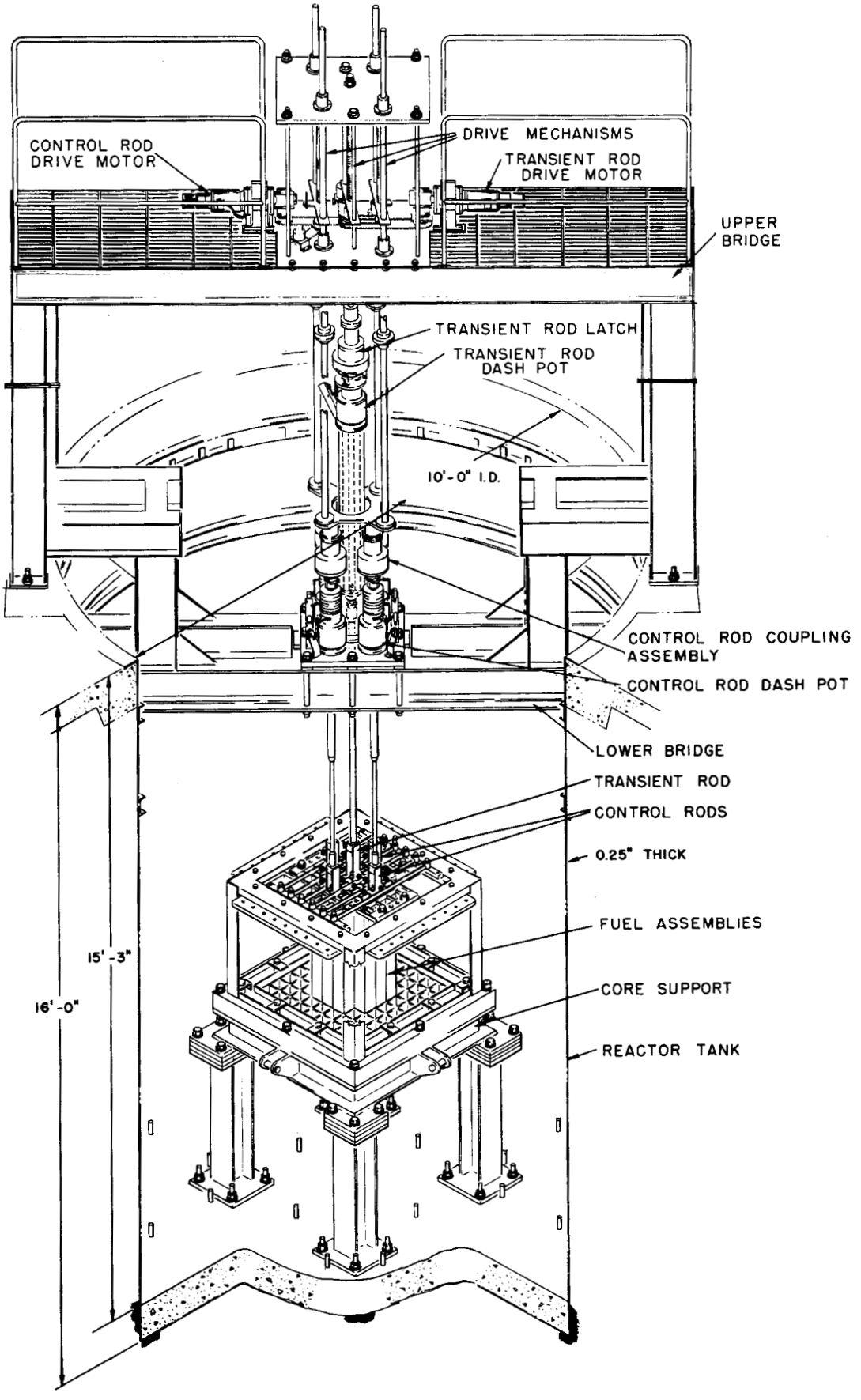

FIG. 1 PICTORIAL VIEW OF THE REACTOR INSTALLATION.

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During the two shortest period tests in this predestructive series (5 and 4.6 msec), some fuel-plate melting occurred. The melting from the 5 msec test was confined to the seven plates nearest the core center and to a small area about three inches below the core center in these plates. About one percent of the total fuel-plate area was involved.

The 4.6 msec excursion caused melting in a region extending over most of the inner nine fuel elements [8]. About 80 percent of the fuel plates were rendered useless as a result of melting or thermal distortion or both, and most of the melted plates were fused to adjacent plates. At this point, no evidence leading to a prediction of large pressure gradients was obtained.

After the 4.6 msec test, the reactor was reassembled and a large amount of special instrumentation was installed in preparation of the destructive test to follow [9, 10]. This included 7 ionization chambers, 34 thermocouples on 16 fuel plates, 19 pressure transducers (all outside the core) strain gauges on various support components, two high-speed cameras looking into a mirror over the tank, 6 cameras of various speeds outside the building, test specimens, and extensive radiological instrumentation extending to a distance of five miles from the reactor. Also included were two television monitoring systems and special, rugged water-level sensors [11].

The siding of the reactor building near the tank was removed before the test and replaced with temporary plastic sheeting, which was folded out of the way for the test. Figure 2 shows this view of the building before the Destructive Test.

The first test occurred at 1225 hours, November 5, 1962, the transient rod being pneumatically driven from the core. It had been previously estimated that the period would be 3.3 msec with a predicted maximum power based on this period and extrapolation of previous data of 2400 MW; an energy release of 33 MW-sec; and a transient pressure peak of 30 to 40 psig. The actual excursion had a period of 3.2 msec, a maximum power of 2300 MW, and a nuclear energy release of 30.7 MW-sec [12]. The most surprising feature of this excursion was that about 15 msec after the power peak and long after the expected pressure transient of 40 psig had disappeared, a sudden pressure transient occured which, it is believed, eventually reached 3600 psig or more and destroyed the core. The mechanism of this delayed pressure pulse is not yet fully understood. Possibly a rapid dispersal of molten fuel was triggered by a steam explosion due to water trapped between fuel plates. It appears that about 3.5 MW-sec of energy was released by the metal-water reaction (with the formation of about 0.4 kg of αAl_2O_3) [13].

During the excursion, considerable damage occurred to the control rod extensions, the core support structure, TV cameras within the reactor building, and various temperature and pressure sensors within the reactor tank. There was gross damage to the core; an estimated 7500 liters of water was expelled some 25 meters above the vessel (Figure 3).

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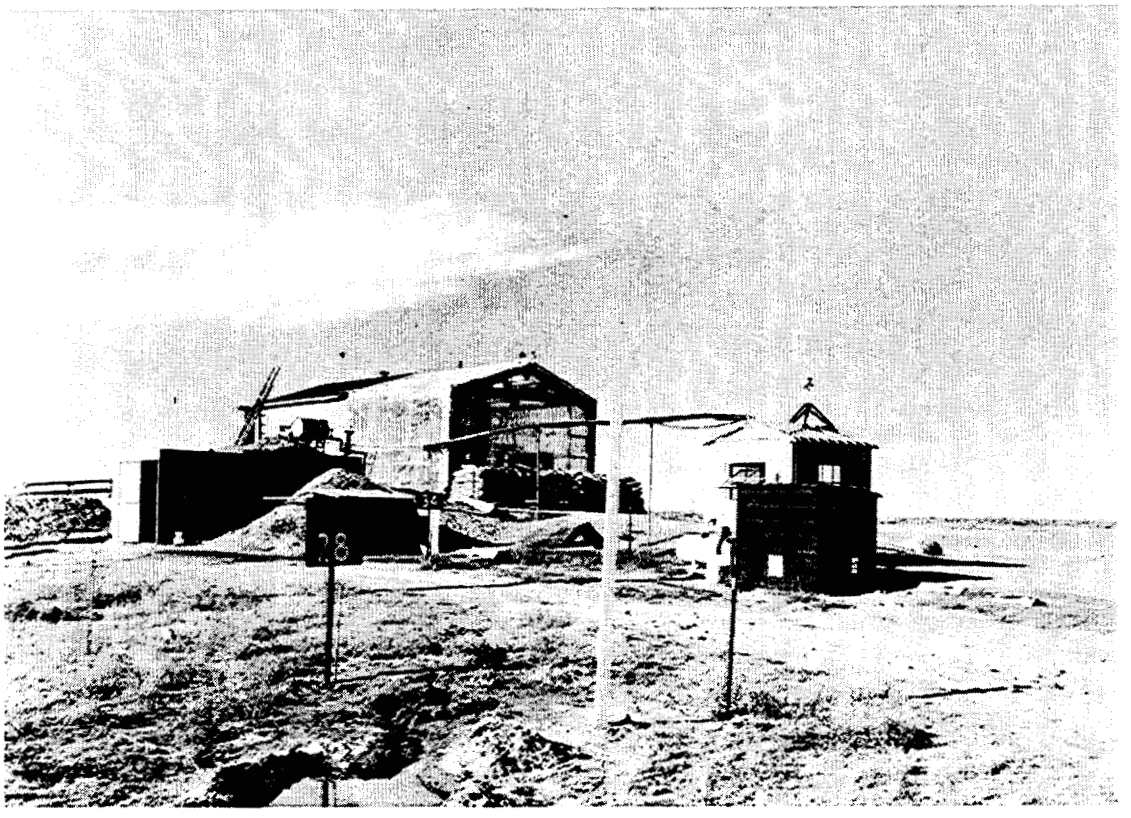

FIG. 2 VIEW OF THE REACTOR BUILDING.

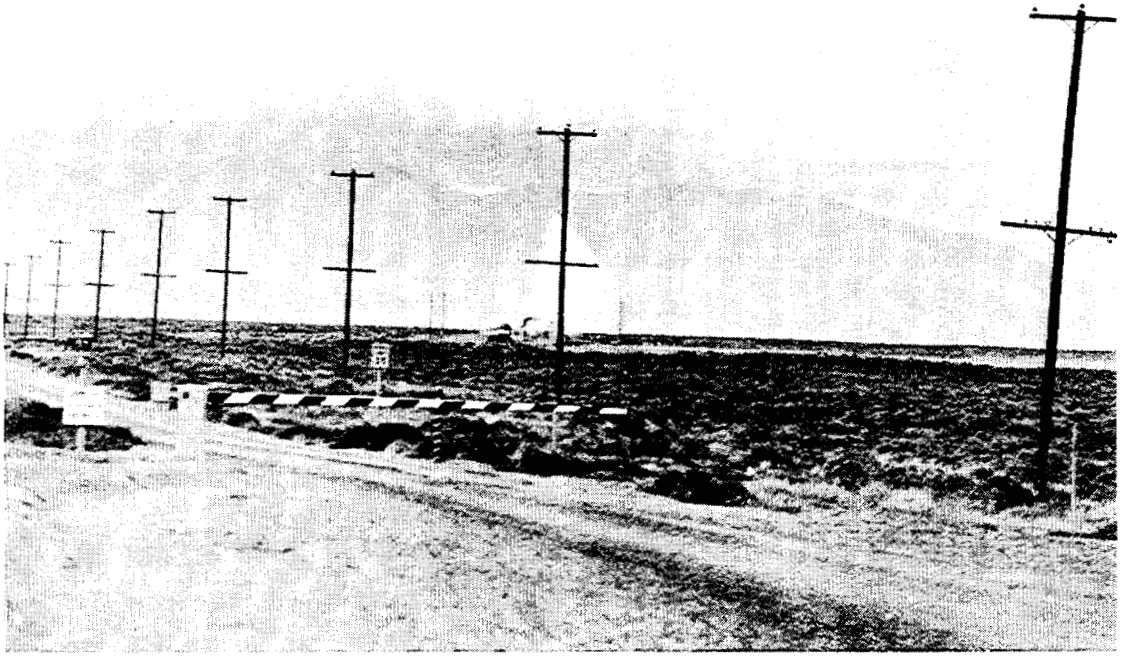

FIG. 3 WATER BURST OF THE FIRST DESTRUCTIVE TEST.

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2. TEST PREPLANNING

2.1 Specific Objectives

The safety responsibilities of the Health and Safety Division included several programs or studies:

(1) Evaluation of Safety Analysis Reports for each reactor was to be the initial consideration of hazards.

(2) Aerial monitoring and cloud tracking were to be used to give rapid evaluation of environmental radiological hazards.

(3) Mobile monitoring and telemetering systems were to complement aerial monitoring by measuring radiation levels at several points downwind.

Phillips Petroleum Company had the responsibility of assuring the safety of all operations within the Spert exclusion area. This included control of access to the area. Studies by the Health and Safety Division of fission products released to the atmosphere complemented studies by Phillips Petroleum Company (PPCo).

(1) Radiation levels experienced due both to the excursion and the passage of the cloud were to be measured directly by film dosimeters placed near the reactor vessel and on the test grid. Attempts were to be made to correlate these studies with indirect measurements of centerline cloud activities and ground level activities.

(2) Dependability and reliability studies of film dosimetry were to be conducted to compare data from test to test with results from other studies.

(3) Investigations of materials which could be used to calculate neutron doses and to estimate the magnitude of an accidental excursion were to be conducted.

(4) Studies of atmospheric release and diffusion were to be conducted. These were considered to be essential in the evaluation of the tests and related directly to environmental hazards.

(5) Environmental studies were to be made, including investigation of the deposition velocity on fallout plates and on grass samples.

2.2 Meteorological Requirements

In order to minimize radiological hazards from an excursion and to minimize the number of sampling stations needed, it was necessary to conduct the destructive test under prescribed meteorological conditions:

(1) Mean wind direction 220 $\pm$ 20°. This described a sector which did not intercept any existing facilities (Figure 4). An additional

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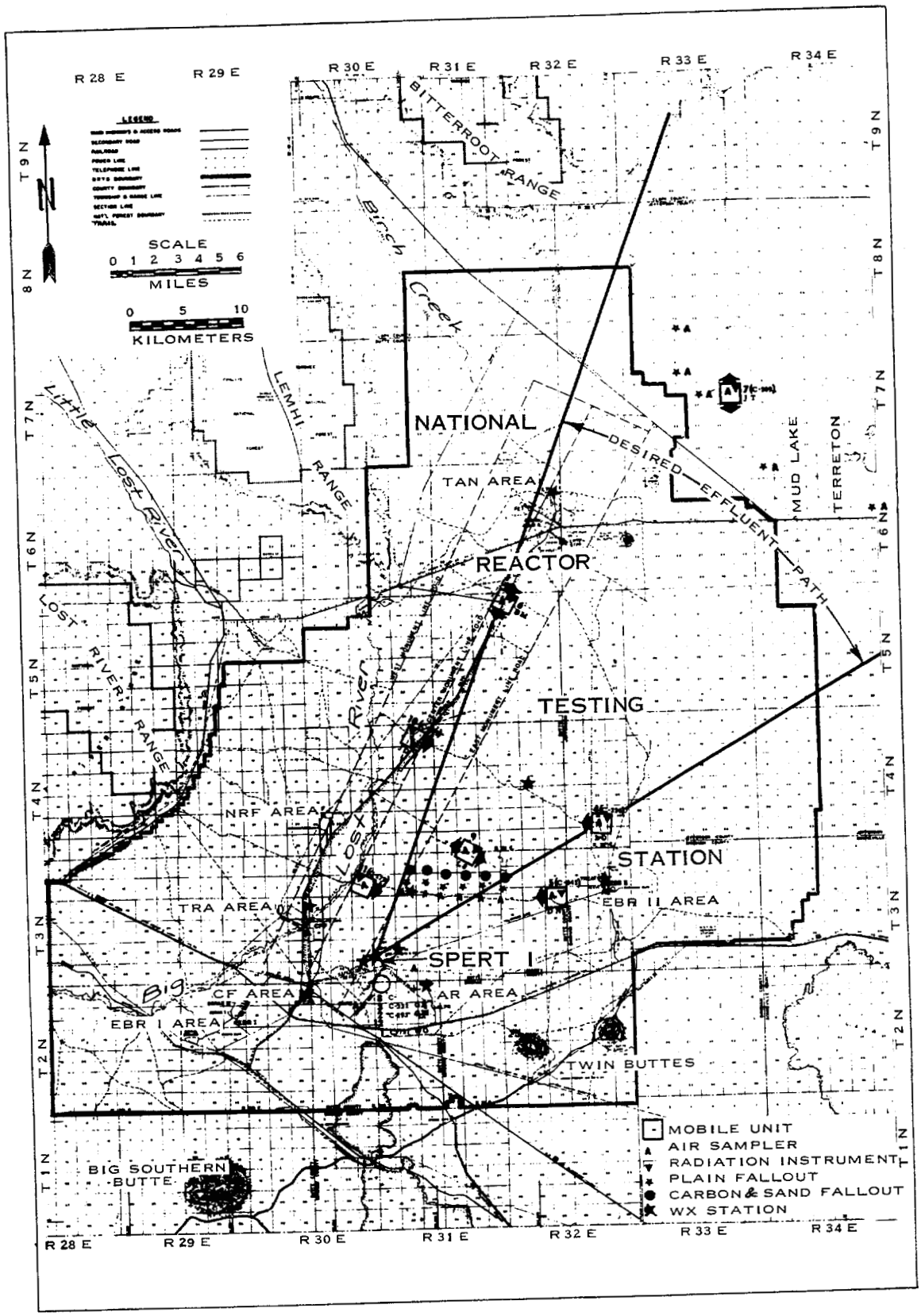

FIG. 4 NRTS MAP.

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20 degrees was allowed on either side for short-period wind fluctuations away from the mean wind direction.

(2) A minimum wind speed of 4.5 meters per second. This lower limit was chosen to ensure that wind conditions would remain stable during and after the test. The maximum wind speed was 14 meters per second.

(3) Temperature lapse conditions and no precipitation forecast over a three-hour period. These last two conditions maximized diffusion and prevented the released fission products from being deposited in the immediate reactor area. The stipulation of no precipitation was also made to ensure optimal sampling conditions.

2.3 Preparation of the Test Grid

A rectangular sampling grid, established in 75-meter increments on N-S, E-W axes, extended downwind 1050 meters from the reactor. The choice of a rectangular grid instead of a circular or arc grid (which is more costly to survey and mark) was determined by the nature of the terrain. The Spert area is typified by rolling hills with lava outcroppings and sparse vegetation. It was recognized that the terrain places limits on the accuracy of information to be derived from environmental research.

To meet the objectives outlined in Section I-2.1, a relatively simple sampling system was used (Figures 5 and 6).

(1) High volume air samplers were placed downwind and adjacent to the reactor area. These samplers were equipped with two standard respirator filters; the first was a high-efficiency filter (BM-2133) and the second, inner filter was a carbon trap (BM-2306). The first was to collect radioactive particulates, and the trap was to collect radioactive halogens and possibly some of the rare gases.

(2) Fallout plates, coated and plain gummed papers, were used to measure ground level activities. These are cheap to make and easy to store. The activity found on fallout plates is considered to be a function of surface area and a function of the collection properties of the material. For example, sand-coated gummed plates have more surface area per unit area than plain gummed plates and would be expected to collect more, at the same location. Carbon plates preferentially collect iodines. Regular gummed paper plates were compared with carbon-coated and sand-coated gummed papers at several locations on the grid. The comparison of activities of plates and air samplers also was intended to measure deposition velocities [as defined by $\mu Ci/m^2$ (plate activity) divided by $\mu Ci\text{-}sec/m^3$ (air activity), and having the units of meters per second].

(3) Vegetation and soil samples were also to be taken in support of fallout plates. While the data to be gleaned from these samples

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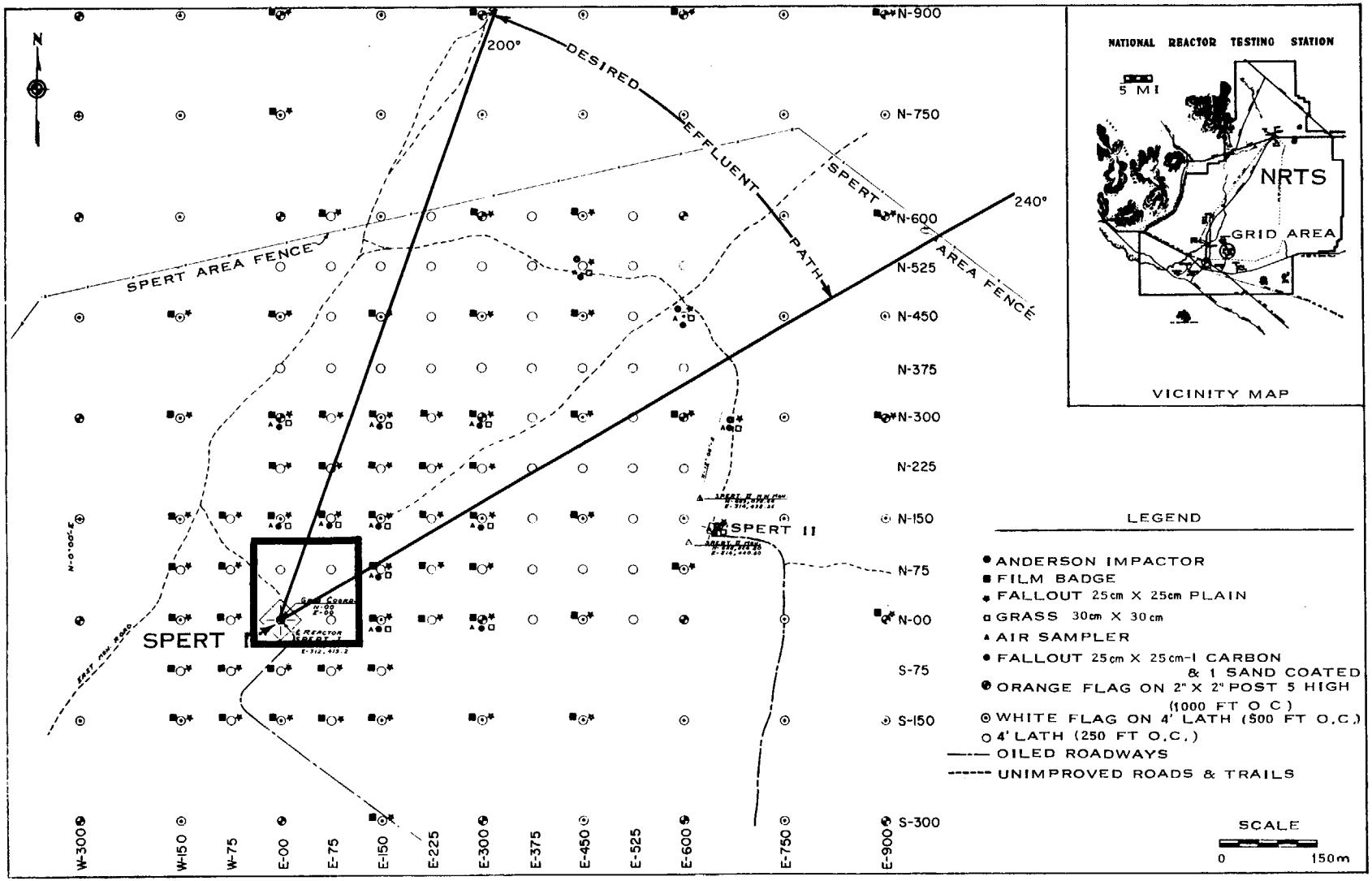

FIG. 5 OUTER GRID MAP.

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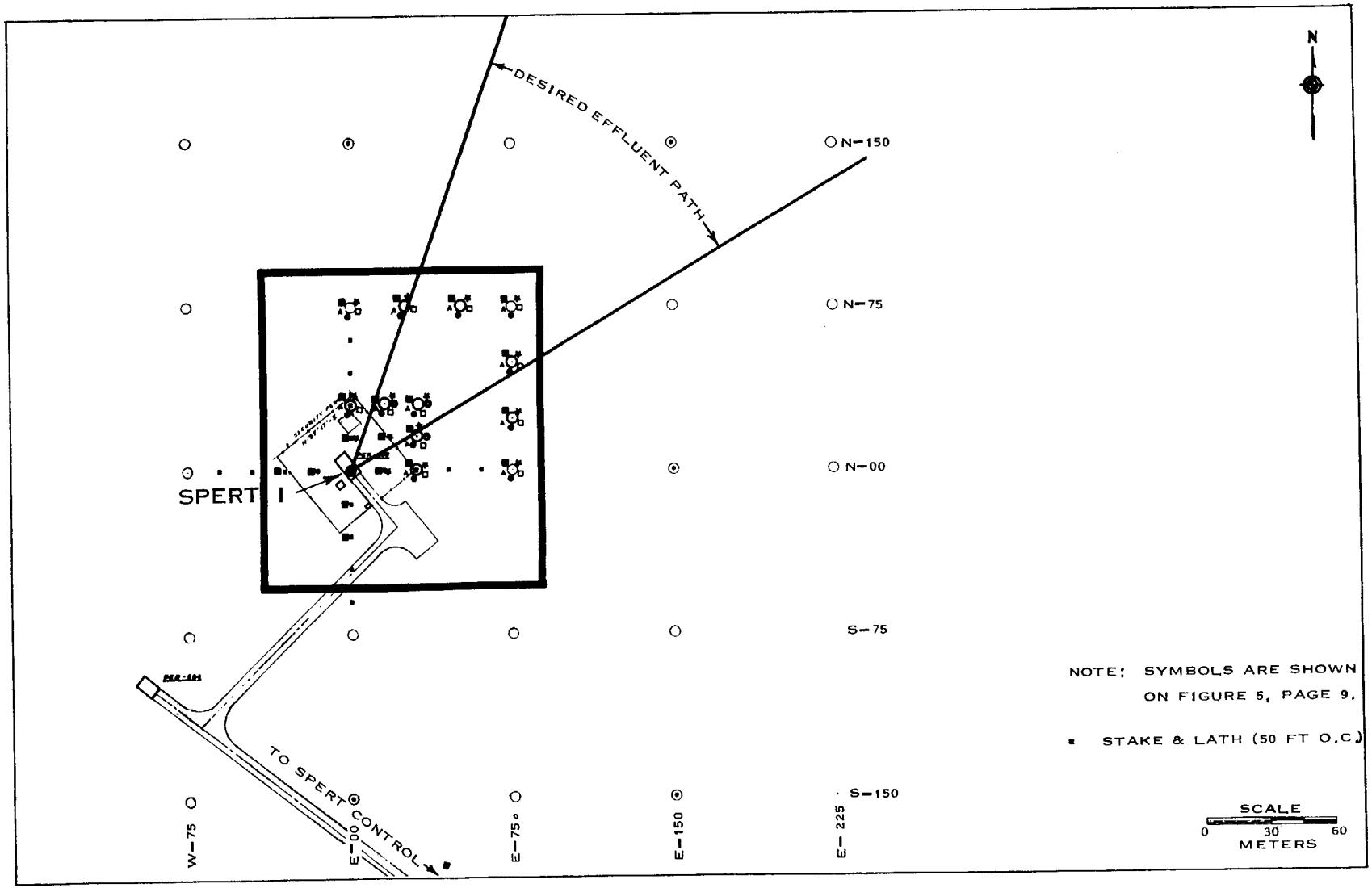

FIG. 6 INNER GRID MAP.

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are less reliable than fallout plates, it does present a more realistic "picture" of ground level activity. Grass samples were prepared prior to the test, and replicate samples placed on the grid immediately prior to the test. Sage was sampled immediately after the test as far as Shell Road about 16 kilometers downwind of the Spert I reactor. Since this is vegetation that predominates in the area, this could at least give an idea of ground level activity.

(4) Anderson impactors on a low-volume air-sampling system, were used to measure distribution of activity with particle size. The system uses several "sticky-impaction" type plates, a carbon cartridge, and filter to separate incoming airborne particles by size. For example, the carbon and filter sections collect only particles less than 1.5 microns in diameter; all others are collected on the preceding stages.

(5) Environmental film badges were placed on the grid at a height of one meter -- to simulate the exposure to the torso of a man. It was believed that correlations could be made with air concentrations.

3. SAFETY

3.1 Pre-evaluation and Safety Controls

Prior to the destructive test, pre-evaluation of the possible radiological hazards was undertaken. Calculations of hazards due to this test [14] indicated that, with adequate meteorological control, the test would not effect any site environmental hazards beyond the Spert access fence. It was assumed that:

> The fission product release to the atmosphere of the reactor building is 100 percent of the noble gases, 50 percent of the halogens, and 1 percent of the solids in the fission product inventory. Of the 50 percent of the halogens released, one-half is assumed to absorb onto internal surfaces of the reactor building or adhere to internal components [15].

Since the precise extent of damage or extent of radiation levels was not known prior to the test, several methods of control were used. All nuclear operations were controlled remotely one-half mile from the reactor site and AEC grid operations were controlled from a trailer at the junction of Wilson and Jefferson roads (Figure 4). In addition, plans were made to ensure that the reactor was critically safe (after the excursion) before personnel were given access to the area. If instrumentation remained intact or operable, then tests could be made directly to determine if the reactor were safe. If instrumentation were destroyed or rendered inoperable, then the reactor water could be drained out of the tank, which would make the reactor subcritical. In case of tank drainage failure, a remotely operable soluble poison injection system was installed for postburst shutdown.

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To provide estimates of personnel exposures before reentry, six Tracerlab Remote Area Monitoring Heads with readouts in the Control Center were placed by Phillips Petroleum Company personnel as follows:

(1) Over the reactor, 1.8 meters from the core.

(2) On the south door frame of the reactor building, approximately 4.2 meters from the core.

(3) Above the south door on a beam, approximately 4.8 meters from the core.

(4) On a post 30 meters from the core, 2.4 m above ground due southwest of the reactor.

(5) On a post 90 meters from the core, 2.4 m above ground, due southwest of the reactor.

(6) At the Spert I guard shack, 800 meters from the reactor.

3.2 Pretest Preparations

In order to maximize the amount of information to be gained from a single release study, it is obvious that grid samples must be carefully prepared and grid crews organized and oriented. Many hours of planning were spent in preparation for the two to four hours actually spent on the grid after the excursion. The following is representative of activities prior to the Destructive Test.

(1) Prepare grid system and map.

(2) Situate the AEC H. P. field trailer at Jefferson and Lincoln roads.

(3) Arrange for Health Physics Net radio to be installed at the field trailer and Spert Control Center.

(4) Position two telemetering trailers at the site boundary (at least one week prior to the scheduled test).

(5) Situate six sampling trailers beyond the Spert access fence.

(6) Situate 44 generators on the grid.

(7) Prepare the following samples:

(a) 45 high-volume air samplers (BM-2133 paper and carbon pack).

(b) 40 -- 25 x 25 cm sticky paper.

(c) 30 -- 30 x 30 cm grass plots.

(d) 95 film badges.

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(e) 20 Anderson samplers with carbon cartridges and backup filters.

(8) Install 20 low-volume pumps on the grid for Anderson samplers.

(9) Equip three vehicles for use as mobile units.

(10) Recall and service all portable HP Net radios.

(11) Prepare personnel and vehicle assignment list.

(12) Notify by memo Analysis Branch outlining the type of analyses required on samples collected from the test.

(13) Prepare schedule for sample collection and handling.

(14) Prepare vegetation grid and obtain background vegetation samples on the grid.

(15) Assemble monitoring participants for orientation and assignments.

The activities of the test day were dependent upon the forecast received at 0830 hours. If the lead time prior to obtaining favorable weather conditions was two hours or less, the primary effort was to ensure adequate environmental monitoring of the test. If more than two hours was available (as was the case), every effort was to be made to activate all research monitoring equipment. Assuming a five-hour lead time, the following activities were to take place:

(1) Place aircraft on standby at D-2 hours; dispatch to check grid clearance at D-1 hour.

(2) Alert all participants to report to the AEC Health Physics Laboratory at D-3 except those working on Test Grid Five.

(3) Activate all stations except air sampling equipment (to be activated at D-1 hour).

(4) Place mobile units on standby; dispatch at D-2.

(5) Alert Security Patrol to establish road block at D-2.

(6) Notify all NRTS Health Physics offices.

(7) Notify AEC Health and Safety Branches of anticipated time schedule.

(8) Obtain final weather briefing from Weather Bureau, grid clearance from aircraft, PPCo, HP, and AEC. At this time, the final part of the countdown begins and all personnel await the test at their prescribed locations.

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3.3 Post-Test Operations

After the test had been completed, all units were notified by radio. Figure 7 shows the lines of communication which were used to maximize the relay of information. Aerial monitoring of the cloud was begun, and, with the aid of Weather Bureau instrumentation, the cloud location and expected trajectory were estimated and field units advised.

Prior to reentry into the reactor area after the first test, briefings were held to discuss specific operations to be performed. Action to be taken depended upon existing hazards (radiation levels, core damage, contamination, and airborne radioactivity). When the hazards had been estimated and it had been determined that personnel could enter the area, the PPCo reentry team approached the Spert I Reactor Building using the Spert I access road. The teams were clothed in plastic suits with self-contained breathing apparatus. They were also equipped with portable radiation survey instruments and portable radio units.

The reentry team entered the area at approximately 1620 hours -- about four hours after the transient. They reported readings of 2 mR/hr at 15 m, 10 mR/hr at the north door of the reactor building, and 25 R/hr at the lip of the reactor vessel [16]. The delay occurred because the excursion had destroyed the instrumentation in the vessel, and it could not be definitely established that the reactor was critically safe. Therefore, until the remaining water could be drained from the reactor vessel, a potential hazard existed.

After the survey was completed, the team left the area and was checked for radioactive contamination. Low-level activity was detected on only one shoe, which indicated that the area was only slightly contaminated.

Soon after grid clearance was given by PPCo-HP, sample collection was begun by the AEC grid crew. The samples were returned to a "Hot-Line" trailer and transferred to clean vehicles for transport to the Health and Safety Laboratory where samples were prepared and then sent to the Analysis Branch to be counted.

During the cleanup operation of the reactor area, there were no external exposures to personnel in excess of the daily administrative limits of 60 mR. Routine analyses and whole body counts taken of personnel involved with the cleanup operation showed no significant exposure.

3.4 Meteorological Support

The U. S. Weather Bureau conducted numerous pretest studies to aid in the evaluation of radiological hazards both on the NRTS and off-site. To this end, three special wind stations were installed in the summer of 1962. One was located at Spert I, one on Stage Road, and one at Shell Road. The latter two stations were about 5 and 16 kilometers northeast of Spert I, respectively. Since long-period climatological records existed for the Central Facilities Area (about 5 kilometers west-southwest of Spert I) and forecasting personnel had a high confidence value for forecast parameters at the CFA, studies were made comparing conditions at Spert I to those at CFA.

It was found that at greater wind speeds there was a greater correspondence of wind direction between Spert I and CFA, as well as a greater directional

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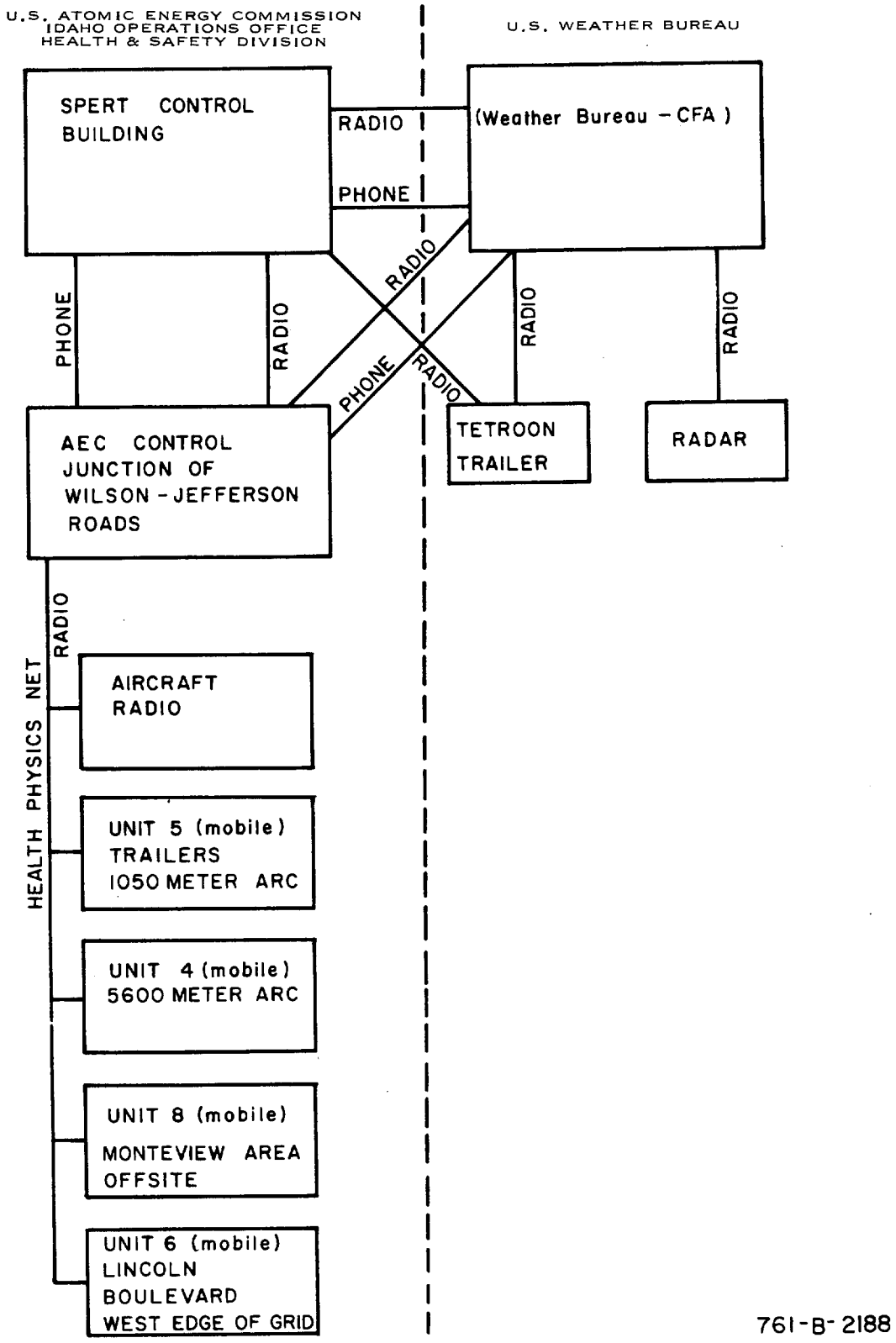

FIG. 7 TYPICAL LINES OF COMMUNICATION DURING A TEST.

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stability, than at lesser wind speeds. This justified the selection of wind speed greater than 4.5 meters per second for operations. The validity of the main reason for the undesirability of low wind speeds for test conditions was provided when a tetroon (constant level balloon) was released at Spert I (at low wind speeds with generally SW directions) and was retrieved on Harrison Boulevard, midway between TREAT and EBR-II (see Figure 4). A flight made during higher wind speeds moved to the northeast and remained clear of all inhabited facilities [17].

In addition to these studies, the Weather Bureau had the responsibility of giving daily forecasts. Since the test could only be conducted under certain meteorological conditions, the Weather Bureau had to provide forecast conditions for the next day. For example, practice forecasts were made on normal working days from August 13 to September 14, 1962. Out of 22 forecast days, favorable conditions were observed 11 days.

On October 26, 1962, preparations were made to conduct the test since the Weather Bureau had given a reasonably optimistic forecast for proper weather conditions. The conditions, however, did not maintain themselves for a long period and a decision was made to cancel activities for the day. The Weather Bureau continued with forecasts and on November 5 the test was conducted successfully. Although a very small amount of precipitation was extant in the vicinity of Spert I, its effects were negligible.

The Weather Bureau also had several important functions during and immediately after the test. First, they provided final assurance that the meteorological requirements were being met and would continue. This function was necessarily exercised up to a few minutes before the excursion. Once the excursion had occurred, the Weather Bureau's instrumentation was designed to give information of wind conditions, which was necessary for any calculations of release fractions. A more detailed discussion of instrumentation is given in Appendix B. In addition, a tetroon was released just before the excursion. This had two prime functions: to estimate a cloud trajectory and to provide a guide trajectory if the location of the cloud was "lost" by the airplane. Also, if a sufficiently large release occurred, it would provide information as to possible areas, off-site, which might be affected. For post-test support, the Weather Bureau described the meteorological conditions during the test, made diffusion calculations based on sampling data, and prepared an estimate of fission products released into the atmosphere.

The average wind conditions during the test were as shown in Table I.

The following Sutton parameters, found in Table I and based on the general meteorological conditions of the test, were selected. These diffusion parameters are typical for the NRTS during such meteorological conditions [18] with the assumption that C_z equals 2/3 C_y.

3.5 Aerial Monitoring

Prior to the tests, aerial monitoring flights were made for the purpose of observing the terrain downwind from Spert I. Additional pretest studies were made on the background levels in the vicinity of Spert I, and radials were mapped from Spert I to the northeast. Plans were made for aerial cloud tracking at the time of release.

1132997

TABLE I

METEOROLOGICAL CONDITIONS DURING THE FIRST TEST

	Spert I	4800 Meter Arc
Wind Speed -- m/sec	10.3	12.9
Wind Direction -- degrees	226	238
Mean Wind Speed -- m/sec	11.6	
Mean Wind Direction -- degrees	230	
Stability Parameter (n) -- dimensionless	0.25 (neutral)	
Horizontal Diffusion Parameter (C_y) -- meters$^{n/2}$	0.178	
Vertical Diffusion Parameter (C_z) -- meters$^{n/2}$	0.118	

An aircraft was used to give a rapid analysis of hazards to the environment by tracking the cloud and determining the cloud dimensions and radiation levels with distance. Thus, samples which were near the centerline of the cloud passage could be noted and analyzed first.

The following equipment was available for use during the test flights:

(1) Transistorized single-channel monitoring scintillation counter with strip chart recorder.

(2) Nuclear Chicago Model 2612 GM.

(3) Jordan Radector.

This is all standard equipment designed to provide both low range (scintillation counter) and high range (Jordan Radector) capability.

On November 5, 1962, under direction of the control center, the downwind grid was cleared to a distance of 16 kilometers of any unauthorized personnel. Monitoring of the cloud path began approximately two minutes after the excursion, on a course established by visual observation of the tetroons released by the Weather Bureau. The cloud was immediately detected by off-scale reading on the scintillation counter. GM readings were taken as the cloud puff was intersected, with maximum readings about 1.2 mR/hr and cloud edges well defined. The plane flew at an average altitude of about 150 meters. The centerline of the cloud appeared to be very near the midline of the grid.

The cloud was followed over the Stage Road, and to a distance approximately 6 kilometers beyond the Shell Road, where the readings had diminished to about 0.1 to 0.2 mR/hr and the cloud dispersed. The cloud width over the Shell Road was estimated to be approximately 600 meters.

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The flight was continued downwind for about 40 kilometers, although activity was no longer detected. The return flight directly upwind to the Spert I site gave no indication of ground level activity up to the area immediately adjacent to the reactor. It was observed that water had darkened the ground almost to the second row of air samplers [19].

3.6 Radiation Levels

Inside the test area, the maximum radiation level recorded was 800 R/hr in the reactor building, 3 meters from the core. An instantaneous dose rate of 1.2 mR/hr was recorded at the control center 800 meters away. The integrated dose from the power burst itself was 3 R at a point 61 cm from the reactor lip, 2.5 R at 1.6 meters, and 900 mR at 2.5 meters. Prompt gamma exposures at these points were 1.5, 1.0, and 0.10, respectively. A beta to gamma ratio of 16 was recorded at 1.6 meters. Figure 8 shows beta and gamma exposures on environmental film dosimeters. The exposures ranged from 360 mrad beta to 350 mR gamma at a point 30 meters from the reactor to 0 beta and 20 mR gamma at 1000 meters. At 30 meters, it is estimated that 360 mrad beta and 300 mR gamma was the exposure resulting from the passage of the cloud.

The relatively high exposures and rapid drop-off of activity with distance from the cloud are due to the passage of radioactive isotopes with very short half-life. By the time the cloud had traveled 1000 meters, most of this short-lived activity had decayed to longer lived daughters.

It is apparent that there was no hazard to the environment from this test. The total dose a man would have received, including neutron exposure (1.2×10^8

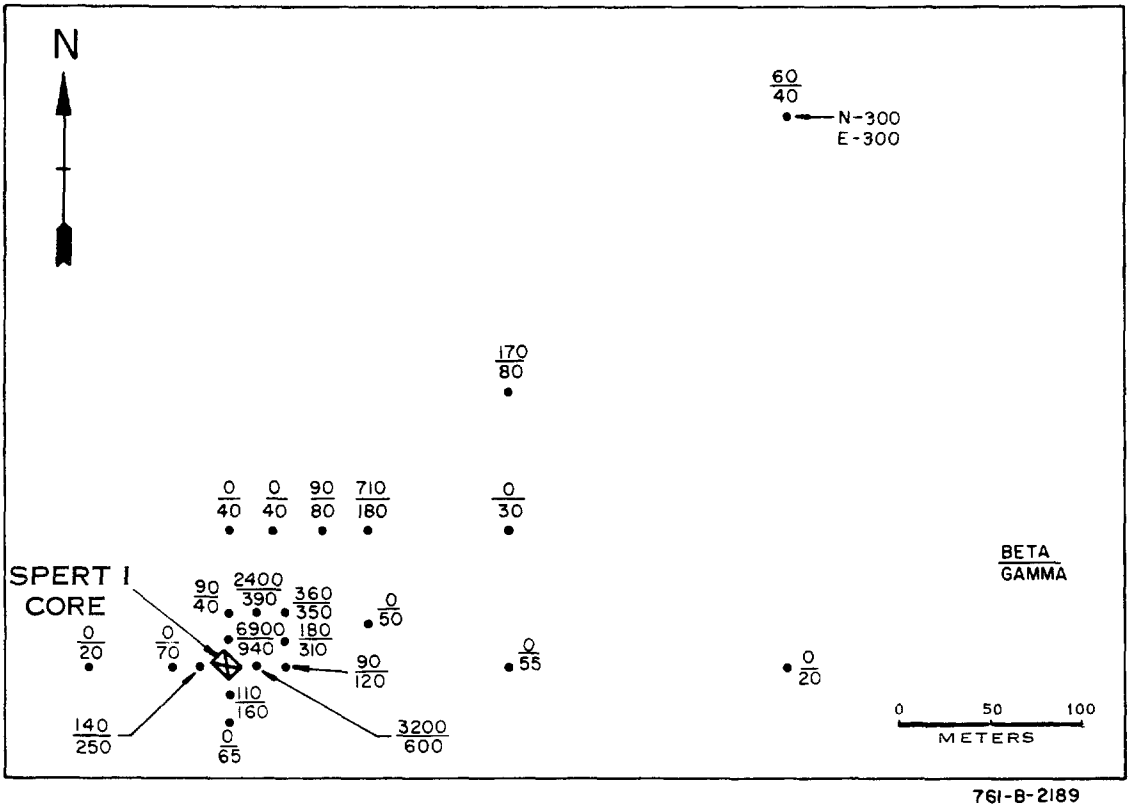

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FIG. 8 FILM DOSIMETRY RESULTS.

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nvt gold foil activation), would have been about 3.1 rem if he had stood next to the reactor.

4. RESEARCH STUDIES

4.1 Air Concentration Studies

After the test, the grid samples were removed, marked, and counted. Each filter was analyzed for gross gamma activity and the activity corrected to a common time. The data were put in final form by approximating curie amounts from the gross gamma activity (with the aid of gamma spectra) and dividing by the appropriate flow rate. Figure 9 indicates crosswind and downwind dis-

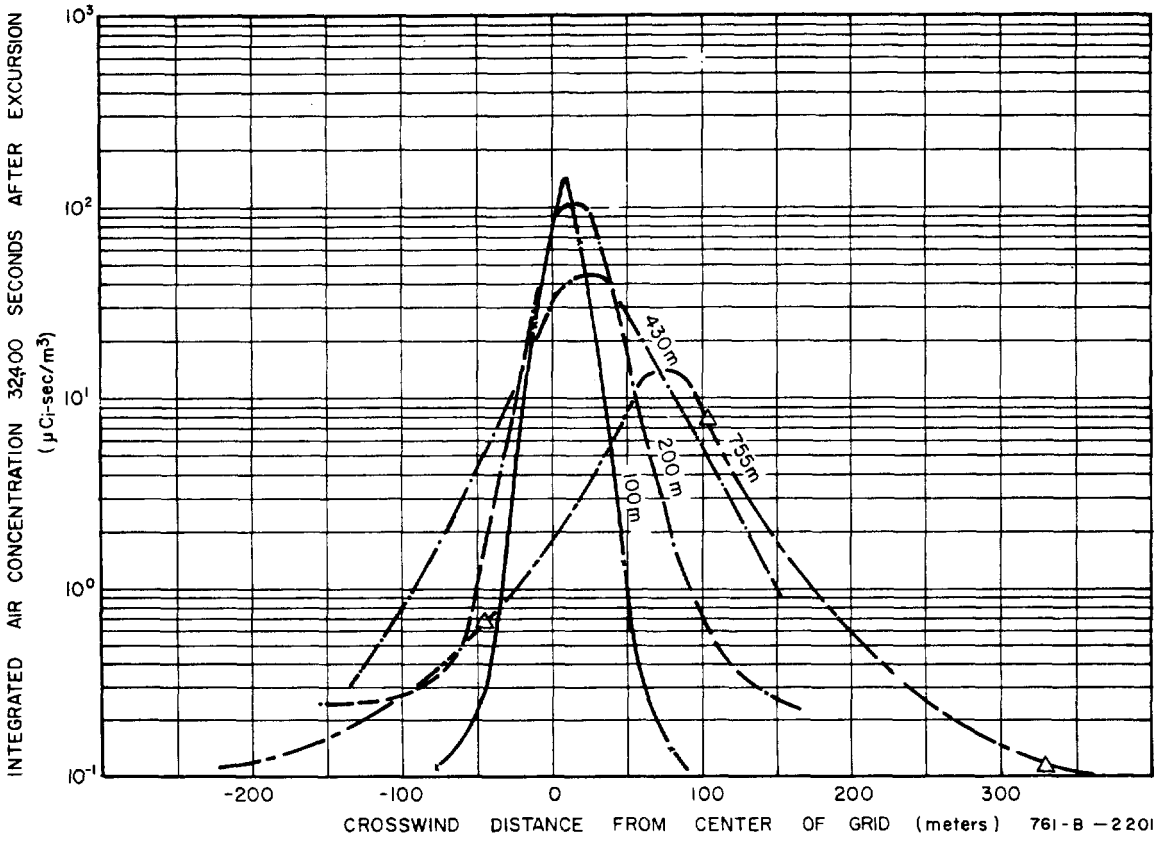

FIG. 9 CROSSWIND AND DOWNWIND DISTRIBUTION OF INTEGRATED AIR CONCENTRATIONS.

tribution of integrated concentrations. It is apparent that the center of the cloud followed a N-NE path from the reactor (Figure 10). At the common counting time (32,400 seconds, 9 hours, after the excursion), the integrated air concentration 100 meters from the reactor was 150/μCi-sec/m^3. By correcting this figure to the time of the excursion, it was estimated that about 0.02 curie was collected from the cloud at the midline of the grid and the cloud had an average air concentration, at that point, of about 0.13 curie/m^3, if it is assumed that the cloud passed in about 10 seconds.

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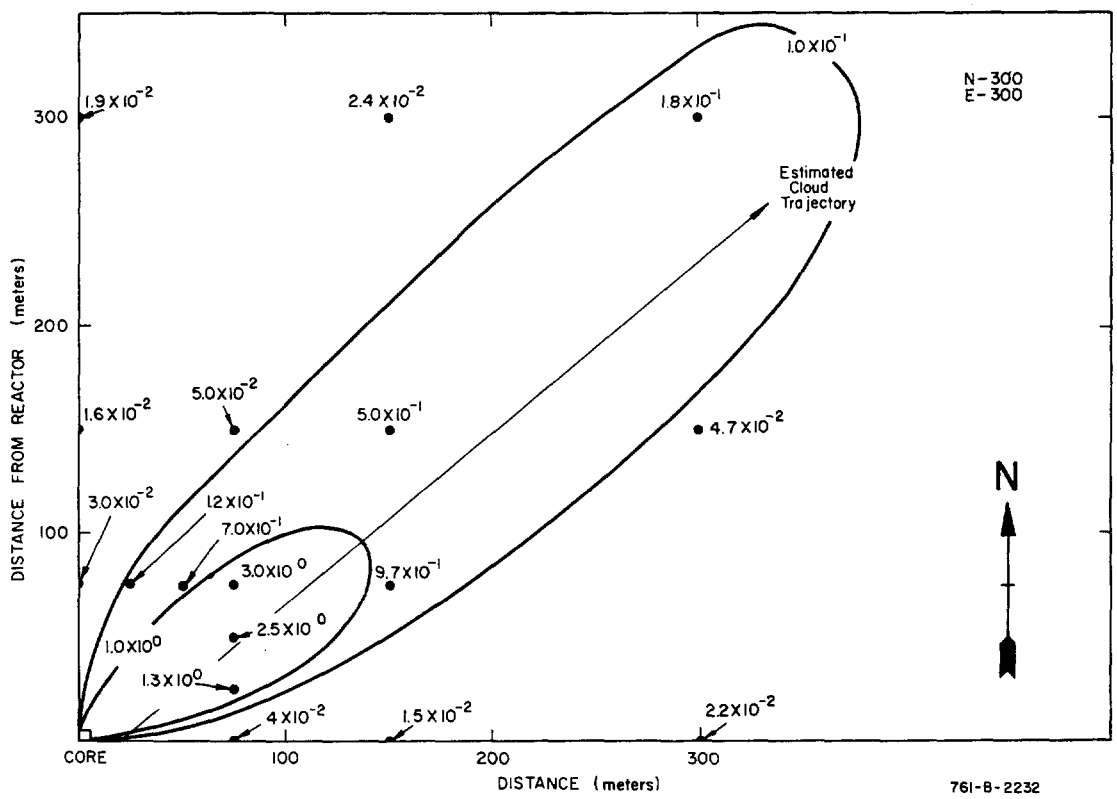

FIG. 10 ISOPLETHS OF AIR CONCENTRATIONS.

The crosswind distribution of concentrations, χ, was plotted and used in the analysis of centerline concentrations of the plume axis dilution values χ/Q. The resultant numbers were then back-corrected to the time of excursion to give an estimate of released fission products. This yielded a calculated release of 3.6×10^4 curies or about 0.7 percent of the 5×10^6 curies produced from a 31 MW-sec excursion.

Analysis of gamma spectra indicated that (from 15,000 to 90,000 seconds after the excursion) practically all the activity consisted of the daughters of Xe-139, Kr-91, and Kr-92 (Figure 11). It is assumed that the other noble gases were released in the same fraction, although their daughters' half-lives were such that they could not be identified. This leads to an estimate that 7.2 percent of the noble gases which were produced by the excursion were released to the atmosphere.

Attempts were made to correlate the integrated air concentrations with film badge data by the following formula:

$$1 \text{ curie-sec/m}^3 = 0.55 \text{ ER} = 0.33 \text{ R} \qquad \text{where } E \approx \frac{0.6 \text{ MeV}}{\text{dis}} \quad [20]$$

R = Dose in rad on Dosimeter

As can be seen in Table II, the ratio of expected dose and estimated dose is fairly constant; examination of other points shows nearly the same ratios as those found at the midline. One explanation for the disparity of expected and

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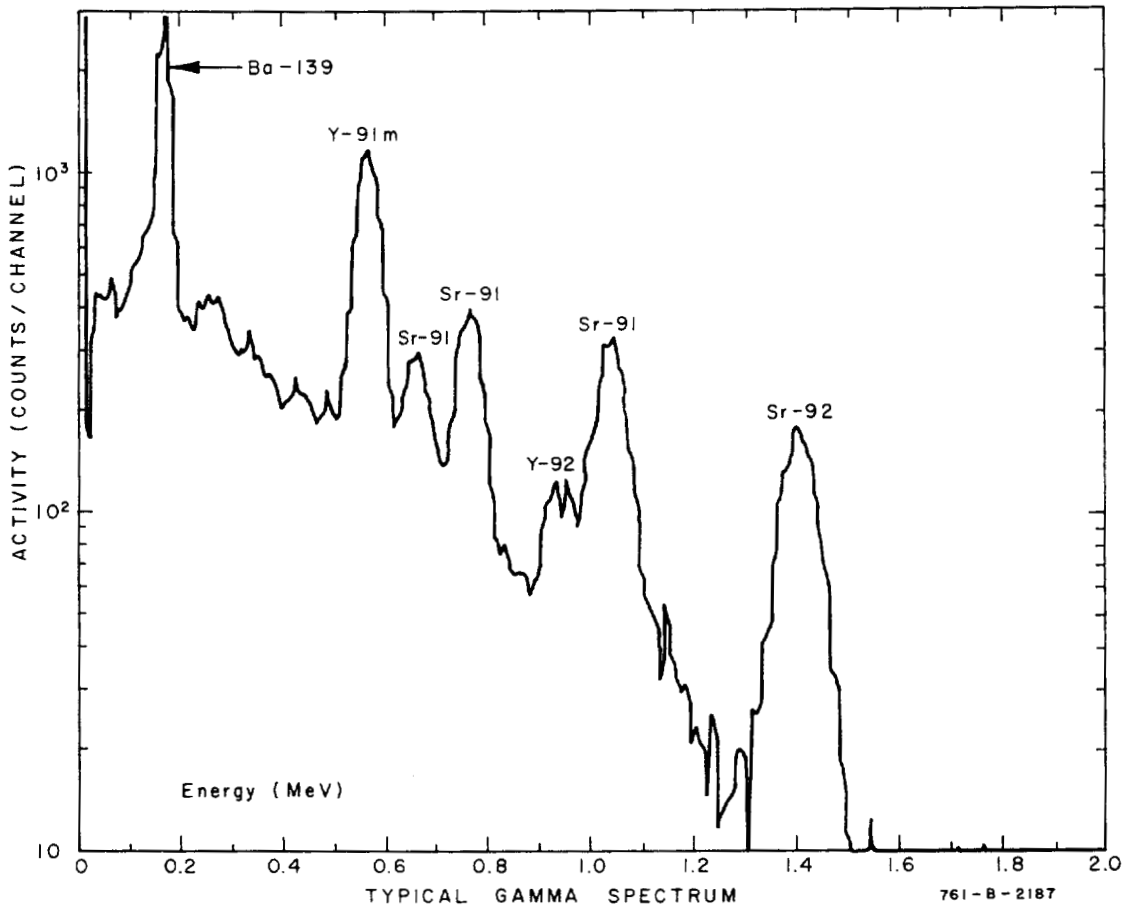

FIG. 11 GAMMA SPECTRUM OF A PREFILTER SAMPLE.

TABLE II

COMPARISON OF DOSES FROM FILM DOSIMETERS AND AIR CONCENTRATIONS

		Curie-sec/m^3	Expected Dose	Film Exposure	Ratio
N-75	E-75	1.20	0.89 R	0.18 R	2.2
N-150	E-150	0.53	0.17 R	0.08 R	2.2
N-300	E-300	0.24	0.79 R	0.08 R	2.0

computed values could be that most of the activity at the time the cloud passed consisted of beta emitters.

Examination of the activity on the carbon traps and prefilters indicated that filter efficiencies remained fairly constant on the grid. Table III gives a list of both crosswind and downwind efficiencies.

1133002

TABLE III

PREFILTER EFFICIENCIES OF THE AIR SAMPLERS

Location			Efficiency (percent)	
N-75	E-00	(meters)	82	
N-75	E-25		79	
N-75	E-50		80	
N-75	E-75		84	Average = 83
N-50	E-75		80	
N-25	E-75		93	
N-00	E-75		82	
N-150	E-00		72	
N-150	E-75		71	
N-150	E-150		89	Average = 79
N-75	E-150		81	
N-00	E-150		79	
N-300	E-00		65	
N-300	E-150		81	
N-300	E-300		81	Average = 78
N-150	E-300		77	
N-00	E-300		84	
				(Mean Efficiency = 80 percent)

Analysis of the Anderson Impactors indicated that about 80 percent of the activity was associated with particle sizes less than 1.5 μ.

Studies prior to the test, using the same air sampling equipment, showed an average of 82 percent collection efficiency for BM-2133 with a range of 76 to 86 percent [21]. These studies were conducted at 25 cfm with 0.9 μ DOP. It would then be expected, as was indeed found, that filter efficiencies would approximate this range.

4.2 Ground Level Concentrations

To complement the above investigations, environmental sampling was planned. The first of the two major objectives was to measure on-site and off-site contamination from this test. To this end, sage was sampled as far as Shell Road. Only one sample outside the Spert fence, at the first arc of trailers, definitely had activity (three to four times background).

Milk was also collected from a farm 48 kilometers downwind from the test. There was no change in activity detected even after several days -- compared with samples taken two days before the test.

The second objective was to study the ratio of ground level activities (as measured by fallout plates and grass) to air concentrations, with distance. Figure 12 shows the crosswind and downwind activity sampled by grass. It is apparent by comparison with Figure 9 that the grass activity followed the air activity fairly closely.

Table IV shows the deposition velocity for grass (gross activity in $\mu Ci/m^2$ divided by air activity in $\mu Ci\text{-}sec/m^3$) and the ratio of the activity found on other fallout plates to that of grass.

The deposition velocity appears to be about 0.025 m/sec. The variation from point to point can be attributed to several reasons (Appendix A-2.5).

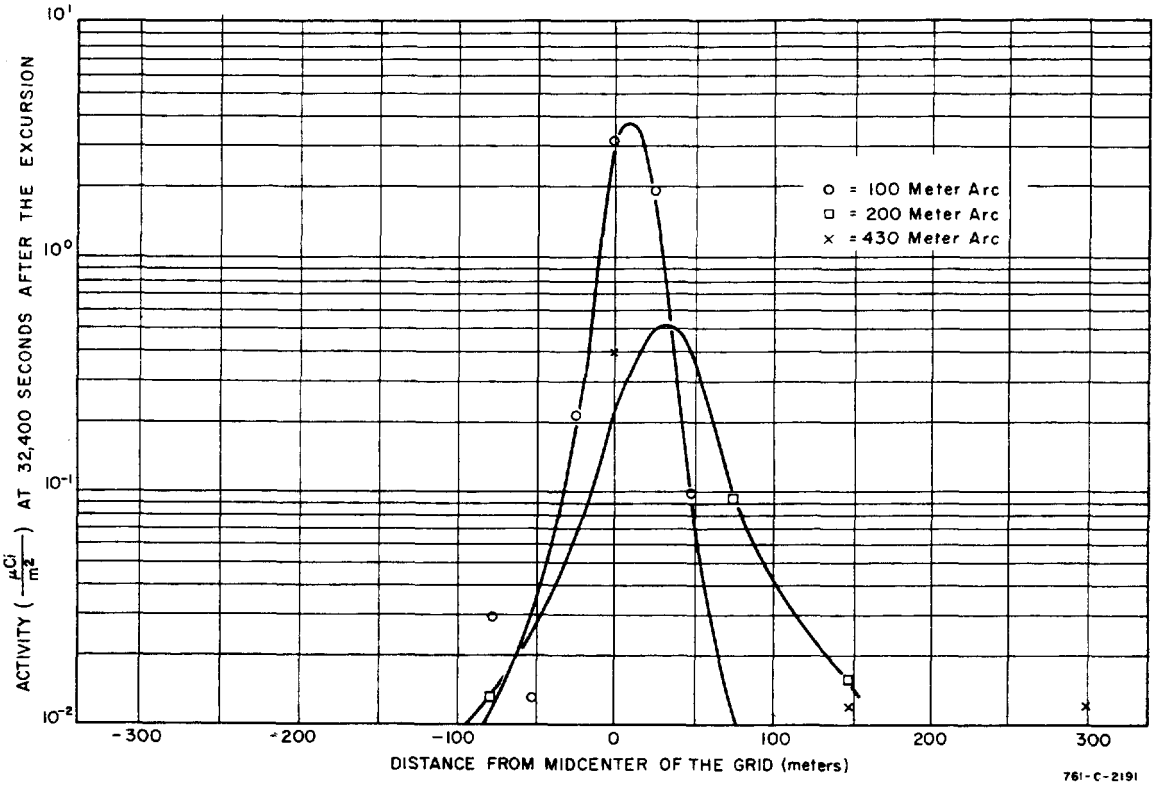

FIG. 12 CROSSWIND AND DOWNWIND DISTRIBUTION OF RADIOACTIVITY FOUND ON GRASS SAMPLES.

1133004

TABLE IV

COMPARISON OF GROUND LEVEL ACTIVITY WITH AIRBORNE ACTIVITY

Location		V_g or $\frac{\mu Ci/m^2}{\mu Ci\text{-}sec/m^3}$	Ratio of Plate Activity to Grass Activity		
		Grass	Carbon	Sand	Gummed Paper
N-75	E-00	0.11	0.13	0.16	0.18
N-75	E-25	0.024	0.43	0.50	0.11
N-75	E-50	0.029	0.50	0.43	0.22
B-75	E-75	0.036	0.34	0.23	0.25
N-50	E-75	0.023	0.29	0.29	0.41
N-25	E-75	0.032	0.31	0.38	0.23
N-00	E-75	0.029	0.23	0.19	0.16
N-75	E-00	0.029	0.20	0.14	0.18
N-150	E-75	0.031	0.20	0.10	0.10
N-150	E-150	0.025	0.08	0.06	0.10
N-75	E-150	0.015	0.20	0.14	0.16
N-00	E-150	0.070	0.16	0	0
N-300	E-00	0.030	0.40	0.30	0.20
N-300	E-150	0.029	0.20	0	0
N-300	E-300	0.015	0.20	0.14	0.25
N-150	E-300	0.019	0.38	0.10	0.20
N-00	E-300	0.017	0.08	0	0

The ratios of activities of the other fallout plates (gummed paper, gummed paper with carbon, and gummed paper with sand) appear to follow no discernable trend. On the whole, the carbon activity is one-half to one-tenth that of grass while sand and gummed papers show even greater fluctuations. It would appear, then, that grass is the most reliable collector of ground activity, as well as the most efficient collector.

4.3 Film Dosimetry Studies

A test program was undertaken to study the reliability of film badge monitoring during a reactor excursion. Fourteen phantoms (20-liter polyethylene carboys filled with tissue-equivalent solution) were placed near the reactor vessel and surrounding building (Figure 13).

Each phantom was circled with 12 film badges. Two film badges were placed under the carboy so that there would be a minimum of backscatter. Each phantom also contained a film badge sealed in polyethylene, positioned in the center of the solution. This particular film badge would yield an indication of depth dose. The tissue-equivalent solution was a mixture of sucrose, urea, sodium chloride, and water. The effective Z number of the solution was 6.99 whereas that of a standard man is 7.13.

Ten of the phantoms were placed on standard "T" type fence posts at distances of 8, 15, and 30 meters from the vessel center. One of these ten phantoms was placed at the top of the bunker, 8 meters from the vessel center and 2.5 meters above the reactor building floor. Four other phantoms were placed on wooden stands, one in each quadrant, three meters from the vessel center. The centers of all the phantoms were approximately one meter above ground, to simulate the torso of an average man.

All film badges were recovered five and one-half hours after the first test. As expected, those films of each phantom downwind from the reactor received a greater exposure than those upwind. The four phantoms placed three meters from vessel center showed a wide variation in average exposure values as shown in Table V. Phantom number 11 had the least equipment shielding and number 14 the most. Very likely, factors such as equipment and water shielding and splash contamination, contributed to the variations in exposure dose to these phantoms. The average external exposures of the phantoms outside the reactor building (in rad) are found in Table VI. For the front-to-back exposure ratios of the four close-in phantoms, beta ratios were approximately six and gamma ratios about three. Analysis of the neutron film and neutron energy threshold detector elements contained in the film dosimeters indicated there were no detectable neutron exposures to the phantoms. Therefore, exposures were less than 13 mrem.

The readings from the badges on the phantoms were compared to those hanging immediately below in free air. These ratios were found to be 1.1 for beta and 1.4 for gamma, indicating that the phantoms did act as a substantial backscattering medium.

It appears that reliable film badge information, consistent with that expected, can be obtained from an incident of this type.

4.4 Criticality Accident Research

One of the major objectives, as outlined in Section I-2.1, was to initiate supporting studies in criticality monitoring research. This largely consisted of neutron activation studies and reactor water analyses. An effort was made to obtain neutron flux, neutron energy distribution, gamma to neutron ratio, and total dose from activation of various foils and other materials which might be expected to be found following a criticality accident. Multiple nuclear accident dosimeter (NAD) systems and a 3-meter length of copper wire were

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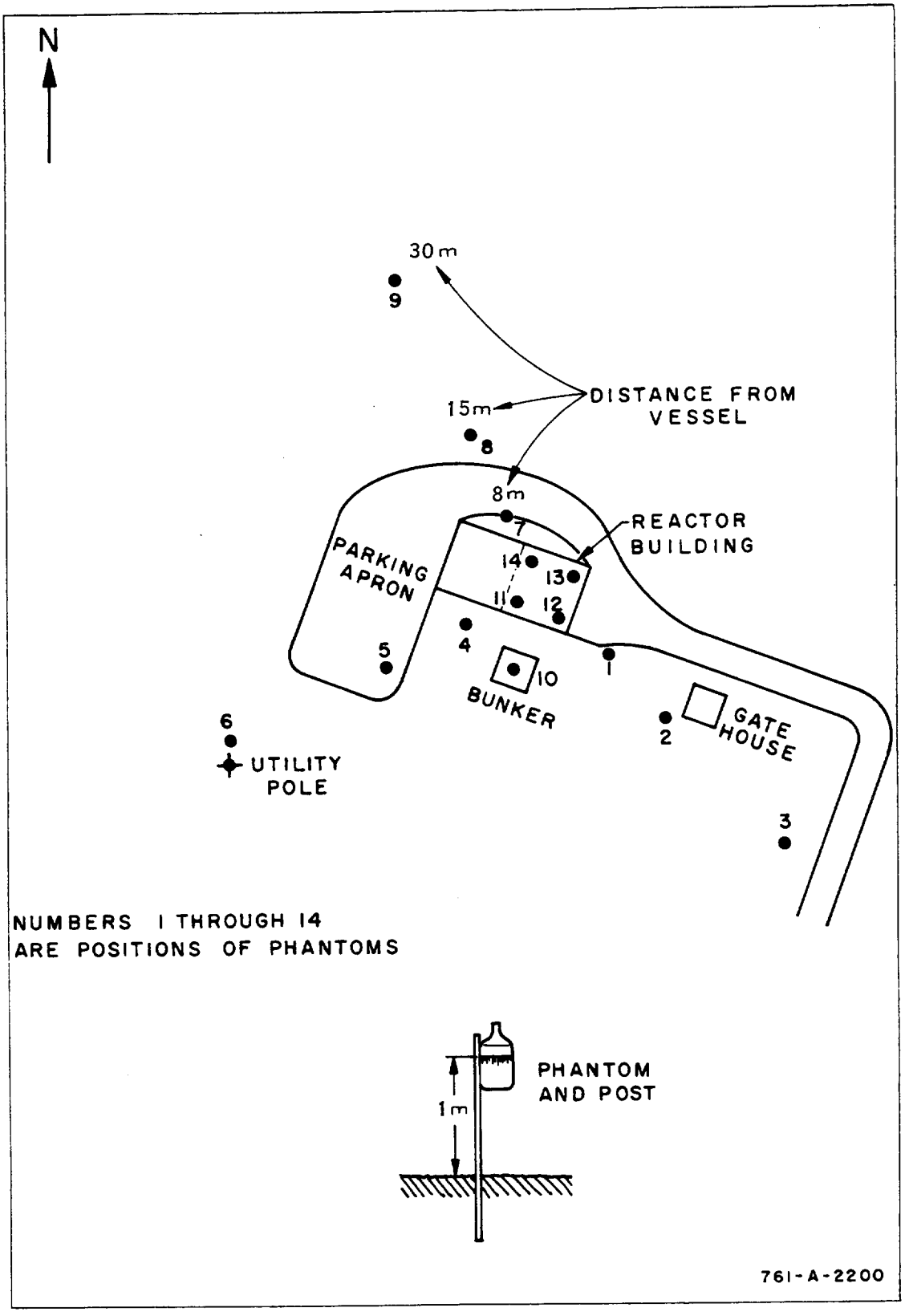

FIG. 13 GRID LOCATIONS OF PHANTOMS.

1133007

TABLE V

FILM DOSIMETER EXPOSURES ON PHANTOMS IN THE REACTOR BUILDING

Phantom	Gamma (rad)	Beta (rad)	Beta/Gamma Ratio
11	15	250	17
12	7.2	140	19
13	2.9	59	20
14	2.3	37	16

TABLE VI

FILM DOSIMETER EXPOSURES ON PHANTOMS OUTSIDE THE REACTOR BUILDING (rad)

	8 m	Beta	Gamma	15 m	Beta	Gamma	30 m	Beta	Gamma
Upwind	1	2.4	0.73	2	0.08	0.12	3	0	0.04
Upwind	4	1.6	0.95	5	0.91	0.13	6	0	0.04
Downwind	7	3.5	1.00	8	4.10	0.64	9	0.58	0.14
Upwind	10	1.6	0.90						

The Film Badges Inside the Phantoms Yielded the Following:

3 m	Gamma	8 m	Gamma	15 m	Gamma	30 m	Gamma
11	5.2	1	0.34	2	0.06	8	0.02
12	2.4	4	0.65	5	0.10	6	0.02
13	1.5	7	0.66	8	0.32	9	0.06
14	1.5	10	0.68				

suspended three meters above the reactor vessel. Examination of the samples following the first test indicated neutron activation of the gold foil in one NAD system and in the copper wire. The estimated thermal nvt was 1.2×10^8 and 8.4×10^7, respectively. The gamma dose was below the detection limit of approximately 50 R of the chemical dosimeters in the NAD system [22]. No activation was observed in tools placed near the vessel.

1133008

4.5 Conclusions

A detailed analysis of the methods and calculations involved in the research studies may be found in Appendix A.

No halogens were identified by gamma spectrometry; and since they are normally expected to contribute the greatest hazard to the environment, calculations were made to determine what amounts might have been present and not detected. For the grid location N-75 E-75, the maximum activities on one spectrum could have been 1.1×10^2 disintegrations/minute/sample of I-131 and 1.3×10^2 disintegrations/minute for I-135. This amounts to a release of 51 μCi of I-131 and 160 μCi of I-135. This compares to estimated yields of 8×10^5 μCi of I-131 and 4.7×10^7 μCi of I-135. Therefore, the maximum possible releases for the given isotopes are estimated to be 0.006 percent for I-131 and 0.0003 percent for I-135. Although the detectable activities on the spectra were essentially the same (110 and 130 disintegrations/minute), calculations involving a higher specific activity and higher fission yield for I-135 created a difference in possible release of two orders of magnitude.

It is apparent, then, that little or no iodine was released. Although water was spewed from the reactor and gross damage occurred, over 99 percent of the fission product inventory was retained in or near the reactor vessel. Of the fraction that was released, the activity had decayed by a factor of 10^5 one day after the excursion.

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II. TEST TWO

1. INTRODUCTION

1.1 The Second Destructive Test

The program for the second test had as its primary objective the study of the nature of the destructive effects which could be produced as a result of a severe power excursion in a low-enrichment oxide core. A top view of the experimental core is shown in Figure 14. The octagonal core was divided into four sections by a 3/4-inch-thick, aluminum rod-guide cross, which housed the four control rod-blades and the centrally located cruciform transient rod.

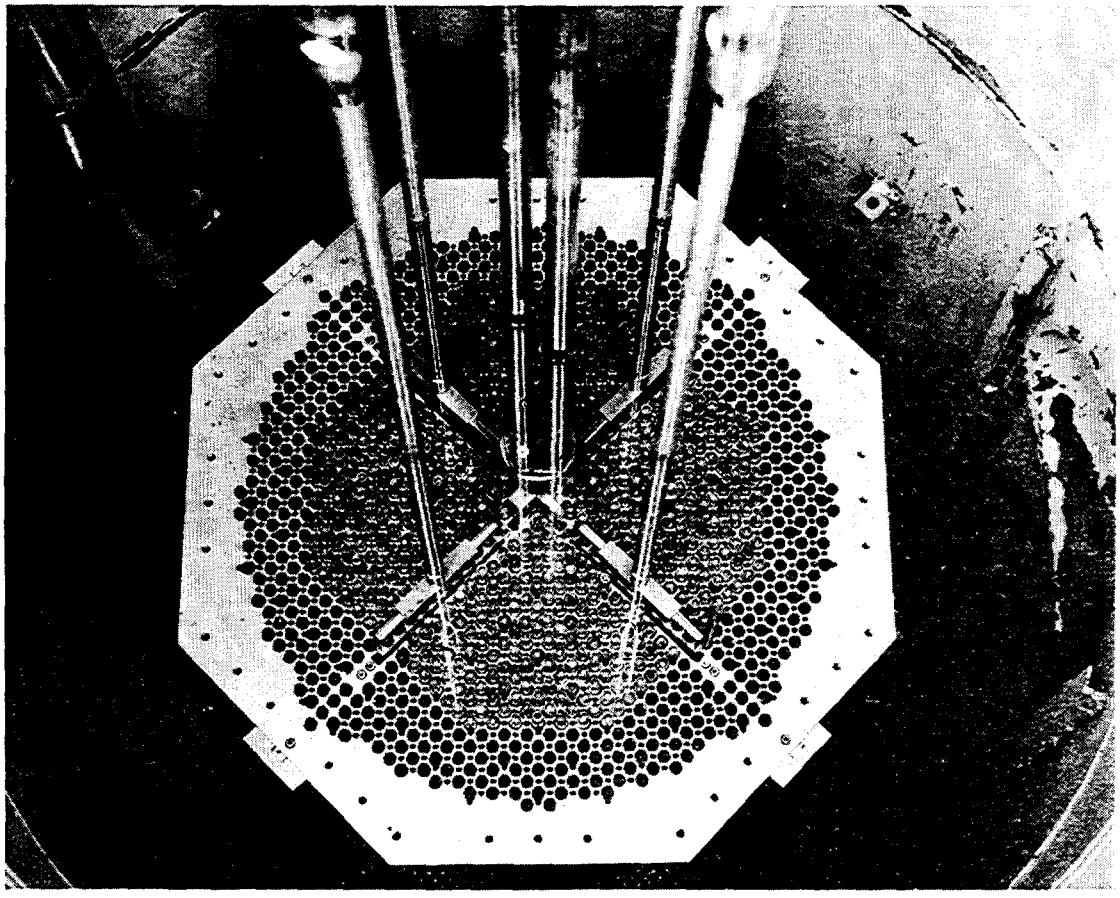

FIG. 14 TOP VIEW OF THE EXPERIMENTAL OXIDE CORE.

The fuel rods comprising the Spert I experimental core were previously used in the Babcock and Wilcox, N. S. Savannah critical assembly [23]. The fuel rods were 1.8 meters long, welded seam, 304 stainless steel tubes, containing low-enrichment uranium dioxide powder, swaged-compressed to an effective density of approximately 87 percent of the theoretical density of UO_2.

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It was expected that as shorter period tests were performed in the test series, cladding stresses and/or melting of the cladding would ultimately cause cladding rupture with the concomitant dispersion of finely divided UO_2 powder into the reactor water. If the fuel dispersion time were sufficiently short, it was further anticipated that this would result in a pressure pulse which might be sufficiently large to cause core destruction on a scale similar to that or larger than that observed in the Spert I plate-core destructive test of November 1962 [24].

The second test occurred at 1427 hours, November 10, 1963, the transient rod being pneumatically ejected from the core. This was followed by an excursion which had a period of approximately 2.2 msec with a total nuclear energy release of 155 MW-sec. During this excursion, two of the 590 fuel pins in the core ruptured and a pressure pulse of less than 100 psi was produced as a consequence of the rupture of one or both of these pins. No significant mechanical damage to the core was produced in this test, except for some bowing of the fuel rod pins as a result of thermal changes and/or the pressure pulse [25].

After a post-test examination was conducted, it was found that both of the two above mentioned pins had an initially defective cladding. This, in conjunction with two similarly appearing ruptures in positions of relatively low power densities in the core, suggested that the observed limited damage in the test may not be typical of that which could be produced in a shorter period excursion in which more widespread cladding failure occurs [26] (Figures 15 and 16).

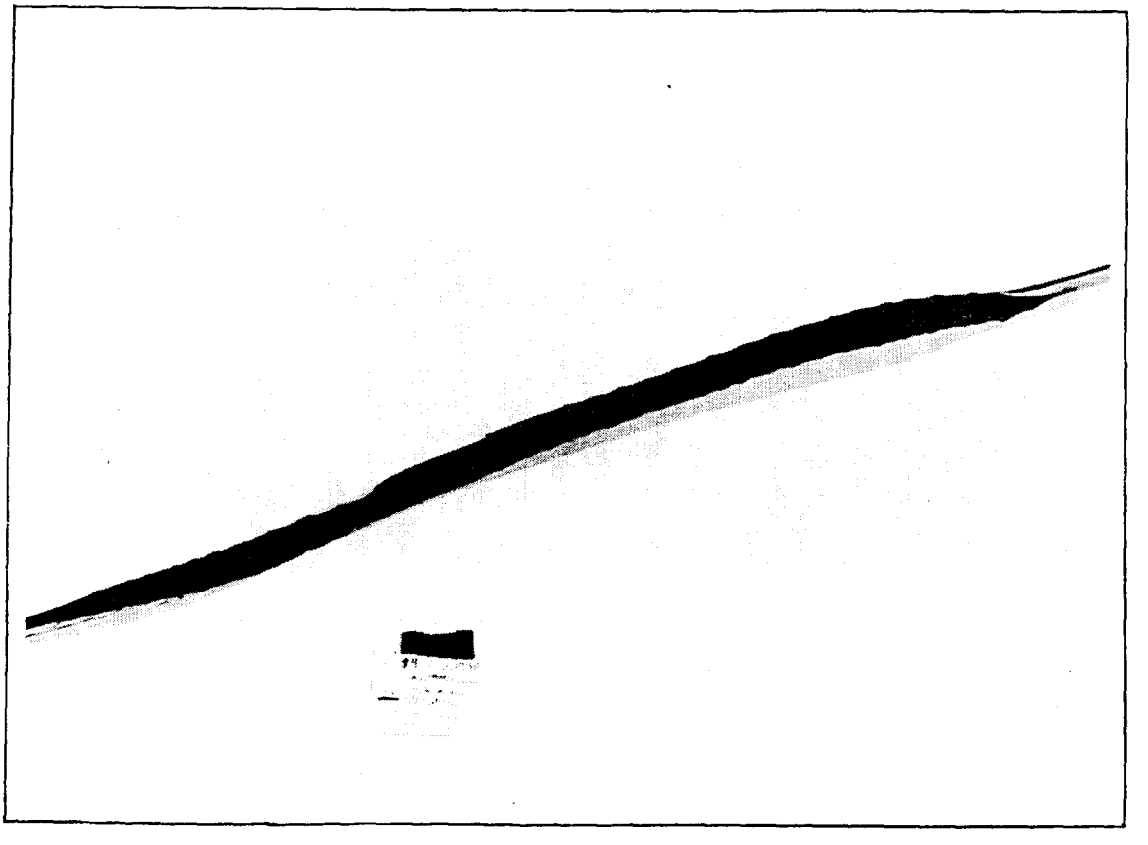
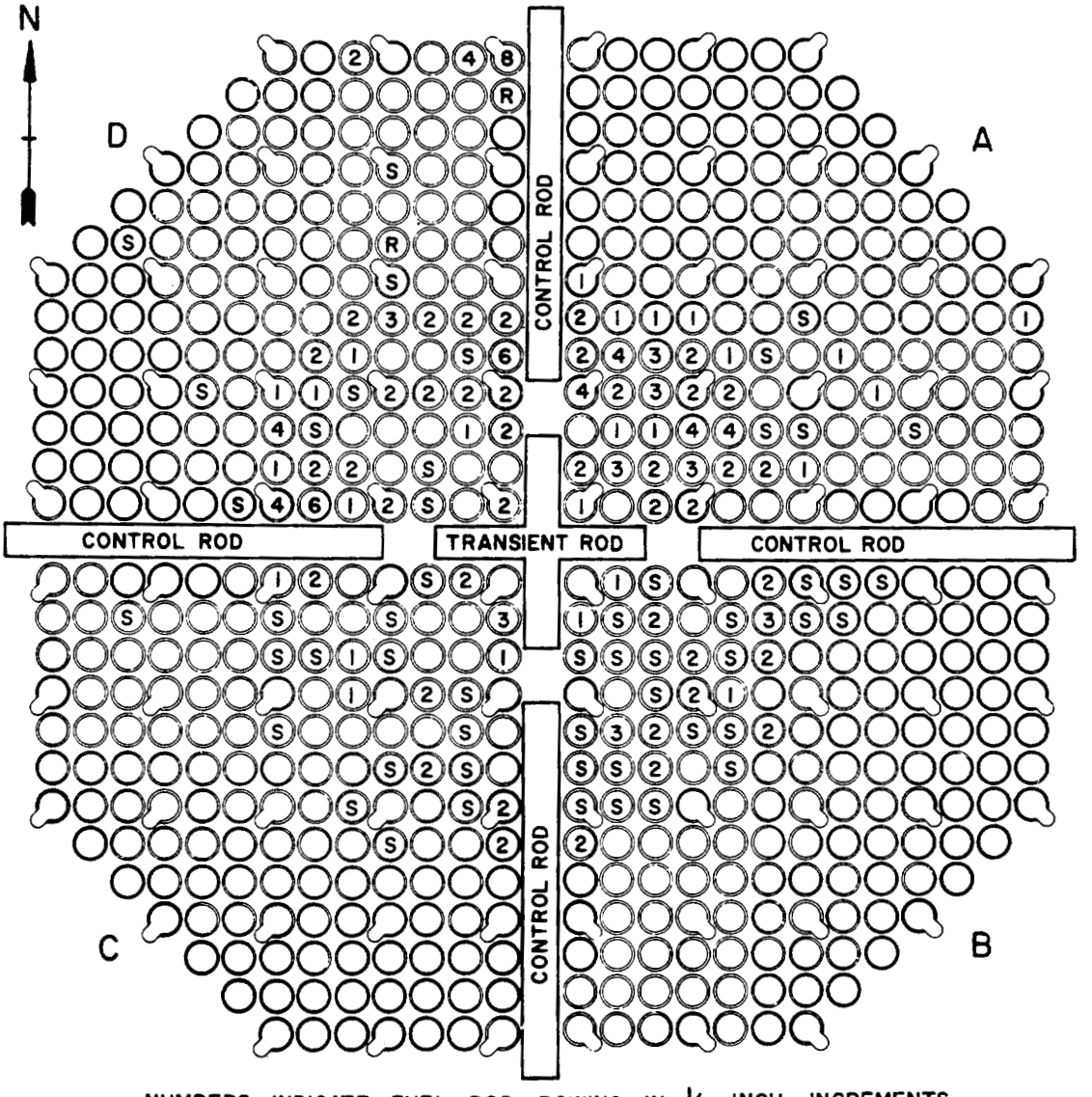


FIG. 15 RUPTURED UO_2 FUEL PIN FROM SECOND DESTRUCTIVE TEST.



NUMBERS INDICATE FUEL ROD BOWING IN 1/4 INCH INCREMENTS
LETTER S INDICATES SLIGHT BOWING, LESS THAN 1/4 INCH
LETTER R INDICATES THAT THE ROD RUPTURED

763-C-8192

FIG. 16 SECTION OF SPERT CORE INDICATING LOCATIONS OF BOWED AND SPLIT FUEL PINS.

1.2 The Test Grid

The grid system was essentially the same as in the previous test, with minor changes to better meet the radiological objectives of the test series.

(1) Several recording dose rate meters were placed on the grid to give better estimates of instantaneous dose rates due to the excursion and to the radioactive cloud. A recording ionization chamber (gamma only) was placed at N-75 E-75 and recording GM's (beta and gamma) placed at N-150 E-150, N-300 E-300, N-450 E-600, and N-525 E-450.

1133012

(2) An air sampling tower was placed at N-75 E-75. This device consisted of seven carbon cartridges attached to a 6 meter pipe through which air was pumped. The cartridges were spaced at one meter intervals from 1/6 to 6 meters from the ground. It was felt that knowledge of the vertical distribution of air concentrations was necessary to compare ground level and airborne radioactivity. Of more importance was the need to know how representative air samples were of cloud activity.

2. SAFETY

2.1 Pre-evaluation and Safety Controls

Prior to the destructive test, a Safety Analysis Report [27] was prepared and reviewed. Calculations of hazards due to this test indicated that with adequate meteorological control, the test would not create an environmental hazard beyond the Spert access fence.

At 0815 hours, November 10, 1963 (Sunday), Spert Operations and the Health Physics Branch received notification by the U. S. Weather Bureau that there was at least a 60 percent chance of achieving test conditions. It was decided at this time to proceed with the test; the additional necessary personnel were then called out [28].

After the excursion had occurred, briefings of the reentry team were held. Procedures were to be the same as in the first test. Since it was quickly established that the reactor was critically safe, the reentry team entered the area about three hours earlier than in the first test.

For post-test support, the Weather Bureau described the meteorological conditions during the test. These are listed in Table VII.

TABLE VII

METEOROLOGICAL CONDITIONS DURING THE SECOND TEST

	Spert I	4800 Meter Arc
Wind Speed -- m/sec	6.7	5.4
Wind Direction -- degrees	228	233
Mean Wind Speed -- m/sec	6.5	
Mean Wind Direction -- degrees	230	
Stability Parameter (n) -- dimensionless	0.20	
Horizontal Diffusion Parameter (C_y) -- meters$^{n/2}$	0.178	
Vertical Diffusion Parameter (C_z) -- meters$^{n/2}$	0.118	

1133013

2.2 Radiation Levels Experienced During the Second Test

Aerial monitoring was conducted as in the previous test. At 750 meters from the reactor, the cloud was 210 meters wide with readings of about 1 mR/hr. Monitoring continued downwind for about 24 kilometers where readings were not significantly above background.

Inside the test area, the maximum level recorded was 900 R/hr in the reactor building, 1.8 meters from the core. The integrated dose was 1.25 R at one meter, 0.400 R at 1.3 meters, and 0.170 R at 1.6 meters. Only three environmental film badges recorded a significant amount of radiation (20 mr) and these were all within 30 meters of the reactor, downwind.

The recording dose rate meters on the grid showed a 250 mR/hr instantaneous dose rate from the excursion at N-75 E-75. No activity from the cloud was detected by this ionization chamber.

At N-150 E-150, an instantaneous level of 10 mR/hr was recorded at 1427; at somewhat less than 1428, the recorder moved past full scale (150 mR/hr).

An instantaneous level of 2 mR/hr was recorded at N-300 E-300 and a little over a minute later the recorder moved off scale.

The dose rate meter at N-525 E-450 did not show a gamma dose from the excursion but did record a 50 mR/hr maximum dose rate from the cloud.

3. RESEARCH STUDIES

3.1 Air Concentration Studies

Samples were removed from the grid and counted about one hour earlier than in the first test. The samples were analyzed in the same fashion as in the previous test with all samples corrected to a common counting time (9 hours after the excursion). Figure 17 illustrates crosswind and downwind distributions of total integrated air concentrations. The cloud appeared to move in a more easterly direction than in the first test and was wider at each arc as compared to the first release. The integrated air concentration at N-75 E-75 was 2.9/μCi-sec/m^3. From this figure it is estimated that about 5×10^{-4} curies were collected during cloud passage at the midline of the grid and the cloud had an average air concentration, at that point, of about 2×10^{-3} Ci/m^3, again assuming a cloud passage of 10 seconds.

Analysis of the data from the air sampling tower at N-75 E-75 showed that the highest activity passed by that point at one meter -- the height at which all air samples were taken. As can be seen in Figure 18, the peak was marked. Apparently a relatively small change in height might lead to significant differences in collected activity.

The crosswind concentrations of the cloud were again used in the analysis of centerline concentrations of the plume axis dilution values, χ/Q. The resultant members were back-corrected to the time of excursion to give an estimate of

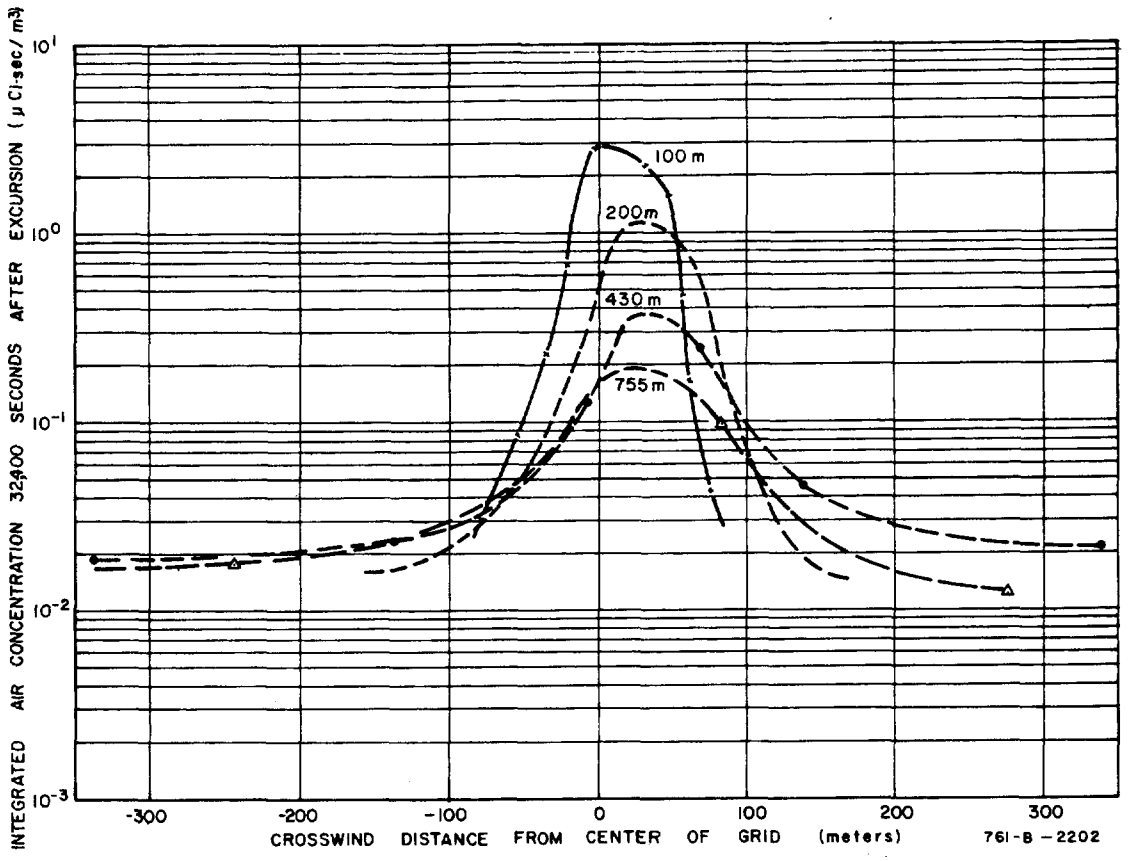


FIG. 17 CROSSWIND AND DOWNWIND DISTRIBUTIONS OF INTEGRATED AIR CONCENTRATIONS.

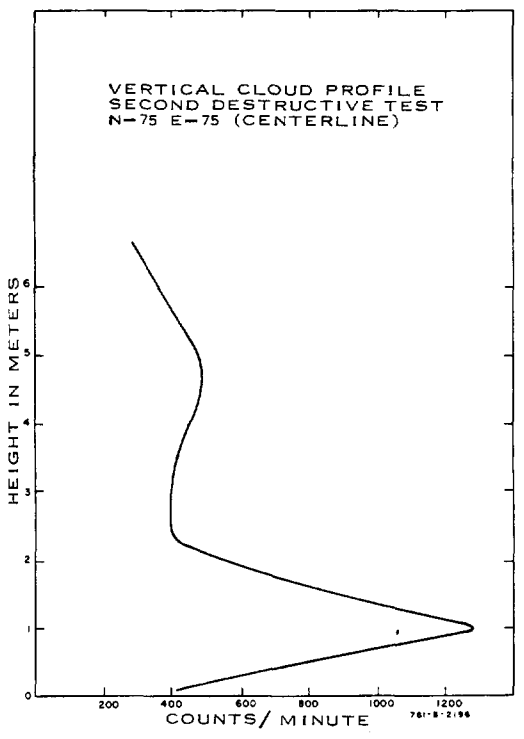


FIG. 18 VERTICAL CLOUD PROFILE.

released fission products. This yielded a calculated release of 530 curies or about 0.002 percent of the 2.4 x 10^7 curies produced from a 155 MW-sec excursion.

Analysis of gamma spectra indicated that (from 15,000 to 70,000 seconds after the excursion) practically all the activity consisted of daughters of K-91, Kr-92, and Xe-139; thus, about 0.02 percent of the noble gases which were produced were released to the atmosphere.

No attempt was made to correlate exposures with air concentrations since no significant exposures were found at locations that had air samplers (> 15 meters from the reactor).

Filter efficiencies appeared to be higher than on the first test with an average of 90 percent and a range of 84 to 98.

1133015

Analysis of Anderson Impactors again indicated that about 70 percent of the activity was associated with particle sizes less than 1.5 μ. This figure was based on a much smaller number of samples than in the first test. Although it appeared that more of the activity was associated with particles from 0.5 to 1.5 μ than in the first test, the total activity was near the detection limit and the uncertainties were greater.

3.2 Ground Level Concentrations

Using the same procedures and calculations as in the previous test, the deposition velocity for grass appears to be about 0.058 m/sec on the 75 meter arc and about 0.036 m/sec on the 150 meter arc. Table VIII shows the variance from point to point and from arc to arc. Since many of the included V_g were at the outside of the arc and natural background radioactivity was known to interfere with accuracy, estimations were made of V_g for the points with known significant activity. This leads to an average of 0.033 m/sec over the grid and 0.040 on the 75 meter arc. This compares to a value of 0.025 to 0.030 for the first test.

Only gummed paper fallout plates were used in this test and, as before, wide variations in collected activity were found as compared to grass. The activity found on the fallout plates was from 5 to 120 percent of that found on grass. (Deposition velocities were therefore as variable.)

3.3 Film Dosimetry Studies

A film dosimetry program, similar to that of the previous test, was carried out in connection with the second Spert I Destructive Test. The phantoms were placed in the same positions as in the previous test (Figure 13) to compare results and study further the reliability of the film dosimeters in a nuclear excursion.

The four phantoms in the reactor building saw beta and gamma radiation; the four phantoms at eight meters saw only gamma; and the rest gave zero readings. The averages of the twelve badges from the phantoms that gave significant readings are given in Table IX.

The front-to-back ratios for the four phantoms which were close were approximately six for beta and three for gamma. Although the doses were much lower, these two ratios correspond to those of the previous test. With further substantiation, these or similar values might be taken as a standard for criticality exposures.

The readings from the badges on the phantoms were compared to those hanging in free air. The ratios were again found to be 1.1 for beta and 1.4 for gamma.

3.4 Criticality Accident Research

Criticality research continued as in the first test, with the same system being used. Examination of the samples following the second test indicated neutron activation in the copper wire. The estimated thermal nvt was 9.3×10^5 as compared to 8.4×10^7 on the first test.

1133016

TABLE VIII

COMPARISON OF GROUND LEVEL ACTIVITY WITH AIRBORNE ACTIVITY

		Grass V_g (meters per second)	
N-75	E-00	0.12	
N-75	E-25[a]	0.036	
N-75	E-50[a]	0.050	Mean = 0.058
N-75	E-75[a]	0.034	Mean = 0.040[a]
N-50	E-75[a]	0.047	
N-25	E-75[a]	0.051	
N-00	E-75	0.071	
N-150	E-00	0.016	
N-150	E-75	0.049	Mean = 0.025
N-150	E-150[a]	0.022	Mean = 0.021[a]
N-75	E-150[a]	0.019	
N-00	E-150	0.020	
N-300	E-00	0.062	
N-300	E-150	0.053	Mean = 0.052
N-300	E-300[a]	0.019	
N-150	E-300	0.072	
N-00	E-300	0.055	

[a] Samples where background activity did not introduce uncertainties in accuracy.

1133017

TABLE IX

FILM DOSIMETER EXPOSURES ON PHANTOMS

Phantom	Gamma (rad)	Beta (rad)	Beta/Gamma Ratio
11	0.53	1.6	3
12	0.57	1.3	2
13	0.57	0.97	2
14	0.36	1.3	3.5

Reactor water samples were analyzed for Zr-97, Mo-99, and Ce-143. The amounts of each were computed and back-corrected to the time of the excursion. From these estimates, the total number of fissions was computed and compared to the number of fissions which should result from a 155 MW-sec excursion. For a 155 MW-sec excursion, 5×10^{18} fissions should occur. Estimated fissions were 3.9×10^{17} by Zr-97, 1.4×10^{19} by Mo-99, and 3.6×10^{19} fissions by Ce-143.

3.5 Conclusions

A detailed analysis of the methods and calculations involved in the research studies may be found in Appendix A.

No halogens were detected in this test by gamma spectrometry. Estimates based on the detection limits for I-131 and I-135 indicated that the maximum possible releases for the two isotopes were both less than 0.01 percent.

Concentrations of airborne radioactivity appeared to be a factor of 100 less than in the first test and the release fraction a factor of 350 less -- although the period was about one millisecond shorter and the nuclear energy release about five times as great.

1133018

III. TEST THREE

1. INTRODUCTION

Since the second destructive test did not produce widespread cladding failure, plans were made to initiate a shorter period test in an attempt to determine if substantially more severe damage would be obtained with higher fuel temperatures.

To accomplish this objective, nine more fuel rods (for a total of 599) were inserted to give an available excess reactivity of about 3.6$ as compared with the 3.2$ available excess reactivity from 590 fuel rods in the second test.

The maximum reactivity addition that could be used in this core by ejection of the transient rod was used in the previous 2.2-msec-period test. In order to place more reactivity in this system and increase the severity of the test, the third test was initiated by a combination of control rod withdrawal and transient rod ejection (a ramp-plus-step reactivity addition). The instrumentation and all procedures, with the exception of the mode of reactivity addition, were essentially the same as in previous tests.

The third test took place at 1314 hours, April 14, 1964. The excursion had a period of approximately 1.55 msec with an energy release of 165 MW-sec. Apparently two fuel pins ruptured before the time of peak power, significantly limiting the energy release. Again, no significant mechanical damage occurred in the oxide core or to instrumentation. Figure 19 indicates the general damage to the core, and Figure 20 shows one of the two ruptured fuel pins. These may be compared with Figures 15 and 16 (from the 2.2 msec test).

1.1 The Test Grid

The grid system was essentially the same as with the second test except for two changes.

(1) The recording dose rate meter chart speeds were changed from 7.5 cm per hour to 1.1 meters per hour. In the previous test, the cloud passage was noted but not described. It was hoped that a faster time scale could give more information on both the configuration of the cloud and the time it took for the cloud to pass.

(2) Towers with High-Volume samplers were placed on the 75 meter arc and fallout towers were placed on the 150 meter arc. The results from the low-volume tower used in the second test indicated that a sampler, collecting at one meter, was not necessarily giving representative information of air concentrations. Since a Gaussian distribution was assumed for the vertical profile and since results from the second test indicated that this was not the case, it was quite possible that calculations involved an overestimate of the source term.

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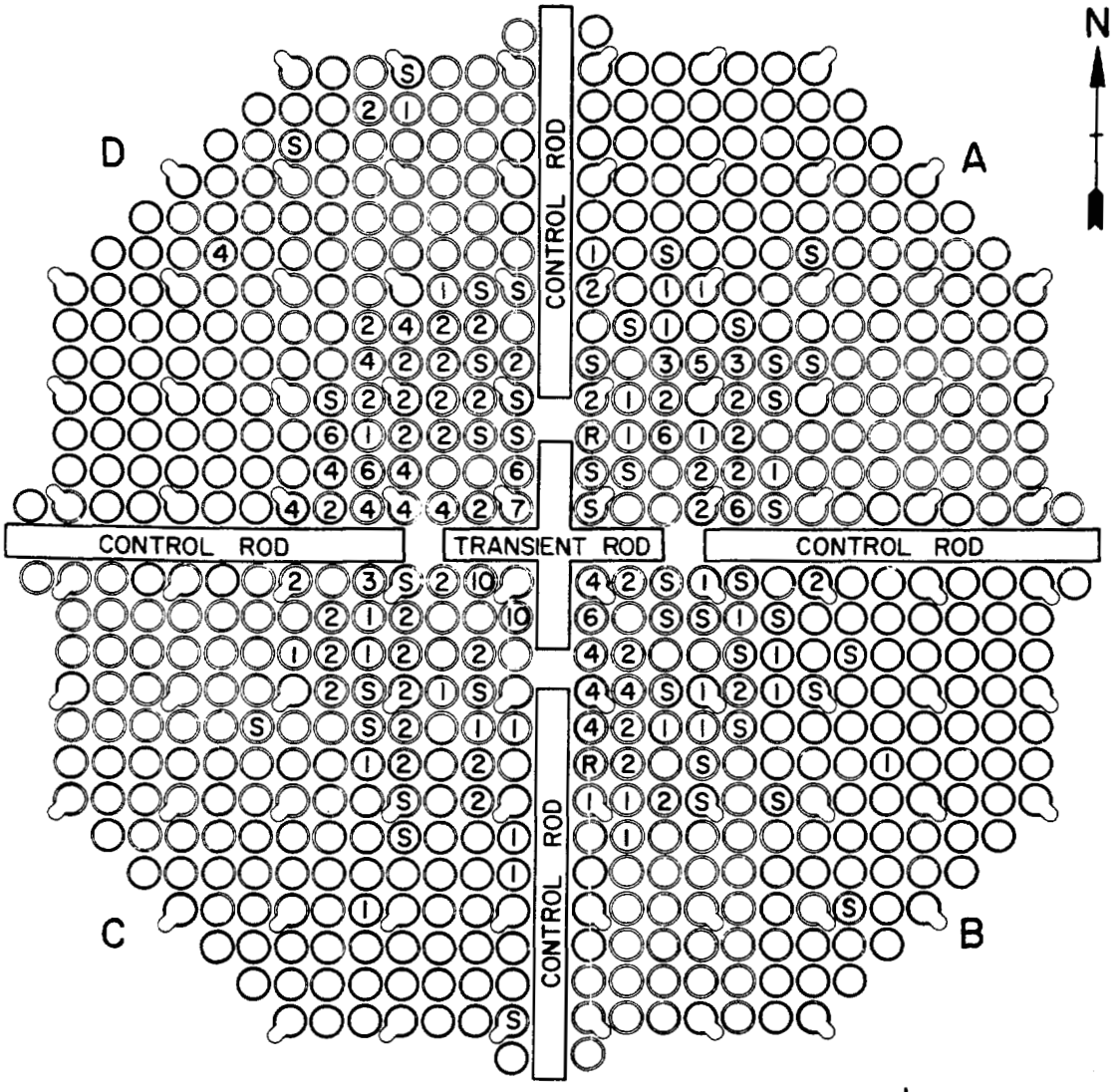

NUMBERS INDICATE FUEL ROD BOWING IN 1/4 INCH INCREMENTS
LETTER S INDICATES SLIGHT BOWING, LESS THAN 1/4 INCH
LETTER R INDICATES THAT THE FUEL ROD RUPTURED

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FIG. 19 SECTION OF SPERT CORE INDICATING LOCATIONS OF BOWED AND SPLIT FUEL PINS.

These Hi-Vol towers were located at N-75 E-25, N-75 E-50, N-75 E-75, N-50 E-75, and N-25 E-75. The collectors were placed one meter apart to a height of 4 meters (one was located 1/6 meter from the ground to approximate a ground level collection yet avoid excessive dust loading).

The fallout towers used at the 150 meter arc were simple and inexpensive to prepare. The plates themselves were in a vertical position -- to maximize the impaction process. Since

the terrain is quite rough at that location, a relative difference of collected activity with height should be adequate to compare results with data from the Hi-Vol towers.

(3) Microsorban filter paper was used as the prefilter in the air samplers. It was felt that these might provide a more efficient collection system.

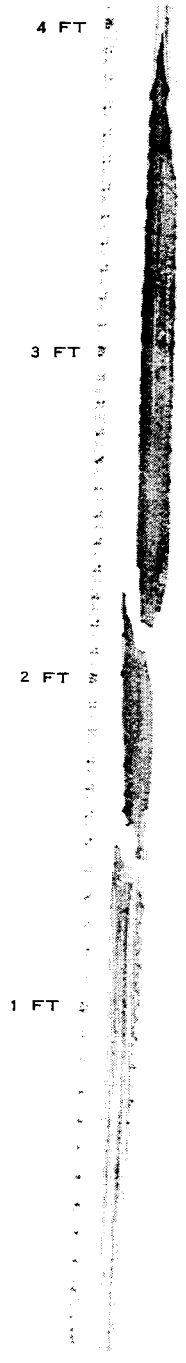

FIG. 20 RUPTURED UO_2 FUEL PIN FROM THE THIRD DESTRUCTIVE TEST.

2. SAFETY

2.1 Pre-evaluation and Safety Controls

On April 14, 1964, Spert Operations and the Health Physics Branch were given a forecast by the Weather Bureau which gave at least a fifty percent chance of achieving meteorological requirements for the test. Since the test was scheduled as soon as weather permitted, the grid crews were immediately dispatched to the Spert facility. The pre-established plans were carried out successfully (Section I-3.2, page 12) and the test concluded.

After the excursion had occurred, briefings of the PPCo reentry team were held. Procedures were essentially the same as in the first test. Since it was soon established that the reactor was critically safe, the reentry team entered the area within an hour after the excursion. Two members of the Health and Safety Division went with the reentry team to expedite recovery of neutron activation samples and high-volume air filters on the grid. The latter was done in order to have samples for decay measurements and gamma spectra as soon as possible after the excursion. For post-test support, the Weather Bureau described the meteorological conditions during the test. These are listed in Table X.

2.2 Radiation Levels

Aerial monitoring was conducted as in the previous tests (Section I-3.3). Levels of 0.2 mR/hr were recorded at the Spert exclusion fence 800 meters away and the cloud was tracked about 4000 meters, at which point levels had dropped to background.

1133021

TABLE X

METEOROLOGICAL CONDITIONS DURING THE THIRD TEST

	Spert I	4800 Meter Arc
Wind Speed -- m/sec	8.5	7.4
Wind Direction -- degrees	245	250
Mean Wind Speed -- m/sec	8.5	
Mean Wind Direction -- degrees	245	
Stability Parameter (n) -- dimensionless	0.2	
Horizontal Diffusion Parameter (C_y) -- meters$^{n/2}$	0.35	
Vertical Diffusion Parameter (C_z) -- meters$^{n/2}$	0.35	

Evaluation of film badge data inside the test area indicated that the maximum beta and gamma doses delivered were 15.8 rad and 16.0 R, respectively. This was at the edge and 0.3 meter above the top of the reactor vessel. The exposure 7.7 meters downwind was 50 mR gamma and 200 mrad beta; at 15.5 meters, 20 mR gamma and 100 mrad beta; and at 31 meters, 15 mR gamma and 40 mrad beta.

The integrated gamma dose from the power burst itself was 1.56 R at one meter, 1.84 R at 1.3 meters, and 0.84 R at 1.6 meters. Prompt gamma exposures at these points were 0.76 R, 0.21 R, and 0.10 R, respectively. At the rim of the reactor, south (downwind), the exposure was 18 R gamma. At the rim of the reactor, north, the exposure was 13 R gamma -- indicating about 5 R gamma due to the airborne activity.

Only four of the dose rate meters on the grid had significant results. The ionization chamber at N-75 E-75 showed a 150 mR/hr gamma peak from the excursion. At the 150 meter arc the recorder at N-150 E-75 (on the minute scale) showed a maximum level of over 50 mR/hr. Figure 21 shows the configuration of this cloud with each division representing about 2 seconds. As can be seen, the cloud appeared to pass by the recorder in about 10 seconds with roughly a Gaussian distribution. A recorder at N-150 E-150 (Figure 22) shows quite a different shape. The highest level, 20 mR/hr, is about half that of 75 meters away, and the cloud appears to pass in about 18 seconds -- approximately twice as long. Figure 23 shows the path of the center of the cloud as well as isopleths of concentration.

Unfortunately, no way was found to accurately determine the length of the cloud from the times that activity was recorded. The difference in time, as indicated in the graph, may be that the recorder with the longer "cloud passage" was nearer the bulk of the cloud activity and, therefore, showed a greater beta and gamma response. Calculations indicate that it would take about five seconds for the cloud to traverse the distance from the closer recorder to the

1133022

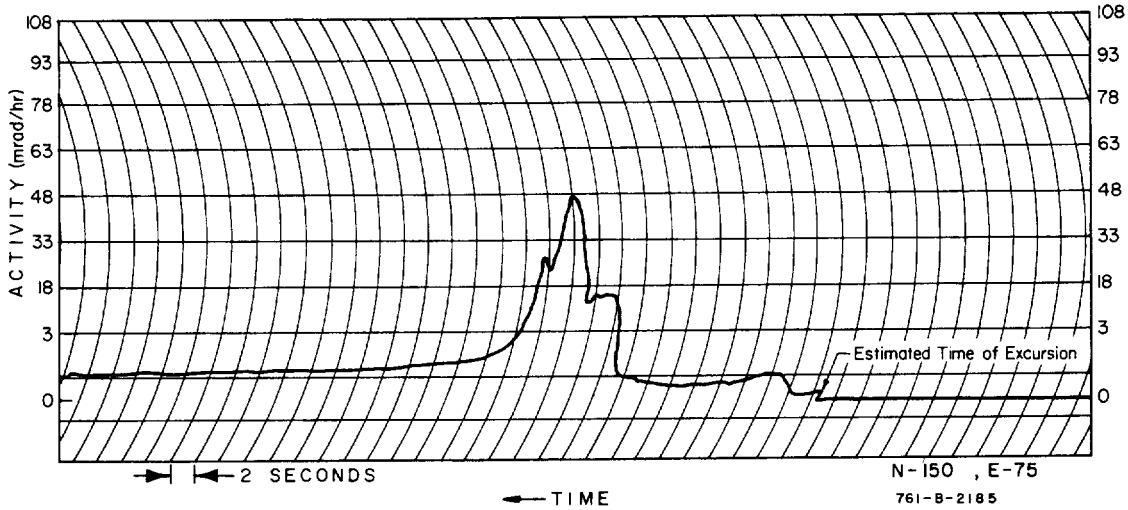

FIG. 21 CHART FROM A RECORDING DOSE RATE METER N-150 E-75.

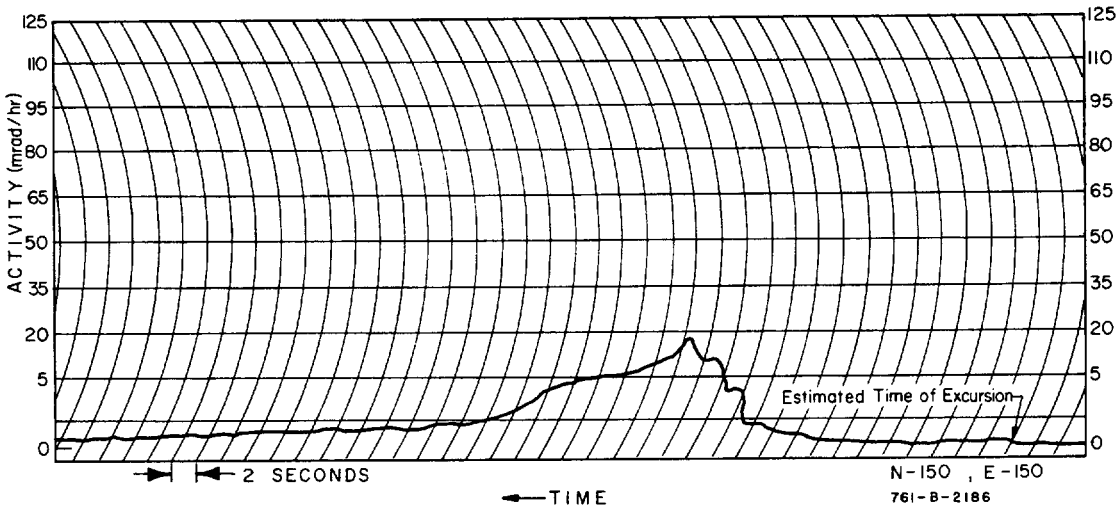

FIG. 22 CHART FROM A RECORDING DOSE RATE METER N-150 E-150.

farther, leading to a decay of about 20 percent of the cloud activity -- with a greater ratio of gamma emission to beta emission at the farther recorder. Therefore, the more remote recorder would record activity longer than the closer -- since gamma radiation has a longer range in air than beta.

1133023

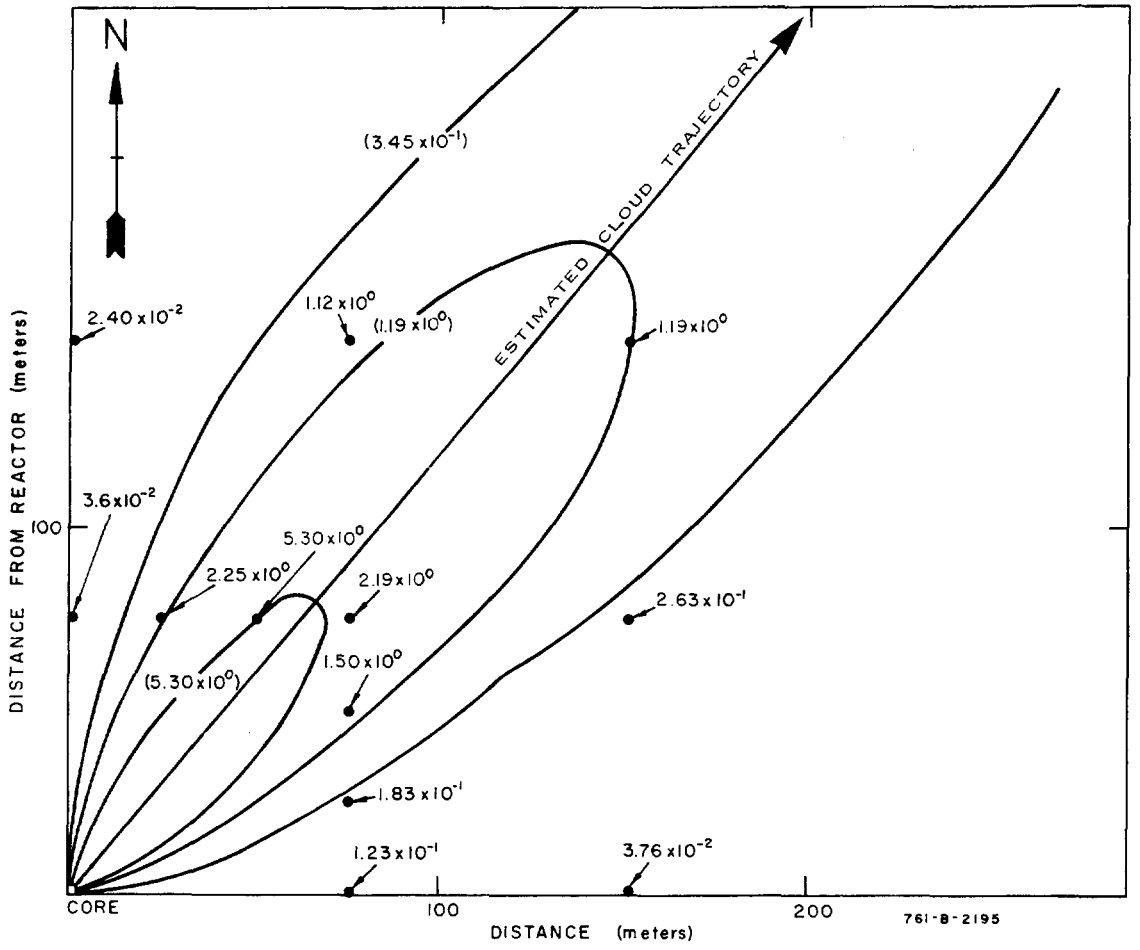

FIG. 23 ISOPLETHS (AND CLOUD PATH) OF AIR CONCENTRATIONS.

3. RESEARCH STUDIES

3.1 Air Concentrations

Since several filters were removed by the first reentry team, air samples were available and counted about 5000 seconds after the excursion. The bulk of the samples was counted several hours later. Figure 24 describes crosswind and downwind distributions of air concentrations at 32,400 seconds after the excursion. The integrated air concentration at N-75 E-75 was about 6.4 μCi-sec/m^3. By correcting this to the time of the excursion, it was estimated that about 8 x 10^{-4} curies were collected from the cloud at that point and that the cloud had an average air concentration of about 8 x 10^{-3} Ci/m^3.

It was estimated that about 1900 curies of noble gases were released to the atmosphere. This is about 0.06 percent of the noble gases produced from a 165 MW-sec excursion and about 0.006 percent of the total fission product inventory. Only Sr-91, Y-91, Sr-92, Y-92, and Ba-139 were identified by gamma spectrometry.

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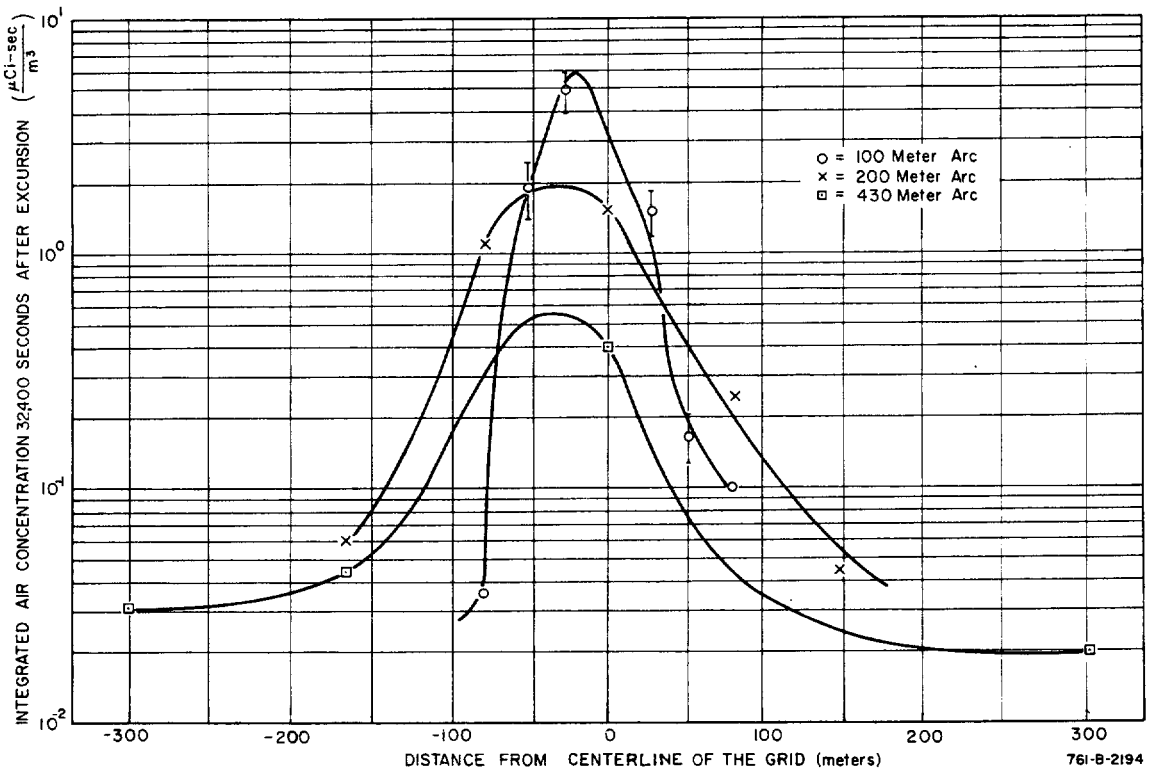

FIG. 24 CROSSWIND AND DOWNWIND DISTRIBUTIONS OF AIR CONCENTRATIONS.

Filter efficiencies appeared to be higher than on the first or second test with an average of 96 percent and a range of 85 to 99 percent. This can probably be attributed to the use of Microsorban filter paper instead of the BM-2133 filter used in the first two tests.

Activity collected on Anderson Impactors was too low to define particle sizes accurately, but the activity that was collected was associated with particle sizes which were less than 1.5 μ.

Analysis of tower samples gave interesting results. As can be seen in Figure 25, the samplers at one meter above ground level generally appear to have collected a greater activity than those at other heights. This tends to support evidence from the previous test. Perhaps more important, however, is that in each of the five towers the lowest sampled activity is about two-thirds that of the highest. If ranges were selected, the samples could vary in estimated activity from one height to another -- or even at the same height -- by as much as a factor of two. It must be assumed then that the differences in collected activity with height are not the major variables.

Measurements of deposition velocity and grass activity were quite limited in the third test. The winter had been longer and colder than normal and all grass samples were prepared in a special plant-growth room (CF-646). Preparations and activities of the SNAPTRAN 2/10A-3 (Water Immersion) Destructive Test which took place April 1, 1964, limited the amount of grass which normally would have been available.

Table XI indicates deposition velocities on the grass samples.

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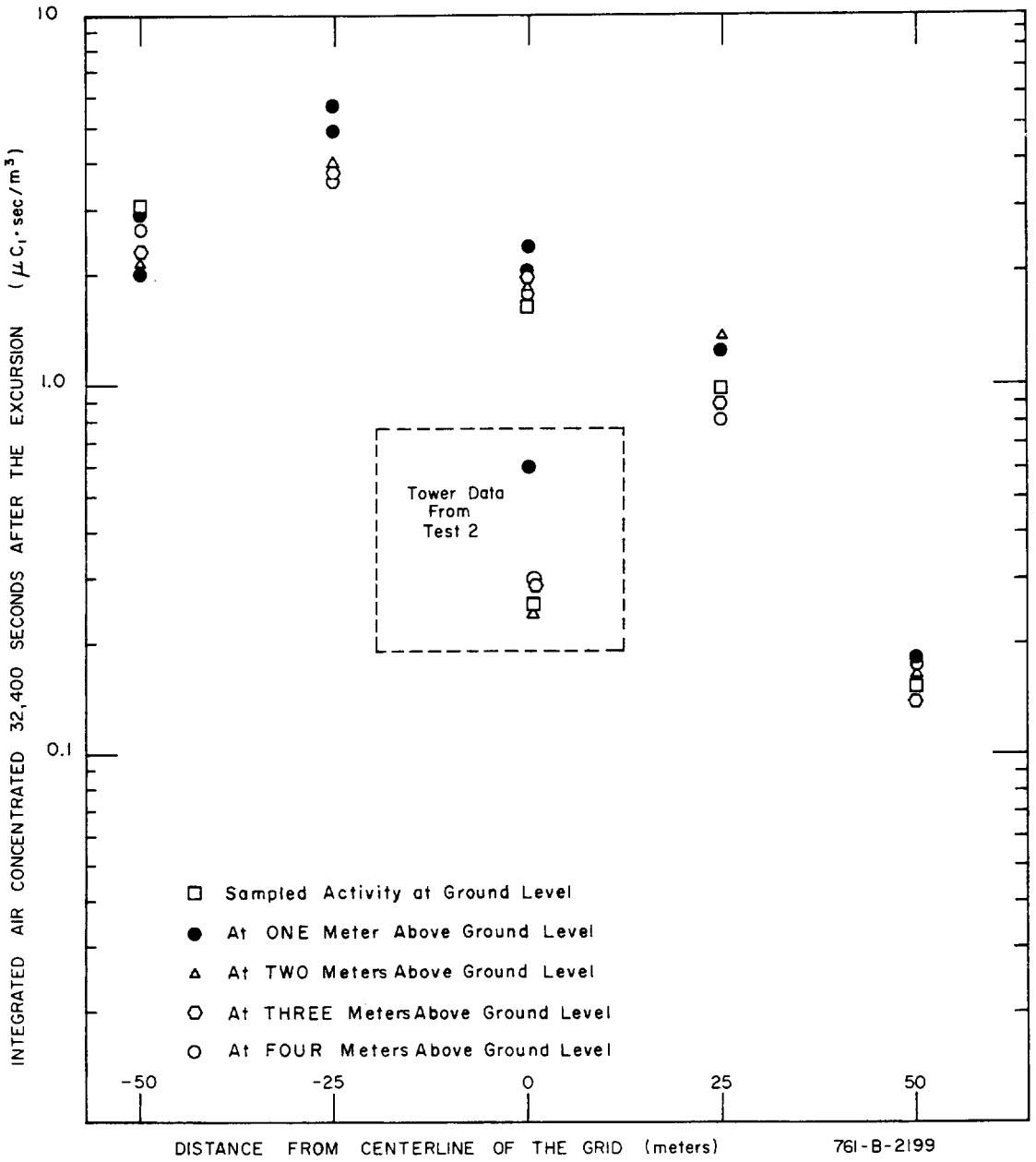

FIG. 25 VERTICAL CLOUD PROFILES FROM TOWER SAMPLERS.

Again V_g's are generally in the range of 0.025 to 0.050. It is interesting to note that while plate activities are generally more variable than grass activities, gummed paper shows about 10 to 20 percent of the activity as grass. No carbon or sand impregnated gummed papers were used.

3.2 Film Dosimetry Studies

A program similar to that of the previous tests was carried out in connection with the third Spert I Destructive Test. The phantoms were placed in the same positions as in the previous tests (Figure 13) to compare results and investigate the reliability of film dosimeters in a nuclear excursion.

TABLE XI

GRASS DEPOSITION VELOCITIES AND RATIOS OF GUMMED PAPER (COLLECTED) ACTIVITY TO GRASS ACTIVITY

Location		V_g or $\frac{\mu Ci/m^2}{\mu Ci\text{-}sec/m^3}$	Plate Activity / Grass Activity
N-25	E-75	0.070	0.30
N-50	E-75	0.032	0.10
N-75	E-75	0.043	0.14
N-75	E-25	0.043	0.10
N-75	E-150	0.097	0.82
N-150	E-75	0.042	0.20

TABLE XII

FILM DOSIMETER EXPOSURES ON PHANTOMS

Phantom	Gamma (rad)	Beta (rad)	Beta/Gamma
11	1.2	1.3	1
12	0.95	1.3	1.3
13	1.1	0.87	0.8
14	0.95	0.90	1

The dosimeters on the four phantoms in the reactor building saw beta and gamma, those on the four at eight meters saw only gamma, and the rest gave zero readings. The averages of the twelve badges of each phantom with the highest doses are found in Table XII.

The average front-to-back ratios from those four phantoms near the reactor were approximately 6.0 for beta (2.3, 4.3, 8.8, and 11.3) and 3.8 for gamma (3.1, 3.6, 4.6, and 3.8). These results are roughly the same as in the two previous tests.

3.3 Criticality Accident Research

Criticality monitoring research continued as in the first two tests, with the same systems being used. Examination of the neutron activation in a copper wire led to an estimate of 2.2×10^6 nvt (about twice as high as from the second test). The neutron flux immediately adjacent to the reactor vessel was too low to permit determination of the neutron energy spectrum. The only activation products detected and positively identified in criticality dosimeters and samples which had been placed around the reactor were In-116 and Cu-64.

A sample of reactor water contained the usual fission products plus the activation products Np-239 (U-238 $\xrightarrow{n}$ U-239 $\xrightarrow{\beta}$ Np-239). The water was analyzed for Ce-143, Mo-99, Zr-97, and total uranium. Based on the results of these analyses, an estimate of 4×10^{19} fissions was made. This may be compared to 5.3×10^{18} fissions occurring with a 165 MW-sec excursion.

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APPENDIX A

ANALYSIS OF METHODS AND CALCULATIONS

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APPENDIX A -- ANALYSIS OF METHODS AND CALCULATIONS

1. AIR CONCENTRATION STUDIES

1.1 Collection of Activity by Samplers

Two systems were used in collecting activity from a passing cloud: high-volume and low-volume air samplers. The former is the only appropriate sampler to be used in determining short-term fission product release.

It is known that the radioactive cloud from an excursion passes by a sampling point in a very short time. On the Spert grid this might vary from 2 to 50 seconds depending upon the location and wind speed. It is necessary then to use an air sampler which will pass a reasonably large volume of air through a filter in that length of time. The Staplex "Hi Vol" using BM-2133 and a carbon trap normally operated from 0.0125 to 0.0175 m^3/sec (25 to 35 cfm). Using Microsorban prefilters this was reduced to a range of 0.0050 to 0.0125 m^3/sec (10 to 25 cfm).

Since the samplers' flow rates are observed visually on flow rate meters, it is necessary to ascribe a deviation to the observed flow rate of ± 1 cfm; therefore, as long as the flow rates are reasonably high, variation is within the limits of error (at 25 cfm, ± 1 cfm lead to ± 4 percent; at 10 cfm, ± 1 cfm leads to ± 10 percent.

For ease of data analysis, concentrations were put in the form of μCi-sec/m^3, or total integrated air activity passing by a sampling point. This is simply the summation of air concentrations in μCi/m^3 over time, in seconds. Stated in another fashion, μCi-sec/m^3 is the total activity sampled in the amount of air passed through an air sampler for the time it was in operation. This can be measured conveniently by dividing the total activity found on a sample (in μCi) by the rate of flow of air through the samplers in m^3/sec.

It was assumed that this system was nearly 100 percent efficient for particulates. The calculations of prefilter efficiencies were based upon this assumption. This can be justified since the carbon traps are of such a nature that they are in themselves nearly 100 percent efficient for particulate matter [29]. This assumption allows calculation of filter efficiencies and comparison of air activity from point to point.

For the same reason, it was assumed that no noble gases were collected. Since only noble gases were released to the atmosphere, this assumption is critical to the development of the release model in Appendix A-2.

Low-volume systems, such as carbon cartridges and Anderson Impactors, obviously collect a smaller amount of activity. Information can be gleaned, however, upon which careful consideration of a release model depends. Anderson Impactors have two very useful functions, the first of course is to measure the distribution of activity with particle size and the second is to allow a comparison of results with that from high-volume samplers. This was useful in the last test where several Hi Vols were operating at 9 to 15 cfm. These low-volume systems normally operate at one cfm ± 10 percent. Thus, three ranges of collection were used.

A low-volume air-sampling tower was used in the second test. Since the variation in flow rate is largely due to the pump, point-to-point comparison could be made. The equipment needed to operate this tower was much simpler than in the towers of Hi Vols. In the former, one pump operated the system, and only one electrical outlet was used. Air was drawn through the cartridges and down the pipe. In the Hi-Vol towers of the third test, each Hi Vol needed an outlet, necessitating the use of two generators at each station. While more meaningful information may be gathered from Hi-Vol towers, they are much more difficult to maintain and to actuate.

Finally, the recording dose rate meters on the grid give invaluable data on the configuration of the cloud. Whereas all the other systems provide total dose or total concentration figures, dose rate meters give a rough estimate of the time for the cloud to pass by a point. It is difficult, however, to determine the exact length of cloud passage. Since the gamma radiation has a long range, it undoubtedly is measured by the GM tube for a much longer time than it takes for the cloud itself to pass. This is further complicated by the fact that the gamma to beta ratio increases with time; thus, the more removed the recorder is, the greater is the effect of gamma radiation as far as the apparent length of the cloud is concerned. However, this information does make it possible to ascribe an average air concentration figure at the time of cloud passage. Since an open-window GM tube was used to detect the cloud, the graphs are probably smoothed over in regard to absolute intensities. Also, the response time of the pen tends to depress the maximum readings from the cloud. Studies were made to calibrate or correct for this, and it appears about $\pm$ 10 percent error in time and in intensities are associated with the use of this instrument, apart from the error involved in analyzing the charts.

1.2 Estimation of Maximum Concentrations with Distance (x)

In each of the discussions of the destructive tests, graphs were shown of crosswind and downwind distributions. These graphs were drawn by plotting each point on the arc and ascribing a variance or range of equal significance to it. Since all the diffusion models used were based on a Gaussian distribution of activity and since dose rate meters also approximated a Gaussian shape, a Gaussian curve was fitted to these values. The peak value was taken to be the point at which the center of the cloud passed. These values were then divided by the appropriate plume axis dilution values, χ/Q (the latter prepared by the U. S. Weather Bureau). The resultant numbers then represented the virtual source strength, Q, at 32,400 seconds after the excursion [30]. This was back-corrected to the time of release to obtain estimates of fission products released to the atmosphere. Due to uncertainties in the estimations of μCi-sec/m^3 at a point, the estimation of a peak concentration is necessarily subject to error. While efforts were made to minimize this (as in the third test where range values were selected from the tower samples), the accuracy of the peak concentration appears to limit the accuracy of the radioactive release.

2. RELEASED FISSION PRODUCTS

2.1 Preliminary Estimates

The first estimates of release fraction for the first test used the methods listed below. Samples were counted in well counters, and as many as possible

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were scanned on a gamma spectrometer. Microcurie values were then determined to arrive at a μCi-sec/m^3 figure, 20,000 seconds after the excursion.

Once a virtual source term, at this time, was computed, this number was back-corrected to one second after the excursion by assuming a decay of $t^{-1.21}$. The $t^{-1.21}$ decay is that usually given for fresh-mixed fission products or fallout. This gave a calculated release of about 2.4×10^5 curies, which was equal to a 0.17 MW-sec release. From the total nuclear energy release reported by Spert personnel, it was estimated that 0.4 percent of the total produced fission products escaped into the atmosphere.

These calculations were based upon several assumptions which were later proved to be in error. First, the $t^{-1.21}$ decay is not applicable to noble gases and their decay products over the time range considered. Decay curves of samples from each test showed a $t^{-1.1}$ decay from 15,000 to 90,000 seconds (Figure A-1). In this region, a $t^{-1.2}$ would not lead to too great an overestimation, but correction back to one second would. Calculations indicate that at one second a $t^{-1.2}$ decay would lead to a release 30 times that of a $t^{-1.1}$, when correcting from 20,000 seconds (Figure A-2).

The method and formula used to calculate the theoretical release (in curies) was that a short-lived nuclear power excursion of 1 MW-sec would result in the production of radioactive fission products which would emit approximately $4.8 \times 10^{16}\ t^{-1.21}$ MeV/sec of gamma energy with an average of 0.7 MeV/dis [31]. This formula overestimates the source strength for $t < 10$ seconds. In fact, for a 31 MW-sec excursion, this formula would predict the formation of 6.1×10^7 curies, whereas more refined calculations (via computer programs et al) indicate the formation of about 5×10^6 curies [32]. For the latter figure, a release of 2.4×10^5 curies is about one-half of all the noble gases produced. Considering that the activity of 20,000 seconds was based on the activity of only three chains and not all the noble gases, this amount seems highly improbable.

2.2 Noble Gas Release

The three observed fission product chains have the following decay schemes:

(139) 2 sec I-139 $\longrightarrow$ 41 sec Xe-139 $\longrightarrow$ 9.5 min Cs-139 $\longrightarrow$ 83 min Ba-139 $\longrightarrow$ La-139 ($\gamma_{139} = 3.6$)

(91) 10 sec Kr-91 $\longrightarrow$ 72 sec Rb-91 $\longrightarrow$ 9.7 hr

$$\begin{array}{lcl} & 0.6 & 51 \text{ min Y-91m} \\ \text{Sr-91} & \nearrow & \downarrow \qquad\qquad \text{Zr-91} \qquad (\gamma_{91} = 3.45) \\ & \searrow & \\ & 0.4 & 58 \text{ day Y-91} \nearrow \end{array}$$

(92) 3 sec Kr-92 $\longrightarrow$ 5.3 sec Rb-92 $\longrightarrow$ 2.7 hr Sr-92 $\longrightarrow$ 3.6 hr Y-92 $\longrightarrow$ Zr-92 ($\gamma_{92} = 1.87$)

γ_i = fission yield of the noble gas (atom produced/100 fissions) [33].

Since only a few isotopes were detectable from one to 24 hours after the test, it was felt that a model might be developed which could utilize the three decay schemes and thus provide a more realistic approach to the nature of the release and to the amount released.

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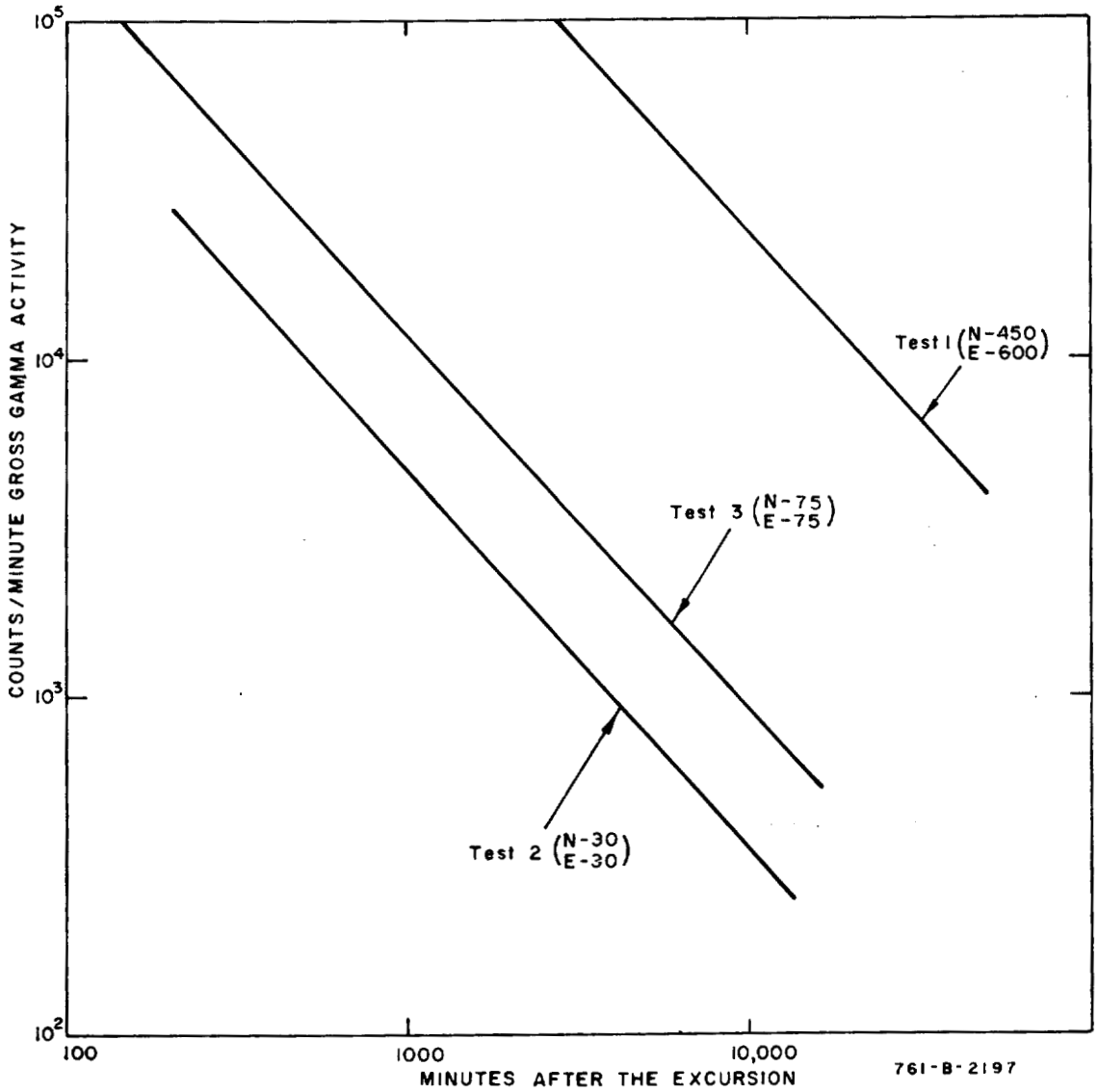

FIG. A-1 GROSS GAMMA DECAY FROM PREFILTER SAMPLES.

To this end, equations were derived to analyze the activity of isotopes with time (Figure A-3 indicates this activity, with time, graphically).

$$F_j = \sum \gamma_i \lambda_i f_i X_o$$

F_j = the total activity at time j with respect to the activity at time t_o

γ_i = the fission yield for each chain (number of atoms produced per 100 fissions)

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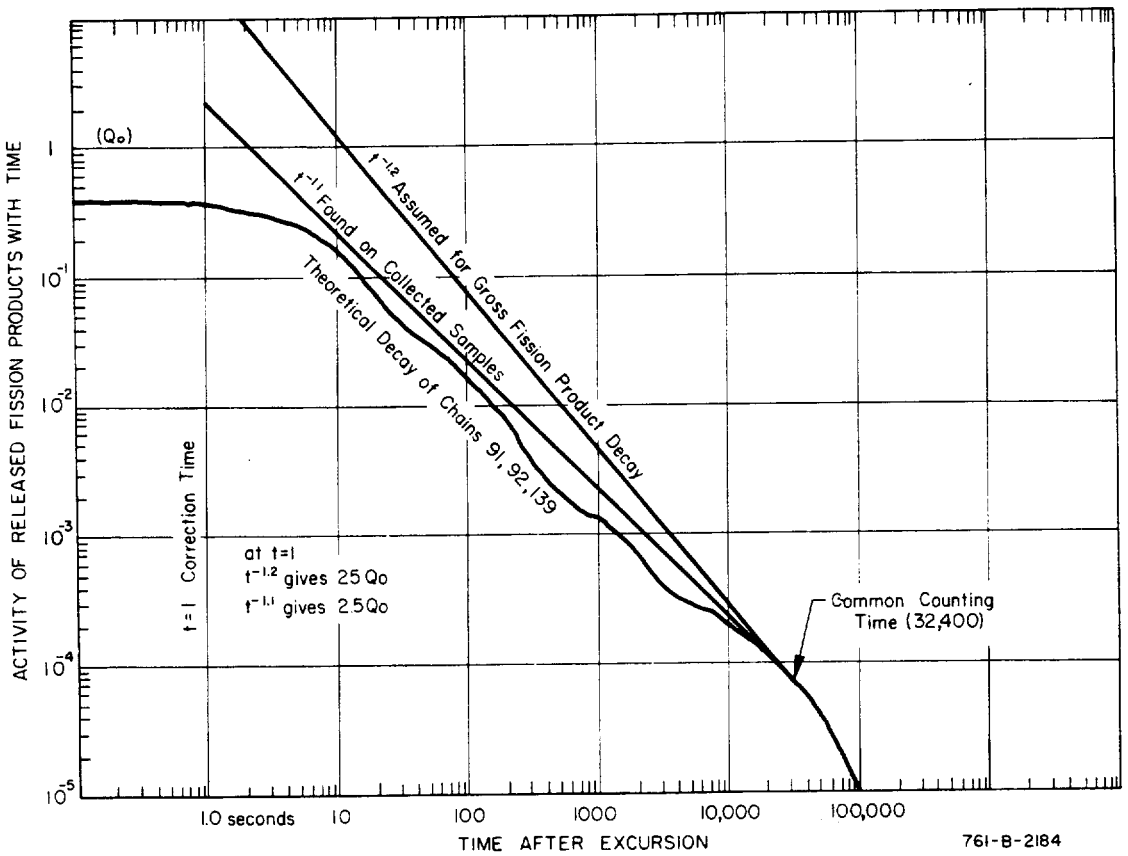

FIG. A-2 COMPARISON OF SOURCE TERM ESTIMATES FROM DIFFERENT METHODS.

f_i = the activity of daughter products with respect to the activity of the parent at some time j

$$= \frac{\lambda_a A + \lambda_b B + \lambda_c + \ldots +}{\lambda_a A_o} \qquad (\lambda_i = \text{decay constant})$$

X_o = a weighting number used to normalize F_j to unity at time, t_o.

Technically speaking, this should include every chain in which a noble gas is produced directly from the excursion. This is, however, quite impractical since the activity of Ba-139, Sr-91, Y-91m, Sr-92, and Y-92 effectively masked the presence of any other isotopes on a gamma spectrometer from 5000 to 100,000 seconds. If the activity from the tests had been much higher, longer decay studies should have indicated the presence of Y-91, Ba-140, and others with relatively long half-lives.

Therefore, it is more practical to derive a decay scheme using the three predominate chains and assume that all the other noble gases are released similarly. Correction, therefore, can be made for the presence of undetected, released fission noble gases and noble gas daughters.

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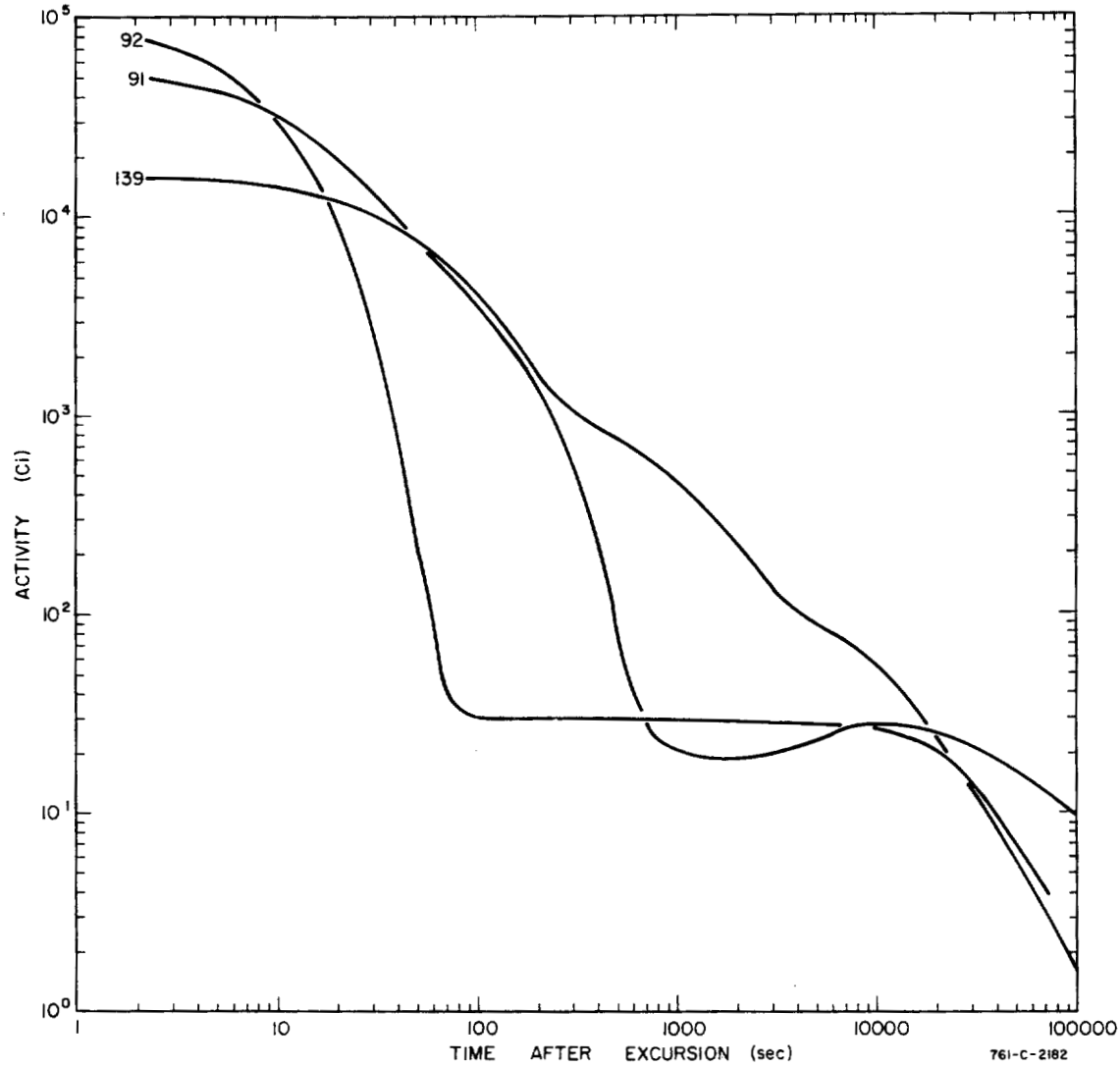

FIG. A-3 THE ACTIVITY OF FISSION PRODUCTS CHAINS 139, 91, AND 92 WITH RESPECT TO TIME (31 MW-SEC POWER EXCURSION).

The total activity at t_o turns out to be 2.4 times the activity of Kr-91, Kr-92, and Xe-139 [33].

Thus:

$$F_j \approx 0.327\, f_{91} + 0.083\, f_{137} + 0.590\, f_{92} \text{ (where } 5000 < t_j < 100{,}000).$$

Figure A-4 illustrates the total activity as a function of activity at the time of the excursion (F_j vs time). With this graph, it is possible to take the activity on a sample at any time, t_j, and by dividing it by $\frac{F_j}{2.405}$ have an estimate at t_o.

In the same manner, calculations of a source term may be made by the following formula:

$$Q_o = \text{released activity} = \frac{\mu\text{Ci-sec}}{m^3} \text{ (collected)} \cdot \frac{Q}{X} \cdot \frac{2.405}{F_j} .$$

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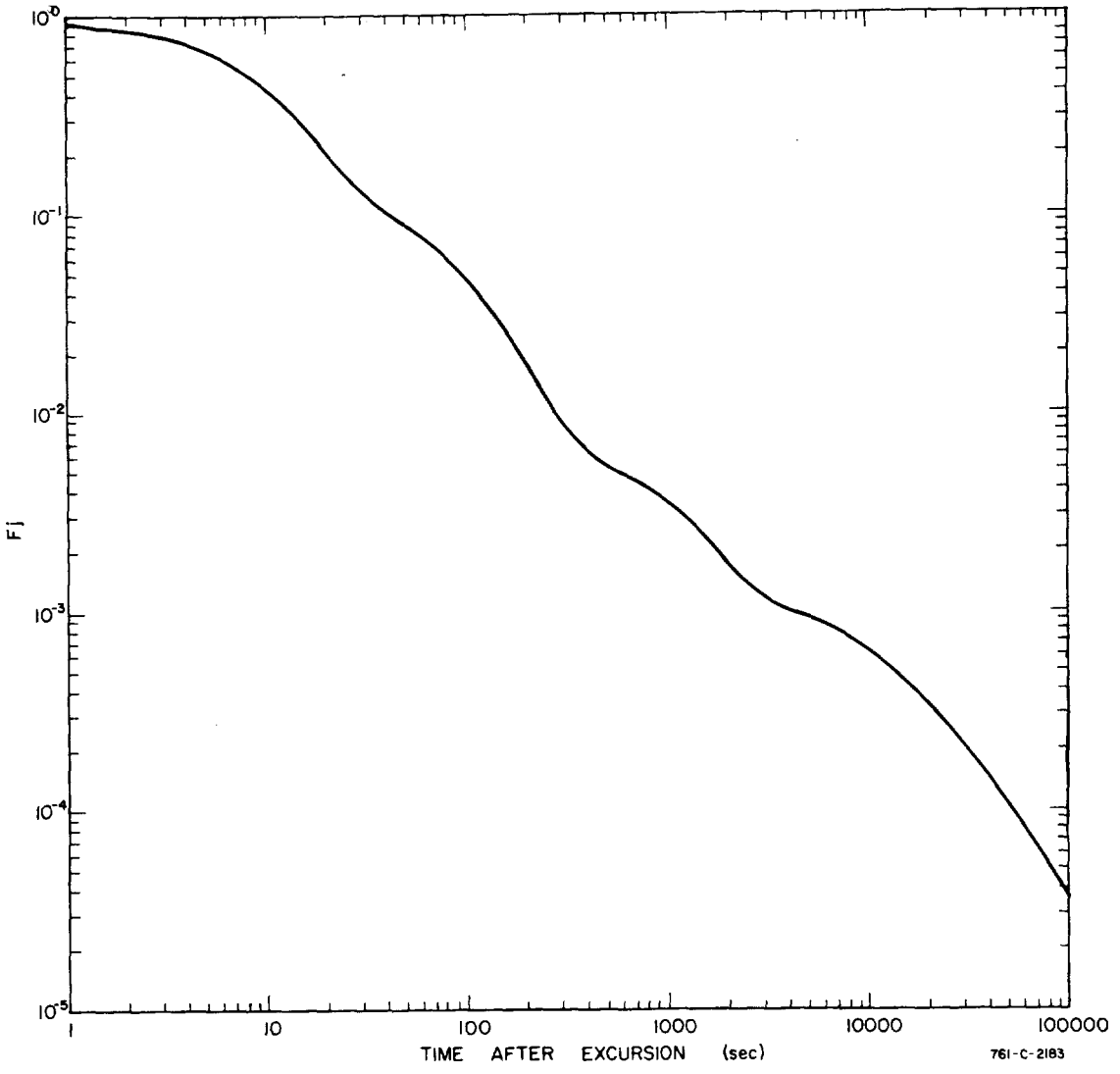

FIG. A-4 THE SUM OF THE ACTIVITY OF THE SUM OF THE THREE CHAINS WITH TIME (F_j).

To be accurate, however, it is necessary to modify the activity μCi-sec/m^3 to indicate peak concentration.

$$Q_o = \text{released activity} = \frac{\mu\text{Ci-sec (peak)}}{m^3} \cdot \frac{Q}{\chi} \cdot \frac{2.405}{F_j}$$

where $\frac{\mu\text{Ci-sec}}{m^3}$ = maximum concentration for the arc in question.

The main problem here is to convert the activity found on filters to a number representing the maximum amount of activity that passed by a certain arc.

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2.3 Source Term Estimates

The major effort, as far as time, in deriving a source term from an excursion is the calculation of peak activity in curies on an arc. A rapid and relatively accurate means to this end is to assign an efficiency conversion factor (μCi/c/m) to the well counters. Since many prefilters were also counted on spectrometers, comparison was possible between gross gamma counts per minute from a well counter and disintegrations per minute from a spectrometer. From this and other data, a counting efficiency of 45 percent was estimated. This is about 1.02×10^{-6} μCi/c/m.

First, all counted activities were corrected a common time (32,400) using decay schemes from the well counters. Figure A-1 shows these schemes for the three tests. The time, 32,400 seconds, was chosen because all three tests had sampled activity at that time, and the decay curves showed that this point would create the least error in back-correcting and comparison. Curie amounts were available for samples counted at that time, so it provided a point at which all counts could be assigned a curie activity.

Once the samples were all corrected to the same time and curie amounts determined, μCi-sec/m^3 curves could be drawn for crosswind and downwind distributions (Figures 9, 17, and 24).

2.4 Release Model

As can be seen in Table A-I, the previous model shows an increasing source term with distance. Since only noble gases are released, a greater fraction should have been decayed to "particulate" form at the outer arcs; hence, more of the cloud would have been sampled. The same phenomena should also hold between the first and second test, wherein the cloud moving at a slower speed should have a greater preponderence of decayed nobles at a particular point than would a faster moving one; thus an evaluation had to be made to correct for the passage of uncollected noble gases.

Analysis of spectra showed that the activity from different sampling stations did have different isotopic compositions, indicating that the activity collected was dependent upon the amount of noble gases that had decayed to the time of collection. Table A-II shows one such analysis. At about 30,000 seconds, the contribution from Ba-139 at 30 meters was only about half that at 780 meters. Since the Xe-139 has a 41 second half-life, this might be explained by the fact that a cloud would reach 30 meters in about 3 to 4 seconds, and only 5 percent of Xe-139 would have decayed to a collectable Cs-139. At 780 meters, over two-thirds would have decayed.

Since the isotopic composition was different at each distance, it was necessary to develop a new release model. First, it would be most difficult to correct samples to a common time if the decay schemes at each point were not known or if a method for estimating isotopic composition was not available. It would also be difficult to calculate curie amounts from gamma counts since each of the major isotopes (Ba-139, Sr-Y-91, Sr-Y-92) have different counting efficiencies, hence, requiring a different conversion factor for each combination of activity contributions. Second, to assume 100 percent efficiency for the system (including noble gases) might lead to an underestimation of source term by as much as a factor of two.

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TABLE A-I

MAXIMUM AIR CONCENTRATIONS AND SOURCE TERMS FOR THE DESTRUCTIVE TESTS

Arc Distance (meters)	Peak Concentration (μCi-sec/m^3) Test 1	Test 2	Test 3
108	150	2.9	6.4
215	115	1.45	2.4
431	44	0.37	0.47
	Source Term (curies)		
	Test 1	Test 2	Test 3
108	1.6×10^4	3.1×10^2	1.4×10^3
215	2.9×10^4	5.3×10^2	1.6×10^3
431	3.6×10^4	5.4×10^2	1.9×10^3
noble gas inventory	5×10^5	2.4×10^6	2.5×10^6
fission product inventory	5×10^6	2.4×10^7	2.5×10^7

The model finally derived was that:

(1) Only noble gases were released in appreciable amounts to the atmosphere.

(2) The noble gases were effectively held in or held by the water for K seconds. On the first test, this is the time for noble gas atoms to become disjunct from the scrubbing action of the water as it was released. In the last two tests, this is the travel time from the core to the air.

(3) The effective length of the releases were finite and short (1 to 30 seconds).

(4) The time to collection (the length of time from the excursion to the time when the highest activity passed by a sampling point) was $\frac{x}{\bar{u}} + \frac{S}{2}$. This is the distance (x) from the reactor divided by the mean wind speed ($\bar{u}$) plus one-half the length of time of the releases.

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TABLE A-II

SPECTROMETRIC ANALYSIS OF THE ISOTOPIC COMPOSITION OF PREFILTER SAMPLES FROM THE FIRST DESTRUCTIVE TEST

Location Count Time	Computed dis/min.			Computed (%)		
	Ba-139	Sr-91	Sr-92	Ba-139	Sr-91	Sr-92
N-450 E-600 22,400	4.53×10^4	3.99×10^4	1.57×10^4	44.9	39.5	15.6
24,240	2.70×10^4	3.76×10^4	1.26×10^4	35.0	48.7	16.3
29,040	1.75×10^4	3.50×10^4	9.23×10^3	28.4	56.8	14.8
41,040	4.22×10^3	2.83×10^4	5.29×10^3	11.2	74.9	13.9
70,440		1.79×10^4	1.49×10^3		92.3	7.7
N-50 E-75 27,840	2.85×10^4	1.26×10^5	4.43×10^4	14.3	63.3	22.4
N-15 E-30 30,120	1.39×10^4	7.42×10^4	2.83×10^4	11.9	63.7	24.4
N-75 E-75 36,840	1.13×10^4	1.19×10^5	2.25×10^4	7.4	77.8	14.8
N-30 E-30 40,320	3.68×10^4	4.46×10^5	8.28×10^4	6.5	78.8	14.7
N-75 E-75 76,140		2.46×10^4	8.56×10^2		96.5	3.5

(5) That there was no preferential sampling. That is, Cs-139 was not collected on the filter to a greater extent than was Rb-91 or Rb-92. Thus, μCi (collected) $= \frac{A_k}{A_o} \frac{(A_k - A_t)}{A_k} \cdot$ μCi (through a sampler).

For each chain 91, 92, and 139,

A_k/A_o = fraction of noble gas undecayed at time K,

$\frac{A_k - A_t}{A_k}$ = fraction of noble gas decayed during travel time,

$t = \frac{x}{u} + \frac{S}{2}$ seconds after k.

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This model gives a working framework to investigate the results of spectrographic analysis. As was mentioned in Section III (test three), recording dose-rate meters indicated that at 230 meters, most of the activity from the cloud was recorded over a time period of about 30 seconds. Actual cloud passage time was estimated to be about 14 seconds. For a near instantaneous release ($\leq$ one second), the actual cloud size is assumed to be approximated by the following:

$$t_{max} = \frac{4.30\ C_x x^{\frac{2-n}{2}}}{\sqrt{2}\ \bar{u}}$$

where t_{max} is the maximum time of passage of 97 percent of the activity at a point $\underline{x}$ meters from the reactor

C_x is the along-wind diffusion parameter taken equal to C_y (0.178)

n is the general meteorological stability term

$\bar{u}$ is the mean wind speed.

At 200 meters, it was expected that t_{max} would be about 10 seconds (for the third test) which was about that actually found. This, and the fact that the maximum concentration is at $\frac{x}{\bar{u}} + 3$ seconds, indicates that a short-term release is involved and that some sort of hold-up mechanism might occur.

Attempts were made, therefore, to postulate a model with numbers for K and $\frac{x}{\bar{u}} + \frac{S}{2}$ and to relate the theoretical abundances of each isotope at a sampling station with that computed.

The value of K was known to be small, so three numbers were chosen for computation: 0, 1, and 2 seconds. Source release times were assumed to be relatively constant for all three tests, and on the basis of recording dose rate meters, a release time of 6 seconds was chosen. Tables A-III and A-IV show the computed values from these numbers.

The validity of a release model depends, therefore, upon a derived set of numbers (as A_k/A_o) which can predict the isotopic composition at a sampling point.

Since the first test had the greatest release and, hence, greatest activity on collected samples, the first check on the release model utilized data from this source. Table A-V lists predicted values (relative) using different values for K. These may be compared with the

TABLE A-III

RELEASE MODEL -- VALUES OF A_k/A_o

	Xe-139	Kr-91	Kr-92
K = 0	1.00	1.00	1.00
K = 1	0.98	0.93	0.79
K = 2	0.97	0.87	0.63
K = 3	0.96	0.80	0.48
K = 4	0.94	0.75	0.39
K = 10	0.85	0.49	0.10

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TABLE A-IV

RELEASE MODEL -- VALUES OF $\frac{A_k - A_t}{A_k}$

Test	Distance (Meters)	$\frac{x}{\bar{u}} + \frac{S}{2}$ (Seconds)	Xe-139	Sr-91	Sr-92
1	34	6.2	0.100	0.349	0.761
1	43	7.0	0.113	0.385	0.802
1	80	10.6	0.165	0.521	0.914
1	108	13.2	0.199	0.600	0.953
1	170	19.1	0.276	0.723	1.000
1	215	23.3	0.325	0.801	1.000
1	341	35.1	0.448	0.912	1.000
1	431	43.0	0.522	0.950	1.000
1	760	77.0	0.728	1.000	1.000
2	34	8.8	0.139	0.457	0.869
2	43	10.3	0.158	0.510	0.907
2	80	16.7	0.245	0.686	0.980
2	108	21.7	0.308	0.777	1.000
2	170	32.1	0.418	0.892	1.000
2	215	39.8	0.491	0.937	1.000
2	341	60.2	0.639	0.985	1.000
2	431	76.6	0.727	1.000	1.000
2	760	113.4	0.853	1.000	1.000
3	34	6.0	0.095	0.341	0.751
3	43	7.1	0.113	0.387	0.806
3	80	11.4	0.174	0.546	0.928
3	108	14.7	0.221	0.577	0.967
3	170	22.0	0.310	0.783	1.000
3	215	27.3	0.369	0.849	1.000
3	341	42.1	0.508	0.946	1.000
3	431	52.6	0.589	0.974	1.000
3	760	91.4	0.788	1.000	1.000

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TABLE A-V

PREDICTED RELATIVE CURIE ACTIVITIES

Test	Count Time (Seconds)	K = 0			K = 1			K = 2			K = 3		
		Ba-139	Sr-91	Sr-92	Ba-139	Sr-91	Sr-92	Ba-139	Sr-91	Sr-92	Ba-139	Sr-91	Sr-92
1	N-450 E-600	5.2	11.0	6.1	5.1	10.2	4.8	5.1	9.6	3.8	5.1	8.8	2.9
1	22440	5.2	11.0	6.1	5.1	10.2	4.8	5.1	9.6	3.8	5.1	8.8	2.9
1	24240	4.1	10.7	5.3	4.0	10.0	4.2	4.0	9.3	3.3	4.0	8.6	2.5
1	29040	2.1	9.6	3.8	2.1	8.9	3.0	2.1	8.4	2.4	2.1	7.7	1.8
1	41040	0.4	7.5	1.8	0.4	7.0	1.4	0.4	6.5	1.1	0.4	6.0	0.9
1	70440	0.0	4.3	0.2	0.0	4.0	0.2	0.0	3.7	0.1	0.0	3.4	0.1
2	N-50 E-75												
2	27840	0.7	6.5	4.2	0.7	6.0	3.3	0.7	5.7	2.6	0.7	5.2	2.0
2	N-15 E-30												
2	30120	0.3	4.6	3.2	0.3	4.3	2.5	0.3	4.0	2.0	0.3	3.7	1.5
2	N-75 E-75												
2	36840	0.2	5.4	2.2	0.2	5.0	1.7	0.2	4.7	1.4	0.2	4.3	1.1
2	N-30 E-30												
2	40320	0.1	3.8	1.6	0.1	3.5	1.3	0.1	3.3	0.1	0.1	3.0	0.8
2	N-75 E-75												
2	76140	0.0	2.5	0.1	0.0	2.3	0.1	0.0	2.2	0.1	0.0	2.0	0.1
3	N-30 E-30												
3	13140	3.9	6.5	10.8	3.9	6.0	8.6	3.9	5.7	6.8	3.9	5.2	5.3
3	24000	0.8	5.4	3.5	0.8	5.0	2.8	0.8	4.7	2.2	0.8	4.3	1.7
3	37500	0.1	4.0	1.8	0.1	3.7	1.4	0.1	3.5	1.1	0.1	3.2	0.9
3	68280	0.0	2.1	0.2	0.0	2.0	0.2	0.0	1.8	0.1	0.0	1.6	0.1

computed values in Table A-II. Graphical representations are shown in Figure A-5.

As can be seen, using K = 3 and the aforementioned release model, computed and predicted values appear to follow much the same trends.

Similar comparisons were made for the other two tests (Figures A-6 and -7). In these two cases, the correspondence was not as good. All decay studies were conducted using samples from the innér arcs where the small variations in release numbers create a relatively large change in predicted numbers. At any rate, it was close enough to warrant estimation of errors inherent in Appendix A-2.3. Table A-VI indicates expected variations in source term calculations with distance, as measured in Appendix A-2.3. This merely accounts for variation of sampled activity with distance. It is interesting to note that the calculations in Table A-I show this very trend.

The model, then, can be used as an important tool to supplement information and data from filter samples. In this case, it was chiefly used to demonstrate the validity of source term calculations in Appendix A-2.3 and to provide information as to the nature of the release. This knowledge was particularly important in the last two tests where only a small amount of activity was released. That is, the significant data were gathered from samples within 100 meters. At 100 meters, calculations lead to a source term about 24 percent less than that actually released; this is about as great an error as is found in the calculations.

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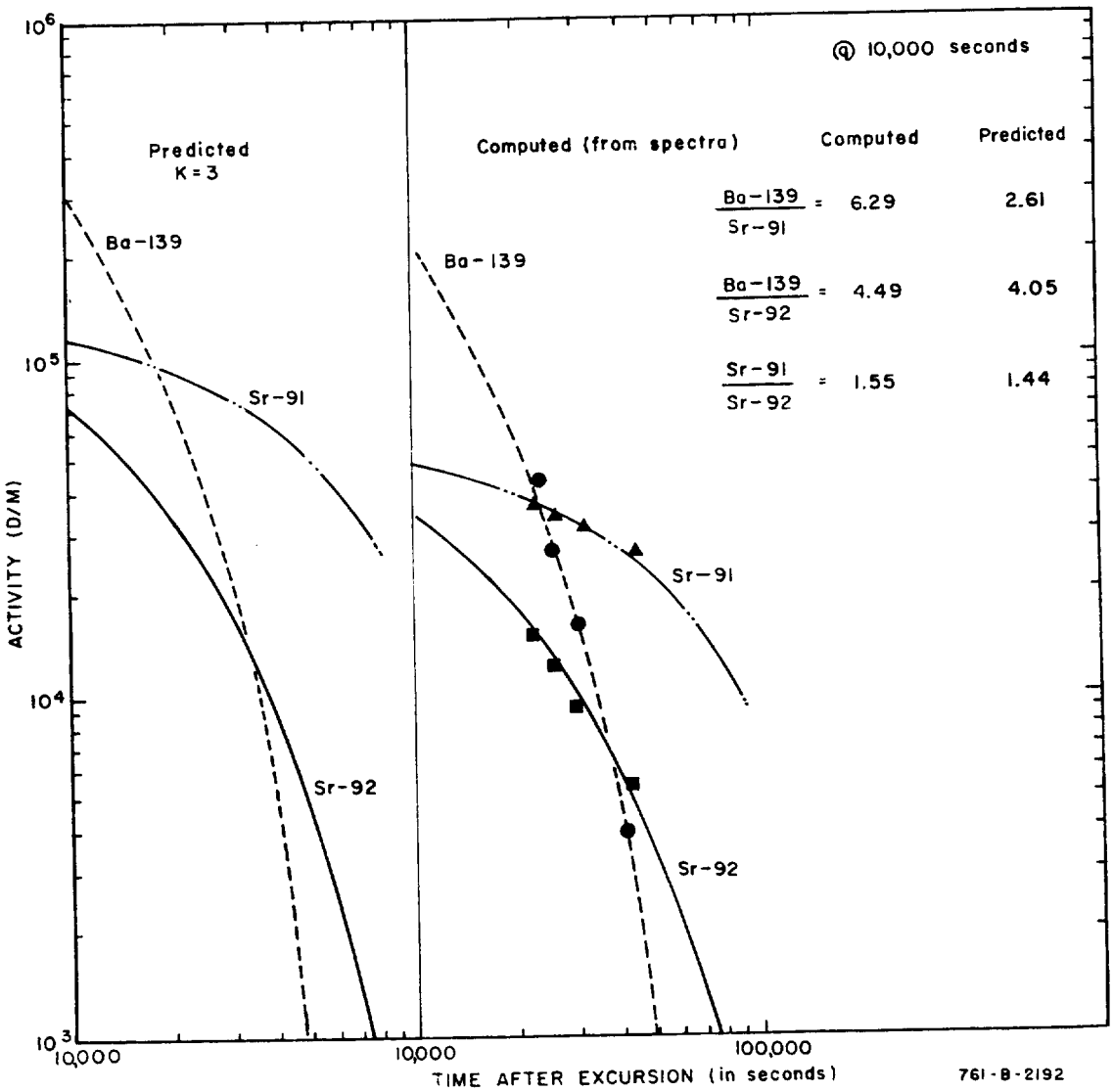

FIG. A-5 COMPARISON OF PREDICTED AND COMPUTED ACTIVITIES ON A PREFILTER, 750 METERS DOWNWIND FROM THE REACTOR E-200.

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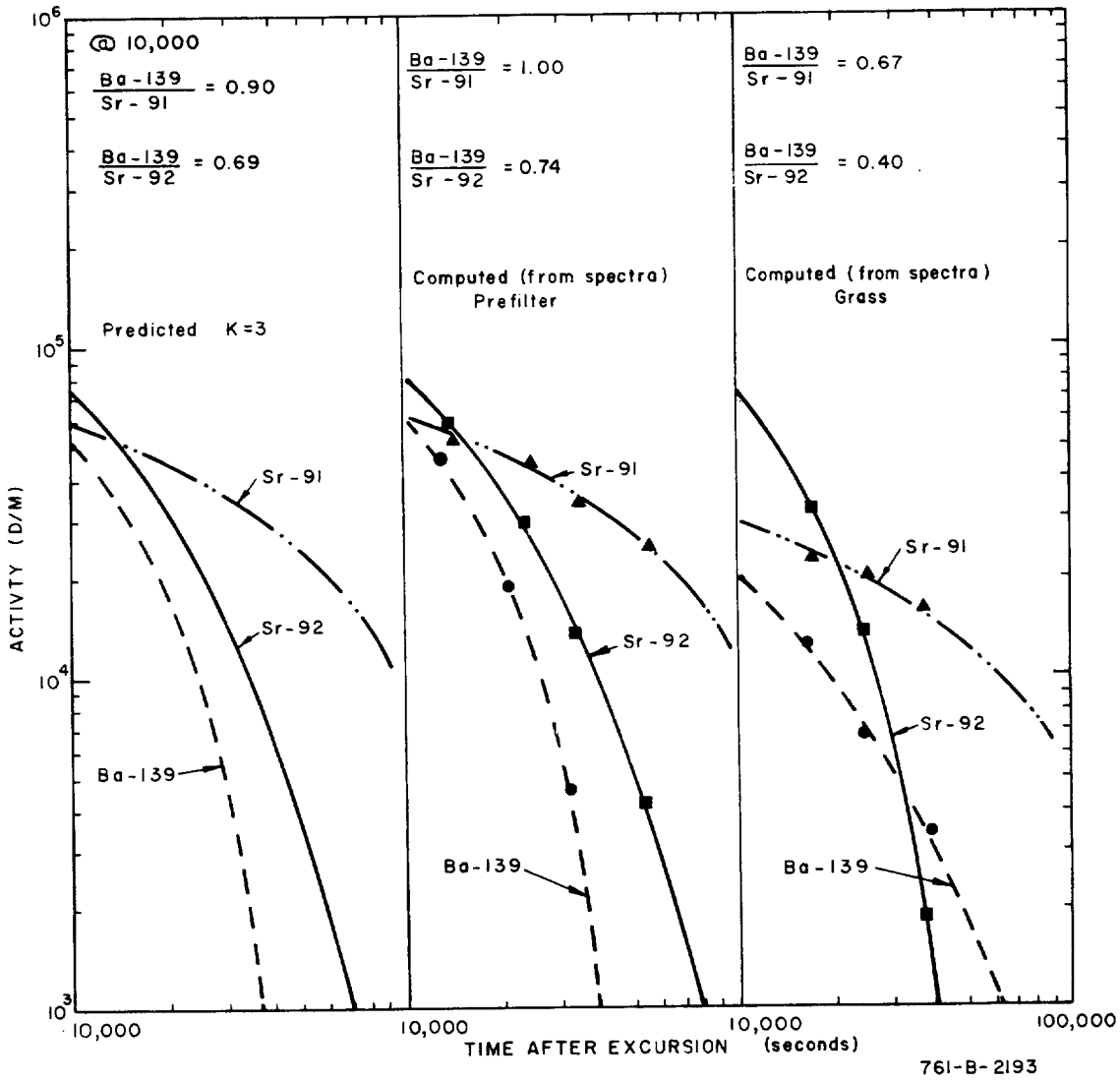

FIG. A-6 COMPARISON OF PREDICTED AND COMPUTED ACTIVITIES ON A PREFILTER AND GRASS SAMPLE, 40 METERS DOWNWIND FROM THE REACTOR.

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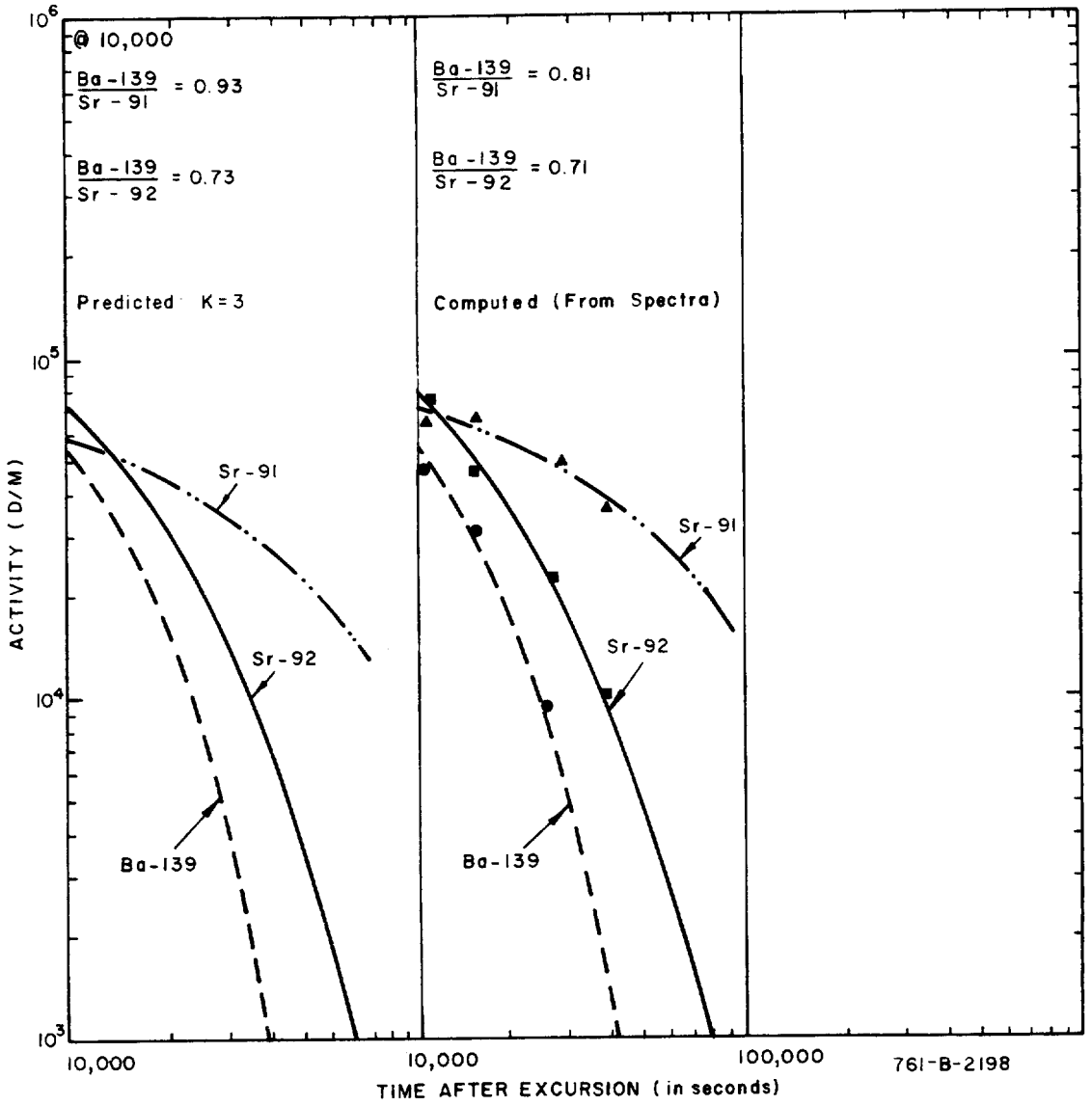

FIG. A-7 COMPARISON OF PREDICTED AND COMPUTED ACTIVITIES ON A PREFILTER, 100 METERS DOWNWIND FROM THE REACTOR.

TABLE A-VI

COMPARISON OF DERIVED SOURCE TERMS BY ARC OR DISTANCE
(Q_o by gross gamma analysis)

Test	107 meters	215 meters	431 meters
1	0.72	0.83	0.93
2	0.82	0.93	0.98
3	0.74	0.85	0.94

Assuming Q_o = 1 as derived by isotopic analysis

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Secondly, this model can check on preferential sampling; if isotopic compositions could be determined on prefilters, carbon cartridges, and grass samples -- at many points. Decay curves of a grass sample and prefilter at the same point had different slopes -- indicating a difference in isotopic composition. This and other information indicates that preferential sampling may occur; however, this can be tested only by more detailed analyses.

2.5 Ground Level Concentrations

The calculation of activity on fallout plates proceeded in the same fashion as did air concentration in Appendix A-2.3 except that activity (in μCi) was divided by the area (in m^2) on which the sample was collected. The actual ratio of ground to air activity should be independent of the method used to calculate activity, since almost all the fallout samples were counted soon after the filters.

The real problem in determining a plate to air comparison (V_g) is in "weighting" each sample. As mentioned above, this is done for air samples by dividing by the flow rate; for ground level samples it is done by dividing by the horizontal area of the sample. The very nature of the latter technique makes the V_g for grass much higher than for sand, carbon, or gummed papers since the latter have a much smaller collecting surface area. Furthermore, the variation from point to point on one type of sample is a function of the exposed surface area and not horizontal area. The range of 10 to 1 cm/sec for grass might very well become 0.5 to 0.3 μCi per gram weight of sampled grass -- if weight were the "weighting" factor. This also suffers from variations in density and height.

It is, therefore, very difficult to make more than a general statement as to a comparison from test to test and from sampling medium to sampling medium. Differences in the medium (density, sampled weight, height) and differences in the grid (ground level turbulence, moisture, vegetation density) might well contribute to 100 percent (or greater) errors.

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APPENDIX B

SOME METEOROLOGICAL ASPECTS OF THE DESTRUCTIVE TESTS

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APPENDIX B -- SOME METEOROLOGICAL ASPECTS OF THE DESTRUCTIVE TESTS

(George R. Yanskey, U. S. Weather Bureau)

1. PREPARATION

1.1 Instrumentation

A 6 meter wind direction and speed instrument at Spert I, with telemetry to the Weather Bureau operations office at Central Facilities Area (CFA) Building CF-612, has been in operation since the first destruct test at Spert I on November 5, 1962. This station was maintained to furnish additional climatological data from the Spert site and to compare with other wind stations during specific synoptic regimes. Two wind direction and speed stations, part of the Health and Safety Division's radio-telemetry, radiological monitoring network, were installed on the Stage and Shell roads with data telemetered to CF-612. These two stations were approximately along the centerline of the Spert I sampling grid, 5 and 16 kilometers from the Spert I reactor building (Figure 4).

Data from wind stations at Test Area North (TAN), CFA, and the Weather Bureau field facility are continuously telemetered to CF-612 for climatological and operational use and were, therefore, available for both forecasting and data analysis. A wind station record at the Southeastern boundary of the NRTS (nontelemetered) was also made available for analysis.

The Weather Bureau high-speed, digital data acquisition system was placed outside the southwest corner of the Spert complex fence, upwind of Spert I. A Weather Bureau bivane and Beckman-Whitley wind system were installed on a 6 meter tower at this location to provide the inputs for the high-speed system. This equipment was installed to provide wind statistics for correlation with any effluent distribution patterns.

To provide a trajectory similar to that which could be expected of airborne radioactive effluent from the Spert I, a series of tetroon (constant density surface balloon) flights were run prior to the Spert I destructive test, using the Weather Bureau M-33 radar at the Weather Bureau field facility for tracking. During these runs, techniques for target identification and tracking by the radar crew and inflation and release techniques using an improvised inflation shelter were perfected. Recently developed transponders [34] attached to the tetroon were used to provide tracking from the release point, regardless of radar ground clutter present at the Spert area. If equipment trouble occurred that could not be repaired before the test, provisions were made to track the tetroon using a double-theodolite system.

1.2 Forecasts

Specific forecasts for the Spert area commenced when the decision to perform the destructive tests in Spert I was made. The meteorological restrictions for the tests to be conducted were (a) lapse stability conditions, (b) wind direction range between 200 and 240°, (c) wind speed 45 to 15 m/s, and (d) no precipitation in the area. The preceding conditions were to prevail for at least

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two hours after the test to ensure that any effluent would be released over the test grid, not affect any inhabitated area, and that samples would be unwashed by natural precipitation. Since extensive photographic coverage of the test was required, cloud cover also became a forecast problem as sufficient light was needed for the long distance cameras. For a specific day to be forecast or verified as a "yes" test day, all of the preceding conditions had to be met. If any one of the above restrictions was not met, a "no" test day was forecast or observed.

When the contractor was ready for the first test under meteorological control, specific forecasts to PPCo Spert Operations and the AEC Health and Safety Division were prepared twice daily. With both the morning forecast for that day and the afternoon forecast for the next day, a briefing on current synoptic conditions, the specific forecasts, and the outlook for succeeding days were given.

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APPENDIX C

SUMMARY OF EXPERIMENTAL DATA

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APPENDIX C -- SUMMARY OF EXPERIMENTAL DATA

	I	II	III
Period (msec)	3.2	2.1	1.55
Nuclear Energy Release (MW-sec)	30.7	155	165
Core Damage	Extensive	Minor	Minor
Neutron Activation (copper wire 3 m above core)	8.4×10^7	9.3×10^5	2.2×10^6
Dosimetry (Phantoms 3 m from core)			
Front to Back Ratio			
Beta	6	6	6
Gamma	3	3	3.8
Beta-to-Gamma Ratio	18	2.5	1
Time of Excursion	1226	1427	1314
Date	11-5-62	11-10-63	4-14-64
Mean Wind Speed (m/sec)	11.6	6.5	8.5
Mean Wind Direction (Degrees)	230	230	245
Stability Parameter (n)	0.25	0.20	0.20
Prefilter Efficiencies	79.9	90.4	96.4
(Test 1 and 2 -- BM-2133)			
(Test 3 -- Microsorban)			
Deposition Velocity (Average)			
Grass	0.025	0.033	0.042
Gummed Paper	0.003	0.005	0.004
Maximum Air Concentrations with Distance (μ/Ci-sec/m^3)			
108 m	150	2.9	6.4
215 m	115	1.45	2.4
431 m	44	0.37	0.47
Source Term (Release to Atmosphere in curies)			
Calculated at 108 m	1.6×10^4	3.1×10^2	1.4×10^3
215 m	2.9×10^4	5.3×10^2	1.6×10^3
431 m	3.6×10^4	5.4×10^2	1.9×10^3
Noble Gas Inventory (curies)	5×10^5	2.4×10^6	2.5×10^6
Total Inventory (curies)	5×10^6	2.4×10^7	2.5×10^7
Fraction Produced that is Released to the Atmosphere (%)	0.7	0.002	0.006

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